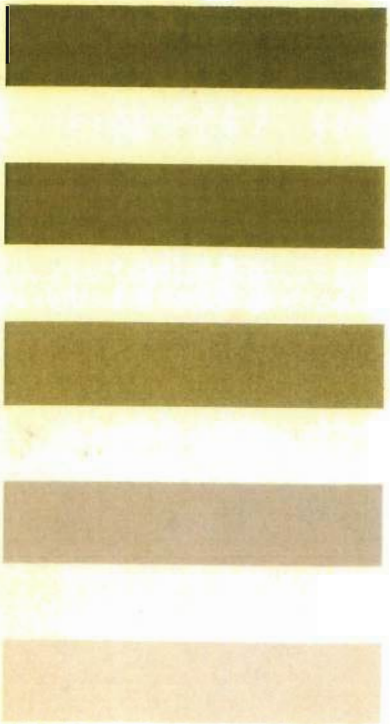
Sustainable Development in Agriculture



J.K. PARIKH
editor

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Sustainable Development in Agriculture

edited by

JYOTI K. PARIKH
Indira Gandhi Institute of Development Research,
Bombay, India

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Foreword

Food problems – the efficient production or procurement of food and its appropriate distribution among members of society – are problems endemic to mankind. Yet the nature and dimensions of these problems have been changing over time. As economic systems have developed, specialization has increased; and this has led to increased interdependences of rural and urban areas, of agricultural and nonagricultural sectors, and of nations.

When the International Institute for Applied Systems Analysis (IIASA) began the Food and Agriculture Program (FAP) in 1976, we started with these objectives:

(1) To evaluate the nature and dimensions of the world food situation.
(2) To identify the factors that affect it.
(3) To suggest policy alternatives at national, regional, and global levels:

  (a) To alleviate current food problems.
  (b) To prevent food problems in the future.

To realize these objectives, FAP was organized around two major tasks. The first task was directed at national policy for food and agriculture in an international situation. Here, computable general equilibrium models were developed for nearly 20 major developed and developing countries and were linked together to examine food trade, aid, capital flows, and how they affect hunger, in addition to the effects of national government policies, which were also considered in detail. This approach, however, needed to be complemented by another approach that dealt with food production at the farm level. The second task, therefore, began in 1980 and was directed to the sustainability of agriculture, with detailed considerations of resources, technology, and environment. This task needed conceptual work as well as case studies to illustrate the major constraints in the sustainability of agriculture. This book presents the results of this second task. Yet another major exercise by Drs. Mahendra Shah and Günther Fischer, in collaboration with FAO, is reported elsewhere. It has a different focus in that it deals with resource potential for agriculture in developing countries.

Dr. Jaroslav Hirš from the CSSR, while he was Deputy Leader of FAP during 1979–1983, established a network of scientific organizations and scientists willing to conduct independent studies on the sustainability of agriculture within a common framework. During this early period, a number of scientists collaborated with Dr. Hirš, notably D. Reneau, S. Münch, H. Asseldonk, and also K. Frohberg, who continued to advise until recently. After the unfortunate sudden demise of Dr. Hirš in 1983, the present editor, Jyoti Parikh, took over this work in 1984. Her contributions exceeded by far the normal editorial duties. She had to reorganize the network, revive the momentum of the group, and compare and evaluate the findings of its members. She could not have completed this task without the enthusiastic support of the network members and authors. At IIASA, Cynthia Enzlberger and Barbara Hauser provided myriad assistance to authors of various chapters, including but by no means limited to retyping their drafts. Ever since this volume began to take shape, Lilo Roggenland has helped us most efficiently.

It should be mentioned that some of the case studies involved not only research scientists, but also policymakers at high level, suggesting that the need for systems analysis in this area is felt not just by the scientists at the forefront, but that its relevance is also perceived in the decision making world. It is hoped that the readers will appreciate the considerable efforts put in by the authors and the editor over several years, be it for conceptual advance or for empirical understanding.

F. Rabar
Program Leader
Food and Agriculture Program
International Institute for Applied Systems Analysis

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CHAPTER 1

Introduction

J.K. Parikh

1.1. Genesis of the Project

The aims of the Food and Agriculture Program (FAP) of the International Institute for Applied Systems Analysis (IIASA) are to evaluate the nature and dimensions of the world food situation; to identify the factors affecting that situation; and to suggest alternatives at the national, regional, and global levels, not only to alleviate current food problems, but also to prevent future ones. The solutions to current problems must be consistent with the goal of a sustainable, equitable, and resilient world that can meet the food needs of the global population, which is expected to be six billion by 2000.

Toward this goal, to investigate policies for improving the availability of food in a number of selected countries has been the main object of the Food and Agriculture Program since its beginning. However, it was realized during this investigation that improving food availability by using appropriate combinations of trade and production policy alternatives might have long-run consequences in some countries; among these consequences are overexploitation of resources, environmental deterioration, and foreclosure of options through adoption of inappropriate technologies (Parikh and Rabar, 1981).

The complexity of the food system necessarily implies that such problems require systems analysis, i.e., multidisciplinary approaches that integrate those aspects relating to agronomy, farm technology, economics, demography, sociology, ecology, and so on. These dimensions cannot be looked at separately. Income level and hunger, population growth and environmental effects, increasing use of natural resources, and rising costs – all of these are inseparable, and examination of their relationships requires a systems approach. But how should the system be specified? What should be included so as to reflect its complexity and what omitted to keep it manageable? The extensive relationships of food and agriculture with such fields as demography and ecology make these questions particularly difficult.

The symptoms mentioned above are global, but because food-producing technologies are locally determined, global solutions are not always possible. Technologies depend on the economic environment, the level of education, the social system, and the available resources – they cannot be investigated outside their environment. Technologically we have to rely on *local* options.

It became clear that, in addition to the investigations using economic models (which we refer to here as FAP Task 1) that deal with international trade, macroeconomic policies on economic growth, income redistribution, taxes, subsidies, etc., oriented to agricultural policy, a long-run investigation of the interactions of resources, technologies, and environment for the sustainability of agriculture would have to be undertaken. Naturally, the two sets of investigations are not independent, but they focus on different elements of the systems, and they require different methods of investigation. This difference is reflected in the present approach of the program. The program was organized around two tasks: Task 1, "Strategies: National Policy Models for Food and Agriculture", and Task 2, "Sustainable Agriculture: Resource Limitations, Technology Utilization, and Environmental Consequences".

1.2. Sustainable Agriculture: Resource Limitations, Technology Utilization, and Environmental Consequences – Issues and Approaches

Larger population, higher incomes, and increased consumption of animal proteins all intensify pressure on land and require more intensive cultivation. The pressure on land is accentuated by the relative scarcity of other resources, such as water, energy, etc.

During the past several decades, there has been a significant increase in agricultural production due to technological advances. While the new technologies have led to an increase in input factors, such as capital, minerals, pesticides, and water, they have also triggered environmental degradation. The environmental consequences vary from region to region and include soil erosion, soil compaction, groundwater contamination, deforestation, loss of soil fertility, etc. The environmental impact of technology-intensive agricultural practices is one of the more critical issues in the sustainable production of agriculture.

The technology selected for agricultural production, characterized by levels of inputs and cultivation practices, not only determines agricultural output, but also affects the quality of the soil and water. For example, some soil erosion and changes in soil chemistry are usually associated with the production of a crop. The future productivity of soil is thus affected.

In general, agricultural production decisions and policies tend to neglect slow-moving variables, such as environmental impacts, which, as stated above, could be changes in soil quality, vegetative cover, soil erosion, etc. These slow changes continue until the time when they suddenly become a major concern. Yet, these concerns have to be balanced by the concerns for resource utilization and available technologies and associated costs. The balance among these factors requires a constant process of adjustment for which some ground rules have to be established, which in turn requires a conceptual framework of the system.

1.2.1. Importance of feedback among resources, technology, and environment

It is thus necessary that one describe an interactive system where adjustments are taking place continuously. In the long run, possible new technologies and natural resources will become increasingly important, and economic conditions that dominate policy decisions may change. Resources and technology cannot be separated and must be investigated together. The choice, and sometimes the development, of technologies is affected by resource availability; however, each technology in turn exerts specific environmental effects on at least two of the primary resources – soil and water. This feedback relation, in the long run, is of primary importance; and if sustainability of production is kept as a desirable objective, as it should be, the feedback relation could transform the economic setting.

Typical resources for agriculture from economists' perspective are land, water, energy, capital, and labor [1]. Long-range resource concerns can be demonstrated as an example through the future role of energy in agricultural technologies. On the one hand, energy, an important labor substitution factor (machinery and fuel), as well as a land substitution factor (fertilizer) and a determining factor in the level of regional specialization (transportation costs), is now becoming an expensive and scarce resource; this change will greatly influence the future of agricultural technology. On the other hand, agriculture can be viewed as a supplier of energy through crop residues, fuelwood (through plantation or social forestry), alcohol production, and biogas generation. In the past, energy-intensive technical development paths may have been preferred because of the abundance of cheap fuel sources. Input factors such as labor and land may have been replaced by machines and fertilizers. The relative energy content of existing and possible new technologies will be an important factor in future development. In addition, as a result of high energy prices, transportation costs will play a more important role in the future and may lead to less regional specialization. This, in turn, could also indirectly affect the choice of technologies.

If the system were hierarchic, resource availability and economic forces would determine the choice of a particular technology among the many available options, and this selection of technology would determine environmental consequences. But this perception is changing very rapidly as environmental concerns grow, leading to the feedback mechanism where alternative technologies are selected so that resource requirements and environmental effects are altered. Thus, the relationships are integrated and reinforcing and therefore ***nonhierarchic***. For example, environmental concerns also determine technology used, as we shall see in some of the case studies.

This book, then, focuses on the interactions between resources, technologies, and environment in agricultural systems and on their consequences for long-run agricultural development. Specifically, the issues addressed are:

(1) How should we estimate biological potentials of a given region, and what are the necessary factors in realizing them?
(2) How do certain technological options, resource limitations, and environmental consequences of cultivation affect each other? What is their relative importance? How should we allocate priorities and establish a process of adjustment?
(3) How does one design a production plan (what to grow, how to grow) for a region that ensures sustainability of production from a long-term point of view?
(4) What are the additional costs of agricultural production, if soil productivity (and this can be operationally defined) has to be preserved?

To address these issues, conceptual as well as empirical work was required. Methodological development for approaching the systems problem was needed. It was felt that to give focus and realism to the methodological work, it would be best carried out in the context of substantive application. Thus, some case studies also needed to be undertaken. The idea was appealing, and a network of interested collaborators was established [2] where, in addition to the case studies, some scientists worked on different methodological aspects.

The outcome of this research has thus been some methodological contributions as well as a set of case studies in different countries representing different economic and ecological conditions.

It should be mentioned that in addition to those described in the three chapters on methodological studies (Chapters 2, 3, and 4), some interesting methods have also been developed in the case studies, notably for the USA and Japan. On the other hand, all the methodological studies have tried to test their validity empirically. To that extent, the distinction between methodological and case studies is arbitrary. It merely refers to the predominant concerns that the authors had while carrying out their work. It should be emphasized again that the contributions of the case studies to methodological development are substantial; but since their focus is the development of the regions rather than methods, we introduce and summarize the methodological work and the case studies separately.

1.3. Methodological Approaches

Methodological development was needed to deal with issues such as:

(1) How could the maximum biological potentials be estimated; and what is the role of natural conditions such as soil quality, solar radiation, moisture and hydrological factors, and soil nutrients in reaching them? Can one develop a model of crop production at an aggregated regional level? Soil quality change?

(2) How does this growth potential, predicted from agronomic principles, compare with what is realized in practice in specific regions, e.g., in the Mugello region of Italy or the Stavropol region of the USSR?

(3) How best to use the data from the more advanced techniques, such as remote sensing, for understanding plant growth?

(4) How to formulate crop rotation problems in a recursive dynamic framework without handling a very large, indeed exploding, number of soil quality classes, which change every year because different crops growing in the soil change its quality.

In the existing literature there are conceptual gaps in dealing with these complexities. While much remains still to be done, some progress has been made in several aspects in the three chapters included here. These developments are added and coupled to the usual approaches of the linear programming type.

1.3.1. Brief descriptions of the three approaches included

The first two questions are dealt with in Chapters 2 and 4 by Konijn and Maracchi *et al*, respectively. They build and validate the physical crop production model from a variety of measurable parameters, such as soil and its quality, and climatological variables, such as precipitation, radiation, moisture, etc.; and they calculate the CO_2 assimilation and biomass generated for C_3 and C_4 plants. Both try to validate the model with actual data, which is averaged over a 10-day period in the case of Konijn's models and a 15-minute period as measured from remote sensing in the approach of Maracchi *et al*. Models of plant growth exist in the literature, but they have not been generally applied at regional scales. Moreover, the existing approaches are not fully formalized and often require expert judgment on a case-by-case basis. The contributions of Konijn and Maracchi *et al.* fill these gaps. Each has developed a fully formal model that is computerized and automated to a large extent.

In addition, Konijn has addressed the questions of changes in soil quality and its feedback on future productivity.

Chapter 4 by Maracchi *et al.*, to some extent, falls into the category of methodological approach and is also a case study in its own right but, since it does not focus on economic decision making, it is considered more appropriate to include it as a methodological approach. Moreover, it provides a framework for integrating data obtained through remote sensing, which is a major advance in operationalizing such approaches.

While the physical crop production model of Konijn is applied and validated in the Stavropol case study, that of Maracchi *et al.* has been validated for three crops in the Mugello region of Italy. Here, validation means that the soil and climate data from a particular region are fed into the model, and the model-estimated yields are compared with observed yields of that region for a number of years.

How to integrate such a biological approach in an economic or decision making model is shown in Chapter 3 by Ereshko *et al.*, which also outlines simplified approaches to deal with the computational complexity of the system. The computational difficulties of determining an optimal sustainable production strategy arise from a number of reasons. First, the feedback processes that affect soil quality and soil productivity are highly nonlinear. Second, the soil quality changes depend on the crop growth, on the technology used, such as the level of fertilizer use and the kind of cultivated practices followed, as well as on the climate. Thus, the number of different soil classes increases in an exponential fashion with the number of seasons considered. Third, the conditions for sustainability of soil along with economic rationality of the production plan make the problem one with multiple objectives. Once the impracticability of determining an optimal sustainable production strategy is recognized, a number of alternative approximations can be introduced to obtain solutions, albeit suboptimal, of interest. Ereshko *et al.* describe some possible alternative computational procedures, some of which are used in the Stavropol case study.

In addition to these three chapters, a working paper by Reneau *et al.* (1981), which is referred to here by several authors in their case studies, outlines modular development of recursive linear programming models.

1.4. Case Studies: Description, Approaches, Issues

1.4.1. Description of case studies

It was possible to enlist cooperation from a number of countries of East and West and also to carry out one case study for a developing country, Bangladesh. A network of collaborators was formed so as to cover a wide variety of economic and agricultural systems. The different regions or countries covered are listed below. There could be a number of ways of grouping them; here they are grouped according to average size of farms: large, medium, and small:

(1) Large regions:
    (a) Stavropol region, USSR.
    (b) State of Iowa, USA.

(2) Medium regions:
    (a) Nitra district, Czechoslovakia.
    (b) Tolbuhin region, Bulgaria.
    (c) Suwa region, Japan.

(3) Countries as regions:
    (a) Hungary
    (b) Bangladesh

The list of collaborators involved in each case study is given in each chapter. The case studies covered different economic systems, such as market economies of the developed countries, centrally planned economies, and the subsistence economy of Bangladesh.

Apart from Hungary and Bangladesh, where the entire countries are considered since the total areas are 93036 km^2 and 144000 km^2, respectively, the remaining studies have narrowed their attention to a smaller region within the country so as to focus upon decisions concerning local environment and technology use.

Most case studies are about the regions that contribute significantly to the nation's production, e.g., Iowa in the USA, Stavropol region in the USSR. Productivities of the Nitra region in Czechoslovakia, Tolbuhin in Bulgaria, and Suwa in Japan are also higher than their respective national averages. The basic objective of most of the case studies is how to ascertain the sustainability of the productivity of these regions, and how to obtain even more production from these regions to support increasing demand, while keeping environmental consequences in view.

1.4.2. Approaches used

Depending on the system under study, some of the case studies have developed their own methods as well. Two of the methodological approaches described in the earlier section, by Konijn and by Ereshko *et al.*, are synthesized in the Stavropol case study in the USSR.

In general, the case studies use a systems analysis approach that integrates agronomic, economic, and technological perspectives in either a static or a dynamic sense, i.e., where the decisions made in the near future also affect the distant future, thereby tracing paths of development. This dynamic approach, using recursive linear programming (LP), is applied to the Japan and US cases. However, even when the conventional LP technique is adopted, its use is by no means conventional because of the disaggregation employed and the nature of its formulation. For example, in Bangladesh income groups of farmers are distinguished to give insights into vulnerabilities of the landless, small, medium, and large farmers. The combination of soil classes, crop rotations, and tillage practices is the kind of disaggregation used in the Iowa case study. In addition, the methodological approach of the Iowa case study consists of a hybrid model in which an econometric model for the rest of the USA is coupled to a linear programming model of Iowa.

1.4.3. Issues considered

In the following, the case studies are briefly compared according to the major themes covered by them, i.e., roles of resources, technology, and environment. *Figure 1.1* illustrates the interactions envisaged between these components.

Resources

The perception of resources and their inclusion in the actual treatment varies from case to case, ignoring them when they are abundant, treasuring them when scarce. For example, labor is ignored in Bangladesh but included in the Nitra and Tolbuhin case studies. By and large, all the case studies consider land as a resource and its qualitative variations in terms of soil types and productivity. Soil and soil quality (fertility) are seen to be the major themes in most of the case studies and, to a lesser extent, water and water quality (Japan). In Bangladesh, where land is scarce, biomass is a generated resource (or output), which has to be allocated for food–fodder–fuel and fertilizers. Energy is considered in Bangladesh and Hungary extensively, and to a lesser extent in Bulgaria and Czechoslovakia.

Technology

The interpretation of this concept is pragmatic in most case studies. Traditionally, agricultural techniques cover a wide spectrum that ranges over cropping practices, irrigation and tillage practices, mechanization, intensifications, etc. However, technologies for reducing environmental impacts are increasingly being included. Thus, we have two types of technologies:

(1) Technologies to increase productivity.
(2) Technologies to control environmental impacts.

These can be elaborated as follows:

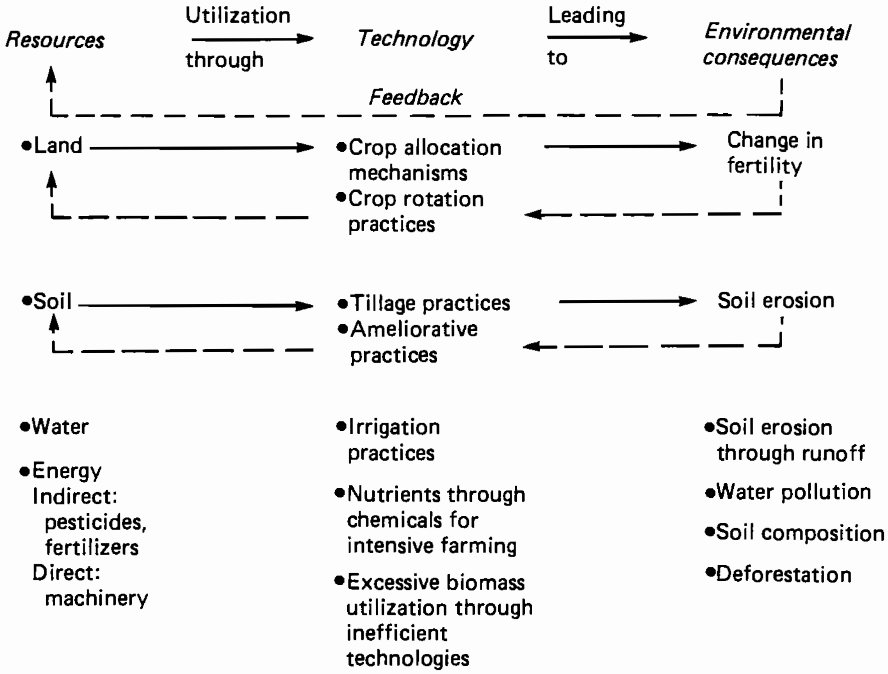

Figure 1.1. Relationships between resources, technology, and environment as covered in the case studies. (The arrows show direct effects, but there could also be cross-effects, such as energy affecting tillage practices or water quality. The hatched lines represent direct feedback.)

(1) Intensification of agriculture through high-yielding varieties is required in those countries where an increase in agricultural productivity is considered essential. This applies to all countries except Japan and, to a minor extent, the USA (where it is essential but with overriding or equal priorities of reducing soil erosion). Thus, Nitra, Czechoslovakia; Tolbuhin, Bulgaria; Stavropol, USSR; and Bangladesh consider raising productivity through intensification. Effects of tillage practices are described in Hungary and the USA.

(2) Crop rotation practices: In the case studies of Iowa and Stavropol, this is considered, respectively, to reduce soil erosion and to increase production (by altering fallow land allocation, etc.). The explicit treatment of these practices necessitated conceptual advances in methodology and computation, which were carried out by Ereshko *et al.* (Chapter 3) and followed by the Stavropol case study.

(3) In the case of the developing countries, i.e., Bangladesh, where biomass is scarce relative to population, the boundary of the system had to be extended to consider technology for efficient utilization of biomass so as to reduce the demand to cope with the problem. Thus, choice of technologies on the demand side, such as biogas, efficient stoves, charcoal making, etc., had to be added.

Environmental issues

A major concern of almost all the case studies is whether overutilization of land could reduce the soil fertility. This common concern ties these case studies together. It shows up in all the countries with a centrally planned economy, in Bangladesh, and also in the USA, where the loss of soil fertility is shown to follow from soil erosion.

Soil erosion is of direct and considerable concern in Iowa and soil–yield relationships are used to show what the yields may be for different soil classes, crop rotations, and tillage practices. Soil erosion also figures in a major way in the case study of Hungary.

Water pollution is explicitly dealt with in a recursive linear programming framework in Suwa, Japan. However, in Tolbuhin (Bulgaria) and Nitra (Czechoslovakia), concerns are only implicitly expressed. In the case of Bangladesh, the problems are loss of soil fertility and deforestation due to extensive use of biomass. However, major contributions in *explicit* treatment of environmental issues are found in the case studies of Iowa, USA, and Suwa, Japan.

1.5. Concluding Comment

Thus, this book presents development of some methodological approaches as well as case studies of differing regions using systems analysis. The case studies cover a wide variety of countries and economic systems, and provide examples of dealing with an extensive range of issues concerning sustainability of agriculture.

Notes

[1] "Noneconomic" resources are soil and soil quality, weather, climate, solar radiation, rainfall, etc.

[2] See the Foreword to this volume, which highlights the contribution to this process made by Hirš *et al.*

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PART I

Methodological Approaches

CHAPTER 2

A Crop Production and Environment Model

N. Konijn

Abstract

In this chapter a dynamic crop production and environment model is described. The model has a hierarchical structure and determines successively the effects of water availability and nutrient availability on the potential biomass produced in the local radiative and temperature regime. Estimates are based on characteristics that describe the physical environment: climate, site, and soil. The response to the physical environment depends to a large extent on the properties of the crop grown. The crop characteristics chosen are of a generally applicable nature. The effect on production of inorganic and organic fertilizers can be determined, which might affect the yields in the long run.

Crop yields can be accompanied by soil loss through erosion and by changes in soil fertility. Through updating the findings on soil characteristics, the effect on productivity in the long run can be determined.

An application of the dynamic crop production model is described in Chapter 5.

2.1. Introduction

This chapter describes a dynamic crop production model (CPM) used in the study of environmental consequences of agricultural production. The role of the CPM in this modeling effort is illustrated in *Figure 2.1*. CPM generates yields for numerous crops on different units of land (land classes) employing different technologies, given the environment measured by its climate, soil, and site characteristics. A particular piece of land might be used in different ways. Every year, the farmer needs to decide what crops to grow and where. The CPM merely generates all possible crop yields of the various land classes and hands the results over to the decision module, which in turn selects the final land use based on the objectives of the modeling effort. Thus, the decision module simulates a farmer's behavior for a free market economy or contains the criteria to describe optimal options for a centrally planned agriculture. This effort is carried out on an annual basis.

Not every crop production model can be used for this modeling effort; most of them require much computing time. Dynamic models that estimate yields based on very small time steps are particularly computer-time-consuming, although they have the advantage of registering intraseasonal effects of, for example, the weather. Another disadvantage of these detailed models is the enormous task of data processing required.

More pragmatic approaches to such modeling efforts tend to follow more empirical–statistical methods. This leads to results much more quickly, but has severe limitations when it comes to extrapolating them. Intraseasonal responses of these models are usually weak.

The CPM is of a dynamic nature. It needs, for example, values for variables related to weather at 10-day intervals. The data for climate, soil, and other characteristics are usually also available. The characteristics on which the estimates are based change with time. To take these changes into account, the input data set of the preceding year is updated. The updating of the resources is carried out after the decision module has allocated the land to certain crop production activities.

Below we describe the CPM and the updating of the input data base, and discuss some problems with regard to the linkage of the crop production and decision module.

2.2. Crop Production Estimation

The relationships used in this crop production model have been derived from different sources, although most of the parameters come from the Centre for World Food Studies (personal communication).

The CPM needs to be run for each unique set of input characteristics. Considering the many options that the farmer has for each land class, one might end up with hundreds of sets of input characteristics.

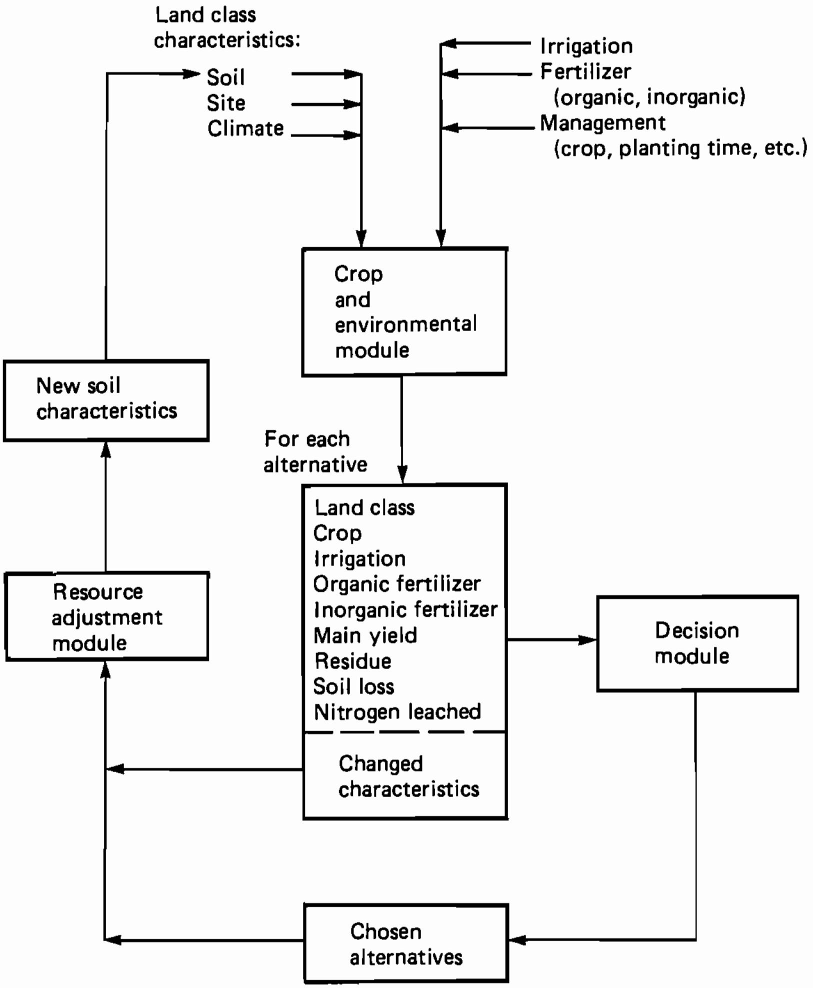

Figure 2.1. Relation between the various modules.

In the real world, climate and soil change gradually, and both can be considered as continuums; however, such gradual transitions are ignored, so the land classes are considered to be homogeneous.

The structure of the CPM is shown in *Figure 2.2*. It has a hierarchical structure, which means that production estimated at a higher hierarchical level can progressively be constrained at a lower hierarchical level. The dynamics of the model are based on 10-day interval estimations, which allow the model to respond to intraseasonal fluctuations of the weather pattern. Therefore, appropriate climate data are required. Such input data determine the temperature, radiative, and water regimes for plant growth. These regimes are taken into account in the three modules of the flow chart.

In contrast, the effect of the nutrient availability upon crop production is determined on an annual basis, for knowledge required to model this section on a 10-day interval basis was considered insufficient.

The following sections of this chapter describe briefly the relationships that have been used in the crop production model.

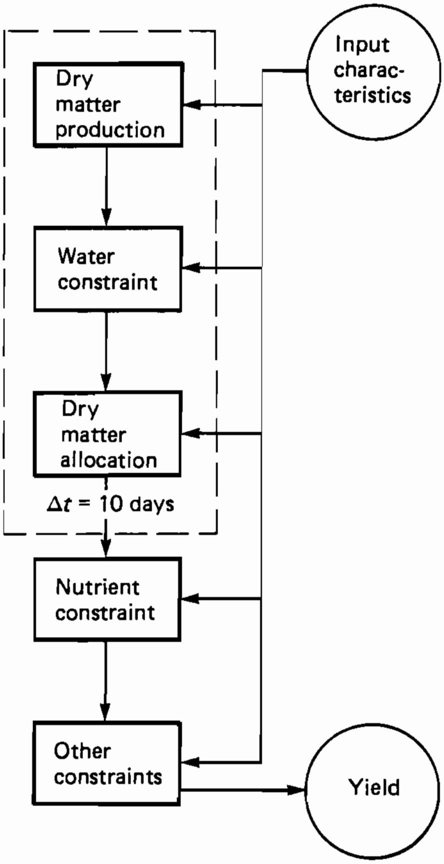

Figure 2.2. The structure of the crop production module.

2.2.1. Photosynthetic dry matter production

The pigments of green plants are able to absorb visible light. The energy accumulated in this way is used for the assimilation of carbon dioxide, which is absorbed by the plant from the atmosphere through its stomata. The assimilates formed in the process of photosynthesis are converted to dry matter according to the plant's properties (see Section 2.2.3).

Experiments have shown that the rate of photosynthesis can be expressed as a function of the absorbed radiation. This has been worked out by De Wit (1965), and has been revised by Goudriaan and Van Laar (1978). *Figure 2.3* illustrates the rate of photosynthesis as a function of the light intensity. The relation can be expressed as:

$$F_n = \frac{F_m + F_d}{H + (F_m + F_d)/E} - F_d \tag{2.1}$$

where F_n stands for net photosynthesis, F_m for gross photosynthesis at high light intensity, F_d is dark respiration, E is efficiency of photosynthesis, and H is absorbed light.

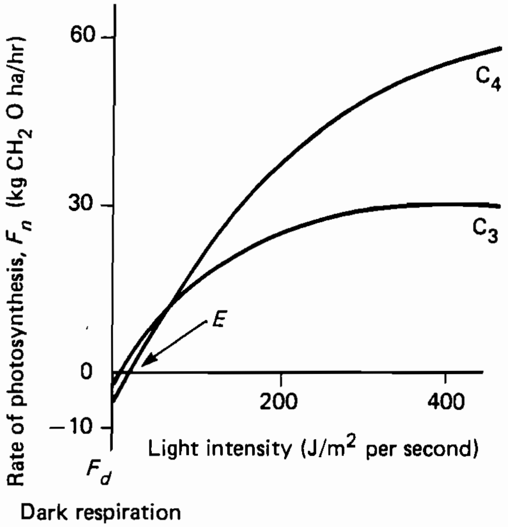

Figure 2.3. Rate of photosynthesis and light intensity.

The radiation that reaches the plant and that will be finally absorbed fluctuates considerably. The following factors play an important role:

(1) The composition of the radiation: cloudy days have relatively more diffuse radiation than clear days. Photosynthesis from scattered radiation is more effective, for it penetrates the crop better than the direct solar radiation.
(2) The geographical location and the inclination of the sun.
(3) Canopy properties determine how far radiation will be reflected and absorbed. These properties are crop-specific and change during crop development.

Since the end of the 1960s, two main groups of plants with different photosynthetic pathways have been distinguished: the C_4 plant type is characterized by the highest rate of photosynthesis, at least under the present carbon dioxide concentrations in the atmosphere and when air temperature is sufficiently high.

The C_3 plant type performs well in the cooler, temperate regions of the world. At present carbon dioxide concentrations it has a less effective rate of photosynthesis.

Based on the relationship in *Figure 2.3*, Goudriaan and Van Laar (1978) prepared tables for the gross daily assimilation of carbon dioxide for various locations and for the 15th of each month. They are presented in *Table 2.1*. By means of the measured global radiation, we are able to interpolate between the CO_2 assimilation on a clear and a cloudy day of *Table 2.1*.

2.2.2. The effect of water availability

Only a few areas are never affected by drought. Precipitation patterns change from year to year, and even within the cropping season shortage of water may restrict the maximum possible production.

The extent to which soil water will limit production is determined by means of a water balance, which can be expressed as follows: For a time interval Δt

$$S_{t+\Delta t} = S_t + P_{\Delta t} - R_{\Delta t} + I_{\Delta t} - ET_{\Delta t} \tag{2.2}$$

where S is soil moisture content of rooting zone, P is precipitation, R is runoff, I is irrigation, and ET is evapotranspiration.

The gains and losses for the rooting zone are evaluated and result in a change of the soil moisture content over the 10-day interval. The value obtained for the actual evapotranspiration, compared to the potential one, will indicate whether or not the crop undergoes stress. The ratio actual/potential transpiration is assumed to have a proportional effect on the reduction of dry matter.

The various components of the water balance will be described. Each of them will directly or indirectly affect the amount of water that the plant can transpire.

Table 2.1. Daily gross CO_2 assimilation of the closed canopy with a spherical leaf angle distribution (kg CO_2/ha) for two standard sky conditions: Cl = clear day and Ov = overcast day.

(*a*) C_3 crop

Northern latitudes (°)		*15 Jan*	*15 Feb*	*15 Mar*	*15 Apr*	*15 May*	*15 Jun*	*15 Jul*	*15 Aug*	*15 Sep*	*15 Oct*	*15 Nov*	*15 Dec*
0	Cl	623	642	654	648	630	616	622	641	654	648	629	616
0	Ov	293	305	312	309	297	289	292	304	312	309	297	28
10	Cl	560	600	638	664	670	669	670	669	652	616	572	549
10	Ov	259	282	304	318	320	318	319	320	311	291	266	252
20	Cl	486	545	610	668	699	711	707	684	637	570	503	469
20	Ov	217	250	286	318	334	340	338	327	301	264	227	208
30	Cl	396	475	566	657	716	742	732	686	607	510	419	375
30	Ov	169	211	260	309	341	353	349	325	282	230	181	159
40	Cl	294	389	507	633	721	763	747	676	562	433	321	270
40	Ov	117	164	225	292	339	360	352	315	254	187	130	105
50	Cl	183	288	429	593	716	776	753	652	499	339	211	158
50	Ov	63	112	181	265	329	359	348	296	217	137	76	51
60	Cl	66	175	333	536	704	790	756	615	417	230	98	38
60	Ov	15	57	130	229	312	354	338	268	170	81	25	8
70	Cl	0	45	220	467	699	846	784	572	318	109	0	0
70	Ov	0	10	72	184	293	357	331	234	116	27	0	0

(*b*) C_4 crop

0	Cl	894	926	946	937	906	883	892	925	947	937	904	883
0	Ov	321	336	345	341	327	316	321	335	345	341	326	316
10	Cl	796	859	920	960	967	964	966	966	941	884	815	777
10	Ov	282	309	335	351	353	350	352	353	344	320	290	274
20	Cl	680	773	873	963	1010	1027	1021	988	915	812	707	654
20	Ov	234	272	314	351	369	375	373	361	332	289	245	224
30	Cl	543	663	803	942	1032	1070	1056	987	865	716	576	511
30	Ov	180	227	283	340	376	390	385	358	309	248	194	168
40	Cl	389	529	707	898	1033	1095	1071	964	790	595	427	354
40	Ov	122	174	242	318	372	396	387	344	275	199	137	109
50	Cl	227	377	584	829	1014	1104	1069	918	688	451	266	192
50	Ov	64	116	193	286	358	393	379	320	232	144	78	52
60	Cl	71	212	437	733	980	1107	1057	850	558	289	107	40
60	Ov	15	58	135	244	336	383	365	287	180	84	25	8
70	Cl	0	47	268	615	948	1151	1066	766	403	119	0	0
70	Ov	0	10	74	193	311	381	353	247	120	28	0	0

Source: Goudriaan and Van Laar (1978).

Precipitation

Under rainfed conditions, precipitation is the major water supplier. Part of the precipitation will not reach the soil: if a crop cover exists, a part will be intercepted. In the model, the interception is considered to be a part of the runoff.

Irrigation

Irrigation is a useful tool to combat effects of drought stress on plants. The model responds to the following input variables for the irrigation:

(1) The amount of water available for the whole growing season.
(2) The amount of water available at the time of application.
(3) A soil water content threshold to determine the time for an application.
(4) The kind of irrigation system.
(5) The efficiency of the irrigation.

The amount of water available for the whole growing season, and each time an application is necessary, is not always and solely determined by the farmer. He might be dependent on a large-scale irrigation system, possibly with regulations that restrict water distribution.

The threshold value for the soil moisture content below which irrigation water will be applied might depend on different criteria. The threshold value might be determined by crop properties, but can also be set by constraints that limit the amount of available water.

The following types of irrigation system are considered: border, furrow, and sprinkler irrigation.

The irrigation efficiency variable applies at the field level, that is, after the water has arrived at the field. This efficiency is mainly determined by the type of irrigation and the soil type, assuming ideal management by the farmer.

Runoff

Usually the soil has sufficient recharge capacity to absorb at least a part of the rainfall. The recharge capacity is determined by:

(1) Interception of the rainfall by the crop cover.
(2) Amount of water intake by the soil.
(3) Possibility of ponding, when rainfall exceeds infiltration.

Infiltration that exceeds the minimum infiltration, interception by the crop cover, and the ponding are together called the ***initial abstraction***. The relation between runoff (R) and precipitation (P) is illustrated in *Figure 2.4*, and is expressed by the Soil Conservation Service (1972) as:

$$R = \frac{(P - I_a)^2}{P - I_a + St} \tag{2.3}$$

where R is actual runoff (cm), P is precipitation (cm), St is recharge capacity (cm), and I_a is initial abstraction.

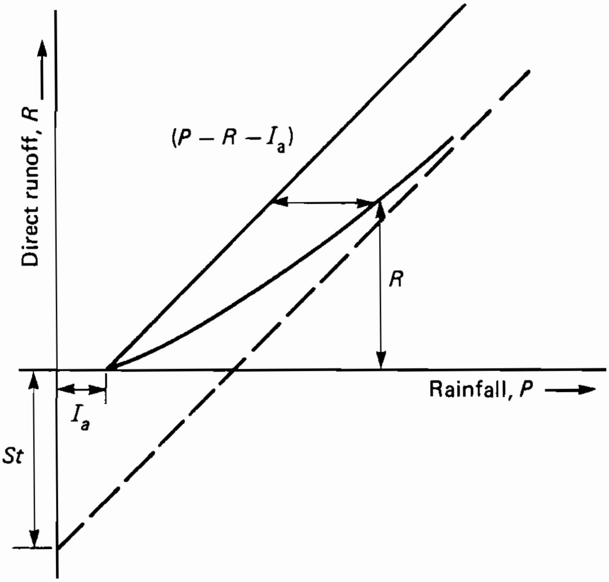

Figure 2.4. Rainfall–runoff relationship.

The maximum recharge capacity is reached when the soil is completely dried out. This recharge capacity is determined by empirically established values for the "curve numbers" (cn). Relations between surface conditions and curve numbers have been experimentally developed. The surface conditions are described by the crop coverage, the infiltration capacity, and the soil structure. *Table 2.2* lists a number of soil surface conditions and gives the related curve numbers.

Knowing the soil porosity (ν_0) and the actual soil moisture content (ν_ψ), the actual recharge capacity of the soil can be estimated by:

$$St_{\max} = \frac{1000}{\mathrm{cn} - 10} \tag{2.4}$$

$$St = St_{\max} (\nu_0 - \nu_\psi) \tag{2.5}$$

Drainage

If the soil moisture content reaches a level where the capillary forces are no longer able to withhold the water against the gravitational force, drainage will take place. This happens when the soil moisture content is above "field capacity", which is at approximately one third bar suction.

Table 2.2. Curve numbers for various minimum infiltration cover-combinations (US Soil Conservation Service, 1972).

	Cover		*Minimum infiltration (cm/h)*			
Land use	*Treatment or practice*	*Hydrologic condition*	*0.95*	*0.6*	*0.25*	*0.06*
Fallow	Straight row	–	77	86	91	94
Row crops[a]	Straight row	Poor	72	81	88	91
Row crops	Straight row	Good	67	78	85	89
Row crops	Contoured	Poor	70	79	84	88
Row crops	Contoured	Good	65	75	82	86
Row crops	Contoured terraced	Poor	66	74	80	82
Row crops	Contoured terraced	Good	62	71	78	81
Small grain[b]	Straight row	Poor	65	76	84	88
Small grain	Straight row	Good	63	75	83	87
Small grain	Contoured	Poor	63	74	82	85
Small grain	Contoured	Good	61	73	81	84
Small grain	Contoured terraced	Poor	61	72	79	82
Small grain	Contoured terraced	Good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured terraced	Poor	63	73	80	83
	Contoured terraced	Good	51	67	76	80
Pasture or range pasture or range meadow		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77

[a] "Row crops" are maize, sorghum, soybeans, sugar beets. [b] "Small grain" are wheat, oats, barley, flax.

Evapotranspiration

Evaporation from a free water surface can be approximated by a formula developed by Penman (1948):

$$E_{ws} = \frac{\dfrac{\Delta}{\gamma} \cdot \dfrac{R_n - G}{L} + (e_s - e_a) \cdot f(u)}{\dfrac{\Delta}{\gamma} + 1} \qquad (2.6)$$

where E_{ws} is evaporation from a free water surface (cm/day), R_n is net radiation (cal/cm^2 per day), G is soil heat flux (cal/cm^2 per day), Δ is rate of change of the saturation vapor pressure with temperature (mbar/°C), γ is psychrometric coefficient (°C/mbar), e_s is saturation vapor pressure (mbar), e_a is actual vapor pressure (mbar), $f(u)$ is wind speed function (m/s), and L is latent heat of vaporization of liquid water (cal/gm).

Equation (2.6) is based on the the "combination method", which means that the energy balance of a free water surface has been combined with an aerodynamic transport equation. Its general applicability has been shown over and over and has led to the development of various empirical relationships so that it can be applied to locations where other climatological parameters have been measured.

The saturated water vapor pressure at air temperature (T, in °C) can be determined with the following equation (Goudriaan, 1977):

$$e_s = 6.11 \cdot e^{17.4T/(T+239)} \tag{2.7}$$

The slope of the saturated vapor pressure curve is the derivative of the preceding one:

$$\Delta = \frac{25409}{(T+239)^2} \cdot e^{17.4T/(T+239)} \tag{2.8}$$

Net radiation (R_n) can be measured directly, but this is not often done. However, the various developed empirical relationships will help us out. For example, Angström (1924) and Prescott (1940) developed a simple linear regression to relate the measured hours of sunshine to the global radiation:

$$R_n = R_a \cdot (1 - r) \cdot [a + b \cdot n/N] - lw \tag{2.9}$$

where R_a is extraterrestrial radiation or angot-value (cal/cm^2 per day), r is reflection of water surface, a,b are climate-dependent constants, n is actual hours of sunshine (h), N is maximum possible hours of sunshine (h), and lw is long wave radiation (cal/cm^2 per day).

The long-wave radiation (lw), lost by the earth's surface, can be approximated by a relationship given by Brunt (1939):

$$lw = \sigma(T + 273.2)^4 \cdot (c - d \cdot \sqrt{e_a}) \cdot [e + f \cdot (n/N)] \tag{2.10}$$

where σ is the Stefan–Boltzmann constant (11.69 × 10^{-8} cal/cm^2 per °C^4 per day), e_a is actual vapor pressure (mbar), c,d,e,f are climate-dependent constants, and T is air temperature (°C).

The global radiation together with the long-wave radiation determine the net radiation. Thus, it is possible to estimate the net radiation from more commonly measured climate parameters.

In situations where agricultural production is at altitudes considerably above sea level, a correction of the psychrometric coefficient will be necessary:

$$\gamma = \frac{c_p \cdot p_h}{L \cdot \varepsilon} \tag{2.11}$$

where c_p is specific heat of air at constant pressure (cal/gm per mbar), p_h is air pressure at altitude h (mbar), L is latent heat of vaporization (cal/gm), and ε is ratio of molecular weight of water over molecular weight of air, i.e., mixed ratio.

The atmospheric pressure at altitude h can be determined by the altimeter equation:

$$p_h = p_0 \cdot e^{-gh/RT} \tag{2.12}$$

where g is gravitational acceleration (m/s^2), p_0 is barometric pressure at sea level (mbar), R is gas constant (J/mol per °C), h is altitude (meters above sea level), and T is air temperature (°C).

To calculate the potential evapotranspiration, we follow the procedure for the free water evaporation; however, the reflection for a water surface is replaced by the reflection coefficient for a crop canopy (Monteith, 1973).

The potential evapotranspiration is converted to the actual crop evapotranspiration by considering the degree of crop coverage. So the crop coefficient depends mainly on the stage of crop development. Values for different types of crops at different stages are taken from the FAO (1977):

$$E = kc_{c,s} \cdot E_p \tag{2.13}$$

where E is crop evapotranspiration (cm/day), kc is crop coefficient, c is crop, s is stage of crop development, and E_p is potential evapotranspiration (cm/day).

Soil Moisture Content

The soil moisture content is related to the soil moisture tension, a variable that expresses the energy status of the water in the soil. It tells us whether or not water is available for uptake by plants. If it reaches a certain critical value, the plant closes its stomata and the transpiration will cease. This critical value varies with the type of crop.

The following equation describes the relationship between the soil moisture tension and the soil moisture content:

$$\psi = e^{[\gamma^{-1} \cdot (\ln \nu_0 / \nu_\psi)]} \tag{2.14}$$

where ψ is soil moisture tension (cm H_2), ν_0 is maximum soil moisture content, which is equal to the soil porosity (volumetric %), ν_ψ is soil moisture content (volumetric %), and γ is a soil-specific parameter.

The "gamma" is soil-specific. It can be determined by regression analysis of the soil moisture content on the soil moisture tension. Values are given in *Table 2.3*. Observations in the Netherlands suggest that the soil texture is a good indicator of the soil moisture characteristics.

Table 2.3. Soil texture and soil parameters (Centre for World Food Studies, personal communication).

Soil texture	*Porosity* (%)	ψ_{max} (cm H_2O)	k_0 (cm/day)	γ
Coarse sand	39.5	80	1120.0	0.1000
Fine sand	36.4	175	50.0	0.0288
Loamy fine sand	43.9	200	26.5	0.0312
Sandy loam	46.5	150	16.5	0.0264
Silt loam	50.9	300	6.5	0.0185
Loam	50.3	300	5.0	0.0180
Clay loam	44.5	300	0.98	0.0058
Light clay	45.3	300	3.5	0.0085
Basin clay	54.0	80	0.22	0.0042

It should be noted that the water balance applies to the rooting zone only. This is another dynamic factor in the plant water availability. Rooting development and rooting depth are crop-specific, one reason why some crops are more drought-resistant than others. In the model, the rooting depth depends on the stage of crop development and crop growth.

Water Constraint on Production

As has been mentioned, the soil moisture tension might surpass a certain value above which the plant cannot extract any more soil water. Above that critical value the plant will close its stomata, and consequently transpiration will cease and no carbon dioxide can be assimilated.

It is not soil moisture tension alone that determines stomatal closure: the evaporative demand may aggravate drought stress on plants. The following equation, developed at the FAO (1979), describes the joint effect of evaporative demand of the atmosphere and the soil moisture available:

$$\begin{aligned} pt = {} & p5(3.05 - 0.577E_p - 2.216p5 + 0.0523E_p^2 + 0.1766E_p \cdot p5 \\ & + 3.33p5^2 - 0.0014E_p^3 - 0.0289E_p^2 \cdot p5 + 0.322E_p \cdot p5^2 \\ & - 0.3778p5^3) \end{aligned} \qquad (2.15)$$

where pt is the fraction of available water, $p5$ is the fraction of available water at standard value, and E_p is potential evapotranspiration (mm/day).

If the actual evapotranspiration turns out to be lower than the potential, water stress occurs and the dry matter production will decrease proportionally with the ratio between potential and actual evapotranspiration.

2.2.3. From biomass to dry matter

The biomass produced is expressed as assimilated carbon dioxide. The final composition, which differs from crop to crop, needs to be considered. The conversion from biomass to dry matter is based on *Table 2.4* (Penning de Vries, 1975), where the biomass produced is expressed as glucose, not as carbon dioxide. The conversion is often called the *growth respiration*.

Table 2.4. Values for the conversion of glucose into the main chemical fractions of plant material (Penning de Vries, 1975).

Chemical fraction	*Product*(g/g CH_2O)
Nitrogenous compounds (normal mix of amino acids, proteins and nucleic acids):	
From NO_3^-	0.404
From NH_3	0.616
Carbohydrates	0.826
Organic acids	1.104
Lignin	0.465
Lipids	0.330

In order to maintain the functioning of their metabolism during growth, plants must respire. This process involves the consumption of a part of the stored assimilates. The rate of respiration is temperature-dependent, being about 1.5% of the standing dry matter at 25°C. The maintenance respiration approximately doubles with an increase of 10°C.

2.2.4. Partitioning of dry matter over plant organs

The distribution of plant material over the various plant organs is dependent on the crop development stage (*Figure 2.5*). The distribution is expressed in relative terms and needs to be converted to the corresponding real length of growing season (Penning de Vries and Van Laar, 1982). *Figure 2.5* presents a small grain crop which, at the beginning of the growing season, shows mainly leaf and root production, then gradually a change to more stem production (stem elongation, heading) takes place and, finally, grain filling becomes dominant.

The final product expressed as a harvest index might reflect the effect of limitations on production during a period in the growing season.

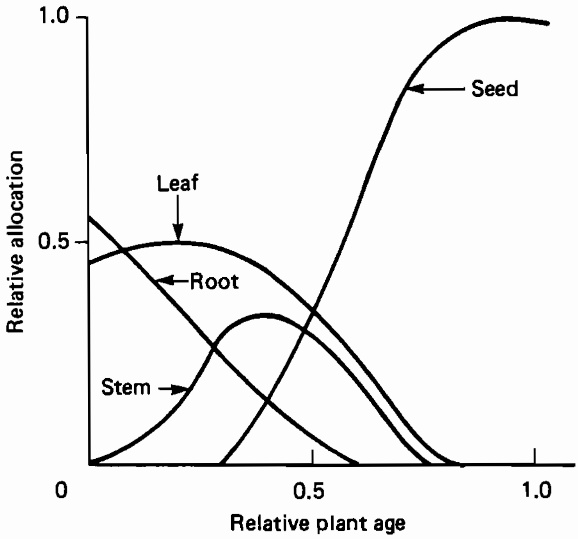

Figure 2.5. Relative partitioning over plant organs.

2.2.5. Nutrient availability

While estimating the effect of water availability on the yield, plant nutrients have been considered as being abundantly available. However, many nutrients are essential for plant growth, and their depletion or absence may restrict plant production. The reason may be an imbalanced nutrient supply or simply a nutrient deficiency.

In general nitrogen, phosphorus, and potassium are the most commonly deficient nutrients. This is partly the result of the relatively large amounts of these nutrients required. However, the soil might simply be very poor and not able to mineralize sufficient amounts of the nutrient, or it might fix nutrients applied as fertilizer.

Concept of Plant Response to Nutrients

The effect of nutrients on crop yields is shown in *Figure 2.6* (after van Keulen, 1982). The presentation is limited to nitrogen, but can be applied to other nutrients as well. The top right-hand quadrant shows the relation between nutrient uptake and the yield–nutrient uptake ratio is crop- and crop variety-specific.

If no fertilizers are applied, the yield depends entirely on the nutrient status of the soil and is therefore the result of the natural soil

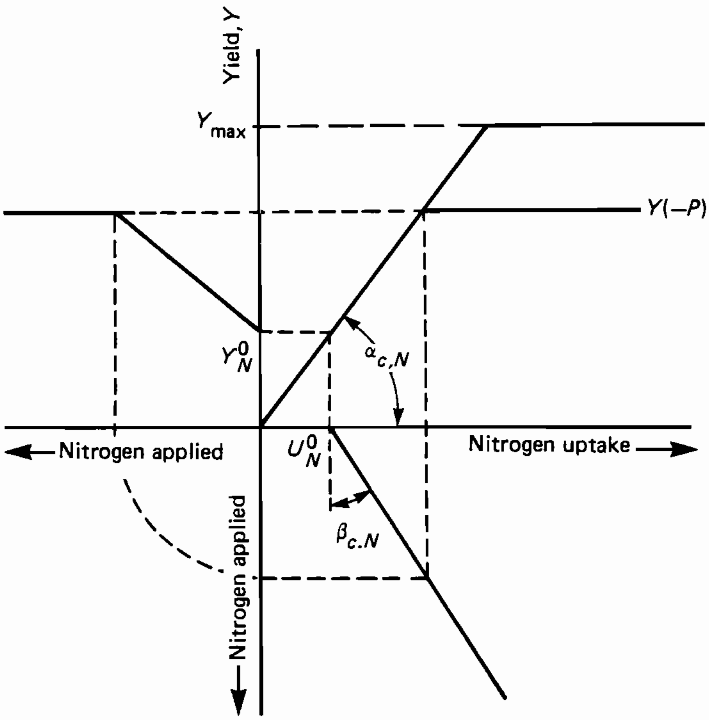

Figure 2.6. Graphical presentation of response to chemical fertilizers.

fertility properties and the nutrient management of the farmer. In the case of nitrogen, the organic matter in the soil is the most important source; some of the nitrogen may, however, come from the air.

The lower right-hand quadrant of *Figure 2.6* shows the relationship between the nutrient uptake and the applied nutrient. This relation is determined by the fertilizer efficiency. The efficiency is a function of the properties of the fertilizer itself, the soil chemical and physical properties, and the time and method of application of the fertilizer. The root system might play a role as well, for the more extensive root systems can intercept more nutrients. The top left-hand quadrant shows the direct relation between yield and fertilizer applied; this is the typical information obtained from field fertilizer trials.

The response to fertilizers can be expressed as:

$$Y_F = Y_F^0 + \alpha_{c,F} \cdot \beta_{c,F} \cdot V_F \tag{2.16}$$

where Y is marketable yield (kg/ha), Y^0 is yield based on natural fertility (kg/ha), V is amount of fertilizer applied (kg/ha), α is nutrient uptake coefficient, β is fertilizer efficiency coefficient, c is crop variety, and F is type of fertilizer.

Soil Fertility Status: Organic Sources

Among the solid parts of the soil, organic matter is subject to the quickest transformations. The changes in organic matter content are even measurable within the growing season. In this section we deal merely with the effect on chemical soil properties of the organic matter; however, organic matter contributes to the soil physical properties as well. *Table 2.5* shows the fractions considered and gives approximate values for the rates of decay for each.

Table 2.5. Fractions of organic matter: their decay rates and heterogeneity.

Fraction	*Heterogeneity* *(q)*	*Decay rate* *per day*	*Decay rate* *per 365 days*
Proteins	0.0008	0.23	0.17
Sugars	0.0035	0.17	0.05
Cellulose	0.0071	0.05	0.0037
Lignin	0.0015	0.0023	0.0013
Humic substances	4.5×10^{-6}	1.2×10^{-4}	1.2×10^{-4}

Organic matter is extremely complex material. Because of its heterogeneity, the model takes six different fractions into account (Centre for World Food Studies, personal communication). Each of the fractions responds differently to decay; the soil organisms that use organic matter as a source of energy show clear preference for certain components.

The rate of decay is described by:

$$\mathrm{d}fr_j/\mathrm{d}t = -k \cdot fr_j \tag{2.17}$$

where fr is amount in fraction, k is coefficient of decay, and j is the fraction.

The coefficient of decay is affected by the quality of the organic matter, the soil acidity, the soil temperature, and the soil moisture content.

The nitrogen mineralized from organic matter might be reincorporated by the organic matter and may partly be taken up by the plant. The possibility of being taken up by the plant is greatly dependent on the distribution pattern of the roots. *Figure 2.7* shows the sigmoid pattern of nitrogen uptake during the growing season.

Soil Fertility Status: Inorganic Sources

Inorganic materials can be important sources for nutrients as well. They will provide the plant in particular with phosphorus and potassium. Soil analysis is our main source of information about the status of the nutrients that stem from inorganic sources.

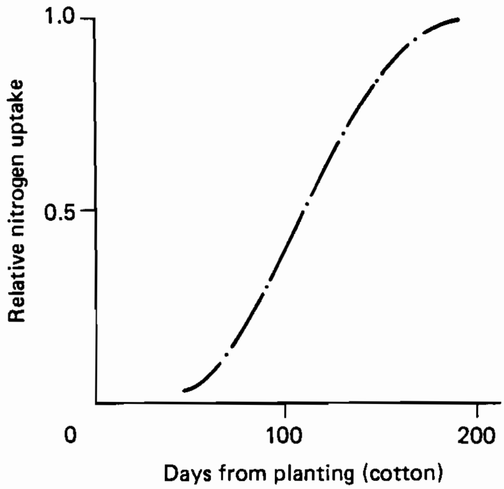

Figure 2.7. Relative nitrogen uptake during the growing season.

Figure 2.8 shows how soil analysis can be used to obtain possible yield. The coefficients are determined by plant and soil analysis, and by information from field fertilizer trials. ε_p is a soil-dependent parameter that relates the soil analysis for phosphorus to the amount of phosphorus uptake, while $\alpha_{c,p}$ is the nutrient uptake coefficient for phosphorus and a certain crop [compare to equation (2.16)]. The relationships have to be derived from local information, for the soil analysis is often area-specific.

2.3. Feedback Effects

To estimate crop yields, we need input characteristics that describe the physical production environment. These characteristics are subject to continuous changes, many of which are too slow to be measurable within the timeframe of a human generation. However, some – for example, organic matter – are known to be rather dynamic. The use of different rotation patterns and the additional application of tons of organic materials to maintain soil chemical and physical properties are based on long-term experience.

Some of the soil properties change because of on-site transformations; organic matter, already mentioned, is an important example. Such changes are not limited to the soil surface but also apply to some soil depth. This is different from the changes in soil properties that result from erosion by water and wind. They act upon the soil surface and remove a part of the

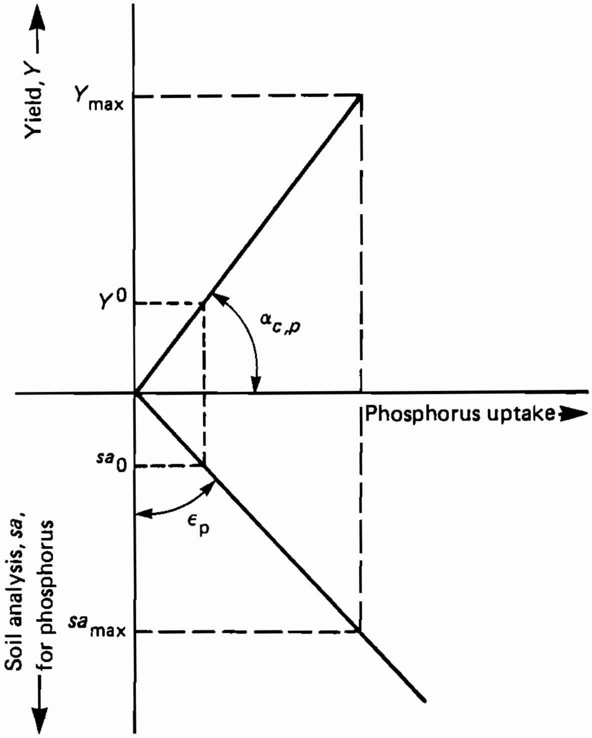

Figure 2.8. Response to fertilizers based on soil analysis.

topsoil layer, which is the most fertile part of the soil. Erosion usually brings about more losses than gains for plant growth. In places where deposition takes place, agricultural production often becomes impossible, unless large amounts of money are invested to level the soil surface

Erosion by water and wind is estimated in connection with the crop production model. The crop coverage is important for biomass production and serves at the same time as a protector from the impact of rain and wind. No attempt has been made here to develop new modules for the water and wind erosion: use has been made instead of the universal soil loss equation (Wischmeier and Smith, 1978) and the Kansas Manhattan wind erosion model (Woodruff and Siddoway, 1965). These equations have been extensively described in the cited literature. The main justification for their use is the lack of alternatives, and the attempts made (and still under way) to improve and to adjust the parameter values of the models for different climatic, soil, and management conditions. Although these equations are of empirical nature, they are based on variables that generally determine soil loss.

2.3.1. Consideration of some specific changes in soil characteristics

In this section, examples are given to show how soil properties change over time. Since the estimation of yields are based on these characteristics, direct effect on yields for the coming production years can be expected.

Soil Organic Matter

The role of organic matter has been described before. Its value needs to be updated from year to year. Its content will change, regardless of whether a crop is grown. Besides the continuing decay and/or increase after incorporation of the crop residue or by application, topsoil losses as a result of erosion are also taken into account. Knowing the soil loss and the soil bulk density, the loss in topsoil is approximated by:

$$tsl = (sl \times 10^{-2} / bd) \tag{2.18}$$

where tsl is topsoil loss (cm), sl is soil loss (metric ton/ha), and bd is bulk density (gm/cm^3).

Soil Moisture Retention Curve

The soil moisture retention curve tells us to what extent soil water is available for uptake by the plant. This relation is affected by a change in organic matter content (*Figure 2.9*). Higher organic matter contents will be accompanied by a higher soil porosity. Consequently, the soil will store more water and the water intake rate will improve. The latter is because the higher organic matter content leads to a better pore distribution.

The following equation expresses the significance of the organic matter:

$$sd = 100 / \sum_i \frac{a_i}{sd_i} \quad \text{and} \quad bd = 100 / \sum_i \frac{b_i}{bd_i} \tag{2.19}$$

where a and b express the percentage for each of the soil components (i), their sums should be 100%, bd is the soil bulk density, and sd stands for the soil's specific density.

Organic matter, with its low specific density compared to the other soil components, will decrease the bulk density when increasing in content.

Nitrogen

Organic matter is the main source for nitrogen. The mineralization occurs at such a rate that organic matter acts as a slow-release fertilizer. No carryover for the nitrogen as applied fertilizer has been allowed for.

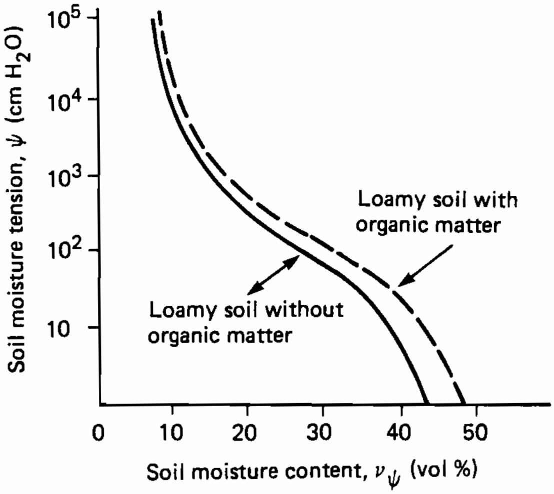

Figure 2.9. Soil moisture retention curv. as determined by organic matter content.

Phosphorus

Phosphorus applications are known for their inefficiency. It has been observed that regular applications of this fertilizer are necessary to maintain yields at a maximum level. This is due to the fixing capacity of many soils. However, after the year of application, there is a residual effect of the phosphorus applied.

In the case where no crop is grown, the rate of change of the residual effect of phosphorus fertilizers is approximately proportional to the amount applied:

$$d(sa)/dt = -b \cdot sa \tag{2.20}$$

The soil analysis (sa) includes the original amount available in the soil and the amount applied. No distinction has been made between these different sources.

When a crop is grown, a part of the available phosphorus is recovered by the crop. This is approximated by a linear uptake during the growing season:

$$d(sa)/dt = -a \tag{2.21}$$

2.4. The Crop Production Model Within the Task 2 Modeling Effort

The size of the case study areas is in all cases large enough to distinguish many different climates and soils. The combinations of soil and climate form the land class or land unit. These classes are themselves considered to be homogeneous. Differences between the classes should be large enough to affect yields substantially in the crop production model estimation.

Generally, the computing facilities and the expected computing time will determine to a large extent how many land classes are allowed for and to what extent aggregation is required: the number of land-use for each of the land classes can become too large to handle.

Decisions on the number of land classes and the land uses to be considered should be based on the cooperation of the different disciplines involved, bearing in mind the objective of the task.

Although various parameters used in the CPM are of general applicability, some need to be adjusted, based on local available information. For example, soils in the case study area might have soil moisture retention curves that do not fit the default values, and in particular the soil fertility status will need elaboration. The relation between the soil analysis and the (relative) yields needs to be available or developed. Expert judgment might sometimes be necessary to estimate the necessary parameters.

The land classes are described by a unique set composed of soil, site, and climatic characteristics. These characteristics are subject to changes over time. The climate cannot be derived by means of models: we need to work with historical or synthetic series. Therefore, the climate is exogenously given. The soil might change as well, although in certain properties it is rather robust. In any event, each of the various management characteristics applied will affect the soil characteristics for the next year's estimation. As a consequence we might have to distinguish at the end of the run more land classes, and the number of land classes might even explode. Regrouping of the land classes might be necessary in order to reduce the number of land classes to a level that can be handled. No method is fully satisfactory, but averaging, based on quantitative knowledge of the effect of changes in input properties on yield, seems the best at present.

Linkage of the various models involved in this task requires agreement upon input and output as connections between the models, but not only that. An aspect that merits our attention as well is the planting time. In temperate regions winter crops are sown in autumn, and various other crops in spring. If the model (including the crop production module and the decision module) is run on an annual basis, it is difficult to decide when the year should end. This becomes obvious if one realizes that the crop production model can only update its data base after the socioeconomic part of the model has made a selection out of the many generated crop yield options.

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CHAPTER 3

Agricultural Planning Models for Stavropol Region: Mathematical Description and Simulation Strategies

F. Ereshko, V. Lebedev, and K. Parikh

Abstract

Finding optimal sustainable production strategies that account for the environmental consequences of production can be cast as an optimal control or a dynamic programming analytical problem. The high dimensionality and nonlinear nature of the processes involved make such formulations impracticable, so simplifications are necessary. Each simplification compromises some optimality, so the choice of a particular approach depends on the specific problem and on the computational resources and tastes of the user. This chapter outlines a number of procedures for tackling the problem based on alternative assumptions and compromises.

3.1. Introduction

The main questions addressed in exploring the interactions of resources, environmental, and technological alternatives in the economic development of the region are:

(1) What production levels can be realized in a sustainable way with the resources of the region and considering the environmental consequences of such production in the region?
(2) What are the appropriate technologies for realizing these sustainable production levels?

A general methodological approach to address these questions of sustainable agricultural production strategies is outlined in Parikh and Rabar (1981). This approach recognizes that the perspectives of agricultural production in a region depend substantially on the potential biological possibilities of different types of soil in the region and on other natural conditions, as well as on policies regarding the use of resources, taking into account various economic and environmental considerations. This chapter describes the specific ways in which such an approach can be practically implemented.

The elements of the system can be schematically shown as in *Figure 3.1.* Formally, the analytical problem can be treated as an optimal control (Pontryagin *et al.*, 1962) or a dynamic programming (Bellman, 1957) problem. Yet the environmental processes involved in the modification of soil productivity that result from agricultural production are sufficiently complex and nonlinear, and the dimensionality so high, that one unified optimizing framework of a dynamic programming approach is computationally not practicable. Once it is recognized that an approach to obtain a global optimal solution is not practicable, a number of alternatives open up to simplify the system for defining second-best strategies. Each simplification leads to compromising certain types of optimality. The choice between the various second-best approaches depends on the problem at hand and on the judgment of the user. Although such approaches have the clear limitations that they do not optimize fully, they do provide practical simulation tools.

At first, a recursive programming approach may seem an obvious option. In such a formulation, the problem of what crop to grow on which soil with what technology and input levels is solved for one period as a linear programming problem. Then the soil quality status is updated, and the linear program for the next period is reformulated. Here, one sacrifices intertemporal optimality that can be realized when decisions for all periods are taken simultaneously. Yet a number of difficulties arise in such an approach as well. Beginning with one soil type, depending on the crop grown and the technology and input intensities selected for the crop, the quality of soil in the next period is modified. Thus, in very few time periods the number of soil classes to be considered becomes very large – and soon solution of the linear program becomes impractical. For example, beginning with one soil class and two crops, the number of soil classes in 10 years could be as many as 2^{10} (= 1024), and with three crops as many as 3^{10} (=59049).

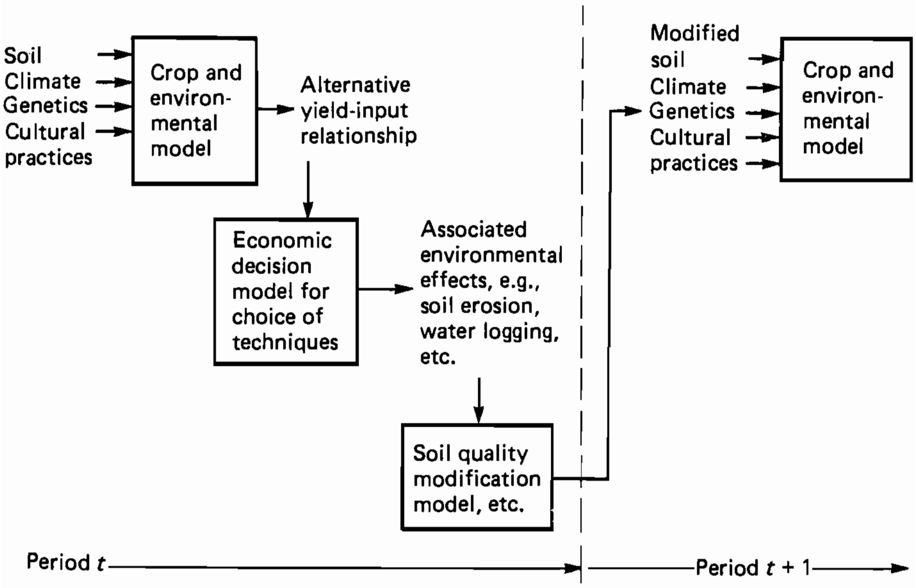

Figure 3.1. Schematic diagram of analytical elements.

Other types of simplification could be based on restriction of options for the choice of crops from year to year, or on separation of the economic and environmental objectives in a hierarchical way. For example, one may in the first step identify crop rotations that extend over a number of years. In the second step, from among these, one may preselect only those rotations that are environmentally acceptable, with acceptability suitably defined. In the third step, from among the environmentally acceptable crop rotations, economically attractive ones are selected. Such an approach may appear severely to restrict economic choices, but the restrictions can be agronomically sounder and may make the system solution more realistic, though nonoptimal.

An extreme simplification is to consider only monocropping. In other words, choice among different crops is not considered. Such a system can be useful in exploring the environmental consequences for individual soils of growing a particular crop.

Finally, one can dispense with any economic rationale for decision making and convert the data sets into a simulation system in which alternative production strategies can be examined for their economic and environmental consequences. Since the system is of high dimension, the number of possible simulations can be very large. To restrict simulations to a small subset of meaningful and interesting alternatives, experts' judgments have to be used.

The experts provide indicators used for evaluating the policies (decisions) under analysis; they also develop scenarios for concretizing values of the decision variables. In addition, they analyze the values of the indicators obtained in interactive computer runs and may also change the values of parameters, and even some relationships in the models, during the analysis. To make such computer-based analysis easier, automatization of computer runs should be achieved.

In this chapter we present mathematical formulations for some alternative approaches to the decision-making problems. These approaches are based on the physical crop production model (CPM), which relates soil and climate data to crop productivity through agronomic principles (including soil quality modification through erosion processes, described in Chapter 2), and also on an economic model developed for the Stavropol case study. Procedures for an interactive analysis using the suggested simplifications are also outlined.

The plan of this chapter is as follows: In Section 3.2 the physical crop production model is described to formalize briefly its underlying structure. Section 3.3 outlines a simulation procedure that does not incorporate any economic rationale for decision making. Section 3.4 suggests a procedure to simplify the dimensionally exploding recursive dynamic computational problems that underlie the substantive problems addressed here. Section 3.5 describes a further simplified model that is still in its initial stage of development.

3.2. The Physical Crop Production Model (CPM)

The physical CPM discussed in Chapter 2 describes the crop growth process using a decade (10 days – the term *decade* is used in this chapter to designate a 10-day period) as a time step, and also soil transformations using one year as a time step. For our purposes – that is, for formulating problems of decisionmaking – it suffices to consider the dynamics of the regional system using the time step of one year because one year is a characteristic interval for making decisions in the region under study. We describe first the state variables, decision variables, and parameters of the CPM. We use symbol t for numbering years. The region is assumed to consist of subregions with uniform characteristics (the notion of uniformity is explained later).

3.2.1. Parameters of the model

The following parameters define a region:

(1) Percentage of clay, silt, sand, and gravel.
(2) Size of the soil granules.
(3) Permeability of soil horizon.
(4) Cation exchange capacity for mineral components of soils, for each soil layer.
(5) Geographical coordinates of the part of the region considered.

3.2.2. State variables

(1) Ph^t – vector of physical characteristics has the following components:

  (a) Thickness of three soil layers.
  (b) Porosity of the layers.
  (c) Density of the layers.

(2) Ch^t – vector of chemical characteristics has the following components for each of the three layers:

  (a) Contents of the organic matter in the soil.
  (b) Nitrogen content.
  (c) Soil acidity.
  (d) Concentration of available phosphorus.
  (e) Concentration of available potassium.
  (f) Soil quality (ratio of carbon to nitrogen).

(3) Or^t – vector of characteristics of the structure of the organic matter in soil has the following components (for six fractions of organic matter and for three soil layers):

  (a) Percentage of a fraction in the total quantity of organic matter.
  (b) Quality (the ratio of carbon to nitrogen).
  (c) Percentage of carbon.
  (d) Cation exchange capacity.

(4) Ws^t – vector of variables that characterize soil moisture for the three layers.

Thus, the vector of state variables, z^t, has the form:

$$z^t = (Ph^t, Ch^t, Or^t, Ws^t)$$

3.2.3. Decision variables

We include in this class the following variables:

(1) N^t – quantity of nitrogen fertilizers applied during a year.
(2) P^t – quantity of phosphorus fertilizers applied during a year.
(3) K^t – quantity of potassium fertilizers applied during a year.
(4) O^t – vector that characterizes the use of organic fertilizers with components:
  (a) Quantity of organic fertilizers applied during a year.
  (b) Decade when the fertilizers are applied.
  (c) Structure of fertilizers (percentages of the six fractions and quality).
(5) W^t – vector of variables that characterize water use for irrigation systems of three types (by basin, furrow, and sprinkler) with components:
  (a) Total amount of water available.
  (b) Maximum delivery capacity of an irrigation system.

  The CPM computes, for each decade, the water demands by crops and the available water supply, using predetermined rules that take into account the maximum capacity of the irrigation systems and the total availability of water resources.
(6) c^t – number of a crop grown on a given land.
(7) A^t – vector of agrotechnical practices with components determined by the number of a crop, c^t, and by the type of plowing and its characteristics. One of the components of this vector is equal to 1 if crop residuals are removed from the field, and is equal to 0 otherwise.

Thus, the vector of control variables, u_t, is:

$$u^t = (N^t, P^t, K^t, O^t, W^t, c^t, A^t)$$

3.2.4. Noncontrollable factors

The vector of noncontrollable factors, ξ^t, is determined by weather and climatic conditions, and consists of a series of decade-averaged observations during a year:

(1) Air temperature.
(2) Relative air humidity.
(3) Wind velocity.
(4) Duration of sunshine (in hours).
(5) Precipitation.

3.2.5. Outcome of the model

The vector of production, y^t, is the output of the CPM. The components of y^t are the output of the basic and supplementary production. The hierarchical relationships of the CPM that determine the vector of production can be characterized by a mapping Ψ which relates y^t to the relevant state variables, decision variables, uncontrollable factors, and parameters of the subregion. Thus:

$$y^t = \Psi(z^{t-1}, u^t, \xi^t, p) \tag{3.1}$$

where p is the vector of parameters defining the subregion.

The associated water soil erosion, e^t, also calculated in the CPM, can be characterized by a similar mapping Φ:

$$e^t = \Phi(z^{t-1}, u^t, \xi^t, p) \tag{3.2}$$

Finally, the dynamic state equation in the CPM can generally be written as a mapping F, as follows:

$$z^t = F(z^{t-1}, u^t, \xi^t, e^t, p) \tag{3.3}$$

The outcome of the CPM is thus (y^t, z^t, e^t).

3.3. Simulation System

The simplest approach is to use the CPM in a simulation system that maps out the economic and environmental consequences of a prescribed production plan. The output (y^t, z^t, e^t) of the CPM serves as an input for the production and resource accounting module. To formulate the model, we divide the region's territory into L uniform subregions. We denote by s_l the area of subregion l and by S the total area of the arable land in the region. The uniformity of a subregion means that all physical, chemical, and other relevant characteristics are assumed to be the same over the area of the subregion. We shall also assume that only one crop and one technology, h, can be used in any subregion. Note that under this assumption the number of the uniform subregions L considered remains constant in time, whereas without it this number generally grows.

We denote by L_{ch}^t the set of subregions that, at the year t, are allocated for growing crop c using technology h. Then, the corresponding set of subregions allocated for crop c is:

$$L_c^t = \bigcup_h L_{ch}^t \text{ and } L = \bigcup_c L_c^t$$

The number of elements in L is determined on the one hand by the diversity of the soils in the region, in terms of physical and chemical characteristics (for the Stavropol region we have 15 classes of soil types considered to be uniform in the characteristics mentioned), and on the other hand by economic considerations, since we must have a sufficient representation of the technologies and crops to be able to analyze, for instance, the required production levels. Therefore, the set L can contain a considerable number of elements.

In this case, the simulation system for the whole region will consist of the CPM, and a production and resource accounting block.

3.3.1. CPM for the subregions

For each subregion l, the equations of the CPM are as follows:

$$z_l^t = F(z_l^{t-1}, u_l^t, \xi_l^t, e_l^t, p_l)$$

$$y_l^t = \Psi(z_l^{t-1}, N_l^t, P_l^t, K_l^t, O_l^t, W_l^t, c_h^t, A_h^t, \xi_l^t, p_l) \tag{3.4}$$

(crop production from unit area in part l)

$$e_l^t = \Phi(z_l^{t-1}, u_l^t, \xi_l^t, p_l), \quad l \in L, \quad t \in T$$

3.3.2. Production and resource accounting

The crop production vector, y^t, is obtained by simply summing production in different subregions. Thus:

$$\sum_l s_l y_l^t = y^t \text{ – vector of production}$$

The resources needed for production in the region are given by:

$$\sum_{c,h} \sum_{l \in L_{ch}^t} r_{ch}^k \, s_l = r^{t,k} \text{ demand for resource } k, \text{ k} \in K$$

where r_{ch}^k is consumption of k-th resource by technology h for crop c per unit area, and K is set of indices of resources, which are:

(1) Electric energy.
(2) Fuel.
(3) Chemicals.
(4) Tractor services.
(5) Transport services.
(6) Grain harvesters services.
(7) Corn harvesters services.
(8) Beetroot harvesters services.

For many agricultural systems, livestock production is integrated with crop production. Thus, it is necessary to account for livestock production. We denote by $d^{t,j}$ the fraction of the production $y^{t,j}$ used as feeds for animals. Then, the production of feeds of type ν is given by

$$\sum_{j \in J} \beta_j^\nu d^{t,j} y^{t,j} = d^{t,\nu}$$

where the coefficients β_j^ν describe the amount of feed ν obtained from one unit of product j used to produce feed ν. On the other hand, demand for feed is obtained as follows:

$$\sum_i k_i^\nu g_i^t = b^{t,\nu} - \text{demand for feed of type } \nu$$

where k_i^ν is consumption per animal head of feed ν, and g_i^t is number of structural units of animal of type i (cows, pigs, sheep, poultry). The output of animal product m is obtained by summing the output from different types of animals:

$$\sum_i \alpha_{im} g_i^t = a^{tm} \quad - \text{output of product type } m$$

where α_{im} is output of product m from structural animal unit of type i.

The difference between feed demand and supply to be imported from outside the region is given by:

$$b^{t,\nu} - d^{t,\nu}$$

The production and resource accounting block, together with the CPM, constitute a description of a general simulation model, which we call GM.

3.3.3. Simulation experiments

The controls in the model are:

$$L_{ch}^t, N_l^t, P_l^t, O_l^t, W_l^t, A_l^t, \text{and} g_l^t$$

We can specify various scenarios by choosing values of the control variables and by using equation (3.4) to obtain sequences of values of:

$$y^t, r^{t,k}, b^t, a^t, e^t$$

from which we can compute the values of the indicators of interest. Here, we shall consider the following quantitative indicators:

(1) Production output in a given proportion (or gross production).
(2) Soil erosion.
(3) Imbalance between demand and production of feed.

We assume that the available amounts of fertilizers and water are limited. Therefore, the objective of simulation is to help experts choose controls that satisfy the following conditions:

$$\sum_l N_l^t \le F^{1,t}, \quad \sum_l P_l^t \le F^{2,t}, \quad \sum_l K_l^t \le F^{3,t}, \quad \sum_l O_l^t \le F^{4,t}, \quad \sum_l w_l^t \le W^t$$

where values $F^{1,t}$, $F^{2,t}$, $F^{3,t}$, $F^{4,t}$, W^t as well as L are fixed at the beginning of the simulation run.

Such simulation experiments are useful in generating alternative production plans, the resources needed for meeting these plans, and for quantifying the associated environmental consequences of the plan. They do not, however, give any guidance about the economic desirability of the production plans generated. Not only is it impossible to say whether such a plan is optimal in terms of some given objective, but one cannot even tell whether the plan is economically efficient with regard to the resources used. Thus, one needs to develop procedures for generating economically meaningful scenarios. The use of these models for analyzing optimization problems (including multiobjective problems) is hindered by the high complexity and dimension of the models and also by the discrete character of the controls. In the following sections we explore some alternatives.

3.4. Crop Rotations to Maintain Soil Quality

The computational difficulties imposed by the exploding dimensionality of a recursive dynamic system can be circumvented somewhat by decomposing the system. By conceiving of crop rotations that preserve soil quality, and by confining production alternatives to only such rotations, one can split the recursive dynamic computational procedure into two steps:

(1) Use the CPM to identify, for a given soil, alternative crop rotations that provide a stationary state for the soil (as defined below).
(2) Select a set of crop rotations that optimize the production plan for a given objective.

Although such a procedure is not fully globally optimal to the extent that the choice is confined to a subset of crop rotations, it does provide a much more meaningful subset of production strategies than can be obtained through pure simulations as described in the previous section. Moreover, crop rotations are widely used in agricultural practice, and much expertise can be brought to bear on the process of generating alternatives.

3.4.1. Stationary crop rotation

To simplify the elaboration of policy-relevant scenarios, we introduce the following assumptions. We assume that for every part of the territory with index l there exists an initial state of soil z_l^0, and time interval T, and a sequence of controls u_l^t, that for some stationary weather conditions ξ^*_l ($\xi_l^t = \xi^*_l$ for all $t \in T$) the final state of the soil is the same as the initial one:

$$z_l^T = \bar{F}(z_l^0, z_l^1, \ldots, z_l^{T-1}, u_l^1, u_l^2, \ldots, u_l^T, \xi^*_l, \xi^*_l, \ldots, \xi^*_l, p_l) = z_l^0$$

We use this notion of stationary conditions in the following way. We divide a given area of land l into T equal subregions, and implement a given sequence of controls in each of them. Let $C = (c^1, c^2, \ldots, c^T)$ be the corresponding sequence of crops. Let us also choose the initial state for each of the subregions in such a way that at time $t = 1$ the initial state of subregion i, $i = 1, \ldots, T$ is z_l^{t-1} and is allocated to crop $c_t \in C$. Then, the state of the area of land l at time $t = 1$ is $(Z_l^0, z_l^1, z_l^2, \ldots, z_l^{T-1})$ and, although the states of the subregions change with time as shown in *Table 3.1*, the actual state of the area of land l remains the same.

Table 3.1. Sequential soil patterns under stationarity assumptions.

Subregion	$t = 1$	$t = 2$	...	$t = i$	...	$t = T$
1	z_l^0	z_l^1	...	z_l^{t-1}	...	z_l^{T-1}
2	z_l^1	z_l^2	...	z_l^t	...	z_l^0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
T	z_l^{T-1}	z_l^0	...	z_l^{t-2}	...	z_l^{T-2}

In this case, at any time t all crops will be present in subregion l and production from this subregion will be constant from year to year under stationary weather conditions. This production structure will be referred to as *crop rotation*. Crop rotations are widely used in agriculture, and for our purposes here we obtained the necessary information from Nikonov (1980).

The relationships describing soil transformation in part l in this case are the same for all parts. Therefore, we can use this type of relationship only for part 1 for which the initial crop is c_l^1 and the initial state is z_l^0:

$$\begin{aligned} z_n^t &= F(z_n^{t-1}, u_n^t, \xi^t, p) \\ y_n^t &= \Psi(z_n^{t-1}, N_n^t, P_n^t, K_n^t, O_n^t, W_n^t, c_n^t, \xi^t, p) \qquad (3.5) \\ e_n^t &= \Phi(z_n^{t-1}, u_n^t, \xi^t, p) \end{aligned}$$

where n is the index of a crop rotation.

The production accounting relationships for the system can be described as follows. Divide the territory of the region into L parts for which there exist sets of crop rotations: N_l^1 - for irrigated lands and N_l^2 for nonirrigated lands. Denote by $x_n^{1,l}$ the area allocated for crop rotation n in part l with irrigation. Assume also that only one production technology is used for each crop rotation. Denote by $y_n^{1,l}$ the vector of production on irrigated lands, and by $y_n^{2,l}$ the corresponding vector for nonirrigated lands. Then:

(1) Vector of production in the region:

$$\sum_l \left[\sum_{n \in N_1} y_n^{1,l} x_n^{1,l} + \sum_{n \in N_2} y_n^{2,l} x_n^{2,l} \right] = y$$

(2) Demand for resources:

$$\sum_l \left[\sum_{n \in N_1} r_n^{1,l} x_n^{1,l} + \sum_{n \in N_2} r_n^{2,l} x_n^{2,l} \right] = r^k, \qquad k \in K$$

(3) Constraints on the areas of irrigated lands:

$$\sum_{n \in N_1} x_n^{1,l} \le S_l^1 \tag{3.6}$$

(4) Constraints on the areas for part l:

$$\sum_{n \in N_1} x_n^{1,l} + \sum_{n \in N_2} x_n^{2,l} \le S_l \tag{3.7}$$

(5) Demand for feeds in the region:

$$\sum_i k_i^{\nu} g_i = b^{\nu}$$

(6) Animal production of type m:

$$\sum_i \alpha_{im} g_i = a^m.$$

3.4.2. Decisionmaking problems using stationary crop rotations

In principle, the formulation of the crop rotation problem will be complete if the problem of choice of the decision variables is formulated.

Consider a problem of increasing the production of agriculture in a given proportion (or increasing the gross agricultural production), under a given level of soil erosion and imbalances in feeds. We determine a finite set of technologies using the CPM, and we then use these technologies in the economic block to obtain a formulation of an auxiliary linear programming problem.

The required set of technologies can be obtained using equation (3.5) for a finite tuple of possible amounts of fertilizers N, P, K, O and of water W for various crop rotations C_n for given sequences $\xi^1, \ldots, \xi^{T_n}$, which reflect experts' judgments with regard to the uncertainty in weather conditions. *Table 3.2* shows the description of technologies for a crop rotation.

Table 3.2. Description of technologies for a crop rotation.

Production output	y^1	y^2	...	y^t	...	y^{T_n}
Crop index	c_n^1	c_n^2	...	c_n^t	...	$c_n^{T_n}$
Weather	ξ^1	ξ^2	...	ξ^t	...	ξ^{T_n}
Amount of fertilizers	N^1	N^2	...	N^t	...	N^{T_n}
	P^1	P^2	...	P^t	...	P^{T_n}
	K^1	K^2	...	K^t	...	K^{T_n}
	O^1	O^2	...	O^t	...	O^{T_n}
	W^1	W^2	...	W^t	...	W^{T_n}
State	z^0	z^1	...	z^t	...	z^{T_n-1}
Erosion	e^0	e^1	...	e^t	...	e^{T_n-1}

From this table we can find amounts of fertilizers and water actually used:

$$f_n^1 = \frac{1}{T_n}\sum_t N^t,\ f_n^2 = \frac{1}{T_n}\sum_t P^t,\ f_n^3 = \frac{1}{T_n}\sum_t K^t,\ f_n^4 = \frac{1}{T_n}\sum_t O^t, v_n \frac{1}{T_n}\sum_t W^t$$

The soil erosion is given by:

$$e_n = \frac{1}{T_n}\sum_t e^t$$

and crop productivity by:

$$y_n = \frac{1}{T_n}\sum_t y^t$$

These are used in the economic block. It may be noted that amounts of water may not be fixed, but are obtained as water demands of crops.

To this economic block, we now add relationships that describe demands for fertilizers and water:

$$\sum_{l}\left[\sum_{n\in N_1} f_n^{1,k}x_n^{1,l} + \sum_{n\in N_2} f_n^{2,k}x_n^{2,l}\right] = f^k, \qquad k = 1,2,3,4$$

with $f_n^{1,k}$ and $f_n^{2,k}$ being consumptions per unit area of nitrogen ($k = 1$), phosphorus ($k = 2$), potassium ($k = 3$), and organic fertilizers ($k = 4$) for irrigated and nonirrigated crop rotations, obtained as discussed earlier.

The water demand is given by:

$$\sum_{n\in N_1} \nu_n x_n^{1,l} = W^l$$

Total erosion of soils in the regions is given by:

$$e = \sum_{l,n} (e_n^1 x_n^{1,l} + e_n^2 x_n^{2,l})$$

Now we can formulate the optimization problem.

Given production and environmental targets Y, A, and E:

$$\max_{x}\left[\min\left[\min_{j\in J}\frac{y^j(1-d^j)}{Y^j},\ \min_{m}\frac{a^m}{A^m},\frac{E-e}{E}\right]\right]$$

subject to equations (3.6), (3.7), and

$$\begin{array}{lll}
r^k \le R^k, \quad k\in K & \text{resources} & \\
f^k \le F^k, \ k = 1,2,3,4 & \text{fertilizers} & (3.8)\\
w^l \le W^l, \ l\in L & \text{water} & \\
\sum_{j\in J_1} \beta_j^{\nu} d^j + \sum_{j\in J_2} \gamma_j^{\nu} y^j \ge b^{\nu} & \text{feeds} &
\end{array}$$

This problem can be reduced to the following linear programming problem:

$$\max_{x} \rho \rightarrow$$

subject to

$$y^j(1-d^j) \ge \rho Y^j, \qquad j\in J_1,$$

$$a^m \ge \rho A^m, \qquad m = 1,2,3,4;$$

$$e \ge \rho E$$

plus constraints as in equations (3.6), (3.7), and (3.8).

Having obtained the solution of the auxiliary crop rotation problem, we should perform its evaluation. This can be achieved by solving equation (3.4) of the CPM and computing values of the indicators. If the solution obtained does not satisfy the experts, the whole procedure can be repeated from any of the previous stages. The whole experimentation procedure can be depicted as shown in *Figure 3.2.*

3.5. One-stage Monocrop Model – A Further Simplification as an Aid to Experts

The procedure outlined in the previous section is computationally feasible, but would require considerable inputs from experts for identifying, evaluating, and assessing relevant crop rotations. In order to provide a feel to the experts on how the system actually functions, it was felt worthwhile to use the procedure for only one crop, rather than a crop rotation, for a number of years. This monocrop simplification thus differs from the basic recursive dynamic system in that, in the recursive dynamic global optimal framework, the decisions regarding what crop to grow, with which technology on which land, are taken every year. In the present simplification, it is assumed that the same crop will be grown on the land for T years. The choice of what crop to grow is done only for the entire period of T years, as in the crop rotation model of the previous section.

Clearly, this is a much less realistic framework than the crop rotation approach. Yet, such a simplification is easier to implement and was developed at the first research stage as an approximate formulation of crop rotations. The region's territory was divided into subregions with uniform characteristics (soil classes). Finite sets of technologies were also specified by experts for each crop, together with the corresponding factors of the resources consumption $k \in K$. From a given series of weather conditions, an expert chose a set Q of relevant sequences of T_1 years. Each year $t \in T_1$ of each sequence $q \in Q$ was also assigned a probability of occurrence, p_q^t, representing his judgment with regard to the uncertainty in weather. The problem considered was that of allocating resources for agricultural production, ensuring a certain level of production in a given proportion under some prespecified limit of soil erosion. Now we turn to a formulation of this problem.

We denote by $S_{ch}^{1,l}(S_{ch}^{2,l})$ an area allocated for crop c with technology h on part l, with irrigation (or without irrigation). For each $t \in T_1$ with fixed amounts of fertilizers and water, we have a form of the the CPM for one step:

$$\begin{aligned} z_l^1 &= F(z_l^0, u_l, \xi_l, p_l) \\ y_{l,ch} &= \Psi(z^{0_l}, N_l, P_l, K_l, O_l, W_l, c_h, \xi_l, p_l) \qquad (3.9) \\ e_l &= \Phi(z^{0_l}, u_l, \xi_l, p_l) \end{aligned}$$

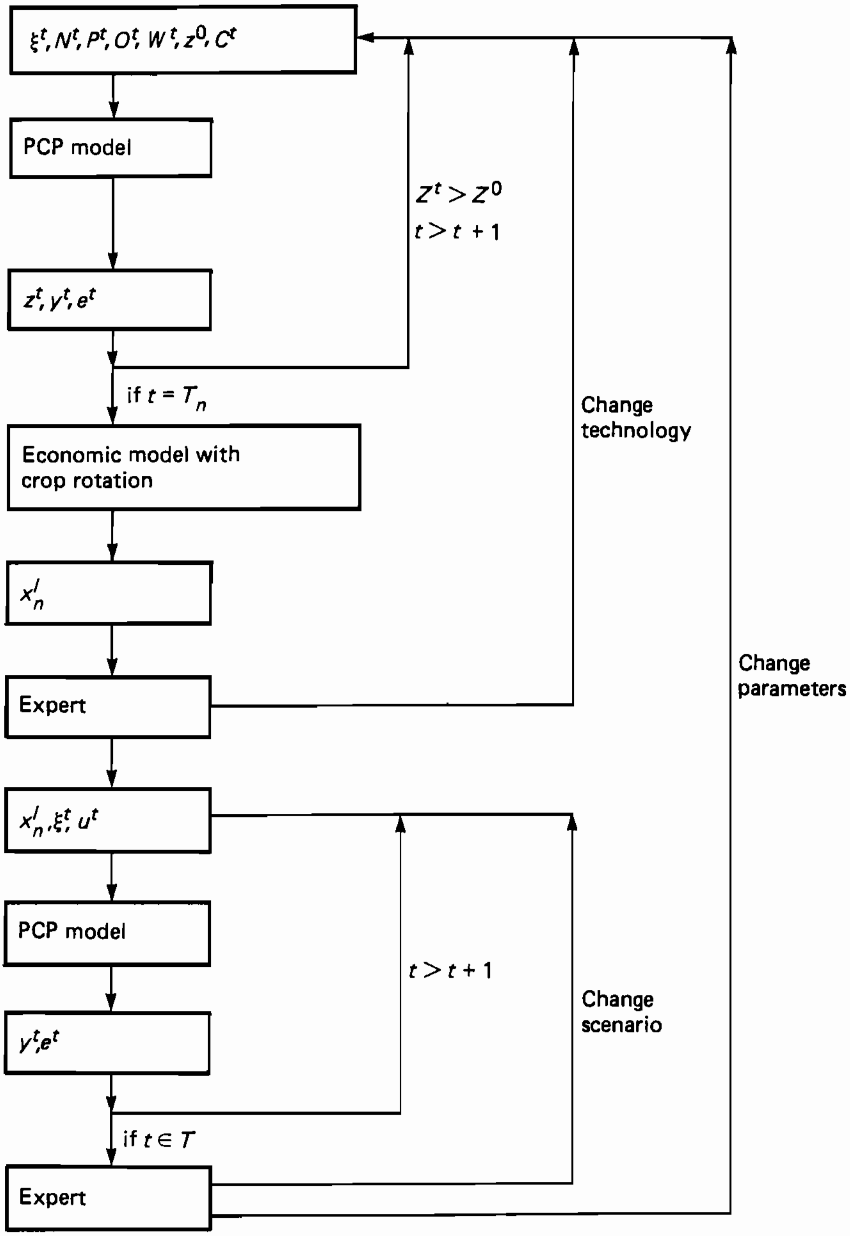

Figure 3.2. Experimentation procedure with stationary crop rotations.

from which we can compute production outputs $(y_{l,ch}^{1,t}, y_{l,ch}^{2,t})$ and soil erosion $(e_{l,ch}^{t})$.

We introduce the notation:

$$y_q^i = \sum_{t\in T_1} p_q^t \left[\sum_l \left(\sum_{c,h} s_{ch}^{1,l} y_{l,ch}^{1,t,j} + \sum_{c,h} s_{ch}^{2,l} y_{l,ch}^{2,t,j} \right) - d^{t,j} \right]$$

for the average production for the sequence of years q.

Now we can formulate a problem of maximizing guaranteed average production:

$$\max_{S} \min_{\substack{p_q^t \\ q\in Q}} \min \left(\min_{j\in J_1} \frac{\sum\limits_{t\in T_1} P_q^t Y_q^j}{Y^j}, \min_{m} \frac{a^m}{A^m}, \frac{E - \sum\limits_{t\in T_1} \sum\limits_{l,c,h} l_{l,ch}^t P_q^t}{E} \right)$$

where Y^j is a given vector of crop production, A_m is a given vector of animal production, and E is a given level of soil erosion, under the following constraints:

(1) Bounds on areas SL and SU in the following equation are chosen to ensure existence of a solution of the system in equation (3.11).

$$SL_c^{i,l} \le \sum_h s_{ch}^{i,l} \le SU_c^{i,l}, \quad i = 1,2 \tag{3.10}$$

(2) Capacity of irrigation systems:

$$\sum_h s_{ch}^{1,l} \le S^{1,l}$$

(3) Availability of area in the subregion l:

$$\sum_{c,h} s_{ch}^{1,l} + \sum_{c,h} s_{ch}^{2,l} \le S^l$$

(4) Availability of resources:

$$\sum_{l,c,h} r_{ch}^{1,k} s_{ch}^{1,l} + \sum_{l,c,h} r_{ch}^{2,k} s_{ch}^{2,l} = r^k \le R^k, \quad k \in K$$

(5) Availability of fertilizers:

$$\sum_{l,c,h} f_{ch}^{1,k} s_{ch}^{1,l} + \sum_{l,c,h} f_{ch}^{2,k} s_{ch}^{2,l} = f^k \le F^k, \quad k = 1,2,3,4$$

(6) Availability of water:

$$\sum_{ch} \nu_{ch} s_{ch}^{1,l} \le W^l, \qquad l \in L$$

(7) Availability of feed:

$$\sum_{j \in J_1} \beta_j^{\nu} d^{t,j} + \sum_{j \in J_2} \gamma_j^{\nu} \sum_{l,c,h} (s_{ch}^{1,l} y_{l,ch}^{1,t,j} + s_{ch}^{2,l} y_{l,ch}^{2,t,j} \ge \sum_i k_i^{\nu} g_i, \qquad t \in T_1$$

where R^k, F^k, W^l are resources available in the regions.

This problem is reduced to the following linear programming problem:

$$\max p$$

subject to the above constraints and

$$y_q^j \ge \rho Y^j$$

$$E - \sum_{t \in T_1} \sum_{c,h} e_{l,ch}^t p_q^t \ge \rho E, \qquad q \in Q$$

Solution to this problem gives some allocation pattern for various crops with different technologies $s_{ch}^{opt,i,l}$, $i = 1,2$. Using this allocation pattern, we can determine the corresponding allocation for crop rotations:

$$\sum_h s_{ch}^{opt,i,l} = \sum_{n \in N_i} \alpha_c^n x_n^{i,l}, \qquad i = 1,2 \tag{3.11}$$

where α_c^n is fraction of crop c in crop rotation n.

The crop rotation solution obtained can be analyzed using simulation runs, as outlined earlier. We should note that the monocrop solution is also of interest to the experts. It can be used, for example, to determine a sequence:

$$\sum_{c,h} s_{ch}^{1,l} y_{l,ch}^{1,t} + \sum_{c,h} s_{ch}^{2,l} y_{l,ch}^{2,t} = y^t$$

of productions for a fixed allocation of land and technologies, with varying weather conditions. However, it would not be proper to draw any conclusions regarding the dynamics of the agricultural production and resource system, as the choice of set of cropping activities is seriously curtailed by assuming that the same crop will be grown for t years on a given piece of land.

The procedure for performing the analysis using the monocrop model can be depicted as in *Figure 3.3*.

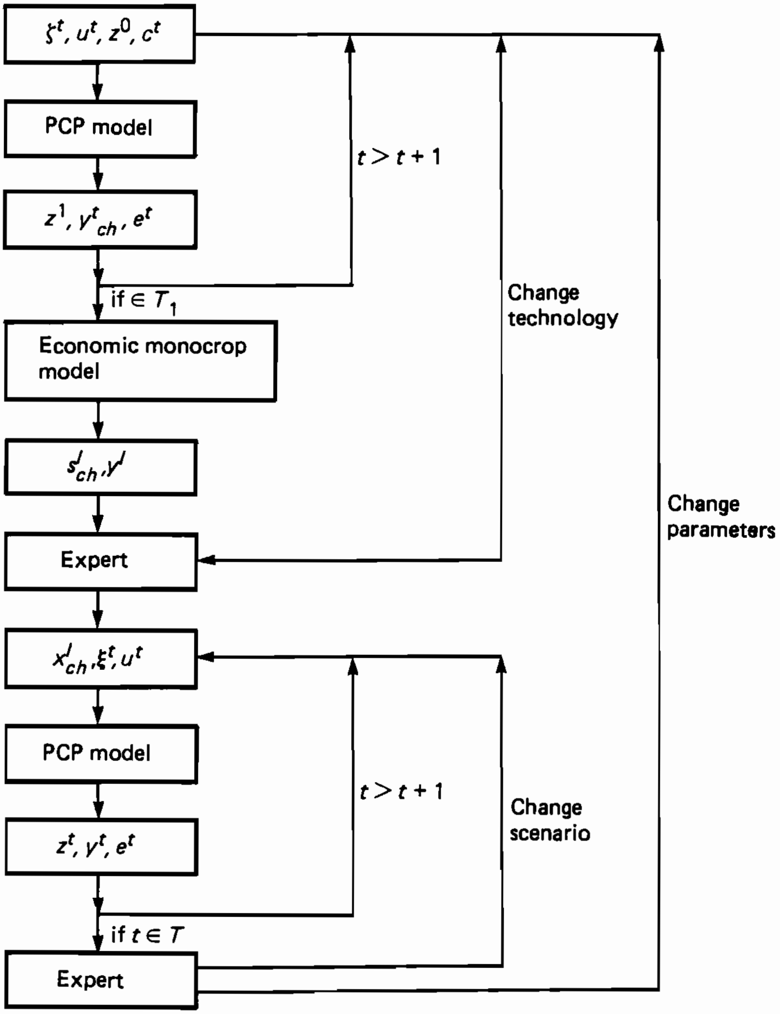

Figure 3.3. Analyzing alternatives using the monocrop model.

3.6. Computer Experiments

The computational procedure outlined in this chapter was implemented for the Stavropol project on IIASA's VAX computer, and also in the Computing Center of the USSR Academy of Sciences. Data for those experiments were prepared by experts (biologists and economists) for the simulation system described in Section 3.3. In particular, this included not only data for resources, but also data concerning crop productivities, demands for fertilizers, and water resources. Using these data, computer programs were developed for the analysis of the optimization problems outlined here. In parallel to this analysis, on the basis of the CPM, production of crops was determined for various amounts of fertilizers applied and water used for irrigation. Using the results obtained, new technologies were introduced into the optimization models outlined.

All the procedures discussed here have been implemented for the analysis of the agricultural production in Novo-Aleksandrovski and, subsequently, the whole Stavropol region has been analyzed on the basis of the one-stage monocrop approach.

3.7. Conclusions

We have described alternative ways to simplify the problem of finding optimal strategies for sustainable agriculture, thus making it computationally practicable. Although full optimality is sacrificed in the suggested procedures for exploring alternative strategies, the simplifications are done based on realistic notions of agronomic cropping patterns. Thus, one may expect that the loss of optimality may not be serious. This, however, is not established by us. One procedure searches for sustainable cropping patterns for each soil class separately in the first stage, and optimal cropping patterns for all the soil classes are selected in the second stage to meet economic objectives. Some of these procedures are applied in the Stavropol case study and have been found to be practicable.

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CHAPTER 4

An Information System for Agricultural Productivity

G. Maracchi, C. Conese, F. Miglietta, and L. Bacci

Abstract

The Mugello case study is an example of the application of ISAP (Information System of Agriculture Productivity), which is mainly devoted to assessing the productivity of a given area in relation to its natural resources in order to highlight the effects of human activity from both an agricultural and an environmental point of view.

The methodology used comprises two main steps:

(1) Compiling a data bank of natural resources and environmental constraints containing data on height, slope, exposure, hydrology, soil types, and climate, beginning with the digitized acquisition of each element. The data are divided conventionally into a finite number of elementary pixels to which the variables' values are attributed. The archives are compiled to enable maximum flexibility in utilization.

(2) Assessing and forecasting potential and actual productivity with a deterministic productivity model based on natural resources and environmental constraints. CROM (CROp Model) describes the most relevant processes concerning the soil–plant–atmosphere continuum. It simulates in 15-minute time steps soil moisture balance and water fluxes in the plant and in the atmosphere. Potential photosynthesis and stomatal resistance are then used to simulate crop growth and yield. Crop physiological parameters and environmental variables are used as model inputs. The effects of different technological levels on final yield may be finally estimated using empirical coefficients. Results of model runs can be used as input to econometric models.

The integration of data bank and crop modeling leads to a methodology that describes each area and is easily transferable among them.

4.1. The Case Study Region

A region for case study was selected based on previous findings on Italian agriculture (Maracchi, 1982), and because of the need for modeling agriculture in hilly and mountainous areas. The region, Mugello, is located in Tuscany in the district of Florence, and covers the watershed of the Sieve river, a major tributary of the Arno river. It is representative of the landscape of the Appennines and the pre-Appennine valleys. The surface area of the Mugello region covers about 104 000 ha, with an altitude range of 200 to 1400 meters (Mt. Falterona, the highest point) above sea level. The area extends for about 45 km in length and 20 km in width. The valley basin was formerly covered by a lake with a depth of 400 meters, which was responsible for the formation of some soils. In *Table 4.1* we present an overview of soil classification. We can distinguish 20 classes of soil type but, from an agricultural point of view, it is possible to divide the area into three main classes according to soil texture and soil depth: deep clay soil and sandy-loam soil together account for about 40% of the total area, and sandy soil of not great depth accounts for the remaining 60%.

Table 4.1. Soil types in the Mugello area.

Soil type	*Age*	*Elevation (m)*	*%*[a]	*Land-use*	*Depth*[b]	*Slope*[b]	*Erosion*[b]	*pH*
Sandy loam	Oligocene Miocene	>500	0.20	Forest Pasture	*	***	***	
Sandy	Eocene Miocene	200-500	0.40	Vineyard Cereals	*	**	**	
Clay	Pliocene	400-800	0.08	Cereals	**	***	***	5
Loam	Pleistocene	300-500	0.10	Pasture	*	**	***	>7
Clay-lime	–	200-400	0.04	Pasture Forest	*	**	***	>7
Sandy	Pliocene	200-350	0.07	Cereals	**	**	*	
Sandy-loam	Miocene	350-450	0.03	Cereals	*	*	*	
Loamy-sand	–	200-400	0.08	Cereals	***	*	*	7

[a] Of total land area.

[b] * Very shallow/low/minimal; ** moderate; *** deep/high/heavy.

The climate of the Mugello region (*Table 4.2*) is influenced by the Appennines; the temperature regime at an altitude of 200 meters differs from that of the Arno valley, where spring comes earlier. Differences in average minimum temperature can also be noted. These factors affect the length of the growing period required by crops, and must be taken into account in any attempts at agroecological classification (Maracchi and Miglietta, 1984). The time variability of the average monthly temperature ranges over a period of 10 years between s.d. = ± 1.5°C and s.d. = ± 2.3°C. The space variability is related to the altitude and the average is about 0.5°C per 100 meters. During the night, some temperature inversions occur.

The rainfall regime is quite equally distributed in the area, with peak figures occurring in the higher altitudes. The time variability of the monthly values of rainfall is quite high, with a variation coefficient ranging from 0.5 to 1.0. The most frequent winds blow from the northwest during the winter and from the southeast during the summer months.

Table 4.2. Climate of Mugello.

	Jan		*Feb*		*Mar*		*Apr*		*May*		*Jun*	
	max	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Temperature (°C)												
200 m	10.7	-1.1	6.5	2.2	13.5	3.9	17.8	6.1	24.9	8.9	28.2	12.5
1000 m	5.6	-2.5	5.8	1.0	7.8	1.2	11.4	2.9	17.8	6.1	21.7	9.8
Rainfall (mm)	111		114		101		98		100		80	
ETP[a] (mm)	43.44		54.33		65.22		122.55		212.88		290.0	

	Jul		*Aug*		*Sep*		*Oct*		*Nov*		*Dec*		*Annual av.*	
	max	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*	*max*	*min*
Temperature (°C)														
200 m	31.9	14.6	32.2	14.3	28.7	11.5	20.3	8.2	14.4	5.2	5.1	0.5	17.2	7.2
1000 m	24.6	11.8	25.5	12.0	22.1	9.2	14.9	3.8	9.0	2.0	5.1	-1.0	14.2	4.8
Rainfall (mm)	39		52		91		142		162		131		1221	
ETP[a]	395.2		342.0		232.6		147.4		68.8		31.6		2006	

[a] ETP is potential evapotranspiration.

The river Sieve regime (*Table 4.3*) is characterized by a very low discharge coefficient during the summer period due to low rainfall and high evapotranspiration; therefore, for annual summer crops, corn irrigation is necessary. During the winter, autumn, and spring the amount and the intensity of the rainfall means that accurate land management is needed on areas of sloping land in order to prevent erosion, while drainage in clay soils is needed to prevent landslides and to keep a sufficient level of oxygen in the soil to allow winter crop roots to respire.

Table 4.3. Hydrological parameters of the river Sieve (1931-1970).

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*
F: Flow discharge (mm)	85	92	83	55	45	27	9	5	10	30	67	88	596
I: Rainfall (mm)	111	114	101	98	100	80	39	52	91	142	162	131	1221
Coefficients F/I	.77	.81	.82	.56	.45	.34	.23	.10	.11	0.21	0.41	.67	.49
Flow (m^3/s)	26	31	25	17	16	9	0.77	1.58	3.26	9.34	21	27	15.80

The morphology of the watershed is represented by:

(1) The valley floor land, which has a slope ranging from 0 to 2% and is about 20% of the total.

(2) The hilly area, which ranges from 250 to 650 m in altitude with a slope of between 5 and 20% and is about 40% of the total.

(3) The mountain area , with a slope of 15% and above (*Table 4.4*).

Table 4.4. Main produce of the Mugello region (1979).

Crop	*Acreage* (ha)	*% of total area*	*Production* (100 kg)	*Production area*[a]
Wheat	8634	8.30	191775	**
Maize	1357	1.30	78710	*
Barley, oats	1750	1.60	35300	***
Legumes	115	0.10	800	**
Vegetables	100	0.09	14516	*
Potatoes	530	0.50	79200	***
Wine grapes	10215	9.80	241165	**
Olives	10841	10.00	33585	**
Pasture	10500	10.00	–	***
Forest	54220	58.30	–	***

[a]* Grown on plains; ** grown in hilly areas; *** grown in mountainous areas.

The main crop grown in the clay and sandy soils of the mountain and hill areas is wheat, while in the sandy and sandy-loam soils of the mountain alfalfa, some barley, and potatoes are grown. Vineyards and olive trees are located in the hills on sandy-loam soils on slopes with a gradient of about 15% facing south, while on the valley floor we find summer crops such as corn or some vegetables in very deep alluvial soils that are irrigated. In the highest area of watershed, there are pasture and forests on sandy soil of not much depth. Multi-use acreage is representative of the Appennine area and allows us to study the physical, biological, and economic features of the Mugello region as a sample of a larger area.

Demographically, the region (*Table 4.5*) has been characterized by the migration of population from both the countryside to the villages and from the villages to the nearby town of Florence during the years 1951 to 1979.

Table 4.5. Population figures and fluctuations for Mugello (1951–1980).

Population				*Fluctuations*			
1951	*1961*	*1971*	*1980*	*1951–1961*	*1961–1971*	*1951–1971*	*1951–1980*
89633	77572	73429	71102	–12061	–4143	–16204	–18531

This urbanization phenomenon has spread over the whole of Italy, and similar migration of the population from the southern regions to central and northern Italy occurred. Changes in cultural behavior are related mostly to these movements and to changes in type of work and professional attitude. From an administrative point of view, the region is divided into 12 districts. The distribution of those employed in the agricultural, industrial, and service sectors corresponds to national figures, and any major differences occur in the different districts. This change in professional activity has led to sharp changes in technology, with a decrease in the total number of people employed in agriculture, an increased use of machinery, and changes in the type of land management.

These changes have had a great impact on the type of agriculture: the use of energy, chemicals, and machinery was accompanied by a low degree of efficiency due to the lack of technical preparation, the complex structure of the land, and the type of natural resources. The type of technology required had to be well adapted to areas with steep slopes, soils difficult to cultivate, and a particular climate. The last factor, climate, is characterized by sharp changes within a few meters. The transfer of technologies of the "green revolution", developed for use in plain areas or for gentle slopes, has not been very successful, with the consequence that more and more people are departing from the agricultural sector. As a result, a large amount of land has been abandoned. *Table 4.6* shows that 65% of the total area cultivated in the watershed was abandoned by 1975. This phenomenon, together with changes in technology, has resulted in land degradation such as erosion, landslides, changes in water cycles, forest fires, etc. We can assume that in the next 10 years a large amount of Mugello's natural resources will disappear (i.e., the soil fertility that has been built up over the past several hundred years) if these trends continue. We need to study new technologies, to find an optimum combination of productivity factors, and a land management structure of property that allows us to find a way to support agriculture as a production and environmental activity.

4.1.1. An information system for agriculture productivity (ISAP)

The changes previously described called for a new assessment of agriculture, both from the point of view of productivity and of agricultural impact on the environment.

For that reason we devised a methodology to compute the productivity on the base of natural resources (Maracchi *et al.*, 1985). This method generates inputs for econometric models that draw alternative scenarios for decision makers, taking into account both natural resources, and social and economic parameters. The output is represented by the yield of main crops grown in the Mugello area for several combinations of soil, climate, and technology. The formation and management of a territorial data bank are dealt with in *Appendix 4A*.

Table 4.6. Abandoned areas in the Mugello region (1975).[a]

	Totally abandoned		*Partially abandoned*		*Forest*		*Total*		*Crop land*	*Forest*	*Pasture*	
District	*Surface*	*No.*	*Surface*	*No.*	*Surface*	*No.*	*Surface*	*No.*	*%*	*%*	*Surface*	*No.*
Barberino di M.	520.61	30	1377.42	125	245.76	22	2 141	177	83	17	–	–
Borgo S.Lorenzo	1156.42	88	818.47	82	113.67	12	2 097	183	79	21	8.65	1
Dicomano	971.00	85	8.40	2	–	–	979	87	78	22	–	–
Londa	1269.71	57	640.36	45	-	-	1 910	102	44	56	–	–
Pelago	–	–	100.41	9	–	–	100	9	75	25	–	–
Pontassieve	425.72	35	799.17	88	3.00	2	1 236	126	98	2	7.40	1
Rufina	299.29	40	171.76	31	41.76	7	538	82	99	1	24.70	4
S.Godenzo	3841.50	91	71.25	3	33.63	1	3 947	95	24	76	–	–
S.Piero a Sieve	263.84	24	667.24	64	–	–	931	88	100	-	–	–
Scarperia	149.22	5	813.45	66	–	–	974	72	68	32	11.50	1
Vaglia	177.3	13	1098.57	103	27.80	4	1 303	120	76	24	–	–
Vicchio	696.30	59	1375.44	175	1.50	1	2 134	242	68	32	60.76	7
Total	9770.75	527	7941.94	793	464.12	49	18 290	1 383	65	35	113.01	14

[a] Surface area measured in hectares; "No." refers to number of farms; and % refers to portion of total area in each district.

4.2. Description of Model

The CROM model consists of two main submodels, defined as *soil* and *crop* modules. A main program is used for data inputs and for daily potential evapotranspiration computations. Meteorological variables must be chosen according to the selected method of computing evapotranspiration. A very simple input can be used and, where necessary, the required meteorological variables are:

(1) Maximum and minimum daily air temperature (°C).
(2) Total daily rainfall (mm).
(3) Daily rainfall duration (hours).

This simple input has been developed so that the model can be better applied to agricultural areas where no standard meteorological network is available. The widest possible application of the model is one of the more important goals of this work.

For each module, a complete description, including explanations and equations, is given in the following two sections. Details concerning inputs and data-bank management are given in *Appendix 4A*.

The linkage of the crop module with the soil module, along with all the structural details, is illustrated in *Figure 4.1*.

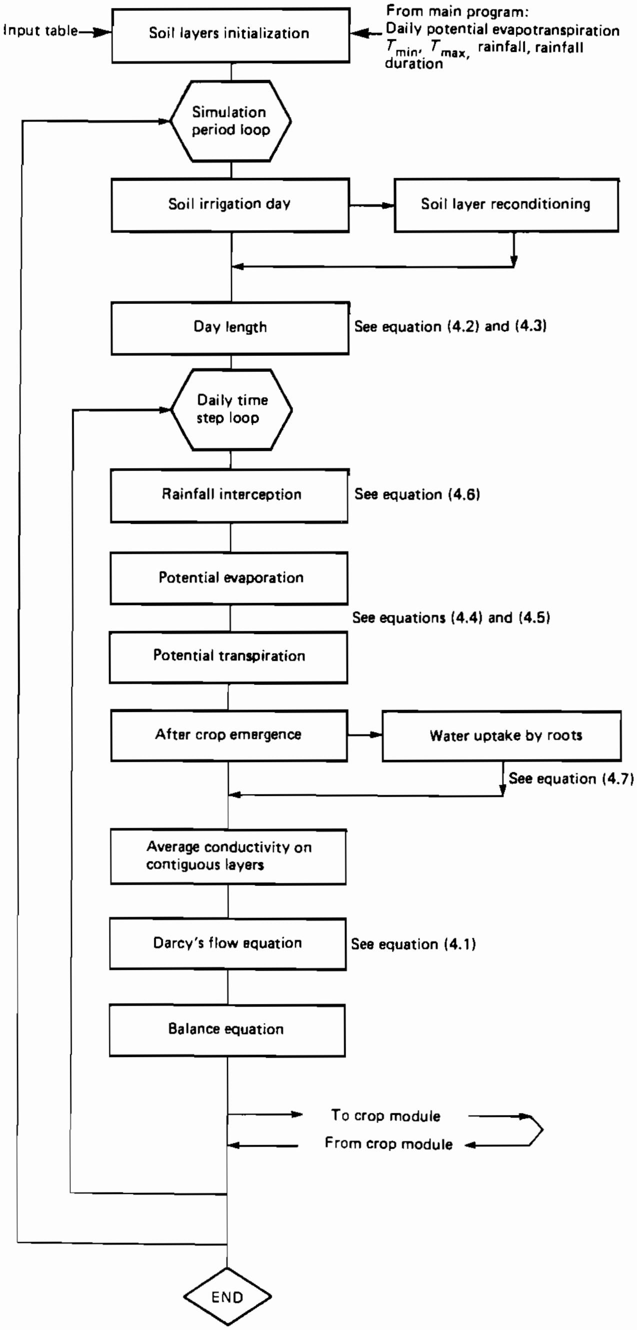


Figure 4.1(a). Structure of soil module.

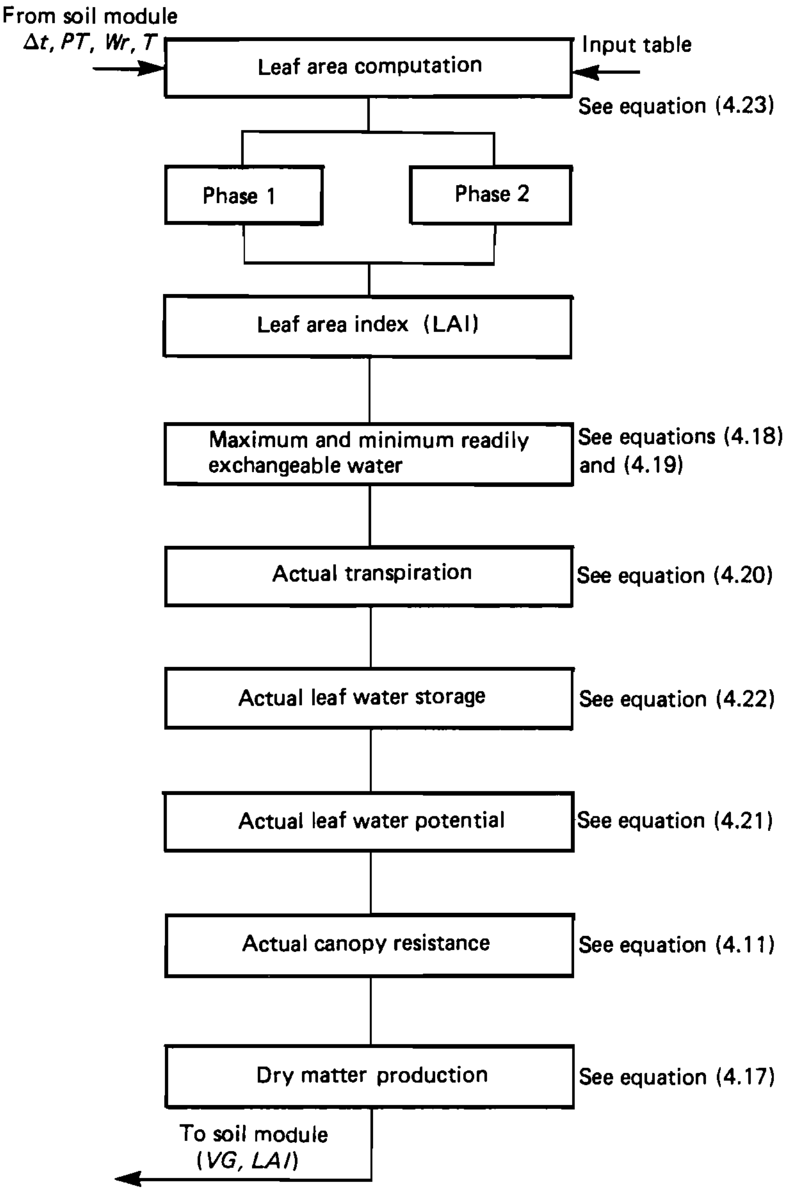


Figure 4.1(b). Structure of crop module.

4.3. Soil Module

4.3.1. Theory and development

Darcy's Flow Equations

The dynamics of water in the soil is given by Darcy's flow equation:

$$dF/dt = dY/dz \cdot K \tag{4.1}$$

where dF/dt is rate of change in soil moisture per unit time, dY/dz is soil potential differential (Y) per unit depth (z), and K is soil unsaturated conductivity.

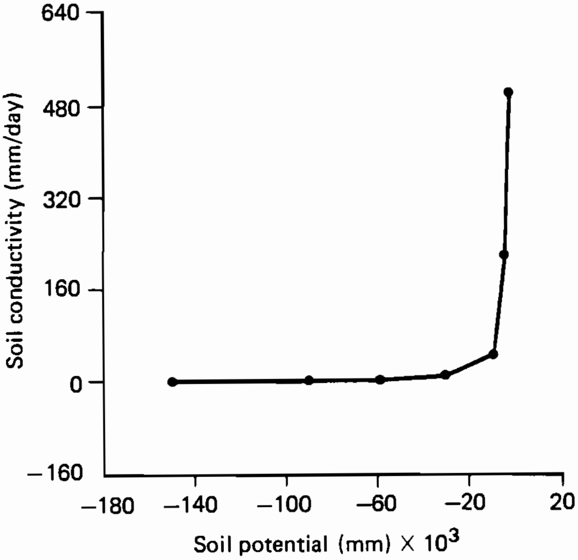


Figure 4.2. Unsaturated conductivity of a loamy soil in soil module approximation.

The CROM model uses a multilayered soil description, ranging from 0.1 cm thickness of the first layer to 10 cm of the last one (soil bottom). Soil profile depth is required as input and no water-table effect is modeled. Saturated soil conductivity is also required and unsaturated conductivities are computed using the Marshall algorithm (*Figure 4.2*). The tensiometric curve (soil matricial potential versus soil moisture, *Figure 4.3*) is also required but, for particular cases, due to low model sensitivity, bibliographic data may be successfully used (Rijtema, 1969). Soil bulk density is then used to compute water volume at each soil layer.

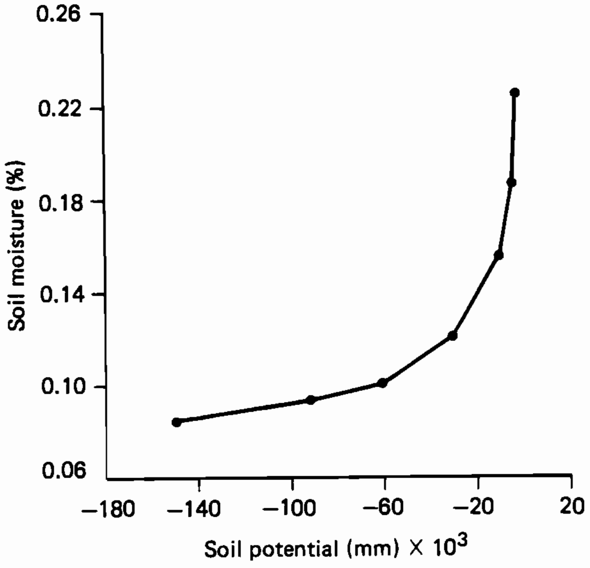


Figure 4.3. Experimental tensiometric curve of a loamy soil at IATA station (Mugello).

ETP as a Forcing Variable

Potential evapotranspiration (ETP), computed in the main program, is modulated at each time step of the model as a sinusoidal function ranging from minimum values at sunrise and sunset, to maximum values at midday (Hillel and Talpaz, 1976). For this purpose, a subprogram to compute day length is used according to the following equation:

$$\cos H = -\mathrm{tg}(l) \cdot \mathrm{tg}(d) \tag{4.2}$$

$$N = 2H/15 \tag{4.3}$$

where l is latitude, d is solar declination, N is day length, and H is hour angle.

The evapotranspirative flux is then partitioned between potential evaporation and potential crop transpiration, using an exponential relationship of the crop leaf area index:

$$PE = e^{(-0.6LAI)}\,ETP \tag{4.4}$$

$$PT = ETP - PE \tag{4.5}$$

where PE is potential evaporation, LAI is leaf area index, ETP is potential evapotranspiration, and PT is potential transpiration.

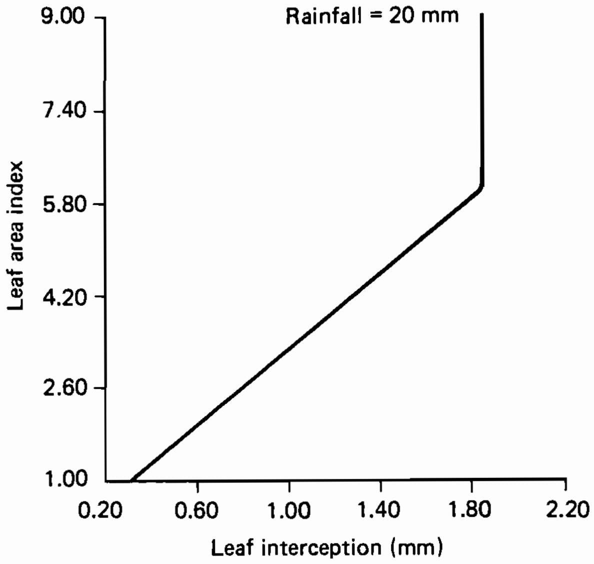


Figure 4.4. Leaf water interception as described in the model. A maximum daily water interception of 1.85 mm is used.

Rainfall Interception and Infiltration

Rainfall infiltration in the soil is modeled in a simple way. Rainfall interception by crop leaves (*Figure 4.4*) is described as follows (Feddes *et al.*, 1978):

$$L_i = a \cdot R^{[b - c \cdot (R - d)]} \tag{4.6}$$

where L_i is water interception by leaves, R is rainfall, and a, b, c, d are crop coefficients.

Empirical coefficients need to be chosen according to the geometry of the crop leaves. Since these data are not available, the model uses a unique approximation derived from experimental data (Feddes *et al.*, 1978). No water interception above 1.85 mm a day is taken into account. Total rainfall and its daily duration is then used to compute average rainfall rate per unit time. Soil infiltration is then modeled by means of an infiltrability code. This coefficient is a multiplicative factor of soil saturated conductivity. Using this rough approximation, together with a direct knowledge of soil characteristics, gives users a better description of the process. Runoff is then calculated as the difference between effective rainfall and infiltration. No particular modeling precautions have been taken for slope aspects of land morphology, and no surface-ponded water is considered. Further improvements will be devoted to a better description of surface effects on soil water regimes.

Water Extraction by Roots

Water extraction by roots is modeled both for balance equations of soil moisture and to compute actual crop transpiration (see Section 4.4). Potential transpiration, as derived from equation (4.5), represents the main cause of water extraction. A root system is described coupling two functions and a maximum depth estimate. A root shape coefficient, ranging from 0 to 1, allows a model of the root system. Lower levels of shape coefficient describe a more superficial root efficiency, while higher values increase root water absorption at deeper soil layers. So, potential transpiration is partitioned among relevant soil layers, and soil conductance is modeled in a linear way (Belmans *et al.*, 1983):

$$Wr_i = PW_i \cdot Cs_i \tag{4.7}$$

and

$$Cs_i = \frac{Y_{a,i} - Y_w}{Y_s - Y_w} \tag{4.8}$$

where Wr_i is water extraction by roots at soil level i, PW_i is potential water absorption by root at soil level i, Cs_i is soil conductance coefficient by root at soil level i, $Y_{a,i}$ is actual soil water potential at soil level i, Y_w is soil water potential at wilting point, and Y_s is soil water potential at field capacity.

Root water uptake and potential transpiration are then used in the crop module to compute transpiration rate.

4.3.2. Soil module output

On a daily basis, the computed values of soil water volume, moisture percentages, soil matric potential, and water extracted by roots are tabulated for each soil layer.

4.3.3. Time constants

The CROM model runs on a 15-minute time step. This time step has been chosen in the model as being well adapted to the numeric integration requirements of both balance and growth equations. Using input keys, it is possible to start soil simulation and crop growth at different dates; this allows for a good soil moisture estimate at the crop emergence. Before crop emergence a bare soil-water balance is simulated. At each time step of the model, a link with the crop module is performed, and crop growth variables are updated.

4.3.4. Soil module input

The following are the parameters used in the soil module.

Group A (Soil Physics Parameters)

(1) Number of soil layers.
(2) Thickness of each soil layer.
(3) Maximum soil depth estimate.
(4) Seven moisture values at corresponding tensiometric points (–0.3, –0.5, –1.0, –3.0, –6.0, –9.0, –15.0).
(5) Bulk density.
(6) Saturated conductivity (mm/day).
(7) Infiltrability code (from 1 to 10, depending on soil texture).

Group B (Crop Parameters)

(1) Maximum root depth (mm).
(2) Root shape coefficient (see text).
(3) Maximum crop leaf area index (LAI).

Group C (Time Parameters)

(1) Julian day of starting soil simulation.
(2) Julian day of ending soil simulation.
(3) Julian day of crop emergence.
(4) Julian day of crop harvest or cutting or grazing.
(6) Julian days of irrigation.

Group D (Meteorological Parameters)

(1) Daily potential evapotranspiration (–mm).
(2) Daily minimum and maximum temperatures (°C).
(3) Daily rainfall (mm).
(4) Daily rainfall duration (hours).

4.4. Crop Module

4.4.1. Theory and development

The instantaneous growth rate of a crop may be linearly modeled as a function of potential photosynthesis and canopy resistance.

Environmental factors, such as air temperature, incoming PAR (photosynthetic active radiation), soil, and leaf water potential, interact with stomatal behavior in the canopy.

This behavior may be accurately modeled, but it requires a large number of parameters and large experimental data sets (Penning de Vries, 1972; Takakura *et al.*, 1975; Jarvis, 1976).

The CROM crop module uses rough approximations to describe canopy resistance.

Air Temperature

For each simulated crop, the effect of temperature may be estimated as a linear function. Minimum air temperature for specific crop photosynthesis efficiency and optimal air temperature values are used as input (data may be derived from Hackett and Carolane, 1982).

According to the application goals of the model and the actual state of the national meteorological network, only two daily air temperature values (maximum and minimum) are required. The diurnal temperature fluctuation is then modeled using a sinusoidal finite-element equation (Floyd and Braddock, 1984):

$$L(T,t,A,B,D) = \mathrm{d}T/\mathrm{d}t + AT - D - [B \cdot \max(0,f(t))] \tag{4.9}$$

where L is diurnal temperature fluctuation, T is air temperature, t is time, A is constant depending on the thermal properties of the material, B is constant depending on the penetration of electromagnetic radiation through the atmosphere and pond water, and D is AT_b where T_b is an ambient temperature.

For each time step in the model, a thermal coefficient (Thc) is then computed according to:

$$\begin{array}{ll} \text{for } T < T_{\mathrm{opt}} & Thc = h(0,1,T_{\min}, T_{\mathrm{opt}}, T) \\ \text{for } T \geq T_{\mathrm{opt}} & Thc = 1.00 \end{array}$$

where T_{opt} is optimum temperature, $T_{\min}$ is minimum temperature, and h is the h-shape function previously defined.

Radiation

On a wide crop range, the diurnal variation in radiative input may partially affect canopy resistance. This effect is not really function-dependent on a global radiation regime, but only lower radiation levels induce a variation in stomatal behavior. For this reason, in the model, stomata start opening at sunrise and reach their maximum aperture, with allowance for other factors, after 10% of the total day length. For both stressed and nonstressed crops with an optimal temperature, stomata aperture trend is shown in *Figure 4.5*.

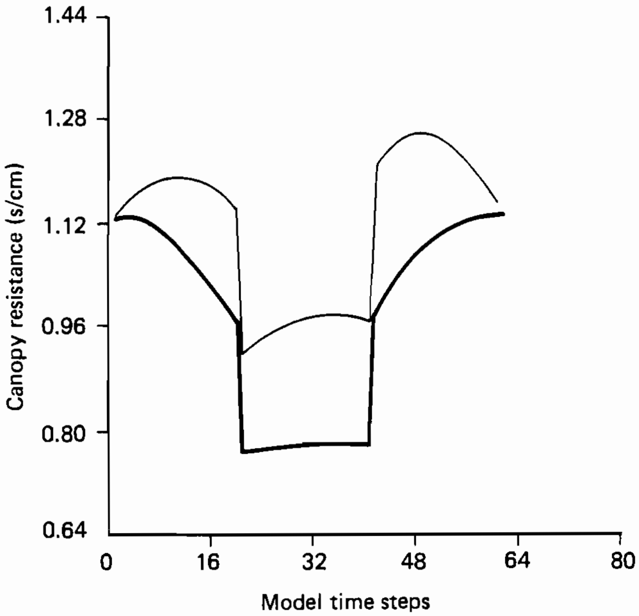


Figure 4.5. The effects of radiation (defined as a daytime function), temperature, and leaf water deficit force the model to define a daily canopy resistance trend. The stomata are closed at night. Thin line for a stressed day; thick line for a well watered day. Each time step is 15 minutes.

Further knowledge on light–stomata relationships for specific crops may improve the actual model design. Field and assimilation chamber experiments must be encouraged for a better definition of crop standards.

As a conclusion: in the model, no direct radiation-resistance function is used; the approximation is clearly less precise, but input data are reduced.

Leaf Water Potential

Leaf water shortage induces stomatal closure (Jarvis, 1976). Transpiration is reduced, and water stress of the biochemical compartment and plant turgidity reduction are avoided.

In the model, a hyperbolic trend of stomatal resistance versus leaf water potential is used. An estimated value of minimum stomatal resistance is required as input. *Figure 4.6* shows how this approximation is fitted on the measured data (Turner *et al.*, 1978) for soybeans. No evidence exists to suppose that this behavior might be modified by different genomes.

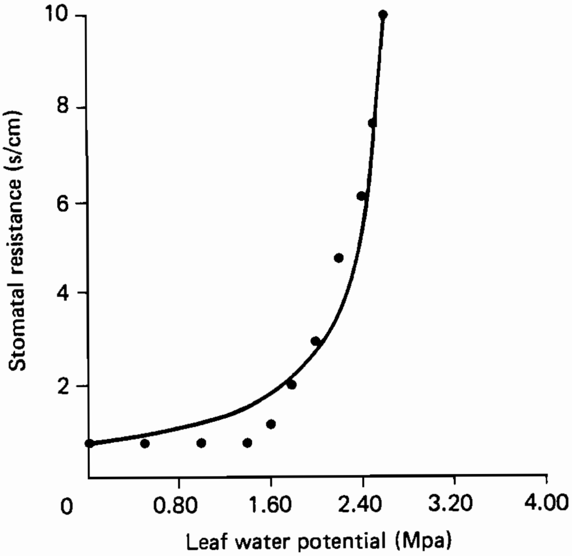


Figure 4.6. Approximated resistance values of CROM are compared with experimental data (Turner, 1978). Good fit shown for hyperbolic approximation.

Soil Water Potential

The soil water availability and crop resistance relationship is better described by the soil resistance concept. In the model, this aspect is solved in the soil module by relating potential evapotranspiration to the computed actual potential transpiration, following the equation:

$$Pr = ETP / Sr \tag{4.10}$$

where Pr is actual potential transpiration, ETP is potential evapotranspiration, and Sr is soil resistance.

Summary of Equations

Finally, the global resistance (R_c) is computed as follows:

$$R_c = \max(R_w, R_t, R_Y) \tag{4.11}$$

for:

$$R_w = R_{c\,\min} + \tfrac{1}{2} R_{c\,\min} \cdot R_f \tag{4.12}$$

$$R_f = \sin[90(\tfrac{1}{2}H - \Delta t]/\tfrac{1}{2}H) \quad \text{for } R_f \leq 0.90,\ R_w = R_{c\,\min} \tag{4.13}$$

and:

$$R_t = h(R_{c\,\max}, R_{c\,\min}, T_{\min}, T_{\text{opt}}, T) \tag{4.14}$$

and:

$$R_Y = \frac{S_n}{(Y_w - Y_a)} \tag{4.15}$$

where H is day length (hours), Δt is time of simulation, $R_{c\,\max}$ is crop resistance at stomatal closure, $R_{c\,\min}$ is minimum crop resistance, R_w is resistance induced by radiation, R_t is thermal resistance, R_Y is resistance induced by leaf water potential, T is actual air temperature, $T_{\min}$ is minimum air temperature, T_{opt} is optimal air temperature, Y_a is actual leaf water potential, Y_w is leaf water potential at wilting point (–2.7 Mpa), S_n is given by $R_{c\,\min}/Y_w$, and h is an h-shape function whose general form is:

$$(x_1,x_2,y_1,y_2,x) = \begin{cases} y_1 & x \leq x_1 \\ (y_2 - y_1) / (x_2 - x_1)(x - x_1) + y_1 & x_1 < x < x_2 \\ y_2 & x \geq x_2 \end{cases}$$

Crop Growth Rate

The basic section of the crop module is the dry matter production equation. Gaastra (1959) hypothesized the instantaneous crop growth rate as a function of resistance and carbon dioxide concentration in stomata and leaf area index:

$$\frac{\mathrm{d}W}{\mathrm{d}t} = \frac{\Delta[CO_2]}{R_s} \cdot LAI \cdot RESP \tag{4.16}$$

where $\mathrm{d}W/\mathrm{d}t$ is dry matter production rate per unit time, R_s is stomatal resistance, *LAI* is leaf area index, *RESP* is respiration coefficient, and $\Delta[CO_2]$ is the change in concentration of carbon dioxide. This approach requires the exact knowledge of carbon dioxide concentration in substomatal cavities.

Goudriaan and Van Laar (1978) defined the maximum hourly crop growth rate using photosynthesis light response curves. For closed canopies ($LAI = 5$), typical values of 60 kg CO_2/ha per hour for C_4 species and 20 kg CO_2/ha per hour for C_3 species were used.

Using these maximum growth rate values, we must define the basic model equation:

$$Dm = \int_t^{t+1} A_{\max} \cdot h(0,1,R_{c\,\min},R_{c\,\max},R_c) \cdot (LAI / LAI_{\max})\mathrm{d}t \tag{4.17}$$

where *Dm* is dry matter production, A_{max} is maximum dry matter production, R_{cmin} is minimum crop resistance, R_{cmax} is value of stomatal resistance at stomatal closure, R_c is actual canopy resistance, *LAI* is leaf area index, and LAI_{max} is estimated maximum crop *LAI*.

The LAI / LAI_{max} ratio approximates the exponential crop growth. The LAI_{max} value can only be based on empirical observations.

Crop Allometric Relationships

The dry matter growth rate (*Dm*) can be cumulated to simulate a growth curve. Each weight increment in the crop structure will also consist of a leaf area variation.

A rough phenological simplification of allometric plant behavior can be constricted in two main growth phases:

(1) Exponential vegetative growth, from emergence to maximum leaf expansion.
(2) Senescence, from flowering to harvest or crop death.

We can assume that the first phase is characterized by a linear relationship between crop dry matter weight and crop leaf area. This linearity is shown in *Figures 4.7 (a)* and *4.7 (b)* for two crop types, and in *Figure 4.7 (c)* for a grassland sward.

In order better to define a minimum emergence value of leaf area, the *DM / LA* ratio is fitted by a log/log regression.

The crop senescence, on the other hand, shows a less clear allometric trend. Normally, a logarithmic curve links dry matter accumulation and leaf area decrement.

The phenophasic switch between the two curve types is actually too rough. Results can be substantially improved by using a more deterministic approach to phenology aspects of crop growth.

Model sensitivity to allometric variations is very high; a good fit for the equation is necessary. Large growth analysis data sets will be necessary in the future, and standardization of allometric crop-specific parameters will best suit model applicability. A model improvement can certainly be reached using a deterministic approach to allometric aspects of crop growth. New leaf area measurement techniques and new morphogenetic models of crop growth models will furnish the required improvement.

An estimated average leaf thickness is also required for the computation of readily exchangeable water.

Plant Water Balance

Leaf water storage is modeled as a reservoir that can balance water root extraction deficit due to transpiration. Leaf water potential is then

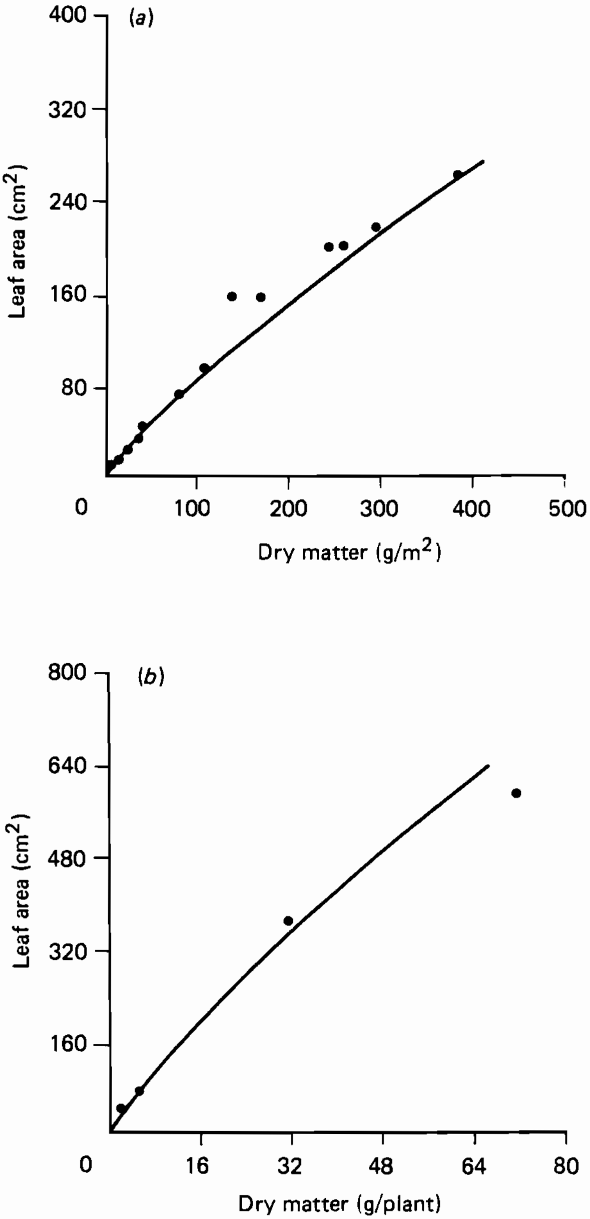


Figure 4.7 (*a* and *b*). Allometric relationships between dry matter and leaf area expansion is given for two tested crops and grassland. Equations are: (*a*) winter wheat (1983/84): $\ln(La) = 5.39 + 0.83 \ln(Dm)$; and (*b*) corn (1984): $\ln(La) = 5.40 + 0.802 \ln(Dm)$.

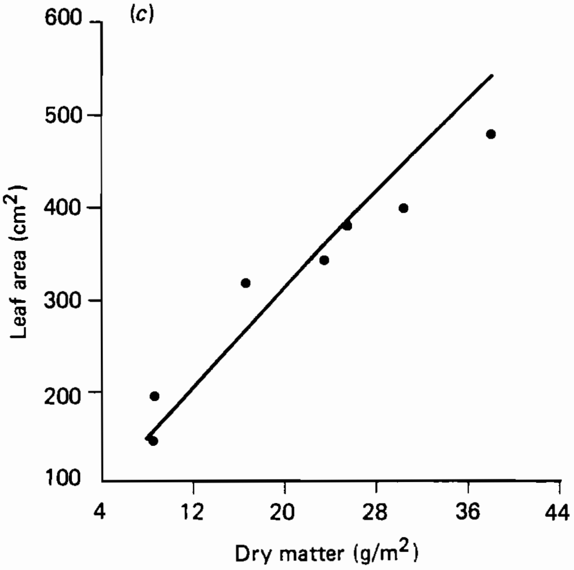


Figure 4.7 (c). Allometric relationships between dry matter and leaf area expansion is given for two tested crops and grassland. Equation [Dactylis (1983)] is: ln (*La*) = 5.54 + 0.840 ln (*Dm*).

balanced by crop canopy resistance and stomatal closure. Night time simulation allows, as really happens, compensation for daily water loss (*Figure 4.8*). No biological damage caused by water stress is taken into account.

The driving equations may be described as follows:

$$VG_{max} = 0.8La \cdot th \tag{4.18}$$

$$VG_{min} = VG_{max} \cdot C \tag{4.19}$$

$$AT = h\,(PT, RW, Y_w, Y_0, Y_a) \tag{4.20}$$

$$Y_a = (1 - VG / VG_{max}) \tag{4.21}$$

$$VG = VG_0 - AT + RW \tag{4.22}$$

where VG_{max} is maximum water content, VG_{min} is minimum water content, VG is actual water content, VG_0 is water content at time $t-1$, C is readily exchangeable water percentage, LA is leaf area, th is leaf thickness, AT is actual transpiration, PT is potential transpiration, RW is root water absorption, Y_0 is minimum leaf water potential, Y_w is leaf water potential at wilting point, and Y_a is actual leaf water potential.

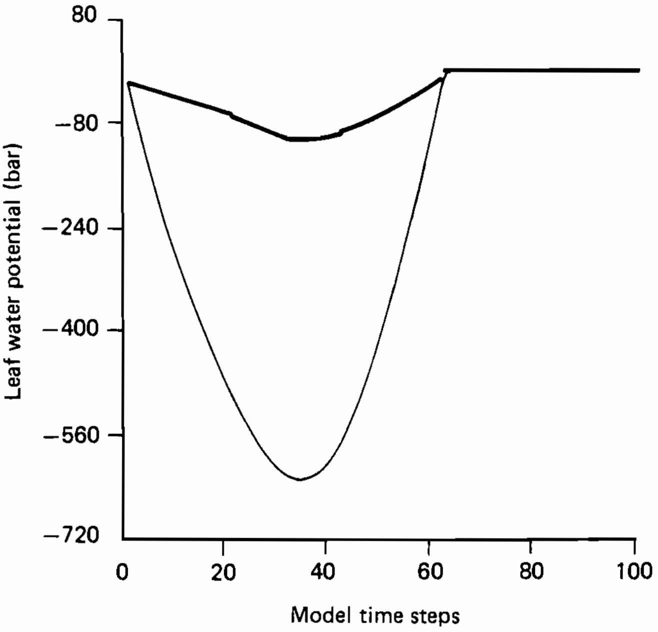


Figure 4.8. Daily fluctuations of leaf water potential for a dry soil (thin line) and a well-watered soil (thick line). The time of day is given in 100 time steps (15 minutes each step). A good water recharge during nighttime is shown for both cases.

Crop Model Output

The model output can be easily driven by some input keys to switch tabular outputs. Normally, daily values of dry matter, leaf area, and LAI are tabulated; for each daily step, an average value of canopy resistance and leaf water potential may be obtained. The model also allows for the selection of particular days, and for the tabulation of the computed values of many model variables for each time step.

4.4.2. Crop Module Input

Group A (Crop Parameters)

(1) Minimum estimated canopy resistance.
(2) Minimum estimated air temperature for crop efficiency.
(3) Optimal estimated air temperature for crop efficiency.
(4) Minimum estimated dry matter at crop emergence.

(5) C_3 or C_4 species.
(6) Average leaf thickness.

Group B (Allometric Functions)

(1) Slope and intercept of dry matter–leaf area log/log (equation (*a*)).
(2) Slope and intercept of dry matter–leaf area log (equation (*b*)).
(3) Crop density, as related to (*a*) and (*b*) measurements.

4.4.3. CROM model validation experiments: CMVE

The CROM model performance has been tested with a large number of experimental data.

The test sites of experiments were located on the Institute for Soil Study and Conservation (ISDS) experimental farm near Florence. The experimental farm is equipped with an automatic meteorological station. Other published data sets used in model validation were kindly supplied by different institutions.

WCMVE 83/84 (Wheat CMVE)

The first field experiment was carried out in the winter of 1983/84, on durum wheat cultivation (cress). It was planted in rows spaced 25 cm apart, with fertilization of optimal nitrogen and other nutrients.

Growth analysis was then performed using large crop samples (1 m^2), and the most important measurements were made weekly. During the spring a period of intensive field work was carried out for the measurement of crop parameters.

A diffusion porometer (LICOR 1600), pressure chamber (PMS model 1000), and infrared thermometer were used for the experiment. Measured data on a complete daily cycle were:

(1) Stomatal and canopy resistance.
(2) Leaf water potential.
(3) Infrared temperature.
(4) Soil moisture, twice a day.

Model inputs: Maximum crop LAI was estimated on flowering to have a value of 2.5.

Allometric parameters for winter wheat were then computed and fitted using regression equations (see *Figure 4.7*).

Minimum air temperature for crop efficiency was chosen as an average daily value of 4°C, while optimal value was above 15°C.

Clay-loam soil moisture was initialized at field capacity.

Crop emergence was at 10 days after seeding, on November 20th, and the crop was harvested on July 10th. In the model, a starting dry matter value of 1.00 g/m^2 was used. Minimum crop resistance was fixed at 0.75 s/cm and average leaf thickness at 0.7 mm.

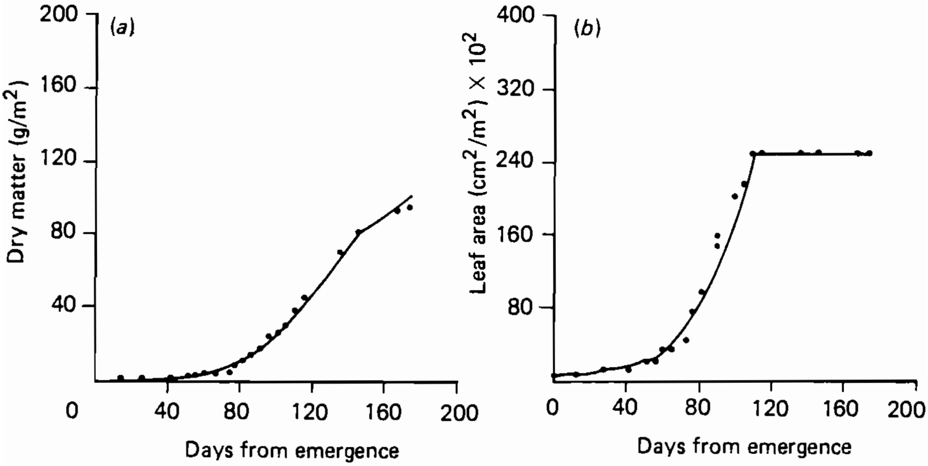


Figure 4.9. A good fit is obtained by CROM simulation of (*a*) crop dry matter; and (*b*) leaf area estimates, for WCMVE (see text). Continuous line indicates simulated dry matter values while dots refer to field experimental data. A maximum crop *LAI* of 2.5 is used.

Figure 4.9 shows the model performance as related to the field test for dry matter and leaf area estimation. *Figure 4.10* shows a comparative test between leaf water potential estimates and field data.

CCMVE (Corn CMVE)

A second validation test for the CROM model has been carried out on a corn field at the experimental station. The Dedalo H cultivar, planted in rows spaced 40 cm apart, with a seed density of 7 plants/mq, was grown in two water regimes. The early irrigation was scheduled on July 10, 1984 for both crops, while a second one, on July 20th, was carried out only on the irrigated field. CROM simulation started on June 10th, the seeding date, with an initial soil conditioning at field capacity.

Model inputs: The root system was described with a maximum root depth of 40 cm, and a shape function of 0.5. The saturated conductivity was estimated according to Rijtema (1969), for a "sandy-clay loam" soil.

Low infiltrability code 1 was used. For the crop module, a dry matter–leaf area log/log relationship was parametrized on a large corn sample and the values were (see *Figure 4.7*):

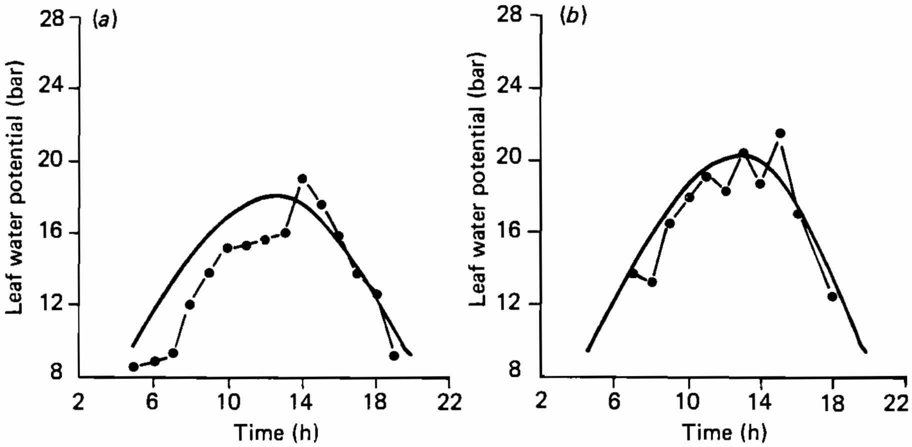


Figure 4.10. During WCMVE 1985 (see text), on two different days, a comparative test between CROM model leaf water potential estimates and field data was performed. A good fit is shown for both daily potential trends.

$$\ln(La) = a + b\ln(Dm) \qquad a = 5.40;\ b = 0.802 \tag{4.23}$$

The maximum crop LAI was estimated to be 6.32, and the optimal average air temperature 20°C.

Figure 4.11 shows the model performance as related to the field test for dry matter estimation, for both experimental trials.

Other Validations

During the growing season 1983/84, an Italian research group (FAAPE) carried out a large experiment on grassland swards, ranging from North Italy locations (Chieri, Novi Ligure, and Padova) to Central Italy (Firenze, Perugia) and Insular Italy (Sassari). Three swards were tested both in grazing and cutting systems (Talamucci *et al.*, 1985).

Other model inputs were tuned to the specific cultivation [see *Figure 4.7 (c)*].

Meteorological data were acquired on conventional network thermopluviometric stations.

The particular crop system (cutting + grazing) forced the model to be run for each growth cycle. Variables from each model iteration were supplied to the next one. In the example shown below, only the first cutting cycle of cocksfoot is given for Florence [*Figure 4.12 (a)*], Padova [*Figure 4.12 (b)*], and Perugia [*Figure 4.12 (c)*], while the complete growing season trend is shown for the Novi Ligure location (*Figure 4.13*), where the model showed the best fit.

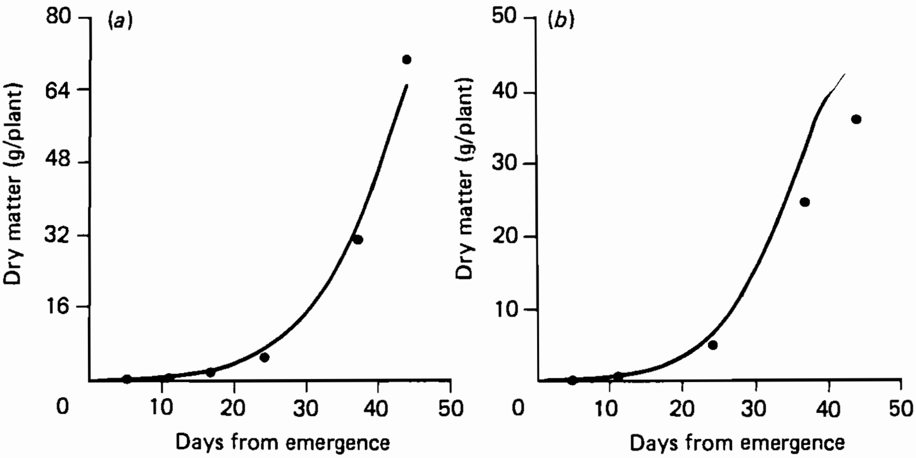


Figure 4.11. A good fit is obtained by CROM simulation of crop dry matter for CCMVE (see text). Continuous line indicates simulated dry matter values while dots refer to field experimental data. (*a*) Irrigated corn; (*b*) nonirrigated corn.

4.4.4. Interpretation of the results and applications

In the simulated crop and grassland, growth curves show a very good fit. Further tests are needed, but a good applicability of the model can be derived from these results.

The model could be used in potential productivity assessment. Land unit classifications on a regional scale may supply soil module inputs.

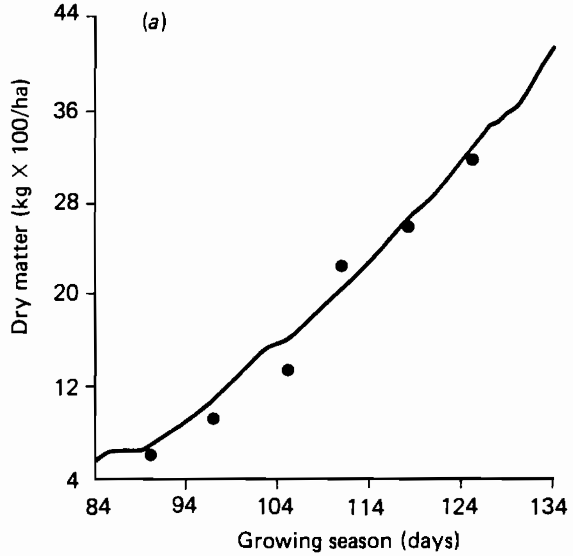
To simplify input availability, tensiometric curves may be derived from bibliographic sources (Rijtema, 1969), texture analysis from available soil maps, and infiltration and conductivity estimates by a correlation technique with soil type (Field *et al.*, 1984).

Crop parameters may be used on the basis of the preceding experiments with large-scale validity, as the cocksfoot example shows. For different crops, new field experiments must be carried out or new experimental data sets must be found.

Meteorological data must be directly acquired from existing meteorological networks.

For the Italian case study, we believe that a strategic configuration of the agrosystem may be summarized by the following three main cultivations: a winter cereal, a summer crop, and a grassland sward. For this reason, an example of land potential productivity is given on the model basis.

For an approximate land unit definition we used:



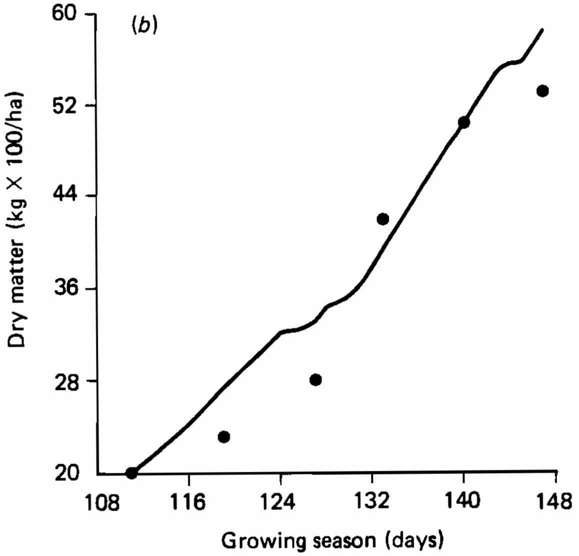


Figure 4.12 (*a* and *b*) Simulated values by CROM model are compared with experimental data for three Italian environments. Good fit shows a high model applicability in every environmental situation. (*a*) Firenze; (*b*) Padova.

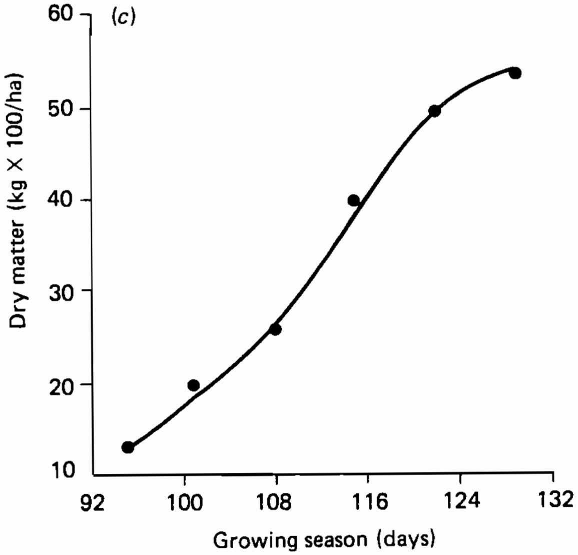


Figure 4.12 (c). Perugia. (See note at foot of page 84.)

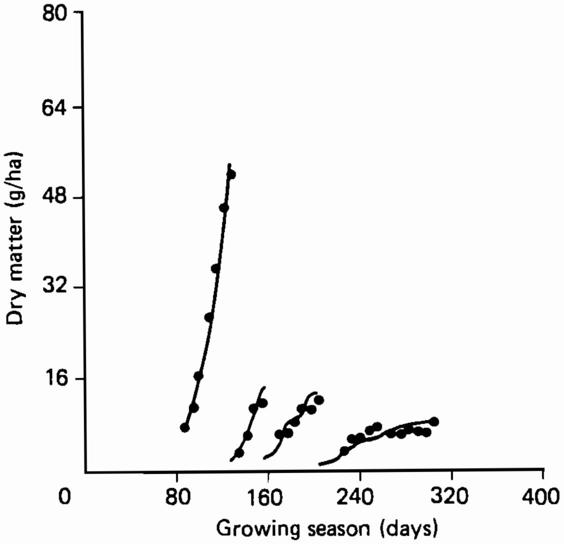


Figure 4.13. A complete cutting + grazing cycle during the 1984 growing season for cocksfoot grassland in Novi Ligure (Northern Italy). CROM-simulated values are displayed by continuous lines while dots represent experimental dry matter data. A good fit is shown for each regrowth cycle. Iterative use of CROM model allows users to perform pastures productivity simulation.

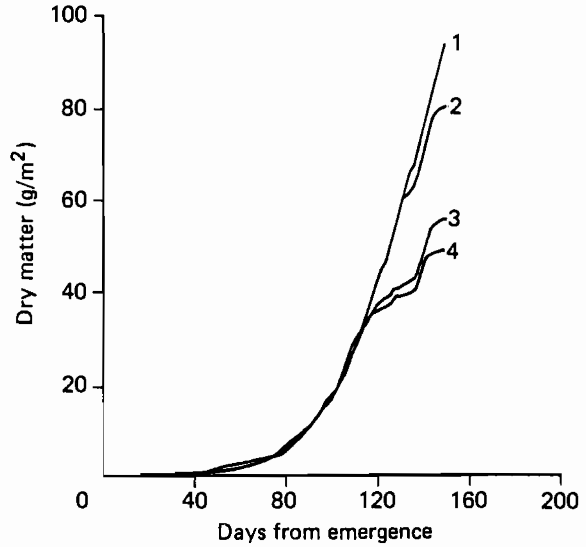


Figure 4.14. Climatic environment 1 and technological level 1. 1 = 1967 soil type 1 (92.90 × 100 kg/ha); 2 = 1967 soil type 2 (80.15 × 100 kg/ha); 3 = 1973 soil type 2 (55.86 × 100 kg/ha); 4 = 1973 soil type 1 (48.81 × 100 kg/ha). Results are for winter wheat.

(1) Two meteorological stations, which represent the best and the worst climatic environments.
(2) Two extreme soil characteristic (clay and sandy soil).
(3) Three main technological coefficients defined for a traditional agriculture, a medium agrotechnical level, and an advanced farming system. Results are shown in *Figure 4.14* and *Figure 4.15* and in *Table 4.7*.

Table 4.7. Land productivity classification in 100 kg/ha units; for each crop, top row = best year's yield; second row = worst year's yield.

Crop	*STC 111*	*STC 121*	*STC 131*	*STC 211*	*STC 221*	*STC 231*	*STC 112*	*STC 122*	*STC 132*	*STC 212*	*STC 222*	*STC 232*
Winter	92.9	74.3	55.7	80.1	64.1	48.0	66.3	53.0	39.7	31.2	25.0	18.7
Wheat:	48.8	39.0	29.2	55.8	44.6	33.5	17.8	14.3	19.7	17.8	14.3	10.7
Corn:	69.0	55.2	41.4	72.2	57.8	43.3	79.0	63.2	47.4	90.8	72.6	54.4
	32.4	25.9	19.4	39.4	31.5	23.6	34.8	27.8	20.8	40.1	32.0	24.0
Cocks-	55.0	44.0	33.0	41.2	33.0	24.7	44.8	35.8	26.8	40.1	32.1	24.0
foot:	38.2	30.6	22.9	36.7	29.4	22.0	28.7	22.9	17.2	27.4	21.9	16.4

S is soil types: 1 – clay soil, 2 – sandy soil; T is technological level: 1 – 1.00 optimum, 2 – 0.80 medium, 3 – 0.60 minimum; C is climatic environment: 1 – Mugello plane climate, 2 – Mugello mountain climate.

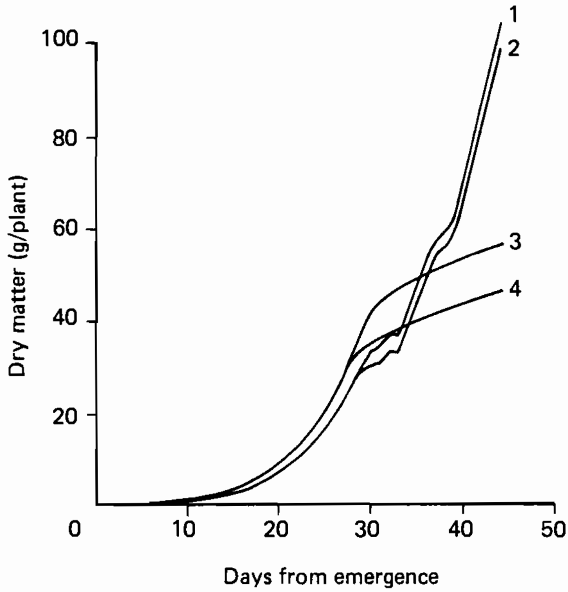


Figure 4.15. Climatic environment 1 and technological level 1. 1 = 1968 soil type 2 (103.25 g/plant); 2 = 1968 soil type 1 (98.65 g/plant); 3 = 1962 soil type 2 (56.39 g/plant); 4 = 1962 soil type 1 (46.38 g/plant). Results are for corn.

From a methodological point of view, the basic land productivity, which is tabulated in *Table 4.7*, may be used as a programming matrix for econometric purposes. In order better to assess the climatic and environmental effects on agricultural productivity, further land units could be defined with a larger factor range.

4.5. Conclusions

Political and administrative decisions are increasingly necessary for a new assessment of the less favored areas of Italy. Great modifications have occurred over the last 30 years as a result of many factors: industrialization, the movement of people from the country to the towns, the morphology of the national territory, and the demand for a new organization of the agriculture in these areas in order to guarantee land conservation, the survival of farmers, and the agricultural gross production.

New methodology, based on the integrated knowledge of natural resources and agricultural techniques, is necessary to build a scenario that is useful in simulating the consequences of changes and decisions.

To achieve this goal, new technologies can be utilized. Computer science, remote sensing of the earth, modeling techniques, and ecophysiological and environmental models all allow us to describe a system as a whole in order to confirm the previous statements.

The results of our research consist in setting up an integrated method to calculate gross production and crop repartition for every land unit of the study area. The criteria on which the work is based are the following:

(1) Utilization of standard methodology to describe, in terms of numerical parameters, all the physical characteristics of land capability such as soil type and depth; atmospheric variables such as rainfall, radiation, temperature, wind, and humidity; crops inventory; hydrology; and soil morphology such as slope, exposure, altitude, and soil chemical parameters.
(2) Implementation of a data bank relating all these characteristics to a geographical reference with flexibility of starting the system from the acquisition and digitalization of contour lines and of a reference grid.
(3) Setting up of a crop model to calculate the net production of the strategic crops.
(4) Verification of the model by conducting the experiment in plots in the area over three consecutive years.
(5) Possible incorporation in the model of such management parameters as fertilization, water management, plowing, land assessment, and crop rotation.
(6) Organization of the information system as an open system, able to receive further information without limits in a very expansible way.

In this way, we have set up a system on which the econometric methodology could be based to allow decision makers to plan agricultural activities in a suitable way.

4A. Appendix: Formation and Management of a Territorial Data Bank

4A.1. Overview

The main natural agricultural resources are:

(1) Soil.
(2) Climate.

(3) Hydrology.
(4) Animal and vegetable germoplasma.
(5) Soil use.

Soil characteristics are very important for agricultural activities. Physical structure, chemical characteristics, and depth represent fundamental parameters for cultivation growth. The soil morphology influences the evenness and size of the fields, the erosion phenomena, the radiation distribution, the other microclimatic parameters (temperature, soil moisture, ruggedness of surfaces), the wind effects on evapotranspiration, and the use of agricultural machines.

Climate is a fundamental parameter for the meteorological adverse elements, water availability, optimum temperatures for growth, photosynthetic active radiation, and the easy execution of agricultural activities.

Hydrology is linked with water availability, soil conservation, and the possibility of structuring water capacities.

Animal and vegetable germoplasma is the heritage accumulated over centuries through the selection of species and varieties that adapt themselves to the local environment.

Further, it is necessary to fix a measurement methodology that quantifies the physiological crop behavior in different environmental conditions. We need to standardize measurements and instrumentations to organize a basic data bank.

The formation of a data bank is based on these fundamental steps:

(1) The building of a grid of reference starts from the acquisition of contour lines of cartography from the National Cartographic Service (IGM).
(2) The coding of every pixel obtained with this procedure.
(3) The acquistion of soil maps with the same system of reference.
(4) The processing of remote sensing data from Landsat D for crop inventory and superimposition on the territorial base.
(5) The acquisition of meteorological data and interpolation between different stations of the network, for a climatic profile of every elementary unit of the system.
(6) The digitization of main rivers.

Points (1), (2), (3), (5), and (6) are useful in the hierarchical processing system (HPS), used to process remote sensing data, starting from additional information on soil morphology, climate, soil type, and hydrology.

The final output is the characterization of every pixel. This should be the input in the productivity model. Pixels with similar characteristics could be plotted in a cartographic form and the areas belonging to each group computed.

4A.2. Cartographic data bank

Acquisition Procedure

To obtain basic cartographic data, we acquired the contour lines of Italian regions in numeric form by digitizing IGM (Military Geography Institute) basic cartography (scale 1:25 000).

Data Acquisition and Storage

Acquisition of data from conventional cartography (tablets) is performed in "continuous mode" following contour lines and rejecting the points whose distance is less than a prefixed tolerance step. This method has been equally efficient but faster than the "point mode" system.

After acquisition, each tablet was controlled by mean of a graphic monitor and stored on disk if correct.

Plotting and Correction

Each tablet is plotted to meet general quality control standards. This operation allows verification of line locations, and rough errors and estimation of inevitable shifts due to manual acquisition. When the errors are too large, the contour lines must be digitized again.

Equidistance of IGM cartography 1:25 000 is 25 meters. For practical reasons it has been necessary to use an equidistance of 50 meters. An elementary pixel is about 1000 m^2. *Figure 4A.1* shows this procedure.

Owing to morphological complexity, some contour lines are incomplete. Where possible, these have been corrected by an interpolation, but this has been strictly limited to avoid arbitrary mistakes.

On average, 2.5 days/person is needed for the acquisition of 10 000 hectares.

Calculation Procedure

Elaboration programs, based on acquired cartography, are designed to perform the following calculations:

(1) Slope (percentage).
(2) Exposure.
(3) Classification of (1) and (2) (in percentage classes with regard to slope, and in angular classes with regard to exposure).
(4) Extension, either single classes or total examined area.
(5) Percentage incidence of different classes with regard to total area of the map.
(6) Creation of a printout file of results, with distribution of altitude classes of the areas belonging to different regions.

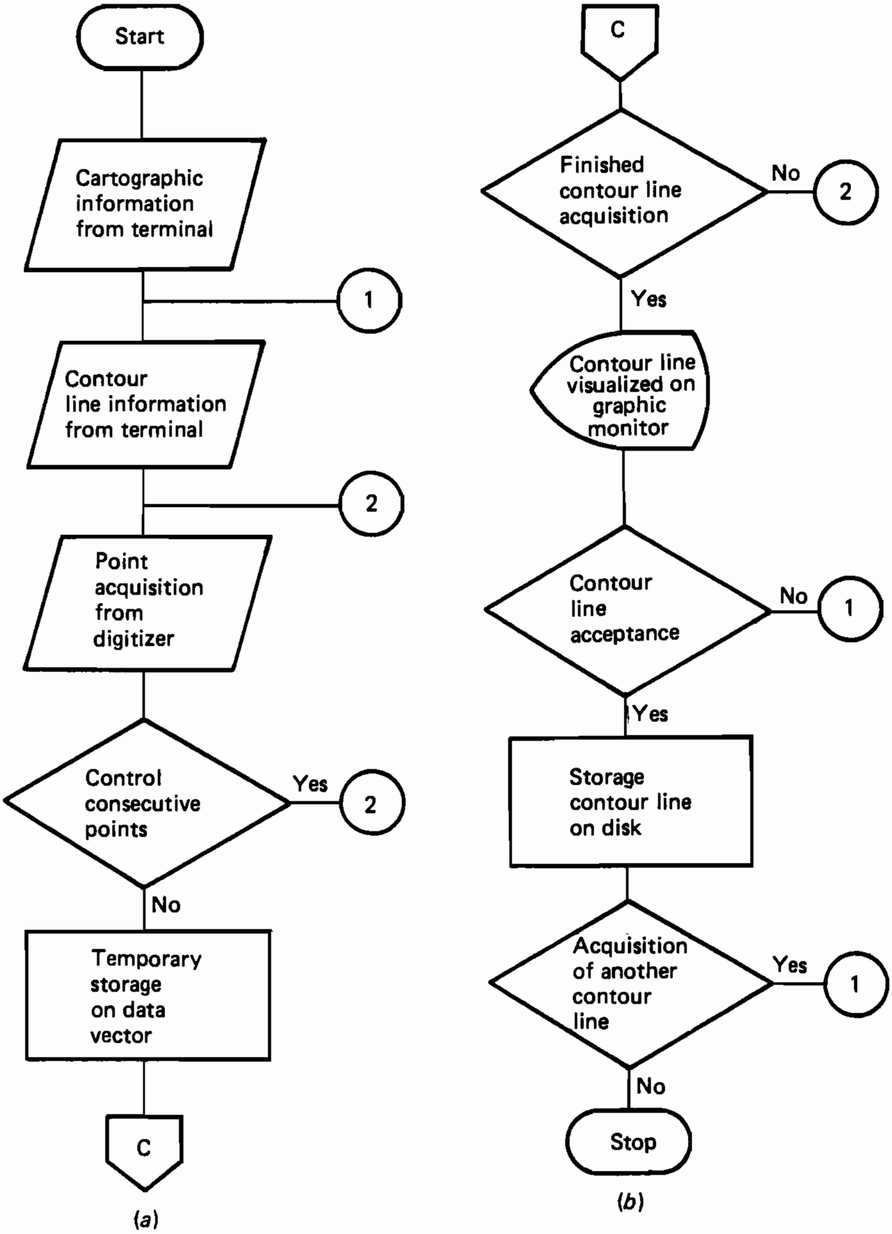


Figure 4A.1. **Acquisition and storage program flow chart. (*a*) first section; (*b*) second section.**

The calculation procedure is performed by two fundamental steps:

(1) The geographic coordinates contained in the data file for each map are compressed in a matrix, 512 × 512, which always contains the same coordinates, but in "rounded" form and therefore with reduced precision.
(2) After this, the analysis shifts to the file containing the original data and considers a limited number of points around those determined by step (1). This method significantly reduces analysis time.

The procedure is carried out twice on the slope: first, starting from the lower altitude and considering the next contour line going to the higher altitude; and the second time in the opposite direction, analyzing those areas not covered in the first analysis.

The calculation time ranges from 10 minutes to 1 hour, depending on the morphology of the analyzed map.

Graphic Return

Graphic results are given in these different forms:

(1) Contour lines (base).
(2) Thematic slopes map (superimposed on base).
(3) Thematic exposures map (superimposed on base).

A cartographic graph is plotted from squares with sides of about 80 m (about 0.5 ha), of which the average slope is calculated. This size has been chosen because it represents a good compromise between necessary precision and painting speed.

The elaboration program reads the data file, plots exposures and slopes, and prints a listing.

The total plotting time for the three maps is about four hours.

The maps covering the case study area are 12, and the area for every map about 100 km^2. In *Table 4A.1* the repartition of areas (ha) computed for each map, in slope and exposure classes, is shown as an example. The repartition could be done choosing any range.

4A.3. Meteorological data bank

Another relevant component of the data bank is the historical series of meteorological measurements derived from Servizio Meteorologico Nazionale and Servizio Idrografico Ministero (LLPP). The kind of data (temperature, rainfall, etc.) and available periods covered depend on the different instrumentation and functions of the meteorological stations.

A 10-year period of surveying is required for minimum statistical significance of elaborations. The data available are:

Table 4A.1. Repartition in slope and exposure classes of Passo della Radicosa.[a]

Slope classes			*Exposure classes*		
Percentage	*Related areas* (ha)	*Related areas* (%)	*Degrees*[b]	*Related areas* ((ha)	*Related areas* (%)
0–5	1.83	1.72	0–45	10.99	10.34
5–10	15.26	14.37	45–90	8.54	8.05
10–15	13.43	12.64	90–135	27.47	25.86
15–20	26.86	25.29	135–180	7.32	6.90
20–25	20.41	18.97	180–225	–	–
25–30	19.53	18.39	225–270	1.22	1.15
30–50	9.16	6.62	270–315	30.52	28.74
>50	–	–	315–360	20.14	18.97

[a] Altitude between 350–400 m; total analyzed area: 106.20 ha. [b] 0° north, clockwise.

(1) Central Institute of Statistics data: monthly averages of data obtained from LLPP stations.
(2) Servizio Meteorologico Nazionale: daily data in numeric form.
(3) LLPP: daily data in numeric form.

The structure of these three kinds of data is as follows:

(1) CODE NAME YEAR DEPART. ALT. LAT. LONG. MONTH MAX DAILY R. MONTHLY R. MAX AVER. TEMP. MIN AVER. TEMP. MAX TEMP. MIN TEMP. AVER. HUM. MAX HUM. ABS. INSOL. REL. INSOL. WIND MAX DIR. WIND MAX SPEED
(2) CODE YEAR MONTH DAY MAX TEMP. MIN TEMP. MAX HUM. WIND MAX DIR. WIND MAX SPEED INSOL. R. HOURS 18–06 R. HOURS 06–18.
(3) CODE J.DAY YEAR RAINFALL MAX TEMP. MIN TEMP.

where CODE is station code, ALT. is altitude, LAT. is latitude, LONG. is longitude, MAX DAILY R. is maximum daily rainfall, MONTHLY R. is monthly rainfall, MAX AVER. TEMP. is maximum average temperature, MIN AVER. TEMP. is minimum average temperature, MAX TEMP. is maximum temperature, MIN TEMP. is min temperature, AVER. HUM. is average humidity, MAX HUM. is maximum humidity, ABS. INSOL. is absolute insolation, REL. INSOL. is relative insolation, WIND MAX DIR. is wind maximum direction, WIND MAX SPEED is wind maximum speed, INS. is insolation, R. HOURS 18–06 is rainfall from 18.00 to 06.00 hours, and R. HOURS 06–18 is rainfall from 06.00 to 18.00 hours.

Acquisition and Storage Program for Meteorological Data

Ease of use and great efficiency are the fundamental characteristics of the data storage program. It allows control of input data reliability (the sources of error are mostly due to the operator introducing wrong data).

Data Access Program

This program gives the user selective access to stored data, allowing either a fast consultation or choice of defined subsets. *Table 4A.2* shows the type of available menu.

Table 4A.2. Menu of the data access program.

D-BASE Interactive management of meteorological archives
Selection of GENSTAT subgroups
daily data management = 1
monthly data management = 2

INPUT :

Parallel selection = [P], serial selection = [S]:

Starting year:
Ending year:
Alphanumeric code of station:
Comment:
Starting Julian day
Ending Julian day
Rainfall:
Max temperature:
Min temperature:
Max humidity:
Wind direction:
Wind speed:
Insolation:
Rainfall 06-18:
Rainfall 18-06:

4A.4. Data bank of soil types

Starting from maps of the Geological Survey, scale 1:100000, we assume a correlation between the rocks and soil types in order to classify the area in a suitable way for the crop productivity model.

4A.5. Land-use inventory

The implemented method for land-use inventory is based both on satellite information and on slope and aspect data matrices.

This information may be very useful in spectral analysis and in the interpretation of LANDSAT images. By using geomorphology in connection with an agricultural expert system, it is possible to maximize satellite spectral information of the surface. The system allows the user, for example, to eliminate the major part of misclassified points from classified images, by removing incoherent land-use interpretations.

The complete classification flow chart is divided into four main steps, as described below:

(1) Registration
    (a) Satellite image matrix.
    (b) Slope aspects matrices.
    (c) Topographic maps.
(2) Standard Spectral Signatures:
    (a) GCP (ground control point) acquisition.
    (b) Distribution and variance analysis.
(3) Maximum Likelihood Image Classification
    (a) Automatic classification.
(4) Expert Analysis:
    (a) Interactive experienced analysis of classification.

Registration

A good approximation in digital registration between satellite images and topographic coordinates may be reached following a statistical approach. This technique needs a set of previous definitions of ground control points, whose coordinates may be exactly defined in both reference systems. Moving these coordinates, a multilinear correlation may be found, and the derived couple of multilinear equations may be used for rotation and superimposition of matrices.

The precision of the digital registration depends on the accuracy of GCP definition and acquisition.

Standard Spectral Signatures

For a supervised image classification, a large amount of "ground truth" information is always needed. For application, therefore, the implemented system needs to be coordinated with one or more representative farms of the area, which must be inventoried.

Geographical registration of images, as referred to under "Registration", is obviously necessary for a good field shape definition and ground truth spectral data collection.

Statistical analysis of ground truth data may, finally, allow the user to have a standard spectral signature for each crop type and its variability. These signatures will work as a reference in the classification algorithm.

Maximum Likelihood Image Classification

The automatic classification is performed following a very simple algorithm, where the spectral limits of each class are defined according to each standard spectral signature (SSS).

This type of classification may produce some misleading results, induced by slope and exposure features of land surface.

For a good final result, a good SSS definition is needed, linking the whole process to a large disposal of ground truth elements.

Expert Analysis

Most of the errors that occur in the previous classification step may be eliminated using an expert interactive system. This system contains, for each crop type, some local information about agricultural features, which mostly refers to average field size, maximum slope, and altitude for a good productive level.

An interactive analysis of each defined field, in the image, may produce quite a good final result, associating remote sensing and cartographic information with local agricultural knowledge.

Land-use inventory may be easily stored in the global territorial data base as a renewable information source.

Acknowledgment

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PART II

Case Studies

CHAPTER 5

Stavropol, USSR: An Agricultural Management Model

A.A. Nikonov, V.I. Nazarenko, L.N. Petrova,
F.I. Ereshko, E.M. Stolyarova, V.Yu. Lebedev,
S.B. Ognivtsev, S.O. Siptits, N.N. Milyutin,
V.N. Popov, R.R. Guliyev, and M.P. Yevsiukov

Abstract

The Stavropol region of the Northern Caucasus is one of the largest producers of high-quality grain and stock breeding in the USSR. A complex management system is required to cope with Stavropol's five agricultural zones, which range in characteristics from drought conditions to highly favorable soil and climate.

Using input data covering the period 1971–1982, the Crop Production Model (CPM) accurately described crop–mineral fertilizer relationships for all crops in all years. However, owing to data deficiencies, soil nitrogen values were not correctly estimated.

Linking the CPM to economic models, it is possible to analyze alternative agricultural policies by formulating and solving various optimization problems associated with target production levels. One important result of the numerical runs is confirmation that fallow areas are efficient in the eastern, semiarid zones of the region. Further increases in total output will probably depend on changing technologies, e.g., developing new drought-resistant types of winter wheat.

5.1. Introduction to Soviet Agriculture Policies

The problem related to agricultural management systems has invariably received a great deal of attention in the USSR. By the early 1980s, systems had been developed for a total of 154 regions, territories, and republics of the USSR. The shift to locally dependent systems was implemented to facilitate the introduction of scientific developments into practice. However, until recently, systems that were developed were mainly of a descriptive nature.

A new qualitative change in the approach to the development of agricultural management systems was made due to the advent of systems analysis. The development of modern agriculture is characterized by a rapid growth of the resource potential and intensification of production processes. Under these conditions the problem of optimization of resource use is becoming more urgent (*Table 5.1*).

Table 5.1. Development of USSR agriculture (data provided by the Central Statistical Bureau of the USSR; Nikonov, 1980).

Indicators	*Units*	*1960*	*1970*	*1980*
Agricultural land including:	million ha	515.4	545.8	553.6
Arable land		220.0	223.5	226.4
Reclaimed land		16.3	19.2	31.0
Power capacities[a]	million HP	155.9	322.1	603.9
Electric energy consumption[b]	billion kWh	9.9	38.6	111.0
Fixed productive assets in agriculture	billion roubles (comparable prices of 1973)	43.9	94.7	227.0
Mineral fertilizer supplies to agriculture	million tonnes of 100% effective nutrient	2.6	10.3	18.8
Annual average number of full-time employees, including seasonal workers	million	26.1	24.1	22.9

[a] Power capacities is a sum of horsepower of all machinery used for agriculture. [b] This refers to rural electricity consumption.

The USSR Food Program involves a considerable increase in the growth rates of agricultural production, a higher stability under unfavorable weather conditions, and an improvement in the structure of the agroindustrial complex. The above goals can be achieved provided the establishment and introduction of agricultural management systems in practice is effected at all levels of the economy, from the national level to individual enterprises.

There are many general factors concerned with agricultural management systems, e.g., political, social and demographic, organizational, legal, economic, natural, biological, and climatological. The systems analytic approach presented here does not deal explicitly with the first four, but deals with the rest.

The USSR agricultural zones are characterized by quite diverse climatic conditions. Up to 70% of agricultural land is in arid and semiarid regions. The sum of active temperatures over 10°C during a whole year ranges from 400°C in the Arctic belt, where only protected ground farming is possible, to 4600°C in the south of Central Asia. The annual precipitation also ranges widely depending on the climate zone: from 100 to 800 mm. The duration of the frost-free period ranges from 60 to 240 days. The intensity of solar radiation varies as well. When comparing natural conditions for agriculture in the USSR and the USA, conditions in the USA are far better (*Table 5.2*).

Table 5.2. A comparison of several indicators for agriculture production of the USSR and the USA.

Indicator	*USSR*	*USA*
Agricultural land as a percentage of total territory	25	68
Percentage of agricultural land lying south of the 48th parallel	33	100
Percentage of arable land lying in the zones with annual precipitation rate:		
Over 700 mm	1.1	60.0
From 400 to 700 mm	58.9	29.0
Below 400 mm	40.0	11.0
Percentage of arable land lying in the zone with annual average temperature below 5°C	60	10

Soil cover in the USSR is quite diverse, not only by geographical zones and regions, but also within the limits of individual farms. The relief is diverse and influences agricultural management systems. While an average water supply index for the country is high for the southern regions, it is far from being satisfactory. Considerable climatic diversities result in a great variety in the levels of intensification of agricultural production. The ratio between output of the economic regions with highest and lowest output per unit area is within the range of 1:25 (*Figure 5.1*).

The structure of agricultural management systems is rather complex: on the one hand it is a complex of production branch systems: soil treatment technologies, crop farming, plant growing, feed production, and animal breeding; on the other hand, management systems are regarded as a combination of such components and characteristics as the socioeconomic forms of enterprise (in the USSR state farms and collective farms prevail), organization (including branch structure, specialization, and cooperation), and the economic mechanism of management. All these factors taken together constitute a method for the use of resource potential. The main problems that agricultural management systems are now faced with are:

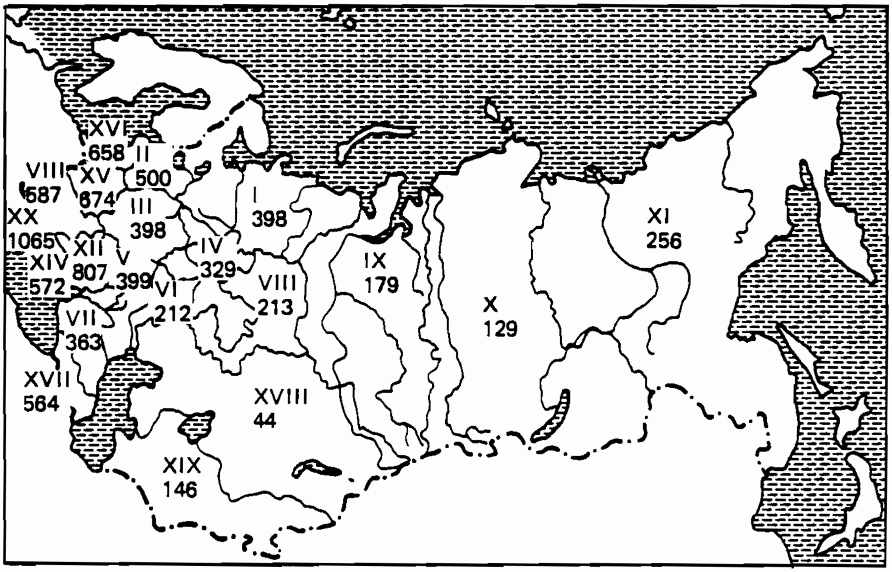

Figure 5.1. Agricultural production intensity by economic regions of the USSR (gross output per hectare of agricultural land, roubles): I = North region; II = Northwest; III = Central; IV = Volgo-Vyatka; V = Central Chernozem; VI = Volga; VII = North Caucasus; VIII = Urals; IX = West Siberia; X = East Siberia; XI = Far East; XII = Donets-Dnieper; XIII = Southwest; XIV = South; XV = Byelorussia; XVI = Baltic; XVII = Transcaucasia; XVIII = Kazakhstan; XIX = Central Asia; XX = Moldovia.

(1) Maximization of high-quality produce output per resource potential unit. The latter includes bioclimatic potential, land, water, labor, plant, energy, and other resources.
(2) Minimization of the resource input per production output (this target is not identical to the first).
(3) Reducing vulnerability to unfavorable factors.
(4) Estimation of possible social and economic consequences.

The requirements laid down to management systems and the essence of the systems need a strict methodological approach: systems analysis with economic and mathematical modeling is fundamental to the development of any management system.

Many different agricultural models at various levels (all-union, republic, regional, etc.) have been developed in the USSR, the most important of which is the Food Program of the USSR. A system of agricultural management is to become a system of models at all hierarchical levels. Quantitative analyses of the impact of natural conditions upon agricultural production have been carried out. Several possible versions of agricultural development were given. In other words, important characteristics have been determined, providing for better control over the development of the agroindustrial complex of a region and its administrative units.

Many items in agricultural modeling need elaboration. Extensive development of research activities will call for very important decisions to be made regarding the advanced training of specialists, changing the structure of research institutions, and the establishment of an information base.

Goals to be attained conform to the economic policy adopted by the Soviet Government for the 1980s. The strategy is based on the dynamic and intensive development of the national economy and on rational use of resources to meet demand.

5.2. Description of the Stavropol State

The Stavropol region is one of the largest producers of high quality grain in the USSR. The region of the Northern Caucasus, where the Stavropol region is situated, has, on the whole, rather favorable natural conditions suitable for the development of large-scale agricultural production.

In the region, there is a general deficiency of moisture and irregularity of precipitation during the year. The latter is the reason for unfavorable conditions for crop growth, even when the total annual precipitation is close to normal. Droughts and dry winds are also typical for the region; practically every third year is a drought year. As a result, the yields of basic crops are characterized by sharp fluctuations from year to year. The yield for winter wheat in unfavorable years can be approximately 30% of the yield for years with favorable weather conditions.

The Stavropol region is situated between 41° and 45° of eastern longitude, and between 43° and 46° of northern latitude; it occupies an area of 80400 km^2. The natural relief is characterized by distinct horizontal and vertical zonality. Agricultural production constitutes 30% of the total production of the region.

The Stavropol region constitutes 0.36% of the territory, 2% of agriculture land, and 1% of population (2.5 million) of the USSR. The region contributes 2% of the country's grain production, 4% of sunflower, 9% of wool, and a considerable quantity of vegetables, fruits, and grapes. Apart from the percentage, what is important is that this grain is of the high quality necessary for bread production. The Stavropol region is an important producer of stock breeding: 1.5% of bovine cattle and pigs, and 2% of goats and sheep of the USSR are concentrated in the Stavropol region (Nikonov *et al.*, 1982).

The main agricultural crops in the region are winter wheat, corn, silage, sunflower, and perennial grasses for forage. The trends of yields of basic crops for the three recent five-year periods are represented in *Table 5.3*.

Owing to considerable diversity of natural and economic conditions in the region, five agricultural zones of production are identified. The zones are characterized not only by climate, soil, and relief peculiarities, but also

Table 5.3. Trends of yields in the Stavropol region for different crops (Nikonov *et al.*, 1982).

	Average yields of basic crops (q/ha)		
Commodity	*1966–1970*	*1971–1975*	*1976–1980*
All grain crops	15.1	16.0	18.6
Winter wheat	15.9	17.1	19.8
Corn	17.0	15.1	12.3
Sugar beet	183	163	223
Sunflower	9.7	9.7	9.4
Corn on silage	73	111	129
Hay (grasses)	13.8	15.3	18.7

by density of population, set of main crops, and prevailing types of agricultural enterprises. The agricultural division of the Stavropol region put forward by Nikonov (1980) is represented in *Figure 5.2.* The first zone (eastern) is mainly sheep breeding; it is characterized by comparatively difficult natural conditions, low density of population, and rather flat relief. Sheep breeding constitutes 46.3% of total agricultural production, grain production (mainly winter wheat) 12.5%, and cattle breeding 17.8%. The second zone is of the grain–sheep breeding type; it is the largest in the region and occupies 33% of the agricultural area. Weather conditions here are better than in the first zone: breeding, grain production (winter wheat), and cattle breeding are 27.8%, 14.2%, and 21.3%, respectively, of agricultural production. The third zone (grain–cattle breeding) occupies the central part of the territory, with fertile black earth soils and a favorable moisture regime. The structure of production is 14% grain, 19.7% sheep breeding, and 24.8% cattle breeding. Sunflower and sugar beet (altogether 9.4%) are cultivated as well. The highest density of population is concentrated in the fourth, "health resort", zone which is characterized by favorable soil and climatic conditions. Besides grain, sheep, and cattle production (8.2%, 6.2%, and 31.3%, respectively), there is vegetable production, fruit growing, and poultry keeping. The fifth zone – mountainous – is characterized by heavy relief and low density of population. The main production is mountain-cattle breeding, with alpine meadows and pastures. Cattle breeding constitutes 37.6% of agricultural production, sheep breeding 26.8%, and potato farming 4.1%.

The most important current problems of agricultural policy in the Stavropol region are:

(1) Specialization and cooperation of leading branches of agriculture (grain production or sheep breeding) under drought conditions.
(2) Expansion of irrigation using local water resources.
(3) Introduction of stable rotations, obligatory with fallows and short rotation, beginning with two-field rotations in extreme drought conditions.

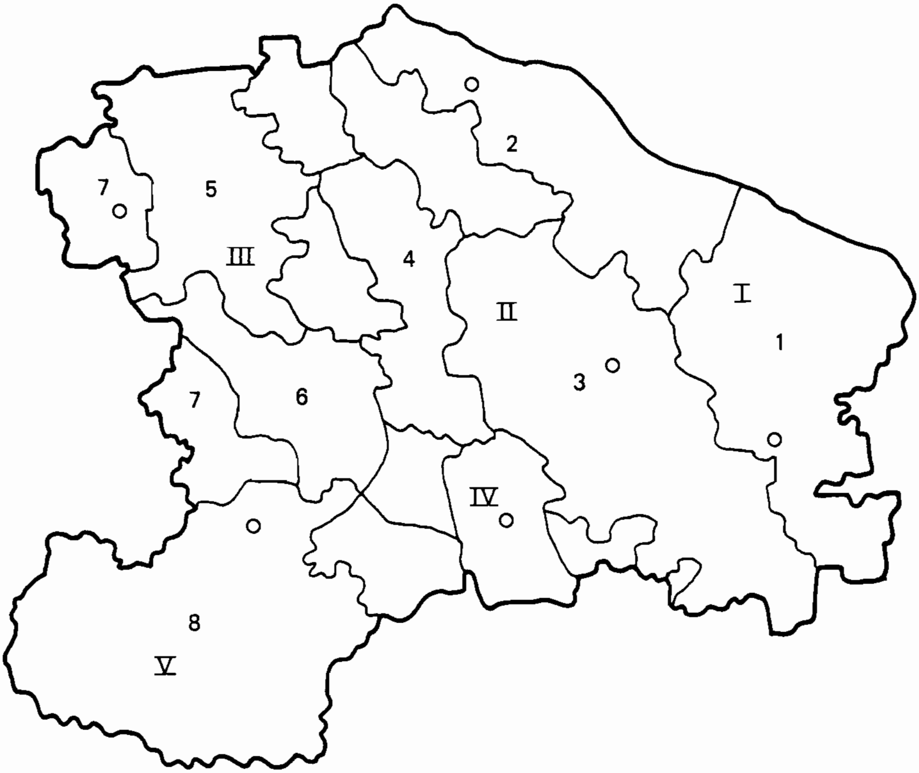

Figure 5.2. Agricultural zones and soil classes of the Stavropol region. III = boundaries and index of an agricultural zone; 8 = index of a soil class; ○ = meteorological stations.

(4) Elaboration of agrotechnical and organizational measures for the preservation and rational use of water.
(5) Shift of forage production to irrigated areas, in order to free nonirrigated areas for winter wheat allocation after best preceding crops.
(6) Introduction of antierosion technologies.
(7) Increasing mineral and organic fertilizer application (which gives the possibility to decrease water use per unit of production).
(8) Mechanization to accomplish the necessary tasks on time.
(9) Improvement of the salinated soils that occupy large areas of the region.
(10) Using drought-resistant crops at every farm.

To attain these goals, it is necessary to elaborate an agricultural regional management system. Such a system must be founded, first, on management systems worked out by agroeconomists and, second, on an adequate quantitative description of the functions of different subsystems in the agroindustrial complex.

In accordance with IIASA methodology, the agricultural management system has to consist of a set of connected mathematical models that describe different processes of agricultural production. The basis of the modeling system has to consist of two models: a physical crop production model, to describe crop growth under different environmental conditions, and an economic technological model for crop allocation (taking into account rotations as well).

Recently, a system of models for agricultural management on a regional level was elaborated by scientists from the Stavropol Institute for Agriculture, IIASA, and the Computing Center of the USSR Academy of Sciences. The main principles for linking models of different physical nature and time scale were elaborated as well. Numerous computing experiments have been carried out on the basis of systems of models to illustrate the following points:

(1) Zonal peculiarities of changes in the yields of grain crops (mainly winter wheat) under different technologies of cultivation.
(2) Estimation of the level of gross output of grain under existing technologies and prospective ones.
(3) Estimation of climate impacts on the yields to ensure stable gross output of grain.
(4) Compensation of unfavorable climate impacts by fertilizer application and the introduction of short rotations with fallows.
(5) Determination of fallow allocation under different weather conditions, technologies, and resource restrictions corresponding to the maximum possible gross output of grain with minimum costs.

5.3. Approach

This section, and those that follow, will be devoted to a description of the principal stages of the implementation of principles and methods of systems analysis, as well as to the general methodological approaches developed by Konijn (see Chapter 2) as applied to the Stavropol region, a vast agricultural area of the USSR. As has already been mentioned, this problem is quite complex, with a great number of closely interrelated natural, economic, social, organizational, ecological, and other factors to be taken into account. Comprehensive studies carried out by Nikonov *et al.* (1982) are basic to the present systems analysis of the Stavropol regional agricultural development project.

It should be mentioned that current important national problems inevitably require the use of a system of mathematical models. In the field of agriculture, the most important are those of biophysical processes (crop yield production models and livestock production models), and economic and technological agricultural management models.

The main body of a formalized description of a regional agricultural production should consist of two models: a plant growth simulation model and a linear optimization economic model with balance constraints. The form of economic model relationships can vary, and in this respect only general recommendations have been developed. As regards plant growth simulation, a universal model is presented by Konijn in Chapter 2, describing plant biomass dynamics as influenced by weather conditions, soil properties at the beginning of the growth period, and fertilizer application. This model embodies experience in the simulation of agricultural crop yield formation. On the one hand, the model takes into account a great number of factors and, on the other, process description can be confined to the level that provides identification of the model using conventional agrometeorological data. The model includes most of the necessary characteristics for 25 agricultural crops, i.e., phenological phases, growth functions, etc.

The Stavropol case study serves to test the methodology for the analysis of regional technological problems in agriculture, as well as to stimulate the improvement of the above methodology. Numerical experiments carried out in the framework of the Stavropol project are representative enough, thus confirming the usefulness of the IIASA approaches. At the same time, during the course of the studies, the physical crop production model needed improvement and the economic model had to be linked with it.

We do not provide a detailed description of the physical crop production model (CPM), since this is done in Chapter 2. *Figure 2.1* shows information support of the CPM and its functioning scheme.

A mathematical description of the CPM with the use of difference equations, i.e., through phase and control variables, and uncontrollable factors and parameters, is given by Ereshko *et al.* in Chapter 3. It should be pointed out that the CPM describes plant growth with a 10-day time horizon and soil transformation with a one-year time horizon. To solve various management problems using a system of linked models, it is sufficient to consider the dynamics of all processes with a one-year time horizon, since major economic decisions are made using just this time interval. Let t designate the number of time periods in a given year, when the jth crop is cultivated on the ith soil type; then the principal equation of the CPM will have the form:

$$y_{ij} = \rho_{ij}\left[\{A_{ij}^t\}, W_0, \{W^t\}, O_0, \{O^t\}, N_0, \{N^t\}, P_0, \{P^t\}, K_0, \{K^t\}, \{\xi^t\}\right] \qquad (5.1)$$

where y_{ij} is the primary and secondary output of the jth crop on the ith soil type; A_{ij}^t is the set of cultivation techniques in the tth period of the year for the jth crop on the ith soil class (plowing, harvesting, stubble breaking, etc.; this vector includes the most important data for the preceding year, e.g., preceding crop), O_0 is the vector designating the amount of organic matter at the beginning of the year t, $\{O^t\}_{t=1}^{t=T}$ is the application of organic fertilizers in the total year, $\left[W_0, \{W^t\}, N_0, \{N^t\}, P_0, \{P^t\}, K_0, \{K^t\}\right]$ is the availability of water, nitrogen, phosphorus, and potassium, respectively, at the beginning of the year and the strategy of their application in the current year, and $\{\xi^t\}_{t=1}^{t=T}$ is the vector of weather conditions (temperature, humidity, etc.).

A 10-day period was taken as the time interval for the CPM. The model also provides for the possibility of obtaining data on soil conditions by the beginning of the next year, as well as of estimating some consequences of weather and management practices, e.g., water and wind erosion.

The other part of the system, which can be arbitrarily referred to as "economic" since its greatest emphasis is on economic and production characteristics, can be described with a regional macromodel that provides for the identification of principal relationships between parameters for the region as a whole.

In the following, the description of the economic model is given.

5.3.1. Description of economic model

The economic model allocates land under various crops and fodder under different technologies, depending on the costs, for which information on yield, soil, chemical nutrients, etc., comes from the physical CPM. The targets for the required crops and feed are given exogenously, but they are varied so as to obtain insights into resource requirements and cost implications.

Main variables of the economic model are areas x_{ijl} under the jth crop on ith soil type; crop j is cultivated with the use of technology l. For each crop, N_l cultivation technologies have been chosen; each technology was based on a set of inputs, N_p, having unit cost per hectare, including electric power, labor, tractors, trucks, combine harvesters, fuel and lubricants, and organic and chemical fertilizers. The economic model included, besides areas x_{ijl}, such variables as feed amount, u_j, and livestock produce, z_m, with $m = 1,2,\ldots,N_m$.

The main constraints of the economic model are presented as follows. The first group includes the required amounts of outputs of crops and livestock:

$$\sum_{i=1}^{N_j} \sum_{l=1}^{N_l} y_{ijl}\, x_{ijl} - u_j \geq \Pi_j, \quad j = 1,2,\ldots,N_j \tag{5.2}$$

$$z_m \geq \Pi_m \quad m = 1,\ldots,N_m$$

where N_f, N_j are number of soil types and crops, Π_j is the target figure of the jth crop output, and Π_m is the target figure for livestock production.

Feed Balance

$$\underbrace{\sum_{j=1}^{N_j} \sum_{i=1}^{N_f} \sum_{l=1}^{N_l} \pi'_{sj} \sigma_j y_{ijl} x_{ijl}}_{\text{feed supply from crop residues}} + \underbrace{\sum_{j=1}^{N_j} \pi_{sj} u_j}_{\text{feed supply from grains}} - \underbrace{\sum_{m=1}^{N_m} d_{sm} Z_m}_{\text{feed consumption}} + \underbrace{\delta_s}_{\text{feasible deficiency}} \geq 0 \tag{5.3}$$

$s = 1,2,\ldots,N_k$

where N_k is the number of feed characteristics (for the Stavropol model it has been assumed that $N_k = 3$: feed units, digestible protein, and dry matter), π_{sj}, π'_{sj} are transformation coefficients for primary and secondary crop production output (to be used for the calculation of feed characteristics), d_{sm} is the feed consumption rate required to obtain the mth livestock output unit, σ_j determines the secondary/primary output ratio, and δ_s is the feasible deficiency in sth feed characteristic.

Land Constraints

$$\sum_{j=1}^{N_j} \sum_{l=1}^{N_l} x_{ijl} \geq F_i \qquad i = 1,2,\ldots,N_f \tag{5.4}$$

where F_i is the area of the ith land type.

Resource Constraints

$$\sum_{l=1}^{N_l} \sum_{i=1}^{N_f} \sum_{j=1}^{N_j} r_{ijlp} x_{ijl} + \sum_{m=1}^{N_m} r'_{mp} z_m \leq P_p \qquad p = 1,2,\ldots, N_p \tag{5.5}$$

where r_{ijlp} and r'_{mp} are the amounts of the pth resource per unit of sown area and unit of livestock production.

Water Resource Constraints

$$\sum_{l \in L} \sum_{j=1}^{N_j} \sum_{i \in I_\tau} b_{ijl} x_{ijl} \leq W_\tau \qquad \tau = 1,2,\ldots,N_\tau \tag{5.6}$$

where L is the number of water-consuming technologies, b_{ijl} is the specific water consumption, I_τ is the land category irrigated from stream τ, W_τ is the amount of water to be used for irrigation, and N_τ is the number of river basins (for the Stavropol model it was assumed that $N_\tau = 3$, i.e., the rivers Kuban, Kuma, and Terek).

Of special importance are constraints that reflect rational crop rotation requirements. In this particular case study, we have confined ourselves to constraints imposed from above and from below:

$$(x_{ij})_{\min} \leq \sum_{l=1}^{N_l} x_{ijl} \leq (x_{ij})_{\max}, \qquad j \in J \tag{5.7}$$

where $(x_{ij})_{\min}, (x_{ij})_{\max}$ are lower and upper bounds given exogenously, and J is the variety of crop indices, where such constraints have to be imposed. We shall arbitrarily call these constraints *rotational constraints*. Let us designate:

$$x_{ij} = \sum_{l=1}^{N_l} x_{ijl}$$

As has already been shown, to solve important national problems one has to use not a single model, no matter how complex it can be, but a system of mathematical models. Let us identify the most characteristic features of such a modeling system, as compared to those of individual models which are components of the modeling system:

(1) Individual models are constructed by various groups of specialists, e.g., a plant growth model is built by biologists, an agricultural production distribution model is constructed by agricultural economists, etc.
(2) Models are constructed in such a way as to provide for the offline operation mode.
(3) Different models are designed to operate in the optimization regime, simulation regime, or both. This depends on the precision of the model description, aggregation level, etc.
(4) Coupling and adjustment of models are often characterized by nonformalized patterns, being a man–machine procedure.

The problem of model coupling is of extreme importance. The principal linkage techniques, which are man–machine procedures, are described in Chapter 3.

In order to develop a system of models, it is necessary that individual submodels should have common methodological, technical, and information backgrounds. Of special importance is the input–output compatibility of models.

For instance, for the physical and economic models of the Stavropol modeling system, a common set of 25 crops was assumed, and 8 soil types identified with 4 representative year types (favorable, dry, etc.). A set of indices was identified as a basis for the linkage of individual model decisions.

Initially, physical and economic models of the system were functioning separately, i.e., all the specific values and right-hand parts in the economic model were assumed. We believe such a procedure to be a necessary and inevitable stage of operation of any system of models.

Thus, in the physical model, for each type of weather condition, soil type, and crop, the following objectives were set:

(1) Identification of rational cultivation techniques in the course of the year.
(2) Identification of rational irrigation strategies.
(3) Identification of rational strategies of mineral and organic fertilizer application.
(4) Identification of rational crop rotation schemes.

In the studies of the economic model, the following objectives were set:

(1) Estimation of the potential of the development of agriculture in the region.
(2) Identification of rational targets of different crops and livestock production.
(3) Estimation of the possibilities of feed supplies.
(4) Determination of rational areas of irrigated land.
(5) Identification of rational strategies of resource use.
(6) Determination of rational distribution of agricultural production by zones with different soil types.
(7) Identification of the most rational and economic crop cultivation technology.

The detailed description of models, their use, and the results obtained are presented in other publications (Konijn, 1983; Ereshko *et al.*, 1983; Lebedev *et al.*, 1984); the models described were operating independently without linkage.

The first stage can be called "the stage of independent model studies", as opposed to interlinked. The subsystems are not independent; on the contrary, they are interrelated and partly supplement each other. For instance, the economic model gives the most effective crop cultivation technologies. Having identified the technologies we obtain a set of specific resources, in particular the total amount of water, mineral, and organic fertilizers to be applied in the course of the year in compliance with the technology identified. The physical model is fed this information to facilitate the elaboration of an economically effective strategy.

Besides that, the interrelationship can be seen in the very structure of the models, e.g., crop rotation constraints of the economic model are to correspond to a similar crop rotation set being studied in the CPM, and are to change when new rotations are included in the CPM.

The following section gives the results of the CPM runs, as well as the improvements and adjustments that had to be made to facilitate solving a number of managerial problems. Then, two principal linkage patterns are described involving plant growth and economic models as implemented in the

Stavropol project. The first linkage pattern was implemented to obtain Pareto-optimum surfaces in the parameter distribution (such as grain production, feed production, meat production, net income, profit, costs, capital investments, etc.) for particular types of weather. The second linkage pattern was implemented under a specially constructed climate scenario (taking into account typical weather conditions and the frequency of occurrence of various types of years). In the construction the total grain production cost minimization criterion was used.

5.4. Validation and Application of the CPM

In this section, the results of the CPM simulation runs, within the framework of the Stavropol project, are presented. The model was applied in numerous optimization experiments, and as a block in the system of "linked" models.

The input data covered the results of the 12-year period of observation and research, 1971–1982. Soils of the Stavropol region were grouped to form eight classes (initially 15 classes were identified); their distribution by districts and five agricultural zones is given in *Figure 5.2*. Soils were grouped according to agroclimatic regionalization of the Stavropol region.

Experimental data of maximum and minimum yields, corresponding fertilizer use and agrochemical parameters were used. A number of indices necessary for the operation of the CPM were taken, based on data in the literature and on the results of experiments with similar models developed by other authors. The data concerning fractional composition of soil organic matter, the amount and composition of plant residues, and organic fertilizers applied are here taken from the literature, but serious efforts are underway to obtain them specifically for the Stavropol region.

A number of indices have been specified in the course of special processing of experimental data. For instance, *Table 5.4* gives the determined coefficients, $\alpha_i (i = N,P,K)$, showing the amount of dry matter of grain or vegetative stages formed per unit of nitrogen, phosphorus, and potassium absorbed, respectively. As can be seen from the table, the coefficients vary with crops. This emphasizes the necessity of specifying the input parameters specific to a given area.

The objective of the first stage of the numerical experiments was to estimate the effect of soil and climatic conditions in the period 1971–1982 on crop productivity, and to compare mineral fertilizer application scenarios. The results of the numerical experiments were compared with experimental yield data on 10–13 major crops for the whole region, obtained from individual subregions, best collective farms, and crop experimental stations; the yield data included average indices for winter wheat, winter barley, spring barley, maize for grain and silage, soybeans, pea, sugar beet, sunflower, etc. The results of some numerical experiments are shown in *Figure 5.3*.

The results obtained have shown that at a qualitative level the model provides a satisfactory description of the yield dynamics, by years, for all

Table 5.4. α coefficients for various crops grown in the Stavropol region: a comparison between values used in the model and experimental data.

Crop/ plant organ	*Model coefficients*[a]			*Experimental data*[b]		
	α_N	α_P	α_K	α_N	α_P	α_K
Winter wheat:						
Grain	37	223	244	40	250	234
Straw	149	1429	86	222	1123	133
Winter barley:						
Grain	45	270	222	43	240	220
Straw	161	2000	50	200	900	120
Spring barley:						
Grain	45	270	222	47	280	200
Straw	161	2000	50	167	1125	120
Maize for grain:						
Grain	57	333	278	58	400	167
Vegetative mass	93	1000	61	110	2500	140
Pea:						
Grain	25	217	88	22	186	86
Vegetative mass	48	417	77	42	320	71
Soybean:						
Grain	14	152	56	17	210	95
Vegetative mass	120	1167	179	83	450	730
Subarbeet:						
Roots	92	417	66	71	375	80
Tops	42	455	17	33	410	228
Sunflower:						
Seeds	35	178	141	27	225	160
Vegetative mass	250	1540	241	125	750	30
Maize for silage	85	900	100	60	560	120

[a] Model inputs refer to the values available in the literature. [b] Experimental data tentatively obtained for the Stavropol region.

the crops studied, depending on soil and climatic conditions. The model provides a correct description of crop–mineral fertilizer relationships for all the years considered, i.e., it reflects the real crop-response pattern.

Yet, for some years and crops the estimated yield values proved to be 25–50% lower compared with actual levels. This is related to the unsatisfactory operation of the soil organic matter block, in particular, to the inadequacy of the estimated soil nitrogen values, which are considerably lower compared with the actual levels. Besides that, the estimated soil nitrogen dynamics do not correspond to the fluctuation pattern of other soil characteristics, and the humus mineralization rate is independent of hydrothermal conditions. We were also unable to reproduce completely the soil organic matter decomposition block as constructed by Konijn, since in the USSR the methods of collecting and processing data on organic matter fractions are different from those used in the CPM.

Thus, the difficulty in obtaining saturation of the soil organic matter block of the CPM with the necessary information specific to the Stavropol

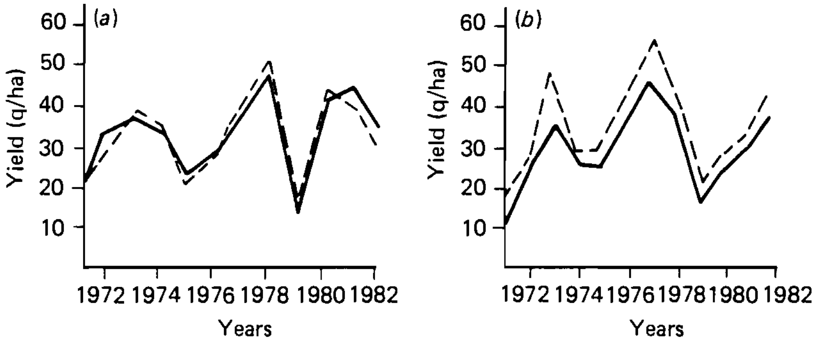

Figure 5.3. The results of two numerical runs: the solid line represents estimated yield; the broken line, actual yield.

region, the insufficient duration of the model's operation, and the inconvenience of its use in mass calculations (e.g., for each fertilizer scenario one has to have separate input files), especially in the crop rotation version, led to the development of an aggregated crop rotation model, describing crop production with chemical nutrients of cultivated plants taken into account (see Petrova *et al.*, 1986). This model is characterized by a combination of constraint principles, with the description of humus, phosphorus, and potassium dynamics in the soil being related to their transformation and utilization by plants. The model is presented in *Figure 5.4.*

In the crop rotation model (Petrova *et al.*, 1986), the following input data were used: soil and climatic characteristics of the five zones of the Stavropol region (such as soil type, bulk weight, wilting point, initial humus, phosphorus and potassium content in soil); coefficients of N, P, and K recovery from organic and mineral fertilizers; N, P, and K uptake by grain and crop residues. These coefficients are regarded as functions of the main soil parameters. Yield values for major crops obtained from the water block of the CPM, where no fertilizer constraints are taken into account, and average annual soil moisture values, estimated with the use of CPM water balance, are used as input data. Soil humus accumulation is assumed to be within the range ± 20%. Optimum P_2O_5 content in soil, with no response to phosphorus fertilizer application, is assumed to be 35 mg/kg.

The yield value is calculated as in the CPM, according to the limiting principle (Liebich law of limiting factors):

$$Y_{\min} = \min\left\{Y_N, Y_P, Y_K, Y_W\right\} \tag{5.8}$$

where Y_N, Y_P, Y_K, and Y_W are yield values limited by the supply of nitrogen, phosphorus, potassium, and water, respectively.

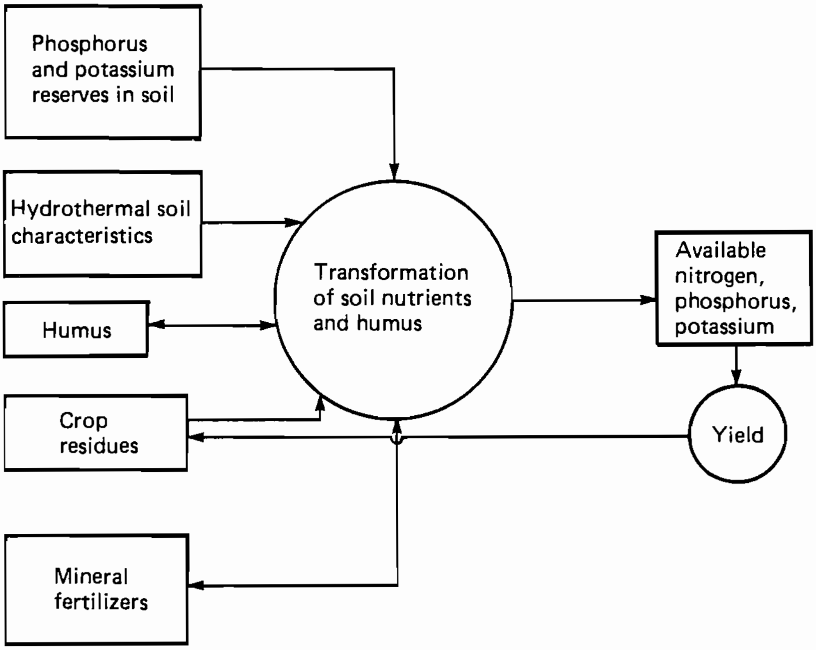

Figure 5.4. Aggregated crop rotation model (Petrova *et al.*, 1986).

Simulation experiments with the CPM and crop rotation model (Petrova *et al.*, 1986) were arranged as follows. The adopted weather classification (Petrova, 1986) in the calculations is based on four year types:

(1) Favorable year (1978).
(2) Humid cold year (1977).
(3) Dry year (recurrent drought, 1972).
(4) Dry year (severe drought, 1979).

The order and frequency of occurrence of various year types in the experiments correspond to the conditions of the scenarios. Meteorological information was provided by the stations at Roschino, Budionnovsk, Stavropol, Georgievsk, and Cherkessk; each station provided information for the corresponding zone. The CPM was used for the computation of the crop yields in all the crop rotations, with photosynthesis and water balance taken into account. The estimated yield and annual average soil moisture values were used as inputs for the crop rotation model (Petrova *et al.*, 1986); this was followed by maximum "cut-off" yield values, with constraints on nutrients taken into account. *Table 5.5* shows typical CPM water block output data. Winter wheat yield is given in quintals (100 kg, also known as centners) per hectare, and average annual soil moisture is expressed as a percentage of minimum water-holding capacity.

Table 5.5. Yields and soil moisture obtained as an output of the water block of the CPM for the Stavropol meteorological station (zone III). Crop rotation: winter wheat/winter wheat (100 kg/ha).

	Harvest year							
	Most favorable year (1978)		*Humid cold year (1977)*		*Dry year (1972)*		*Severe dry year (1979)*	
Pre-ceding year	*Yield* (q/ha)	*Soil moisture*	*Yield* (q/ha)	*Soil moisture*	*Yield* (q/ha)	*Soil moisture*	*Yield* (q/ha)	*Soil moisture*
1978	45.63	0.67	47.21	0.65	27.89	0.53	25.47	0.53
1977	52.14	0.68	58.82	0.69	32.33	0.58	25.22	0.51
1972	55.49	0.63	52.05	0.60	28.35	0.58	33.79	0.56
1979	59.23	0.66	64.99	0.60	34.67	0.56	46.21	0.53

Given below are some steps of the numerical experiments conducted during the course of the simulation runs using the CPM and the crop rotation model (Petrova *et al.*, 1986), according to *Figure 5.4*.

(1) Maximum possible winter wheat yields for all zones of the Stavropol region, for all soil classes in various crop rotations, in various year types, are determined.

(2) Optimum organic and chemical fertilizer application rates providing for the maximization of yields in various crop rotations under various cultivation technologies are identified.

(3) The necessary mineral fertilizer resources and their distribution by zones for winter wheat and other crops are identified.

(4) Various problems are solved regarding the distribution of limited mineral fertilizer resources by zones.

(5) Optimum fallow distribution by zones is identified using two criteria under various fertilizer application scenarios (*Table 5.6*); the identification was made for the climate scenario with a 12-year time horizon and frequency of occurrence of the above four year types similar to that for the period 1971–1982.

As can be seen from *Table 5.6*, zones I and II – which are poor lands with dry conditions – require that 33% of the land be kept under fallow so as to obtain better yields with less than 40 kg/ha of fertilizers. However, when the fertilizer dose increases to 60 kg/ha, the percentage of fallow could decrease to 24.2%. The share of fallow land increases to 50% when the optimality criterion is stability of yields rather than maximization of outputs.

Table 5.6. Results of the CPM: optimum fallow distribution, as percentage of the area sown to wheat, under maximization of the total output and a high stability of wheat yield.

Agricul-tural zones	*Fertilizer application rates N:P* (kg/ha)	*Actual fallow distri-bution* (%)	*% of land under fallow for maximi-zation of the total output*	*% of land under fallow for maximi-zation of yield stability*	*Yield sta-bility* (%)
I	40:40	49.1	33.2	50.0	75
II	40:40	34.3	33.3	50.0	75
III	40:40	24.4	0.0	0.0	83
IV	40:40	17.1	0.0	0.0	85
V	40:40	0.0	0.0	0.0	85
I	60:60	49.1	33.2	50.0	79
II	60:60	34.2	24.9	50.0	79
III	60:60	24.4	0.0	0.0	88
IV	60:60	17.1	0.0	0.0	91
V	60:60	0.0	0.0	0.0	91

5.5. Linkage of CPM with the Economic Model

In this section the results of the implementation of two different "linkages" of the CPM and economic model are presented.

Let us consider the first "linkage" pattern. It should be mentioned that at present only partial linkage has been achieved, i.e., the crop growth model and the economic models have been linked. It will take several years more to finalize the construction of a system of models, including animal growth models, environmental and transport models, etc. We believe that the scheme presented below will be useful in the development of linkage techniques for a variety of models differing in structure, aggregation, and mathematical descriptions. Man–machine systems that have been developed to date can be characterized as in *Figure 5.5*

Contour 2-3-8-5-2 and 6 reflects the operation of a physical model at the first stage, and contour 2-1-7-4-2 characterizes the operation of an economic model at the same stage. Index 7 designates the set or bank of economic models in the economic block. The need to construct a set of models and not just a single model is described by Ereshko *et al.* (1983). This modeling system is to be provided with a dialogue system of information input regarding various scenarios of regional development (generally, the statistical model scenario is constructed using a set of programs, resources, etc.). The system covers scenario generation (module 1) and service programs providing the results in a form suitable for economic analysis (module 4). Modules 3 and 5 play the same part in the physical block as modules 1 and 4 do in the economic block.

The generator of climate situations (module 6) in this case is the strategy of choosing a year type or a succession of weather conditions that took place in the course of the preceding 12-year period.

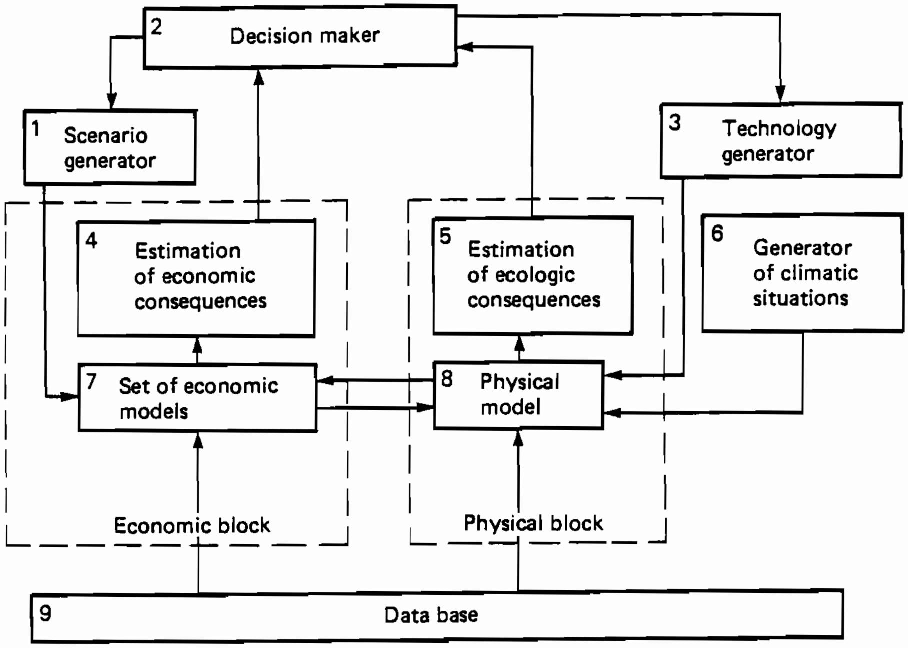

Figure 5.5. Man–machine system diagram.

Finally, we discuss the linkage between blocks 7 and 8. Let:

$$r^t_{ijp} = \left\{A^t_{ij}, W^t, O^t, N^t, P^t, K^t\right\}$$

$$r^0_{ijp} = \left\{A^0_{ij}, W_0, O_0, N_0, P_0, K_0\right\} \qquad t = 1,2,\ldots,T \tag{5.9}$$

Let us introduce the value

$$r_{ijp} = \sum_{t=1}^{T} r^t_{ijp}$$

having a function similar to that of specific indices of an economic model. It should be noted that the components r^0_{ijp}, r^t_{ijp}, and r_{ijp} describe the set of inputs to be used on one hectare during the beginning of the year period t, and during the whole year under technology A^t_{ij} (machinery, tractors, combine harvesters, and plant protection materials). The specific values can be taken from existing flow sheets.

Let us assume that in the first stage of the calculation based on the CPM for each weather type k, crop j, soil class i, and resource r_{ijp} we obtain:

$$y_{ij}^{k} = \rho_{ij}^{k}(r_{ijp}) \tag{5.10}$$

where p is the resource type index.

Naturally, such a relationship can be obtained only as an approximation resulting from a great number of physical model experiments. It should be noted that from the moment the elaboration of a coordinated decision starts, there is no need to know all the ρ_{ij}^{k} functions for all r_{ijp} sets. However, one does need a set of points that is sufficiently representative, especially in areas regarded by experts as specific reference values for the economic model.

Let us assume that decision makers estimate a system based on several major criteria. Such criteria generally include the production of individual types of animal and crop commodities, total grain production, feed production, meat production, net income, profit, costs, investments, etc. These criteria can be expressed as follows:

$$\Psi_{\chi}^{k} = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} C_{ij\chi}^{k}\, y_{ij}^{k}\, x_{ij}^{k} + \sum_{m=1}^{N_m} C'^{k}_{m\chi}\, z_m \tag{5.11}$$

$$\chi = 1,2,\ldots,N_s \qquad k = 1,2,\ldots,K$$

One of the most important objectives of model systems studies is to establish relationships between these criteria. In the case where the criteria are equal, the objective is to obtain the Pareto-optimum surfaces (or their parts) in the space $\{\Psi_s\}$ for each type of weather condition. To construct Pareto-optimum surfaces, it is sufficient to solve a series of optimization equations with the functional:

$$\Psi'^{k} = \sum_{\chi=1}^{N_s} \lambda_{\chi}^{k} \Psi_{\chi} \tag{5.12}$$

i.e., to identify the Pareto-optimum point one has to solve the following equation for the system of models:

$$\sum_{\chi=1}^{N_s} \sum_{j=1}^{N_j} \sum_{i=1}^{N_i} \lambda_{\chi} C_{ij\chi}^{k}\, y_{ij}^{k}\, x_{ij}^{k} + \sum_{\chi=1}^{N_s} \sum_{m=1}^{N_m} \lambda_{\chi}^{k} C'^{k}_{m\chi} z_m \Longrightarrow \max \tag{5.13}$$

at

$$y_{ij}^{k} = \rho_{ij}^{k}\,(r_{ijp}) \tag{5.14}$$

$$\sum_{i=1}^{N_i} y_{ij}^{k} x_{ij} - u_j \geq \Pi_j \tag{5.15}$$

$$\sum_{j=1}^{N_j} \sum_{i=1}^{N_i} \pi'_{sj} \sigma_j y_{ij}^{k} x_{ij} + \sum_{j=1}^{N_j} \pi_{sj} u_j - \sum_{m=1}^{N_m} d_{sm} z_m \geq 0 \tag{5.16}$$

$$z_m \geq \Pi_m \tag{5.17}$$

$$\sum_{i=1}^{N_f} \sum_{j=1}^{N_j} r_{ijp} x_{ij} + \sum_{m=1}^{N_m} r'_{mp} z_m \leq P_p \tag{5.18}$$

$$\sum_{j=1}^{N_j} x_{ij} \leq F_i \tag{5.19}$$

$$(x_{ij})_{\min} \leq x_{ij} \leq (x_{ij})_{\max} \tag{5.20}$$

where $i = 1,\ldots,N_f$; $j = 1,2,\ldots,N_j$; $p = 1,2,\ldots,N_{p+1}$; $s = 1,2,\ldots N_k$; $m = 1,2,\ldots,N_m$; and y^k_{ij}, (r_{ijp}), x_{ij}, u_j, z_m are variables. In the model, basic constraints are given for planned outputs, feed, resources, and land. For the sake of simplicity, resource constraints cover water constraints.

As can be seen from the description, we have formulated a mathematical programming task. Given below is an iterative procedure for obtaining the solution:

(1) For each crop j, on each soil class i, in the year k, a corresponding technology is chosen, which has resource requirements r^0_{ijp}.

(2) Using the CPM, we obtain the yield value:

$$y^{k_0}_{ij} = \rho^k_{ij}(r^0_{ijp})$$

(3) Using the physical model, specific resources (organic fertilizers, nitrogen, phosphorus, etc.) are increased by Δr_{ijp}; we then obtain corresponding small yield increments, $\alpha_{ijp} \cdot \Delta r_{ijp}$. As a result, crop yields can be represented as linear functions of small specific resource increments:

$$y^k_{ij} = y^{k_0}_{ij} + \sum_{p=1}^{N_p} \alpha_{ijp} \cdot \Delta r_{ijp} \tag{5.21}$$

(4) Let us substitute the yield values into the functional and the model; the substitution results in the following:

$$\sum_{\chi=1}^{N_s} \sum_{j=1}^{N_j} \sum_{i=1}^{N_f} \lambda_\chi C^k_{ij\chi} \left[y^{k_0}_{ij} + \sum_{p=1}^{N_p} \alpha_{ijp} \Delta r_{ijp} \right] x_{ij} \tag{5.22}$$

$$+ \sum_{\chi=1}^{N_s} \sum_{m=1}^{N_m} \lambda_\chi C'^k_{m\chi} z_m \to \max$$

$$\sum_{i=1}^{N_f}\left[y_{ij}^{k_0}+\sum_{p=1}^{N_p}\alpha_{ijp}\cdot\Delta r_{ijp}\right]x_{ij} - u_j \ge \Pi_j \qquad j=1,\ldots,N_j \tag{5.23}$$

$$\begin{aligned}&\sum_{j=1}^{N_j}\sum_{i=1}^{N_f}\pi'_{sj}\sigma_j\left[y_{ij}^{k_0}+\sum_{p=1}^{N_p}\alpha_{ijp}\cdot\Delta r_{ijp}\right]x_{ij}+\sum_{j=1}^{N_j}\pi_{sj}u_j\\ &\quad-\sum_{m=1}^{N_m}\alpha_{sm}z_m \ge 0 \qquad s=1,\ldots,Nk\end{aligned} \tag{5.24}$$

$$\sum_{i=1}^{N_f}\sum_{j=1}^{N_j}(r_{ijp}^{0}+\Delta r_{ijp})x_{ij} + \sum_{m=1}^{N_m} r'_{mp}z_m \le P_p \qquad p=1,\ldots,N_{p+1} \tag{5.25}$$

$$\sum_{j=1}^{N_j} x_{ij} \le F_i \qquad i=1,\ldots,N_f \tag{5.26}$$

$$z_m \ge \Pi_m \qquad m=1,\ldots,N_m \tag{5.27}$$

$$(x_{ij})_{\min} \le x_{ij} \le (x_{ij})_{\max} \tag{5.28}$$

$$\Delta r_{ijp} \le \Delta r_{ijp}^{+} \qquad i=1,\ldots,N_f,\ j=1,\ldots,N_j,\ p=1,\ldots,N_{p+1} \tag{5.29}$$

where Δr_{ijp}^{+} is the maximum increment value. Substituting new variables $\Delta v_{ijp}=\Delta r_{ijp}x_{ij}$, we arrive at a linear programming problem.

(5) Having solved the linear programming problem, we find areas to be sown by each crop on each soil class, feed amounts, livestock production output, and new specific resource values r_{ijp}^{+}. Then we return to (2) of the procedure, and repeat.

Let us assume now that the functions ρ_{ij}^{k} are twice differentiated, monotonic, incremental, and convex in the domain of interest. It should be noted that in the functional and in the constraints, only $r_{ijp}x_{ij}$ and $y_{ij}^{k}x_{ij}$ are nonlinear. If one substitutes the variable $v_{ijp}=r_{ijp}x_{ij}$, the resource constraints will become linear, and the second nonlinear term will have the form:

$$x_{ij}\rho_{ij}^{k}(v_{ijp}/x_{ij}) \tag{5.30}$$

Using the function ρ_{ij}^{k} for property assumptions, and having calculated the Hessian matrix, and using the Sylvester criterion (Gantmacher, 1959), we can show the product to be described by a convex function. Hence, choosing appropriately the increments Δr_{ijp}^{+}, we have brought the procedure to a global maximum.

Thus, we have shown how to obtain a Pareto-optimum point. Changing weight coefficients λ_{χ} in the functional ψ'^{k} and solving ensuing problems, we can obtain all the needed Pareto-optimum points for each climate scenario. Thus, the Pareto-optimum points obtained give the upper boundary of the regional possibilities. Lower boundary estimates can be obtained as follows. For a chosen type of weather conditions, k, the solution $x_{ij}^{k}, r_{ijp}^{k}, \ldots$ is obtained by maximizing the value ψ'^{k}. Substituting this solution in the model and in the functional, for all other given versions of weather conditions k', we obtain a lower boundary for the functional $\psi'^{k'}$ estimates. (It should be noted that in this particular case, the admissibility of solutions for all constraints and all versions of weather conditions was assumed. This can be attained provided Π_{j} and Π_{m} are considered to be variables and dealt with as functionals ψ_{χ}.)

As a result, at this stage we obtain upper and lower boundaries for each k value in the space $\{\psi_{\chi}\}$. These estimates, with the corresponding cropping patterns and resource distribution, are studied by an expert. The expert chooses a small number of alternative versions.

Finally, these alternatives (with some adjustments where needed) are tested in the simulation runs of the physical model using various sets of weather conditions. At this stage the stability of the alternative versions, as well as the ecological and economic consequences of their implementation, are estimated.

All the computations were carried out for a favorable year type and, hence, water is not considered to be the limiting factor. Besides that, crop rotations projected lead to favorable conditions for soil organic matter.

With these rather simplified assumptions, the above iterative procedure can be reduced to a single-step operation. An optimum decision obtained for a given year is tested in the simulation runs of the physical model with a chosen weather set. The expert evaluates the decision under various weather conditions and, if necessary, changes the original objective function. One can replace the criterion used or change the economic model constraints. After that, the process starts anew. Based on the results of a series of experiments, a solution is obtained that satisfies the conditions of all year types chosen.

Figure 5.6 shows one of the numerous cross-sections of the Pareto-optimum surface obtained using the above procedure in the subdomain of two criteria: grain production and feed production. We consider three distinctly different scenarios. While maximizing forage (feed), grain output constraints in equation (5.15) are:

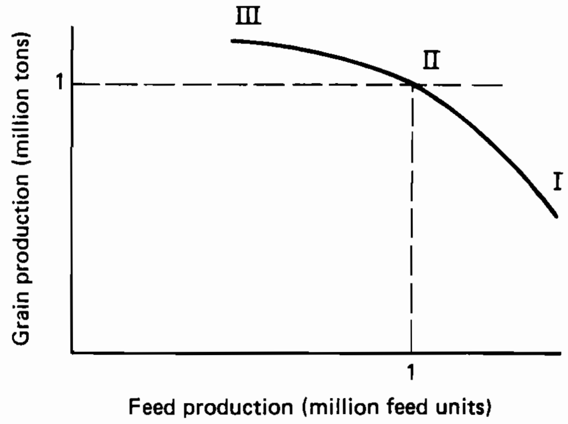

Figure 5.6. Pareto-optimum surface section for allocation of grain and feed.

(1) Minimum possible grain output.
(2) Average possible (close to existing) grain output.
(3) Maximum (close to potential) grain output.

These are illustrated in *Figure 5.6.* Using such a curve, a decision maker obtains graphical information regarding the relationship between various criteria. For instance, *Figure 5.6* shows that the insignificant decrease in grain production from scenarios (2) and (3) can result in a considerable increase in feed production. *Figure 5.6* is a schematic representation for which actual values can be seen in *Table 5.7* for four different types of weather.

Four year types are considered: favorable, humid and cold, dry (recurrent drought), and dry (severe drought). *Table 5.7* makes it possible to study decision versions depending on these weather conditions, e.g., to evaluate the decision stability against its response to weather conditions, and to estimate how decisions (1), (2), and (3) are affected by weather conditions.

Table 5.7. Ratio of grain feed production obtained for different optimization criteria.

Levels of output for optimization	*Types of weather condition*			
	Favorable year	*Humid cold year*	*Dry year*	*Severe dry year*
Minimum	(0.8;1.1)	(0.7;1.1)	(0.5;1)	(0.5;0.8)
Average	(1;1)	(0.8;0.9)	(0.5;0.7)	(0.5;0.6)
Maximum	(1.2;0.8)	(1.2;0.8)	(0.8;0.6)	(0.7;0.5)

The second "linkage" pattern of growth and distribution models was implemented using total grain production and cost minimization criteria with constraints imposed on the total output.

For the four identified year types, the frequency of occurrence was determined, which varies slightly in the agricultural zones of the Stavropol region based on the available data for 11 years. The frequency of occurrence for the first type of year is 30%, for the second type 40%, for the third and fourth type 15%. Accordingly, a climate scenario was constructed with frequency of occurrence the same as that in the preceding 11-year period (*Table 5.8*). The duration of the time series in the scenario is 11 years.

Table 5.8. Frequency of occurrence of different year types in the Stavropol region (Petrova, 1986; Petrova *et al.*, 1986).

Year type	*Frequency of occurrence (%)*
Favorable	36.3
Humid, cold	27.2
Recurrent drought	18.1
Severe drought	18.1

Let us consider the proposed linkage pattern for models that describe winter wheat cultivation in various crop rotations.

Let y^r be the average winter wheat yield in the rth year type, and p^r be the frequency of occurrence of the rth year type in the scenario. Then, the average yield value (mathematical expectation) y can be obtained from the formula:

$$y = \sum_{r=1}^{4} p^r y^r \tag{5.31}$$

To determine y^r values, the following scheme was elaborated. The yield is generally expected to depend to a considerable extent on the weather conditions of the harvest year, as well as on weather conditions of the preceding year. The effect of the previous years was quite insignificant, as confirmed by experimental data. Also, because of the lack of any regularity in the year type succession (which was confirmed by the results of meteorological observations that have been carried out in the Stavropol region over a period of 100 years), all the year type combinations of two successive years were believed to be characterized by equal probabilities. For that reason Petrova *et al.* (1986) used the combination of the CPM and the crop rotation model to calculate winter wheat yields y_p^r for all possible combinations of harvest year weather conditions, r, and the preceding year, q, for $r = 1,2,3,4$ and $q = 1,2,3,4$. The yields were determined for all agricultural zones, crop rotations, and technologies; the y^r value for the harvest year of type r was obtained as a q-mean value, i.e.:

$$y^r = \frac{1}{4}\sum_{q=1}^{4} y_q^r \tag{5.32}$$

In equation (5.32), for the sake of simplicity, the indices of crop rotation, agricultural zone, and technology are omitted. Based on y^r values, an average statistical y value for the weather scenario in question was calculated using equation (5.31). The y values for all crop rotations, agricultural zones, and technologies are part of the input information in the allocation model. Thus, the crop growth model and the allocation model were "yield-linked", with yields calculated for crop rotations and technologies employed in the allocation model, using the crop growth model and the crop rotation model.

Let x_{ijk} designate areas sown to winter wheat cultivated under the jth technology in the ith agricultural zone in kth crop rotation. In the Stavropol region, five agricultural zones have been identified: $i = 1,...,5$. It is known that in dry regions, unfavorable climatic impacts on winter wheat yield can be compensated for by the use of fallows and fertilizer application; in the zones with recurrent droughts the negative effect can be amended by using such preceding crops as peas, cropped fallow, etc. For the sake of simplicity we do not distinguish between winter wheat preceded by bare fallow and by a good preceding crop, i.e., we consider two crop rotations: $k = 1$ (wheat preceded by wheat) and $k = 2$ (wheat preceded by fallow, cropped fallow).

The land crop and technology allocation or distribution model being considered employs 10 technologies: five nonfallow and five fallow. The technology vector consists of 11 components, each being the resource unit cost in monetary units (as calculated per hectare of arable land): $l = 1$ (electric power), $l = 2$ (fuel and lubricants), $l = 3$ (labor costs), $l = 4$ (pesticides), $l = 5$ (organic fertilizers), $l = 6,7,8$ (nitrogen, phosphorus, and potassium fertilizers), $l = 9$ (tractors), $l = 10$ (trucks), and $l = 11$ (grain harvesters). An example is shown in *Table 5.9* for fallow technologies in zone III.

Let C_{ijkl} designate the unit costs of the lth resource used under the jth technology in the ith zone in the kth crop rotation. Let y_{ijk} designate the average statistical yield corresponding to the climate scenario chosen, which was calculated for the ith zone, jth technology, and kth crop rotation using equation (5.31). The components of the technology vector (the resource unit costs) are connected by linear relationships. Some of these are yield-dependent and some are yield-independent, giving two terms in the following equation:

$$C_{ijkl} = \sum_{i=l}\left[b_{ijkl'}C_{ijkl'} + b_l y_{ijk}\right] \tag{5.33}$$

with the possibility that some coefficients b_{ijkl} are equal to zero. For instance, the relationship:

$$C_{ijk10} = 10C_{ijk5} + 7y_{ijk}$$

Table 5.9. Input requirements, per hectare, for fallow technologies in zone III of the Stavropol region.

		Technologies				
Inputs	*Units*	*1*	*2*	*3*	*4*	*5*
Electricity	10^3 kWh	78.070	104.610	49.950	47.260	50.830
Fuel	tons	24.400	24.200	22.000	19.800	26.000
Pesticides	tons	1.500	1.500	1.500	1.500	1.500
Organic fertilizers	10^3 tons	10.000	20.000	0.000	0.000	0.000
Nitrogen	10^2 tons	0.000	0.150	0.200	0.300	0.600
Phosphorus	10^2 tons	0.200	0.300	0.200	0.300	0.600
Potassium	10^2 tons	0.000	0.000	0.050	0.100	0.200
Tractors	1000 machines per shift	0.480	0.500	0.460	0.480	0.550
Trucks	10^3 ton-km	114.500	217.500	14.500	10.800	19.700
Grain harvesters	10^3 machines per shift	0.154	0.154	0.154	0.154	0.154

used in the model means that the yield and organic fertilizers are carried by trucks. The coefficients b_{ijkl}, b_l in equation (5.33) are based on experimental data provided by the Economic Department of the Stavropol Research Institute of Agriculture.

In the model, natural constraints that reflect existing agricultural practice are used. For instance, it was assumed that the application of organic fertilizers will maintain soil fertility at a certain level; for that reason, the following constraints have been imposed:

$$\sum_{j=1}^{2} C_{ij25} x_{ij2} > \alpha_i S_i \qquad i = 1,\ldots,5.sp\ .3 \tag{5.34}$$

where S_i is the sown area of the ith zone, and α_i is the coefficient of organic fertilizer constraint (average normative rate of organic fertilizer application in t/ha); the summing is done with two fallow technologies, which implies the use of organic fertilizers that is taken into account. The lower boundaries for fallow areas are assumed for each zone:

$$\sum_{j=1}^{5} x_{ij2} > \beta_i \cdot S_i \qquad i = 1,\ldots,5 \qquad 0 < \beta_i \le 1 \tag{5.35}$$

where β_i is the coefficient. Total area sown to winter wheat in each zone should not exceed the total sown area, i.e.:

$$\sum_{j=1}^{5} x_{ij1} + 2\sum_{j=1}^{5} x_{ij2} \le S_i \qquad i = 1,\ldots,5 \tag{5.36}$$

The total winter grain output target figure was assumed to have been set for the total sown area of the Stavropol region, which corresponds to the constraint:

$$\sum_{i,j,k} y_{ijk} x_{ijk} \geq \Pi \tag{5.37}$$

where Π is the target figure.

Let a_l designate the lth resource unit cost; then the total winter wheat production cost that needs to be minimized is:

$$J = \sum_{i,j,k,l} a_l \cdot C_{ijkl} \cdot x_{ijk} \qquad \text{(objective function)} \tag{5.38}$$

Thus, the allocation problem translates into the minimization of the total production costs [equation (5.38)] under the constraints described by equations (5.33) to (5.37). It should be emphasized once more that the yields were calculated for all technologies and crop rotations using CPM and the crop rotation grain production model, based on the climate scenario in question. The C_{ijkl} are specific expenditures of resources. The expression $\sum_l a_l C_{ijkl}$ represents the costs of the jth technology for i agricultural zones and k rotations; they are given in *Table 5.10*. It can be seen that the differences in the costs and yields between having fallow and nonfallow as the precursor is quite substantial, especially in zones I and II. On the other hand, for zones III, IV, and V, fallow technologies are costly and lead to no further increase in yields, which are already substantially higher compared to those in zones I and II.

The task represented by equations (5.33) to (5.38) is a linear programming task which has been done using MINOS batch and input/output generator GEMINI [7]. The task was done for 20 values of the Π parameter, for one weather scenario, five agricultural zones, and two crop rotations.

Fallows are known to be the best winter wheat predecessors in dry regions. Zones I to IV of the Stavropol region have various fallow shares according to the technologies practised in these zones. For this reason, the total fallow area and fallow distribution by zones are of great importance, since these parameters are directly linked to the total output. In their turn, fallow distribution and fallow share depend on climatic conditions and the existing agricultural practice. In the present study, fallow areas in the climate scenario in question are regarded in terms of the minimization of total costs with constraints imposed on the total output.

The allocation model in equations (5.33) to (5.38) was shown to reflect reality quite satisfactorily. *Table 5.11* shows that, given that the average total output value is close to the real level, and using a weather scenario with the real frequency of occurrence of year types (as in the period 1971–1982), fallow distribution by zones and their share in each zone are close to reality.

Table 5.11 shows that the existing fallow distribution pattern is close to optimum if one minimizes total costs. The discrepancy in the bottom line can be accounted for by the fact that the distribution model does not distinguish between bare fallow and cropped fallow.

Table 5.10. Costs and yields for fallow and nonfallow precursors for five zones of the Stavropol region.[a]

	Zone I	*Zone II*	*Zone III*	*Zone IV*	*Zone V*
Zone I					
Nonfallow technologies:					
Costs	52.71	57.58	63.49	73.31	82.03
Yields	0.95	1.07	1.16	1.23	1.28
Fallow technologies:					
Costs	91.94	128.54	66.81	72.78	91.00
Yields	2.04	2.58	1.75	1.89	2.23
Zone II					
Nonfallow technologies:					
Costs	52.99	57.85	63.81	73.61	82.34
Yields	1.24	1.34	1.48	1.54	1.59
Fallow technologies:					
Costs	92.26	129.19	66.97	72.91	91.07
Yields	2.37	3.24	1.91	2.03	2.30
Zone III					
Nonfallow technologies:					
Costs	54.27	59.25	65.12	75.03	83.80
Yields	2.54	2.76	2.81	2.98	3.07
Fallow technologies:					
Costs	92.78	129.80	67.95	73.87	91.97
Yields	2.89	3.86	2.90	3.00	3.22
Zone VI					
Nonfallow technologies:					
Costs	54.33	59.20	65.31	75.43	84.26
Yields	2.60	2.71	3.00	3.38	3.54
Fallow technologies:					
Costs	92.15	129.84	68.04	74.07	92.19
Yields	2.25	3.90	3.00	3.20	3.44
Zone V					
Nonfallow technologies:					
Costs	55.20	60.09	66.04	75.95	84.74
Yields	3.48	3.62	3.74	3.91	4.03
Fallow technologies:					
Costs	93.62	130.66	68.83	74.79	93.05
Yields	3.75	4.73	3.80	3.93	4.31

[a] Fallow technologies involve the costs over two seasons and the yield in the second season.

Figure 5.7 shows the relationship of total output/costs for a given climate scenario; the curve describes fallow shares corresponding to a given range of the total output. As can be seen, the fallow share increases with an increase in the target level. ***Figure 5.7*** provides for the determination of costs required to reach the target figures, and vice versa, given the production costs, the target to be set under the given scenario, and which fallow distribution pattern will be effective.

Table 5.12 gives the dynamics of fallow distribution under various technologies. As can be seen, at comparatively low total output values, cheap

Table 5.11. Existing and optimal fallow distribution patterns calculated in the Stavropol region (Petrova, 1986; Petrova *et al.*, 1986).

Agricultural zones	*Existing fallow distribution pattern* (% of sown area)	*Fallow distribution pattern* (%), *as obtained with the use of the model at* Π = 150%
I	49.1	49
II	34.3	36.4
III	24.4	24
IV	17.1	19
V	0	15

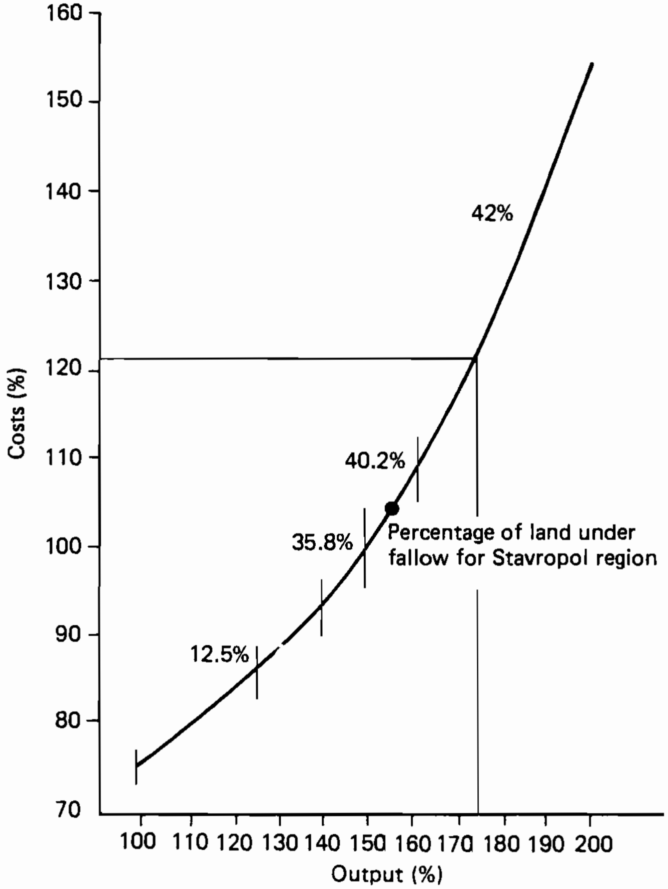

Figure 5.7. Results of economic model showing fallow land distribution required for different levels of outputs and costs for climatic conditions corresponding to 1971–1982. Output of 100% corresponds to 1960. Costs of 100% corresponds to 150% of output in 1960.

Table 5.12. Fallow distribution patterns under various technologies[a] (100 = 1960 level of winter wheat production).

Target figures	*Percentage of fallow land under different fallow technologies*				
	1	*2*	*3*	*4*	*5*
100	20.5	4.7	7.3	0	0
110	20.5	4.7	7.3	0	0
120	20.5	4.7	7.5	0	0
125	20.5	4.7	7.3	0	0
130	20.5	4.7	7.3	0	0
140	3.0	13.5	16.0	0	0
150	0	15.0	20.8	0	0
160	0	15.0	25.2	0	0
170	0	15.0	8.3	17.0	17.0
175	0	18.5	0	21.8	1.7
180	0	22.8	0	17.4	1.8
190	0	30.3	0	5.7	6.0
200	0	42.0	0	0	0
210					
220					

[a] Description of technologies 1 to 5 is given in *Table 5.9*.

technologies are used. The production costs increase with an increase in the target figures, and the second fallow technology is used, implying the application of the maximum amount of organic fertilizers and providing for yield maximization. Naturally, with the increase in total output, the fallow share increases to a maximum share of 42%. Beyond this, it will not be productive to increase the share of fallow land. Organic fertilizer is expensive to transport in the USSR, which makes technology 2 costly.

5.6. Concluding Remarks

A system of agriculture is formed under the influence of political, economic, scientific and technical, biological, organizational and legal, social and demographic, and natural factors. Their objective evaluation and the projection of possible behavior of systems under various conditions predetermine the nature and structure of models to describe the system of agricultural management in the Stavropol region. These submodels describe the growth of plants and their productivity, production distribution, and the structure of inputs, such as agricultural machinery, tractors, and nutrients.

The main problem is to introduce measures for reducing the dependence of agriculture on weather conditions and for ensuring sustainable production by introducing progressive technologies, such as land reclamation, mechanization, application of fertilizers, and electrification, i.e., ensuring stable economic conditions in all regions, especially in those with unfavorable weather conditions.

The evaluation of various alternatives of agricultural development and the analysis of certain aspects of agricultural policy are possible by formulating and solving various optimization problems. The most desirable future optimization tasks are the following:

(1) Analysis of resource availability. The task is to attain target levels of primary crop growth and feed production with minimum expenditure, for which limiting resources would have to be identified and additional investment be determined.
(2) Maximization of total grain crop production, with target figures for feed production to be attained. No constraints on resources are imposed, but additional investment in resources is to be determined.
(3) Maximization of feed production. No resource constraints are imposed. A wide range of experiments need to be carried out with various percentages of grain used for livestock feeding. Resource requirements and possibilities of feed production are to be determined.
(4) Studies of the regional potentials to be carried out with hard constraints imposed on the resource use. Efficient methods of feed supplies and ways of reaching crop production target figures are to be established.

It is well known that fallow is the best precursor for winter wheat, and the utilization of fallow is extremely necessary to ensure moisture content and soil fertility in the Stavropol region, especially in zones I and II which have severe droughts. Therefore, the magnitude and distribution of fallows are directly related to total grain output. The quantity and allocation of fallow, in turn, are largely influenced by weather conditions and by the agricultural technologies selected.

The results of numerical runs show the fallow allocation dynamics along with the necessary technologies. The cost of nonfallow technologies is increasing gradually with the increasing doses of chemical fertilizers. As to fallow technologies, the first two use organic fertilizer and are therefore rather expensive. The remainder are comparatively cheap as they use only chemical fertilizers. So, while the values of output are comparatively low when comparatively cheap technologies are used, when outputs are increased the fallow area and costs increase as well; finally, technology 2 is chosen, which appropriately gives the most quantity of manure and the most output. The solutions, illustrated in the form of cost–output dependence, may be easily used by decision makers to see what costs are necessary for achieving certain targets, and what quantity of fallow areas is necessary. The appropriate technology may be chosen.

Also of great importance for decision makers is the first scene of the linkage (with several criteria). This allows the experts to choose a solution at several stages: to set the weights of separate criteria, to set constraints on different kinds of agricultural production, and to choose the points (appropriate version of solution) on the Pareto-optimal surface. For example, an insignificant decrease in grain production of about 10% results in considerable (about 30–40%) increase of feed production.

In the second linkage scheme of the CPM with the economic technological model, the problem of allocation of fallow areas was considered as a problem of minimizing the total costs of grain output necessary to obtain certain planned outputs of crops and fodder.

The results of calculations show that fallow is of great efficiency in the eastern zones (zones I and II) of the Stavropol region, i.e., in semiarid conditions. It has already been shown that expenditure and percentage of fallow area grow with the increase in total grain output. For a target of, say, 200% of the 1960 level, 42% of land is required under fallow for the given optimization criteria. The further increase of total output is possible only by changing technologies: for example, inculcating pest control and elaborating new drought-resistant types of winter wheat.

Finally, it should be said that these results have provided encouragement to carry out a number of other numerical experiments, which are currently under way to assist the decision-making process.

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CHAPTER 6

Iowa, USA: An Agricultural Policy Analysis

B.C. English, D.A. Haney, A. Kapur,
and W.H. Meyers

Abstract

Using Iowa as an example, we simulated a region's agricultural section with a hybrid model. This model incorporates an LP model that represents the supply of agricultural commodities and an econometric portion that simulates the price impacts.

Three different policies on resource options are examined. The first and second options restrict the activities placed on the land to 20 and 10 t/ha, respectively. The final alternative restricts nitrogen availability to 652706 t.

The modeling technique employed in this analysis allows the interactive nature of supply and demand to operate. In addition, the physical adjustment to yield owing to changes in depth of the topsoil are incorporated. This method requires further study and evaluation; however, on the basis of this study it appears to merit allocation of substantial resources to examine the methodology.

6.1. Introduction

6.1.1. The problem of soil loss

Throughout much of human history, man has kept deprivation at bay primarily by moving from one piece of land to another as soils in the former were exhausted. Asia and South America supply a record of ancient civilizations that lived where desert conditions prevail today (Gustafson, 1937). The disappearance of these civilizations resulted largely from the destructive effects of wind erosion. Today, however, movement from depleted soils to virgin, high-quality soils is infeasible, for few of these remain in the world. Much of the remaining new land is of marginal quality and would require extensive improvements before it could be made agriculturally productive. Meanwhile, the demand for food soars as the world's population increases by about 80 million persons per year (Brink *et al.*, 1977).

Soil erosion was accepted as an inherent part of farming and received little attention in the USA until Hugh Hammond Bennett began illustrating the impacts of it in 1918. In 1982, a USDA publication estimated the annual loss of soil to be 1.5 billion tons (US Department of Agriculture, 1982). Expanded agricultural production over the years has been accompanied by soil erosion losses and water runoff, cropland deterioration, and environmental degradation. Many studies warn that erosion is taking place at a rate that threatens the future food production of the USA. These studies emphasize that productive agricultural soil must be protected if the USA is to continue to meet domestic food needs and help alleviate world food shortages. In spite of such warnings, 42% of the cropland nationwide has no conservation treatment (Cory *et al.*, 1978).

Not less than one third of the valuable topsoil on US croplands has been lost during the last 200 years. About 91 million hectares in the USA were ruined or seriously impoverished for crop cultivation by soil erosion before 1940, and the land continues to erode. Pimental *et al.*, (1976) estimated that water runoff and wind erosion result in a gross annual transfer of 4.5 billion metric tons of soil loss to streams, etc. This is the equivalent of about 17.8 cm of soil from about 2 Mha. Estimates of the average annual loss of topsoil from agricultural cropland range from 13.6 to 31.7 t/ha.

Shifting the focus to Iowa, in the spring of 1974, Iowa farmers were plowing fence row to fence row. During the ensuing rains, a loss of 34-45 t/ha was not unusual on unprotected land, and many farms lost in excess of 113 t/ha. Soil loss in Iowa, in 1974, was at the highest level in 25 years, with 1.8 Mha having a gross loss of more than 20 t/ha (Iowa Department of Environmental Quality, 1975). Gross loss of 90-115 t/ha was not uncommon and reached levels as high as 450 t/ha in some areas.

While soil is lost to erosion each year, it is also continuously being formed. The rate of soil formation is difficult to measure and depends on many factors such as climate, vegetation, soil disturbances, and the nature of the subsoil. Under ideal soil management conditions, soil may be formed at a rate of 2.5 cma in about 30 years, and under natural conditions at a rate of 2.5 cm in 300-1000 years. McCracken estimated that under normal agricultural conditions, soil is formed at a rate of 2.5 cm in 100 years; that is about 3.3 metric tons of topsoil formed per hectare per year (Pimental *et al.*, 1976).

6.1.2. Objectives of the study

Task 2 of IIASA's Food and Agriculture Program (FAP) is to examine the relationships between agricultural production technologies, resource use, and the environment that will affect the long-term stability and sustainability of the global food and agricultural system. To achieve this goal, a model focusing on resource use in the State of Iowa is developed as a case study.

A description of Iowa's agriculture is presented to acquaint the reader with the productive characteristics in Iowa. Then the method of analysis and the model coefficient are described. Finally, alternative potential policies are examined.

6.1.3. Overview of agriculture within the State of Iowa

Iowa is located in the midsection of the USA (*Figure 6.1*). Because Iowa is in the midst of one of the most important agricultural areas in the world, it is classed as an agricultural state. Iowa farmers received US$10.5 billion from farm marketing in 1982. Iowa ranked first in corn production, and second in soybean and alfalfa hay production. It produced 23% of the hogs slaughtered in 1982, ranking first among the states within the USA with cash receipts of US$2.8 billion (Iowa Crop and Livestock Reporting Service, 1983).

Primary crops produced on 90% of the hectares harvested in 1983 included corn, soybeans, grain sorghum, wheat, and hay (*Table 6.1*). Iowa's production of corn, soybeans, and oats accounted for 18.9, 14.1, and 9% of the 1982 US production, respectively.

In addition to producing crops, Iowa plays a prominent role in beef and pork production. The state produced 1245 Mkg (total liveweight) of beef and had an 11% share in fed beef production. It had 14.3 million hogs and pigs on hand December 1, 1982, or 27% of the nation's hogs.

Yield trends in Iowa during the past 12 years for the six primary crops are shown in *Table 6.2*. Yield for all crops except sorghum increased during the past 13 years, and average corn yields increased 28% during the past 12 years.

While productivity has increased on Iowa's soils, there is concern over the loss of potential future increases through resource exhaustion. In Iowa, soil is being eroded at a rate that exceeds the natural replenishment rate.

Figure 6.1. Iowa's location in the conterminous USA.

Table 6.1. Harvested acreage and quantity of corn, oats, soybeans, sorghum, and wheat in Iowa and the USA, 1982 (Iowa Crop and Livestock Reporting Service, 1983).

	Acres harvested (kha)		*Quantity produced* (Mt)	
Crop	*Iowa*	*USA*	*Iowa*	*USA*
Corn, grain	5177	28800	40.4	213.3
Oats	394	4158	0.8	9.0
Soybeans for beans	3366	27867	8.7	62.0
Sorghum	4	5609	[b]	19.1
Wheat	139	34361	0.1	76.4
Hay[a]	882	23889	6.4	123.5

[a] In metric tons. [b] Less than 100 hectares.

Concern over the long-term sustainability of agricultural production in Iowa is most evident by the public attention over soil loss and land use.

Because of the public concern and importance of agriculture to the state, the Iowa Legislature has passed laws to provide incentives for employing conservation practices and imposing penalties for erosive conditions. These include both mechanical and vegetative means for reducing soil erosion. Some of these methods include:

(1) Mechanical:
  (a) Terracing.
  (b) Contouring.
  (c) Grass waterways.
  (d) Reduced tillage methods.
(2) Vegetative:
  (a) Rotations encompassing hays and small grains.
  (b) Strip cropping.

Table 6.2. Average Iowa crop yields, 1970–1983.

Crop	*Average yield, 1970–1974* (kg/ha)	*Average yield, 1978–1982* (kg/ha)
Corn	6053	7742
Hay	5352	7530
Oats	1999	2219
Sorghum	4216	4193
Soybeans	2232	2640
Wheat	2379	2419

6.2. A General Description of the Regional-National Recursive Hybrid Model

The model used in this analysis is a regional-national recursive hybrid model that traces the path of various economic variables over the time period 1980 through 2000. The model is regional because the linear programming (LP) model is set up for the region or State of Iowa. It is national because the econometric model is solved for the USA, excluding Iowa. It is recursive due to the sequential nature of the solution. It is hybrid, since a combination of two modeling techniques is used (Kapur, 1983).

The focus of the term "recursive" is on the hybrid model as a whole. The linear programming solution at time t determines production levels in Iowa. These values together with production levels estimated for the rest of the USA in the econometric model determine prices, acreage allocations, and production levels at time $t+1$. Further, each crop rotation-management system in the linear programming solution at time t has a soil loss associated with it. This differs on the basis of the producing area and land class under consideration. The decrease in soil depth and its impact on yield are then estimated. Therefore, the estimated production patterns determined by the LP model at time t affect soil depth, yield levels, and hence the optimal production pattern at time $t+1$.

The LP model is solved once every five years starting with the year 1980. The optimal farm production plan is, therefore, assumed to remain optimal for five years. The econometric model is solved for each year over the time period under consideration. On the basis of the values of the economic variables estimated in the econometric component of the model, the optimal farm plan determined in the LP component is revised once in five years.

6.2.1. The hybrid model

The three main components of the hybrid model under consideration are:

(1) A regional linear programming model for Iowa.
(2) A national econometric simulation model for the USA, excluding Iowa.
(3) A linkage procedure, which transfers information between the programming and econometric components and adjusts the relevant variables.

Detailed descriptions of each of the above components of the model are presented in Sections 6.2.2, 6.2.3, and 6.2.4.

6.2.2. The regional linear programming model for Iowa

In the regional component of the regional-national model, a linear programming model for the State of Iowa is divided into 12 producing areas (PAs). Each producing area, or region, is an aggregation of contiguous counties based on similarities of soil and other characteristics. These regions are consistent with Iowa's soil conservancy districts and were used initially by Nagadevara *et al.* (1975); see *Figure 6.2.*

Land in each producing area is further divided into five land classes. These five land groups represent an aggregation of the 29 class-subclasses in the National Inventory of Soil and Conservation Needs, 1967 (Conservation Needs Inventory Committee, 1971). The Conservation Needs Inventory Committee places all soils in eight capability classes. The risks of soil damage or limitations in use become progressively more severe from land class I (few limitations) to land class VIII (no beneficial agricultural uses). Four land capability subclasses are defined according to the general kinds of limitations on agricultural use. These are susceptible to erosion, *e*; drainage problems of excess water, *w*; soil limitations within the rooting zones, *s*; and climatic conditions preventing normal crop production, *c* (Heady and

Table 6.3. Organization of the land groups defined for the Iowa model.

Land group in Iowa model	*Land capability class and subclasses*
I	I
II	II*e*, *w*, *s*, *c*; III*w*, *s*, *c*; IV*w*, *s*, *c*; V*e*
III	III*e*
IV	IV*e*
V	VI*e*, *w*, *s*, *c*; VII*e*, *w*, *s*, *c*; VIII*e*, *w*, *s*, *c*

Langley, 1981). Organization of the 29 land capability class-subclasses into the five land groups defined for the Iowa model can be seen in *Table 6.3*. A schematic diagram of the model is presented in *Figure 6.3*.

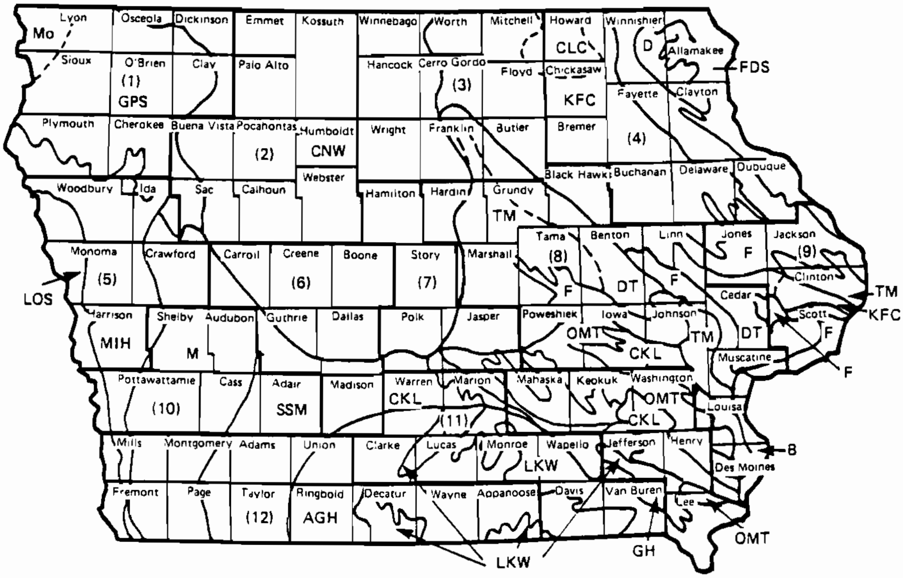

Figure 6.2. Iowa's 21 principal soil association areas (letters) and 12 producing areas (numbers). B = Soils of Miss. Bottomland: thick line is gradational boundary, thin line is abrupt boundary, broken line is tentative boundary; AGH = Adair-Grundy-Haig; ASE = Adair-Seymour-Edina; CKL = Clinton-Keswick-Lindley; CLC = Cresco-Lourdes-Clyde; CNW = Clarion-Nicollet-Webster; D = Downs; DT = Dinsdale-Tama; F = Fayette; FDS = Fayette-Dubuque-Stonyland; GPS = Galva-Primghar-Sac; CH = Grundy-Haig; KFC = Kenyon-Floyd-Clyde; LKW = Lindley-Keswick-Weller; LOS = Luton-Onawa-Salix; M = Marshall; MIH = Monona-Ida-Hamburg; Mo = Moody; OMT = Otley-Mahaska-Tainter; SSM = Shelby-Sharpsburg-Macksburg; TM = Tama-Muscatine.

The Objective Function

The objective function is defined to maximize the net returns or profit from crop production in Iowa, subject to the availability of land, nitrogen fertilizer, and restrictions placed on levels of soil erosion [1]. It is of the form:

$$\max Z = \sum_i \sum_j P^s_{ijt} C^s_{ijt} - \sum_i \sum_k \sum_l \sum_m T_{iklmt} \cdot L_{iklmt} - \sum i \; P^n Q^{nb}_{it} \quad (6.1)$$

where i is 1 to 12 for the producing areas; j is 1 to 8 for the crops produced; k is 1 to 9 for the conservation-tillage practices; l is 1 to 30 for the crop rotations in each producing area; *m* is 1 to 5 for the land groups; *t* is the time period in which optimization occurs; P^s_{ijt} C^s_{ijt} is the gross return received by farmers for selling crop *j* at price P^s_j in producing area *i* in period *t*, T_{iklmt} L_{iklmt} is the cost of production *T* in dollars per acre of rotation *l* with conservation-tillage practice *k* on land group *m* in producing area *i* in period *t*, multiplied by the level of crop production activity *L*; and $P^n Q^{nb}_{it}$ is the price of nitrogen fertilizers, P^n, multiplied by the quantity of nitrogen purchased, Q^{nb}, in producing *i* in period *t*.

		Crop rotations			Corn sell		Non-legume hay sell		Legume hay sell		Oats sell		Sorghum sell		Soybean sell		Wheat sell		Nitrogen fertilizer				
		R1AEB001		R5DGB012	CRNB0001	CRNB0012	NLHB0001	NLHB0012	HLHB0012	HLHB0001	OTSB0001	OTSB0012	SRGB0001	SRGB0012	SBNB0001	SBNB0012	WHTB0001	WHTB0012	NITB0001	NITB0012	Type of RHS	RHS	
Objective function	OBJO001	$-c_1$		$-c_m$	p_1^1	p_1^{12}	p_2^1	p_2^{12}	p_3^1	p_3^{12}	p_4^1	p_4^{12}	p_5^1	p_5^{12}	p_6^1	p_6^{12}	p_7^1	p_7^{12}	p_N^1	p_N^{12}	N		
Land rows	CLDO1001	1. PA1 1																			L	w_{11}	(a)
	CLDO5001																				L	w_{51}	
	CLDO1002		1. PA2 1																		L	w_{12}	
	CLDO5002																				L	w_{52}	
	CLDO1012			1. PA12 1																	L	w_{112}	
	CLDO5012																				L	w_{512}	
Nitrogen	NFRO0001	-x	⋱																		G	0	
	NFRO0012			-x																	G	0	
Soil erosion	SOIL1001	z	⋱																		N		
	SOIL5012			z																	N		
Corn pdn	CRNO001	y	⋱		-1																G	0	
	CRNO0012			y		-1															G	0	
Silage pdn	SILO 0001	y	⋱																		G	v_1	(b)
	SILO 0012			y																	G	v_{12}	
Non-legume hay pdn	NLHO0001	y	⋱				-1														G	v_1	
	NLHO0012			y				-1													G	v_{12}	
Legume hay pdn	HLHO0001	y	⋱						-1												G	v_1	
	HLHO0012			y						-1											G	v_{12}	
Oats pdn	OTSO 0001	y	⋱								-1										G	0	
	OTSO 0012			y								-1									G	0	
Sorghum pdn	SRGO 0001	y	⋱										-1								G	0	
	SRGO 0012			y										-1							G	0	
Soybean pdn	SBNO 0001	y	⋱												-1						G	0	
	SBNO 0012			y												-1					G	0	
Wheat pdn	WHTO 0001	y	⋱														-1				G	0	
	WHTO 0012			y														-1			G	0	

Figure 6.3. The Iowa linear programming component: (a) quantities of land; (b) roughage requirement for livestock production.

The Crop Sector

Crop production, crop selling, and nitrogen purchasing activities are considered. Crop production activities simulate rotations producing corn grain, corn silage, leguminous and nonleguminous hay, oats, sorghum grain, soybeans, and wheat, in crop management systems that incorporate rotations of one to four crops (*Table 6.4*). Each rotation is defined for three conservation methods: straight row, strip cropping, and contouring. Each conservation method is associated with three tillage practices: conventional tillage in the fall, conventional tillage in the spring, and reduced tillage. Each of

Table 6.4. Crop rotations defined in the Iowa linear programming component.[a]

Rotation	*Corn*	*Oats*	*Grain sorghum*	*Leguminous hay*	*Nonleguminous hay*	*Soybeans*	*Wheat*
ae	0	0	100[a]	0	0	0	0
ao	50	0	0	0	0	0	50
br	60	20	0	20	0	0	
bs	50	25	0	0	25	0	0
bt	40	20	0	20	0	0	0
bv	34	33	0	0	33	0	0
bx	20	20	0	60	0	0	0
cd	17	16	0	0	67	0	0
ch	50	0	0	0	0	25	25
cj	50	0	0	0	0	50	0
cl	50	0	0	0	25	0	25
cm	25	25	0	0	50	0	0
cn	20	0	0	0	60	0	20
cs	67	0	0	0	0	33	0
cu	34	33	33	0	0	0	0
cz	20	20	0	0	60	0	0
db	17	16	0	50	0	17	0
dc	40	20	0	0	20	20	0
df	0	14	28	44	0	14	0
dg	0	0	0	100	0	0	0
dh	40	0	0	0	20	20	20
dl	34	0	0	0	33	0	33
dy	0	0	0	0	25	50	25
hn	50	25	0	0	0	25	0
ho	40	20	0	20	0	20	0
hq	28	0	0	30	0	14	28
hs	28	28	0	44	0	0	0
kf	0	0	67	0	0	33	0
kg	0	20	40	0	40	0	0
ot	100	0	0	0	0	0	0

[a] Numbers indicate the percentage of land devoted to a particular crop. For example, ae is 100% grain sorghum, and cj is 50% corn and 50% soybeans (i.e., a corn–soybean rotation).

these combinations is defined on the land group to which it applies. Thus, each rotation combined with a specific conservation-tillage practice defines a unique crop management system (*Table 6.5*). Coefficients defined for each activity include the cost of production, land use (one acre), the quantity of nitrogen required, the yield adjusted for conservation-tillage practice, and the average level of gross soil loss leaving the field during a one-year period.

Crop yields are estimated using average country yields. These yields are then weighted by average production to obtain producing area yields. Yields are adjusted for land group and conservation-tillage practice.

Livestock Roughage Requirements

The livestock industry forms a crucial part of Iowa's agricultural output. However, the linear programming model does not explicitly take livestock production and selling activities into account. In order to ensure that the solution to the model is realistic, Iowa's livestock activities are accounted for in the LP model by imposing lower bounds on production levels of silage, leguminous hay, and nonleguminous hay. Values of the constraint for each of the 12 PAs are set at existing levels of use of each of these inputs by the livestock industry.

Table 6.5. Conservation-tillage practices defined in the Iowa linear programming component.

	Conservation-tillage practice[a]								
Land group	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
1	*[b]	*	*	NA[c]	NA	NA	NA	NA	NA
2	*	*	*	*	*	*	NA	NA	NA
3	*	*	*	NA	NA	NA	*	*	*
4	*	*	*	NA	NA	NA	*	*	*
5	*	*	*	NA	NA	NA	NA	NA	NA

[a] Conservation-tillage practices defined as: *a* is straight row, residue removed; *b* is straight row, residue left; *c* is straight row, reduced tillage; *d* is contour, residue removed; *e* is contour, residue left; *f* is contour, reduced tillage; *g* is strip cropping, residue removed; *h* is strip cropping, residue left; and *i* is strip cropping, reduced tillage. [b] An asterisk, *, indicates that the conservation-tillage practice is defined for the particular land group. [c] NA indicates not applicable.

6.2.3. The US econometric simulation component

The purpose of the US econometric simulation component of the model is to estimate resource use and commodity output originating in the USA, excluding Iowa. These estimates are summed with those originating in Iowa (from the LP component) to determine economic variables in the national market.

The econometric component of the hybrid model is based on the Center for Agricultural and Rural Development national agricultural econometric simulation model (CARD-NAES), originally specified by Ray and Heady (1974), Roberts and Heady (1980), and Schatzer *et al.* (1981a; 1981b), with some restructuring done for this study.

The demand equations from the CARD-NAES model are incorporated into the hybrid. Demand equations are used for feedgrains, wheat, soybeans, beef, and pork. These equations are recursive in structure. *Figure 6.4* illustrates the wheat output model used in this study.

Schatzer *et al.* (1981a) point out that the recursive structure of the model complies with the biological production process of many agricultural commodities. When farmers plant their crops, they do not know what the price will be at harvest time. Therefore, they use an expected price in making their planting decisions. In the model presented, lagged prices are assumed to be rough approximations for expected prices. As a result, given supply, the current year's price adjusts to clear the market.

6.2.4. The linkage component

The linkage component of the Iowa regional-national system does the following:

(1) Transfers information between the linear programming and econometric components.

(2) Revises and adjusts selected variables between time periods to simulate the recursive sequence of agricultural production and its interaction with the environment.

The regional LP component is first solved for the profit maximizing level of crop production and resource use for the State of Iowa (*Figure 6.5*). These values are summed with estimates of production and input use occurring in the USA excluding Iowa (estimated from the national econometric simulation component) to obtain national totals. Commodity prices and other important economic variables are estimated in the econometric component. Crop yield adjustment factors are determined based on inches of topsoil lost. These factors are used to revise the crop yields in the LP sector. The newly estimated commodity prices are used to revise the coefficients associated with the crop selling activities in the LP objective function in the next time period. After the LP input data matrix is revised, the programming component is solved for the next time period, thus repeating the entire process again until the predetermined number of simulations are completed.

The linkage component can be decomposed into three subsectors: retrieval, adjustment, and revision. Information retrieved from the Iowa LP component includes production levels of endogenous crops, soil loss, nitrogen fertilizer use, and land use in each of the five land groups for each of the producing areas. Crop production and fertilizer use are inputs to the

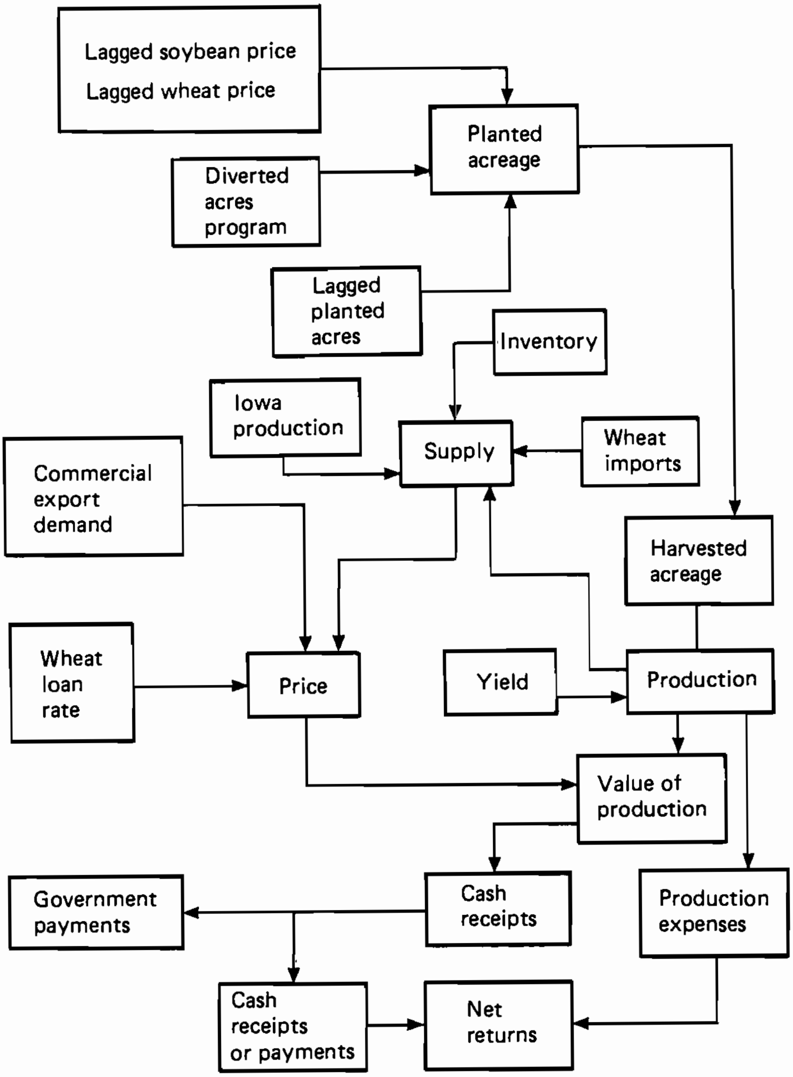

Figure 6.4. General scheme of wheat submodel.

econometric component, while soil loss and land use are inputs to the adjustment and revision subsectors of the linkage component.

The adjustment subsector adjusts the estimated crop yields for the effects of soil loss. A definite tendency for yields to increase with depth of surface soil up to 20-25 cm has been observed. For depths over 25 cm,

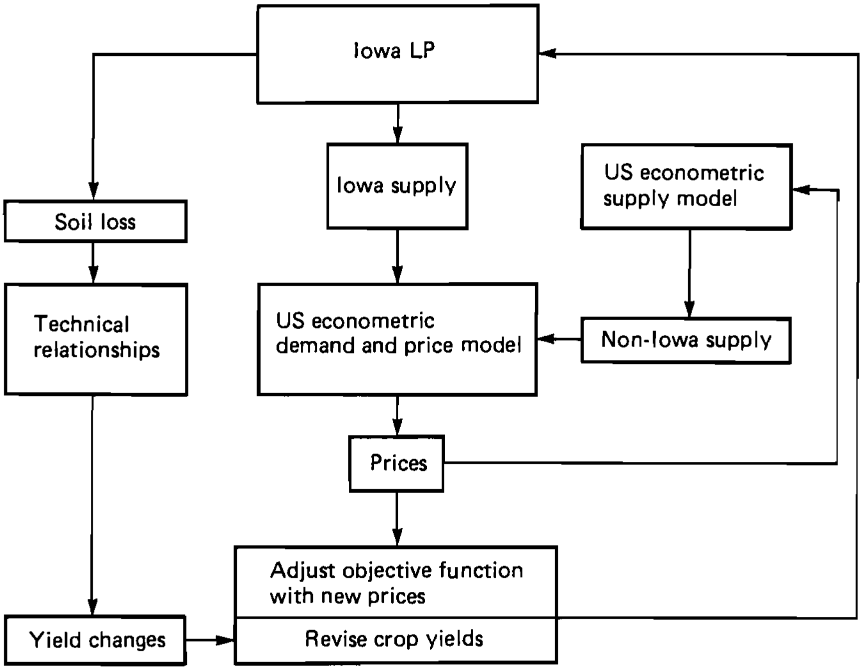

Figure 6.5. Structure of the hybrid recursive regional–national model.

there is apparently no clearly defined relationship between depth and yield (Murray *et al.*, 1939). As noted by Peterson (1964), Wischmeier found a highly significant inverse correlation between crop yields and erosion losses. Based on 8000 plot years of soil loss data from 21 states, he found a marked inverse relationship between the yield of corn and erosion. This relationship was curvilinear, however. The correlation between yield per hectare and soil loss was much closer at lower yields; it diminished markedly when the level of approximately 4900 kg/h was reached.

Where favorable surface and subsurface horizons exist, crop yields are not greatly different on soils with different degrees of erosion, especially if good management and fertilizer are used. Erosion on soils with favorable surface horizons will initially show only slight reductions in yields. With continued erosion, yields will decline progressively. If erosion occurs on soils with limited surface horizon depth overlying coarse fragmented material, crop yields may continue at reasonable levels for a short time and then drop sharply.

Crop yields decrease as soil depth decreases (*Figure 6.6*). This relationship differs depending on soil type. *Figure 6.6* depicts the decline in corn yield that occurs as erosion decreases soil depth. At any point in time, given the depth of soil, the corresponding yield can be determined.

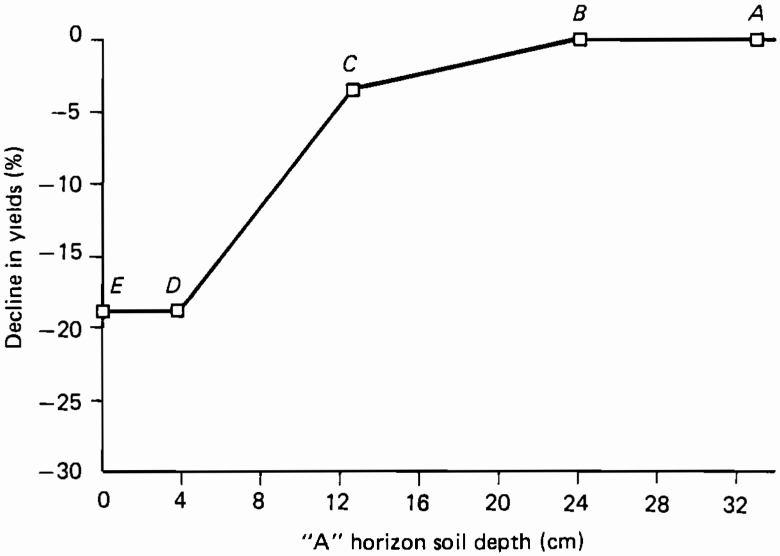

Figure 6.6. Relationship between corn yield and topsoil depth: □ = BASE policy.

Soil depths of 3.8, 12.7, and 24.1 cm correspond to average soil depths of erosion phases 3, 2, and 1, i.e., slightly, moderately, and severely eroded, respectively. Given corn yields corresponding to each of the above three soil depths, the corn yield–soil depth relationship can be graphed by joining these points, on the assumption that the relationship between these points can be depicted by a linear approximation. For soil depth greater than 24.1 or less than 3.8 cm, the function could be assumed to be horizontal.

Based on the principal soil association areas in each producing area, USDA dominant soil classification by land group for each Major Land Resource Area (MLRA), and information on 18 Iowa farms obtained by the CARD-BMP study (Pope *et al.*, 1982), 60 such benchmark corn yield–soil depth functions are estimated for each of the five land groups for 12 producing areas. These functional relationships are used for each of the crops in the study.

Data for the five-year period 1970–1975, published in *Iowa Agricultural Statistics*, are used to obtain average yields for the eight crops in the 12 PAs. The data are then adjusted by land group. These average yields (or YBARYLDS) are used in conjunction with the benchmark corn yield–soil depth graphs, such as that depicted in *Figure 6.6*, to adjust yields of each crop from one year to the next based on changes in soil depth.

Tons of soil loss associated with each activity are estimated by the universal soil loss equation. These are then converted to centimeter of soil loss using the equation:

$$ISL = \frac{TSL}{SBD \cdot TACRE} \tag{6.2}$$

where *ISL* is soil loss (cm), *TSL* is soil loss (tons), *SBD* is soil bulk density, and *TACRE* is total acres.

Revised soil depth is then determined as:

$$SOILD_t = SOILD_{t-1} - ISL \tag{6.3}$$

where $SOILD_t$ is the average soil depth at time period t.

The methodology to be used to adjust crop yields is presented below.

Using *Figure 6.6*, let Y_1, Y_2, and Y_3 be the corn yields corresponding to soil depths of 24, 12, and 4 cm, respectively. Set slope:

$$\text{over } AB = m\,(1) = 0 \tag{6.4}$$

$$\text{over } BC = m\,(2) = \frac{(Y_1 - Y_2)/Y_1}{9.5 - 5} = \frac{1 - (Y_2/Y_1)}{4.5} \tag{6.5}$$

$$\text{over } CD = m\,(3) = \frac{(Y_2 - Y_3)/Y_1}{5 - 1.5} = \frac{(Y_2 - Y_3)/Y_1}{3.5} \tag{6.6}$$

$$\text{over } DE = m\,(4) = 0 \tag{6.7}$$

where A, B, C, D, and E are points on *Figure 6.6*.

Based on the benchmark graphs, the yield adjustment factors, or YADJ, will be computed:

$$\text{if } SOILD_t \geq 9.5, \text{ yield adjustment } = 1 \tag{6.8}$$

$$\begin{gathered}\text{if } 5 \leq SOILD_t < 9.5, \text{ yield adjustment } = \\ m\,(2) \cdot (SOILD_t - 5.0) + (Y_2/Y_1)\end{gathered} \tag{6.9}$$

$$\begin{gathered}\text{if } 1.5 \leq SOILD_t < 5.0, \text{ yield adjustment } = \\ m\,(3) \cdot (SOILD_t - 1.5) = Y_3/Y_1\end{gathered} \tag{6.10}$$

$$\text{if } SOILD_t < 1.5, \text{ yield adjustment } = Y_3/Y_1 \tag{6.11}$$

Using the appropriate yield adjustment factor on the basis of soil depth determined above, at time t, yield will be determined for crop j in land group m in producing area i as follows:

$$CHNGYLD = YBARYLD \cdot (1 - YADJ) \tag{6.12}$$

$$YIELD_t = INITIALYLD - (CHNGYLD \cdot WGT) \tag{6.13}$$

where *CHNGYLD* is change in yield; *YBARYLD* is average yield per crop by land group and PA, based on agricultural statistics data corresponding to the base year 1980; *YADJ* is yield adjustment factor; $YIELD_t$ is crop yield at time t; *WGT* is weight of crop in a rotation; and *INITIALYLD* is YBARYLD adjusted by conservation-tillage practice.

Once this is determined, the crop yield used in the LP model in the next time period is adjusted.

The revise subsector of the linkage component takes information from the retrieval and adjustment subsectors, and revises prices and crop yields in the LP component for the next time period.

The hybrid model specified above is used to study the impact of alternative erosion control policies on increasing the long-term sustainability of agricultural production in Iowa over the 20-year span from 1980 to 2000.

6.3. An Analysis of Results

The regional-national hybrid model described in the preceding section is used to study the effect of erosion control policies on land use, production levels, and net returns to Iowa farmers over the 20-year span from 1980 to the year 2000. The focus of the analysis is on studying the economic impact of alternative policies directed at increasing the long-term sustainability of agricultural production through erosion control.

A baseline solution, representing present policy, is initially solved. Then, four other solutions are obtained, based on alternative policies aimed at controlling soil loss. Thus, the effectiveness of four different policy alternatives is analyzed in terms of their effectiveness in decreasing soil loss.

(1) The baseline solution (or BASE) is concerned with determining the pattern of resource allocation that will maximize profits for Iowa farmers in the absence of any erosion control policy for the state.

(2) Policy alternative I (or 20 TON), limits soil loss per hectare to 20 tons on all land groups in each producing area [2]. On average, this level of soil loss could be considered to be approximately twice the T level of

soil loss per cultivated acre in Iowa. The *T* level is the "tolerance" level, and specifies the maximum allowable amount of annual soil loss per hectare that can be tolerated while still maintaining productive capacity with present technology. This is generally considered to be approximately 10 tons/hectare per annum.

(3) Policy alternative II (or 10 TON) limits soil loss per hectare to 10 tons on all land groups in each producing area. Therefore, any combination of cropping system, tillage method, and conservation practices that result in more than 10 tons of soil loss hectare per annum would not be legally allowable.

(4) Policy alternative III determines a tax system on production activities based on levels of soil loss associated with them, such that it would yield exactly the same levels of net returns, resource allocation, and soil loss as: (a) the 20 TON mandatory maximum soil loss solution, and (b) the 10 TON mandatory maximum loss solution.

(5) Policy alternative IV (or NITR) considers the extent to which a restriction on the availability of nitrogenous fertilizer would control soil loss. Availability of nitrogenous fertilizer is restricted at the use-level in 1980 in the BASE solution. The objective is to limit the use of commercial nitrogen. This will result in less intensive, more sustainable cropping practices. Rotations with legumes will in some cases replace those with higher nitrogen requirements. Since livestock is not endogenously included, increased use of monomers is not incorporated.

6.3.1. The effects of time and policy on net returns to land and management on Iowa farms

Time and soil conservation policies both have a significant impact on net returns to Iowa land management, as can be seen from *Table 6.6* and *Figure 6.7*. If the objective is solely to maximize net returns in 1980, this would be met by adopting the solution determined by the BASE (or no policy) alternative. The 10 TON alternative yields the lowest net returns for that year. For 1980, the NITR solution yields the same results as the BASE, since nitrogen levels are restricted at 1980 use levels.

By 1985, the order is reverse and net returns are highest with the 10 TON alternative, followed by 20 TON, BASE, and NITR, in that order. A reduction in net returns is experienced with the BASE alternative by 1990, while marginal increases of 0.17 and 3.49% occur with the NITR and 20 TON solutions, respectively. However, a 13% increase in net returns accrues between 1985–1990 with the 10 TON restriction on soil loss. Net returns increase in all four alternatives over the period 1990–2000. By the year 2000, the 10 TON solution yields a net return that is 98.13% greater than that in the BASE, 78.01% above that in the NITR, and 33.69% higher than that in the 20 TON solution. Further, while net returns increase 2.17 times,

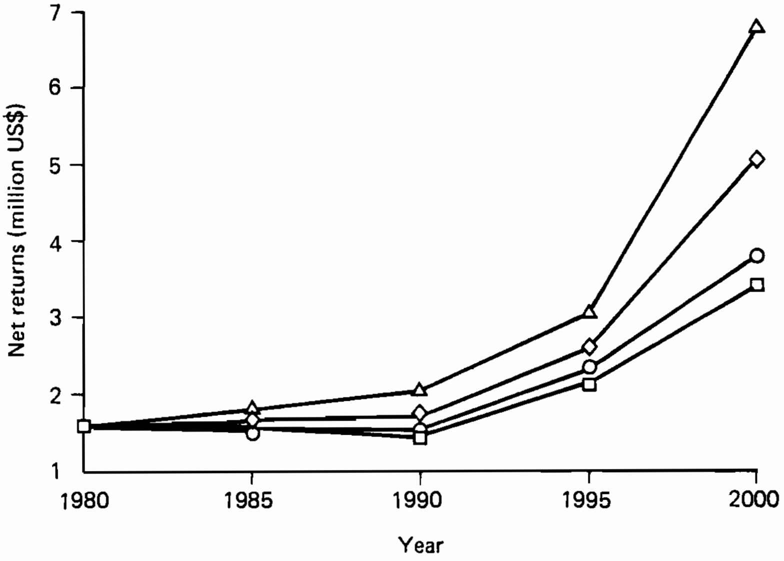

Figure 6.7. Net returns to land and management in the four alternatives: □ = BASE; ○ = NITR; ◇ = 20 TON; Δ = 10 TON.

Table 6.6. Projected net returns to land and management on Iowa farms in the four alternatives.

Year	*BASE*	*NITR*	*20 TON*	*10 TON*
	(million 1975 US$)			
1980 (actual[a])	1 574.60	1 574.60	1 574.60	1 574.60
1985	1 582.65	1 547.48	1 661.11	1 805.02
1990	1 454.55	1 550.15	1 719.04	2 050.74
1995	2 157.66	2 334.54	2 613.54	3 069.19
2000	3 427.14	3 814.47	5 079.28	6 790.26

[a] Source: Iowa Crop and Livestock Reporting Service (1980).

from US$1 582 million in 1985 to US$3 427 million in the year 2000 in the BASE, they increase 3.76 times from US$1 805 million to US$6 790 million over the same period in the 10 TON alternative.

The dominant factor in these differing net returns is the change that occurs to price. Higher yields do occur resulting in increased supply (*Table 6.7*). Yields generally increase when constraints resulting in lower erosive practices are imposed, as can be seen when comparing the 10 TON yields to those in the BASE.

Table 6.7. Estimates of acres allocated, yield, net return per unit, and net returns per acre.

	BASE				*10 TON*			
Item/year	*Corn*	*Sorghum*	*Soybean*	*Wheat*	*Corn*	*Sorghum*	*Soybean*	*Wheat*
Hectares allocated:								
1985	3127.13	802.02	3645.34	137.25	3799.19	231.17	2736.84	252.23
1990	2844.13	1191.90	3693.12	122.67	3635.63	126.32	2876.11	410.93
1995	3270.85	874.90	3751.42	110.93	3936.84	0.00	2860.32	414.98
2000	4042.91	186.23	3792.31	112.15	6596.76	0.00	569.23	274.49
Yield (Mkg/ha):								
1985	7277.91	5265.73	2419.99	2352.77	7215.17	5713.87	2487.22	2554.44
1990	8030.79	5769.89	2554.44	2419.99	7905.31	6498.13	2621.66	2554.44
1995	8595.46	6386.09	2621.66	2487.22	8532.72	0.00	2688.88	2621.68
2000	9034.64	5881.93	2756.10	2554.44	9222.86	0.00	2890.55	2756.10
Net returns per acre ($/ton):								
1985	57.80	59.01	190.84	34.13	68.03	68.70	218.37	40.00
1990	52.30	51.53	172.12	43.31	61.73	63.86	232.31	59.82
1995	53.48	54.17	206.62	57.99	72.74	0.00	278.92	77.44
2000	65.67	61.66	256.90	85.14	134.09	0.00	363.70	130.29
Net returns per hectare ($):								
1985	421.18	311.12	462.38	80.40	491.41	393.03	543.77	102.31
1990	420.49	297.66	440.20	104.93	488.62	415.45	609.77	152.99
1995	460.21	346.34	542.34	144.40	621.45	0.00	750.88	203.26
2000	593.99	363.09	708.89	217.76	1238.14	0.00	1052.54	359.51

6.3.2. Changes in the allocation of Iowa land among crops over time

The econometric simulation component of the hybrid model is used to determine the area harvested and levels of production of feedgrains, soybeans, wheat, cotton, and tobacco. These estimates are added to Iowa production levels determined by the linear programming model to estimate US production, supply, price, demand, inventories, value of production, etc. Feedgrains include corn, sorghum, oats, and barley. In addition, the econometric model estimates national levels of production, inventories, prices, imports, exports, etc., for beef, pork, lamb, chicken, and turkey.

The BASE

Analysis of *Table 6.6* and *Figure 6.8* shows that in the no-policy measures BASE solution, soybean area increases gradually over the period 1980–2000, and wheat area decreases gradually from 1980 to 1995, increasing marginally thereafter. However, considerable changes in the opposite direction occur with respect to area allocated to corn and sorghum. As expected, corn and soybean are the major crops in Iowa in the BASE solution with 72.82 and 3.93 Mha, respectively, in 1980. Sorghum and wheat are allocated 1.21 and 0.24 Mha, respectively. Land in soybeans increases over the entire period under consideration. This is a result of the relative net returns within the model. Also, net returns per kilogram are higher for soybeans than for any other crop. Land allocated to wheat declines gradually until 1995, and then increases marginally in the year 2000, since the net returns per kilogram and per hectare of wheat increase relative to corn and soybeans compared with the 1995 estimates.

Figure 6.8. Area allocated to the four crops in the BASE solution: □ = corn; ○ = sorghum; ◇ = soybean; Δ = wheat.

Further, it can be concluded from *Figure 6.8* that sorghum competes with corn for land. The area allocated to corn increases over the period 1980–1985, while that allocated to sorghum decreases. The area allocated to sorghum increases over the period 1985–1990, while that allocated to corn declines. Net returns per hectare of sorghum increase relative to soybeans over this period. Subsequently, land in corn increases to over 4.52 Mha by the year 2000, while the sorghum area decreases to 0.21 Mha by that year.

20 TON

The 20 TON alternative makes it illegal to engage in any activity that produces more than 20 tons of soil loss/hectare per annum. A comparison of *Figures 6.8* and *6.9* indicates that the main effects of this restriction are decreased production of soybeans and sorghum, and increased production of corn. Further, more of the less erosive conservation–tillage practices are used to produce the crops.

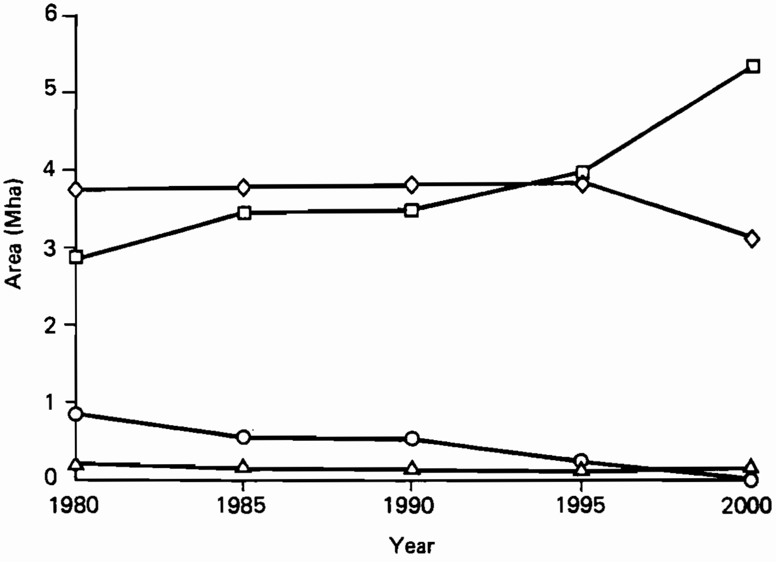

Figure 6.9. Area allocated to the four crops in the 20 TON solution: ☐ = corn; ○ = sorghum; ◇ = soybean; Δ = wheat.

Land in soybeans increases gradually from 3.72 Mha in 1980 to 3.84 Mha in 1995, and then decreases sharply to 3.11 Mha in the year 2000. The decline occurs both because the relative net returns per kilogram and per hectare of corn increase relative to soybeans, and because the absolute net returns per hectare from corn production are higher than those from soybeans in that year. Soybean production is lower in the 20 TON than in the BASE due to the erosivity of the crop.

The area allocated to corn increases over the entire period, although the rate of increase is lowest during 1985–1990 and highest during 1995–2000. The lower rate of increase over 1985–1990 can be explained by the fact that the net returns per kilogram of corn relative to soybeans, sorghum, and wheat decline over this period. By 2000, the net returns per hectare of corn are higher than for any other crop, and the corn–bean ratio of net returns per hectare moves in favor of corn, so that corn replaces sorghum production and is substituted on soybean land as well. Sorghum decreases over the 1980–1995 period and declines to zero in the year 2000.

Returns per hectare are the lowest for wheat. The net returns per hectare and per kilogram of wheat relative to corn and soybeans decrease over the period 1990–1995 and increase over the period 1995–2000, respectively. Correspondingly, wheat land decreases gradually to 0.12 Mha in 1995 and increases marginally (3.6%) by 2000.

10 TON

The 10 TON alternative bars all production activities that have more than 10 tons/hectare per year of soil loss associated with them. While the overall pattern of results obtained is similar to that in the 20 TON alternative, a comparison of *Figures 6.9* and *6.10* reveals that the shifts in land allocation between the crops are much sharper in the present case, and occur at earlier points in time.

Figure 6.10. Area allocated to the four crops in the 10 TON solution: □ = corn; ○ = sorghum; ◇ = soybean; Δ = wheat.

The net returns per hectare of sorghum decrease relative to corn and soybeans, which explains the reduction in the area allocated to sorghum over time. *Figure 6.9* shows that by 1995, sorghum area drops to zero.

Net returns per kilogram of wheat increase relative to corn over the period 1985–1995, and decrease during 1995–2000. Correspondingly, the area allocated to wheat increases from 0.28 Mha in 1985 to 0.46 Mha in 1995, and decreases to 0.30 Mha thereafter. Net returns per hectare of wheat increase relative to corn between 1985 and 1990, increase relative to soybeans between 1990 and 1995, and decrease between 1995 and 2000.

Absolute net returns per hectare are highest in regard to soybean production until 1995, after which corn yields US$176 per hectare more than soybeans. This explains the sharp reduction in soybean production from 3.2 Mha in 1995 to 0.63 Mha in 2000. Corn area increases substantially from 4.4 Mha to 7.3 Mha. The corn–soybeans ratio of relative net returns per hectare moves steadily in favor of corn over the period 1985–2000, thus explaining the higher corn area relative to soybeans over the entire period.

NITR

Availability of nitrogenous fertilizer is restricted at the 1980 use level of 652706 metric tons in the BASE solution for Iowa. As a result, the solution is identical to that in the 1980 BASE.

The major difference between the results obtained from NITR and those in the 10 TON or 20 TON solutions is that land allocated to soybeans does not decline sharply, and that allocated to corn does not increase as much in the former. Soybean area increases gradually from 3.93 Mha in 1980 to 4.05 Mha in 1995, after which it marginally declines. The estimates indicate that the net returns per hectare of soybeans are higher than from any other crop over the entire period. The marginal decline in soybean production in *Figure 6.11* can be explained by the change in the relative net returns per hectare in favor of corn and against soybeans in the year 200. This also explains the increase in corn area from 2.97 to 3.47 Mha, and the decrease in sorghum area from 1.0 to 0.5 Mha between 1995 and 2000.

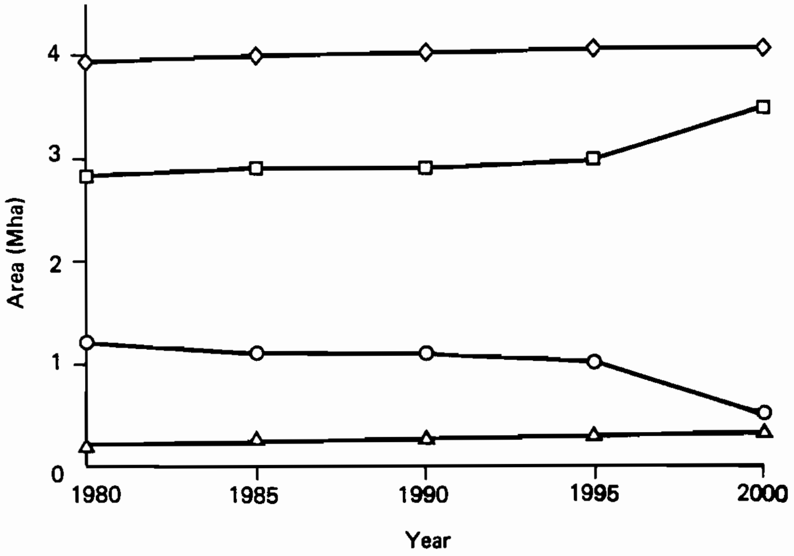

Figure 6.11. Area allocated to the four crops in the NITR solution: □ = corn; ○ = sorghum; ◇ = soybean; Δ = wheat.

Wheat area, however, increases steadily from 0.24 Mha in 1980 to 0.33 Mha in 2000. Again, the net returns per hectare allocated to wheat increase relative to corn and soybeans over the entire period under consideration. Further, the higher levels of soybean and wheat production in the NITR solution occur because they require only 1.44 and 49.85 kg of nitrogenous fertilizer per hectare, respectively, compared with 156.47 kg required by corn and 116.62 kg by sorghum.

6.3.3. The aggregate soil loss and nitrogenous fertilizer use picture

Aggregate estimates of soil loss in Iowa evidence considerably higher levels of erosion associated with the crop management systems entering the basis in the BASE and NITR solutions, compared with the 10 TON and 20 TON alternatives. In 1980, the BASE and NITR solutions are characterized by annual soil loss of as much as 158.13 million tons on 9.81 million hectares of Iowa cropland. Imposition of the mandatory 20 TON restriction on soil loss reduces this estimate by 43.46% to 81.1 Mt on 9.2 Mha of land. The 10 TON restriction on soil loss further diminished soil loss to 59.8 Mt on 9.0 Mha of land. Therefore, soil loss in the 10 TON solution is 58.28% lower than in the BASE. The soil loss estimates are given in *Table 6.8*.

Table 6.8. Total soil loss and nitrogen purchase in Iowa for the four alternatives.

	1980	*1985*	*1990*	*1995*	*2000*
			Soil loss in Iowa (Mt)		
BASE	143.4	154.2	159.7	165.5	171.9
20 TON	81.1	87.3	88.3	94.1	97.1
10 TON	59.8	67.9	67.8	68.9	58.6
NITR	143.4	126.8	127.1	128.8	122.9
			Nitrogen purchase in Iowa (kt)		
BASE	652.7	705.9	712.0	737.4	759.8
20 TON	612.5	659.8	659.9	686.0	849.9
10 TON	535.3	749.8	713.6	734.0	1179.2
NITR	652.7	652.7	652.7	652.7	652.7

Total annual soil loss increases to 171.9 Mt in the BASE, and to 97.1 Mt in the 20 TON alternative. However, by the year 2000 a decline in soil loss occurs in the 10 TON and NITR solutions: the levels decrease to 58.6 and 122.9 Mt, respectively.

However, *Table 6.8* indicates that the lower soil loss level in the 10 TON solution is accompanied by increased use of nitrogenous fertilizer, from 535.3 to 1179.2 kt, over the period 1980–2000. A reduction in soil loss is attained by reducing the production of soybean and sorghum, combined with higher levels of corn and wheat production based on less erosive conservation-tillage practices (*Figures 6.12* to *6.15*). Since corn uses more

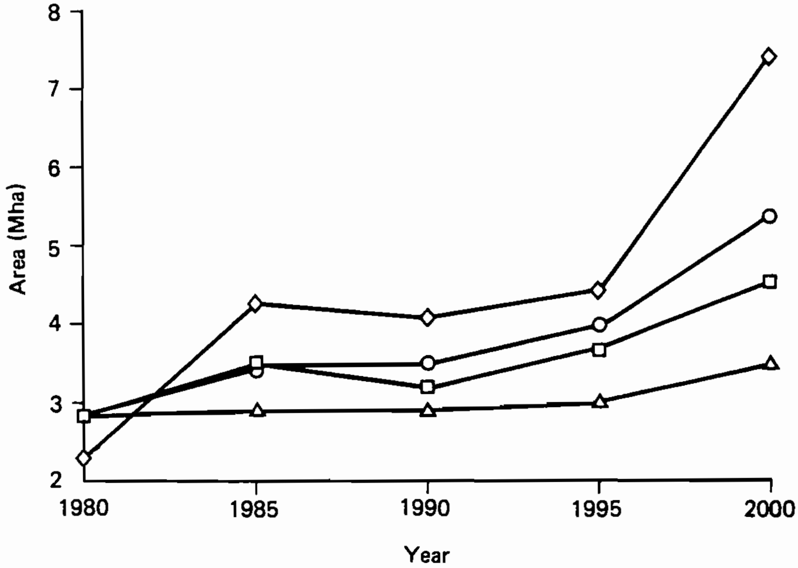

Figure 6.12. **Corn area for the four alternative solutions: □ = BASE; ○ = 20** TON; ◇ = 10 TON; Δ = NITR.

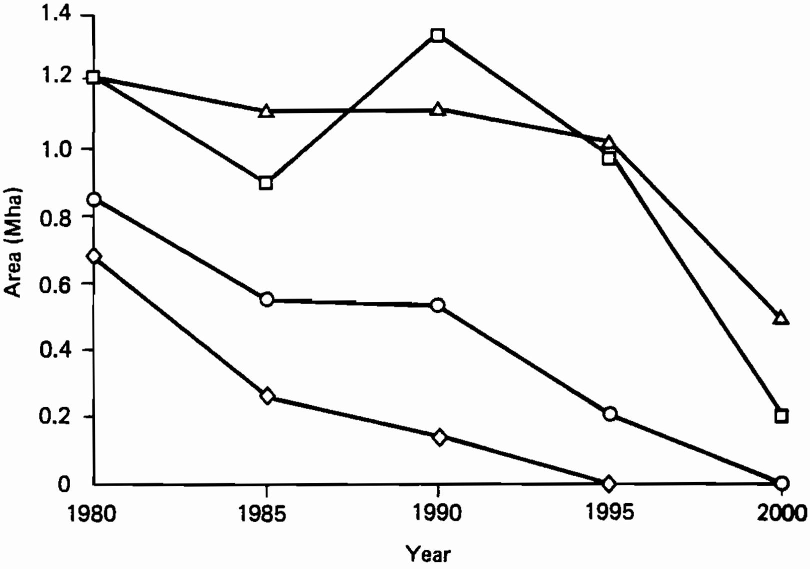

Figure 6.13. **Sorghum area for the four alternative solutions: □ = BASE; ○ = 20** TON; ◇ = 10 TON; Δ = NITR.

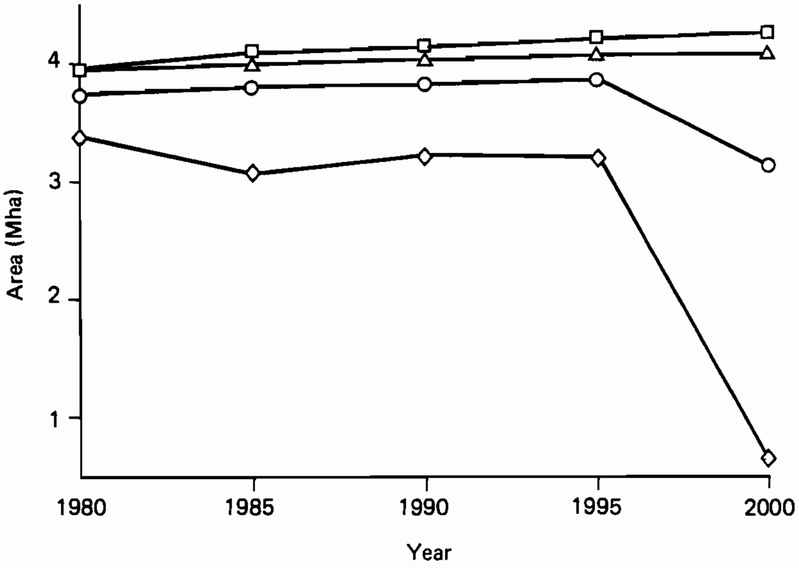

Figure 6.14. Soybean area for the four alternative solutions: □ = BASE; ○ = 20 TON; ◇ = 10 TON; Δ = NITR.

nitrogenous fertilizer than the other crops, massive increases in use of this input manifest themselves.

The 20 TON solution follows the same basic pattern as the 10 TON solution, but diverges less from the BASE. Soil loss levels increase from 81.1 to 97.1 Mt between 1980 and 2000, while nitrogenous fertilizer use-levels rise from 612500 to 849900 t over the same period. Production of soybeans and sorghum is less than in the BASE, but the levels lie well above those in the 10 TON. On the other hand, more corn is produced than in the BASE after 1990, but the level lies below that in the 10 TON after 1985. The lower level of fertilizer use than in the 10 TON can be attributed to the fact that more soybeans are produced, and they require extremely low quantitites of fertilizer.

The NITR solution attempts to reduce the quantity of availability of nitrogenous fertilizer to Iowa farmers (719600 t). While soil loss levels decrease from the 1980 BASE level of 143 to 122.9 Mt in 2000, the estimate is still more than twice the 10 TON level for that year. In comparison, the BASE solution has an increased level of nitrogenous fertilizer use from 719600 t in 1980 to 837670 t in 2000, with soil loss increasing by 28.5 Mt over the same period. Analysis of *Figures 6.12* to *6.15* indicates that both the NITR and the BASE solutions are characterized by higher levels of soybean and sorghum production, and lower levels of corn production than the 10 TON and 20 TON alternatives. However, considerably higher levels of the

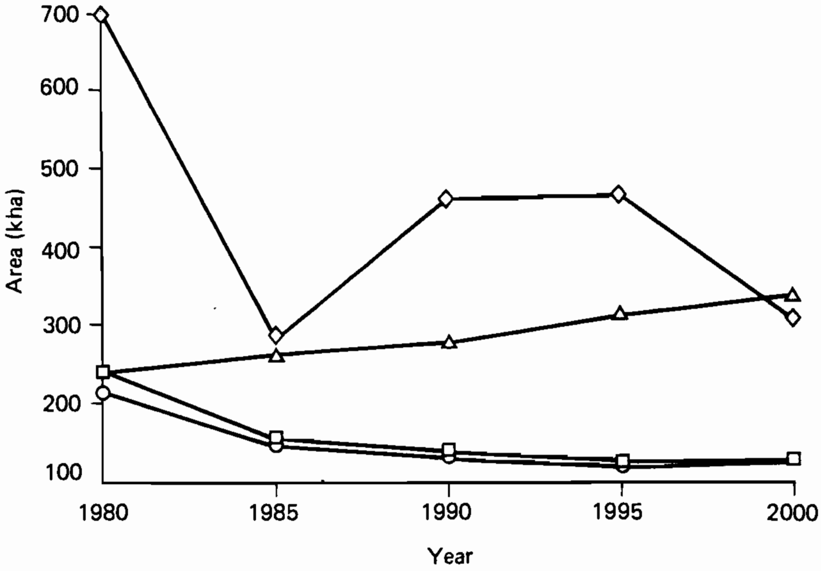

Figure 6.15. Wheat area for the four alternative solutions: □ = BASE; ○ = 20 TON; ◇ = 10 TON; Δ = NITR.

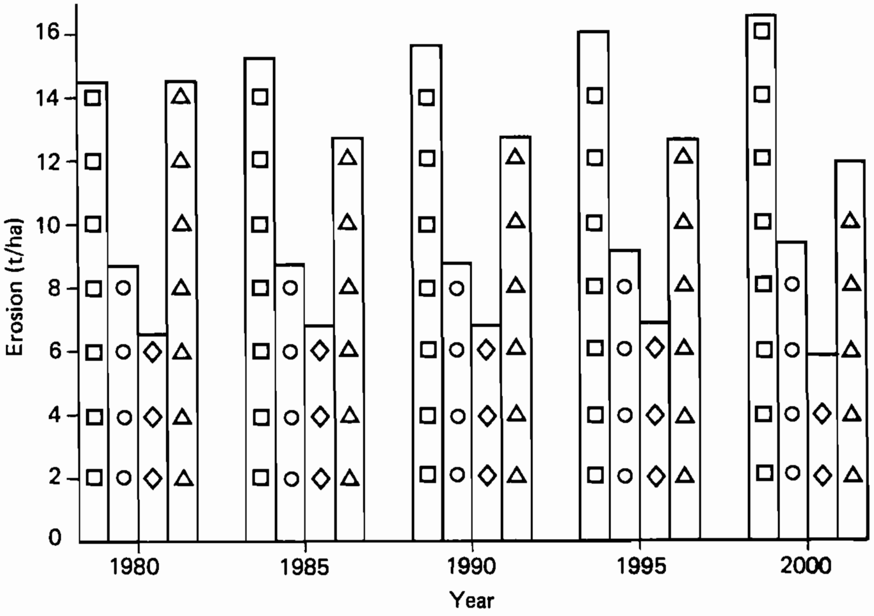

Figure 6.16. Average erosion per hectare for the four alternative solutions: □ = BASE; ○ = 20 TON; ◇ = 10 TON; Δ = NITR.

low nitrogenous fertilizer-using wheat crop occur in the NITR as compared with the BASE solution.

On average, soil loss per cropped hectare increases from 7.29 to 8.30 t in the BASE, and from 4.38 to 4.70 t in the 20 TON situation. In contrast, the corresponding estimates decline from 3.31 to 2.93 t in the 10 TON, and from 7.29 to 5.98 t in the NITR solution. The impact of policy controls on levels of soil loss is obviously substantial. This is clearly indicated by *Figure 6.16*, which shows that on average, over the period 1980–2000, soil loss levels are high and increasing in the BASE, high but decreasing in the NITR, almost halved but increasing in the 20 TON, and more than halved and decreasing in the 10 TON solution.

6.3.4. Validity of the model results and some limitations

Since all models require simplifications and involve assumptions, caution needs to be given concerning the validity of the results and the limited conditions under which they apply.

This study does not incorporate the increased costs on increased levels of output because of erosion. Nutrients, in some cases, can be added to the soil to overcome the adverse impacts of erosion. Also, present analysis is beginning to provide information on yield variability. As soil erodes, data are now indicating the average yields can remain approximately constant with slight increases in inputs, but yields are more variable. This also is not incorporated into the analysis.

It should be noted that the 1995–2000 results would probably not occur. The reason that they do is because the assumption of Iowa's constant share in US total production, as determined by past, is incorporated by the econometric component of the model. In actuality, national shifts in production may occur among the regions. While the model improves on the assumption of constant prices over time made in most intertemporal work in this field, a naive price expectation model is assumed. Other expectation models should be explored. Further, the model does not determine a single optimal program for the entire period under consideration. Instead, static solutions are determined sequentially for each period of time such that each solution is affected by the preceding one.

A change in the specification of the objective function would yield substantially different results. The current specification of the objective function in the baseline solution assumes that farmers are myopic, and are solely concerned with maximizing net returns at each point in time. Therefore, while the BASE solutions yield higher net returns than the other alternatives in 1980, by 1985 the ordering is reversed. The unconstrained 1980 BASE solution obviously yields higher net returns than the restrictive 10 TON alternative. The higher net returns in the BASE are associated with a more erosive product-mix than that yielded by the other alternatives. This implies greater reduction of soil depth and crop yields associated with the baseline solution. The reversal in the ordering of net returns by 1985, with the 10 TON solution yielding the highest and the BASE the lowest returns, is a natural consequence of the myopic behavior implicitly assumed by the objective function.

A dynamic solution would obviously yield maximum returns in the unconstrained situation, since that necessarily has the constrained solution available to it. Of course, the unconstrained optimum may be identical to the restrictive 10 TON solution, but that cannot be established unless the dynamically optimal solution is obtained. Unfortunately, the computer linkages required by the hybrid, the size of the model, and the level of funding currently prohibit any attempt at a single optimal solution for the entire time period under consideration.

6.4. Conclusions and Limitations

The purpose of this study is to develop a method of analysis that can simulate an agricultural production system. As a case study, Iowa was selected so that the relationships between the production of agricultural commodities and the case of scarce resources could be explored. Land degradation, as a result of the production of crop commodities and the loss of topsoil, is incorporated in the analysis.

To achieve this, a hybrid model is constructed. This model has three basic components. The programming portion of the model reflects the production possibilities in Iowa and operates under a profit maximization motive. An econometric model is used to reflect the imports of production changes in Iowa as a result of a change in policy on expected prices for the next period of analysis. The final component is a simulation model that evaluates the condition of the soils in the model and the impact that crop production has on the inherent productivity of Iowa soils.

The linear programming model is divided into twelve producing regions. Each region is characterized by five soils representing different land types. Corn, soybeans, and hay are the major crops produced, with wheat, sorghum, and oats also represented in the model. Cropping practices are defined with one to four crops in a sequence of six years or less on a given soil type, in a specified region using one of three conservation practices and one of three tillage methods.

The analysis indicates that technology will continue to mask resource degradation in Iowa during the next 20 years. The marginal lands, however, become more marginal as the cost of production per production unit increases as soil erodes at higher than replaceable rates. From the results, however, it appears that if the planning horizon of an individual farmer could be lengthened, more soil-conserving methods would be employed on some of the marginal lands. There are some soils in Iowa, however, that incur no impacts to yield as soil erodes. These are the deep soils with 6–12 m of topsoil. Inherent productivity of these soils is not impacted by sheet and rill erosion.

There are three basic causes for a change in net returns. These include a change in price, change in productivity, and/or change in costs. As erosion levels are reduced, costs on a per acre basis increase. However, after the initial years, the price response outpaces the change in costs so that there is a net increase in net returns. There is little impact on productivity levels over the period of analysis. Reduced tillage practices and changes in rotations employed result in decreased erosion levels at small increases in costs of production. These changes result in long-term productivity maintenance, and increased profits. However, a short-term decrease in net returns does occur.

While resource degradation and maintaining our soils for future generations dominate our resource base conservation discussion, offsite impacts must be analyzed and evaluated prior to requiring farmers to limit their production method in order to achieve a tolerable soil loss level. The onsite benefits achieved at a level of 10 t/ha are minimal on most Iowa soils. Further analysis as to the susceptibility of a given soil to ephemeral or gully erosion must be conducted.

This is a first-generation model, and it is hoped that the future will bring with it the possibility of improving these modeling techniques. There is a definite need for micro and macro models that closely approximate the complex set of factors that characterize farmers' behavior with respect to soil use and soil conservation. This report makes no pretense of meeting these needs. However, it does constitute a step in the right direction.

Acknowledgment

The authors are indebted to the work and guidance that Wen-Yuan Huang and Jim Langley, both of the Economic Research Service, and Earl O. Heady, Center for Agricultural and Rural Development, provided. Without their assistance this chapter could never have been undertaken.

Notes

[1] This assumes that Iowa is viewed in a modeling framework as a farm with 60 different farm fields (12 PAs times 5 land groups). Because this does not reflect reality, additional constraints on acreage and quantity of crops sold are needed so that simulation can occur.

[2] Currently, Iowa law requires the attaining of 2 TON, or approximately 20 tons per acre, by 1990 and 10 tons by the year 2000. A legal framework exists to force landowners to these levels if damage is caused by excessive erosion.

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CHAPTER 7

Nitra, Czechoslovakia: Regional and Technological Development of Agriculture

J. Hirš, L. Kátrik, P. Kubaš, and D. Lupták

Abstract

The large-scale organization of agricultural production, which resulted from socialization of the productive basis of the Czechoslovakian economy, created the preconditions to efficiently implement large-scale production technologies, on the one hand, but increased the threat of soil degradation, on the other. Since resources (soil, water, and energy) are limited and requirements for food production are increasing, this study aimed to answer the following main questions:

(1) What maximum production could be achieved through the application of modern technologies to agriculture and nutrition without causing any serious deterioration to the living environment?
(2) What conditions need to be created to achieve both objectives?

Nitra was chosen for the experiment since, to a considerable degree, it represents a region with average agricultural conditions; the information obtained can thus be applied to a wider area. Moreover, the region ranks among the largest in the state and its gross agricultural output per ha slightly exceeds the whole-state average. Further agricultural development of Nitra is limited by scarce water supplies.

The proposed LP model permits interaction of output intensification, material and energy inputs, and the quantitative estimation of soil quality impacts. The results should provide managers with data that might be useful in the specification of investment targets; distribution of machines, technology, and agrochemicals; and, in particular, the adjustment of the animal and plant production structures to local peculiarities.

7.1. Introduction

7.1.1. An overview of Czechoslovakian agriculture

Czechoslovakian agriculture has changed substantially over the last two or three decades. First, small farmers established cooperative farms with an average acreage of hundreds of hectares. Then, some of these cooperatives, realizing the possible efficiency to be gained by large-scale farming, grouped together and built complexes on a scale of several thousands of hectares.

The relatively small farms of the postwar period covered 43% of the total agricultural land area, with an average size of 10 ha; only 13% of the land belonged to farms of an average size of 21.7 ha. The process of concentrating production gave rise to today's picture, where 65.5% of the land is worked by cooperative and state farms, with an average size of between 2000 and 5000 hectares. Now, 13.3% of our agricultural land area is worked by enterprises of 5000 ha or more. Only 0.1% of the land is covered by farms having less than 500 ha. A few private farms still exist under exceptional conditions where the concentration of production into larger units would be economically unfeasible.

However, this has had remarkable impacts not only on the choices of technologies and management systems to be used in the various stages of development, but also on the sociological, psychological, and institutional aspects. Changes in the technologies used and introduced into agriculture made 1.5 million active workers available from agriculture, a factor which was of great importance to the development of other branches of the national economy. The number of persons employed in agriculture subsequently fell (1976) to 40% of the total employed during the postwar years.

Limited land resources, diverse geographical conditions within the country, and industriai growth – all contributed to the development of an intensive, specialized, and centrally managed agricultural sector with different input factors, i.e., with increased use of machinery and energy. The higher agricultural yield in general (a 420% increase in total production for the market compared to 1946–1948 levels) characterizes the intensity of production, since land resources for agricultural production are limited (the total arable land area has even decreased over the past few years). The use of fertilizers increased from 21.5 kg/ha nutrients in 1948 to 224 kg/ha in 1979, and further increase is likely. The utilization of regionally specific conditions, land in particular, becomes a very important aspect.

Of the total agricultural land, 84.3% is considered to be average or below average in quality, and only 15.7% has a high fertility level.

Climatic conditions differ both in precipitation level and temperature. Total precipitation varies (long-term average) between 530 and 821 mm per year; the temperature level is between 6.1 and 10.3°C, but this also differs substantially from region to region. Land height varies between 200 and 1000 m above sea level, a considerable acreage of field land being on a slope,

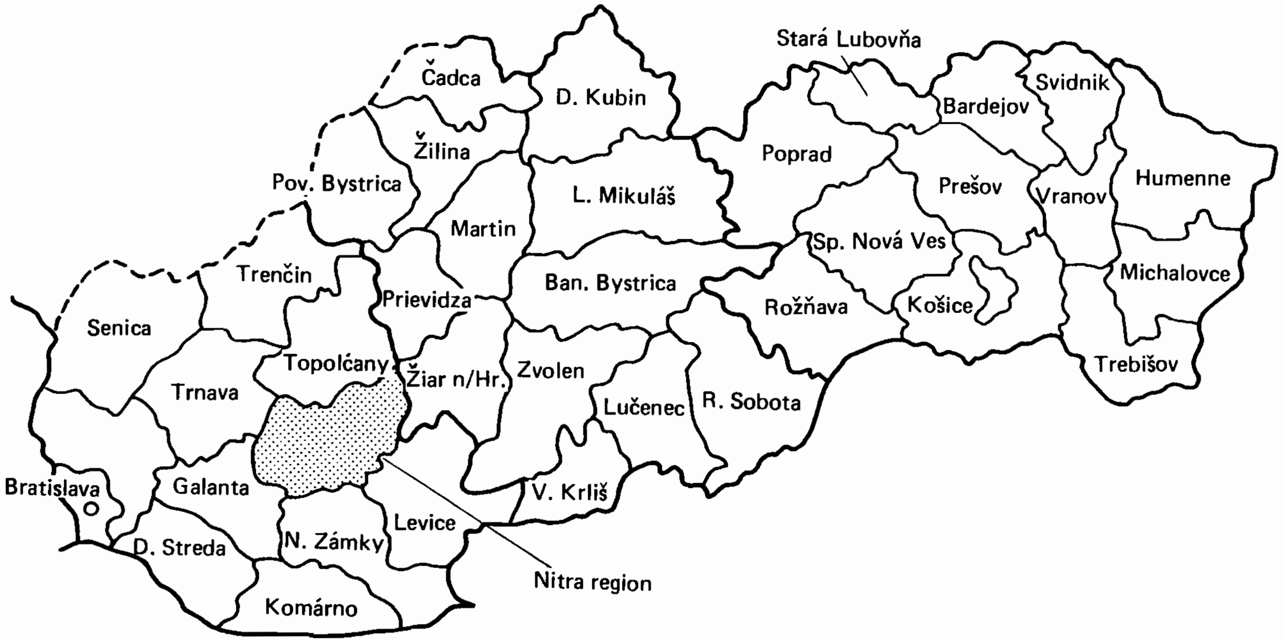


Figure 7.1. Position of the Nitra region within Czechoslovakia.

in areas where the technologies presently used usually result in erosion and runoff.

One of the major goals set for agriculture is to reach a certain degree of self-sufficiency in the major agricultural products, to meet the increased demands due to a rise in income and a larger population (the latter increase is estimated to be approximately 1.6 million by the year 2000, which is equal to 10% of the present population).

This aim, together with the goal to achieve a certain level of agricultural exports, would require efficient utilization of the given natural resources in all regions to provide enough food for the population on a long-term basis.

7.1.2. Status of agricultural research

Several research projects have been started over the past few years to explore and address the potential production possibilities and plant genetic resources, and to characterize in detail the natural resource base, especially soil. A complex land monitoring system was developed for the whole country. Further, more than 800 defined units have been grouped into 91 major sets, each taking both natural and, to some extent, social and economic conditions into consideration.

This provides a basis for modeling various alternatives of production allocation, given the targets for the required overall production in the country. In Czechoslovakia, the management and decision making is hierarchically divided into the federal (country), state (Czech and Slovak), regional, district, and farm levels, all having their own responsibilities. A number of models or systems of models were developed to estimate various alternatives for the national as well as the regional levels. These systems were generally built as hierarchical ones, starting at the national level going down to the regional or even the district and farm levels.

However, these models considered mainly the production aspects, and never touched on the long-term development of natural resources and environmental aspects. But environmental quality has turned out to be a serious problem over the last few years, especially in those parts of the country where agricultural production is intensive and likely to be even further intensified during the next few decades. In some cases, such regions are identical to those that provide drinking water for the large urban areas (southwest Slovakia, for example), where the goal of increasing production still further – since the potential is high – conflicts with the interest of improving environmental quality.

7.1.3. Current research problems

Among the main questions to arise from the long-term point of view, the following primarily need to be addressed:

(1) What is the maximum sustainable potential production of a given region in the long term, given the expected input levels and technological alternatives? How can the region contribute to the achievement of the total production (demand) required by the country?
(2) What will be the likely technological choices if energy prices continue to increase? To what extent could the use of new or nontraditional technologies alleviate the energy problem in the long run?
(3) What production structure and technology combinations would be most appropriate in order to achieve production requirements should environmental concerns increase, and to what extent could environmental protection efforts affect actual production and the given target (existing demand level)?

The questions formulated above are all related to the central problems, namely, what the future technological choices are likely to be, how they may influence productivity growth, and what might be the environmental consequences (or limits) of their use. These problems have relevance both for the national level (overall economic conditions, setting up of production targets, etc.) and for specific regions (mainly related to the natural conditions). A very important focus in this study, in comparison to those carried out earlier, is the link between economic aspects and those related to environmental impacts.

7.2. Description of the Region and Its Position in the National Economy

The Nitra region (*Table 7.1*), which was chosen for experimental design of further agricultural development, covers an area of 101042 hectares. As far as the natural and ecological conditions of this territory are concerned, it can be said that sloping land prevails and the climatic conditions correspond to the average conditions of Czechoslovak agriculture.

The degree of the agricultural production intensity of the region can be characterized by certain intensity indicators, for example:

(1)	Agricultural land in total:	101042 ha
	of which arable land (85.1%) is:	85943 ha
(2)	Consumption of pure N,P,K nutrients (kg/ha):	305 kg
(3)	Percentage of irrigated arable land:	2.9 %
(4)	Cattle density (heads per 100 ha):	74.6
(5)	Milk production (litre/ha):	1021 litres
(6)	Meat production in liveweight (kg/ha):	468 kg
(7)	Land/man ratio:	7.92 ha
(8)	Number of inhabitants nourished by one permanently employed worker (inhabitants/employee):	16.6
(9)	Average annual milk yield per cow:	3660 litres

(10)	Average daily gain in cattle fattening:	0.96 kg
(11)	Average daily gain in pig fattening:	0.60 kg
(12)	Average annual egg yield of one hen:	213.9 pieces
(13)	Cereal production per inhabitant of the region:	1.23 t
(14)	Meat production per inhabitant of the region:	421.6 kg
(15)	Population of the region (in thousands):	approx. 160

Table 7.1. Sowing structure for Nitra's major crops.

Crop	*Area sown* (ha)	*Arable land* (%)	*Yield* (t/ha)
Wheat	24140	28.1	5.40
Barley	12611	14.7	5.03
Grain corn	1600	1.9	5.77
Sugar beets	5592	6.5	42.51
Feeds on arable land			
Annual	13970	16.2	8.20
Perennial	7968	9.3	35.90
Legumes	3550	4.1	2.21
Mixtures	11123	12.9	25.3
Pastures	9900	–	6.6
Subtotal A (without pastures)	80554	93.7	–
Sunflower	2000	2.4	2.26
Tobacco	610	0.7	–
Paprika	550	0.6	–
Potatoes	400	0.5	–
Vegetables	1829	2.1	–
Subtotal B	5389	6.3	
Total (A + B)	85943	100.0	

In order to improve the water regime of the region for 6689 ha of land were drained. Irrigation facilities were built to supply an additional 3476 ha.

The average area of agricultural land worked by regional enterprises is 4213 ha, which implies a high degree of land concentration.

In the Nitra region, if compared with other regions of Czechoslovakia, land with relatively low volumes of humus is worked. Therefore, no conditions have been created for optimum utilization of the applied fertilizers. The region, if compared to the whole of Czechoslovakia, represents the following percentages:

(1) Acreage of agricultural land: 4.0%.
(2) Value of the gross agricultural output: 5.6%.
(3) Value of the market output: 5.8%

The relationship of the agricultural output of the Nitra region to that of the whole of Czechoslovakia is shown in *Table 7.2.*

Table 7.2. Comparative agricultural outputs.

Indicators	*Nitra Region*	*Czechoslovakia*
Cow density per 100 ha of agricultural land	59.7	58.8
Average milk yield (litres)	3660	3039
Number of calves per 100 cows	96.9	93.3
Average daily increase in fattening (kg)	0.8	0.8
Concentrates consumption (kg) per kg of milk	0.3	0.3

Of the permanent agricultural workers, 3.3% have university education.

7.3. Further Intensification of Nitra's Agricultural Production

Within the framework related to the systematic and purposeful development of agricultural production in Czechoslovakia, two comprehensive production units/regions were chosen for which technical, technological, investment, and other measures should be designed and carried out. These sites would test the conditions for further and considerable agricultural intensification in the respective regions. On the basis of the information and conclusions drawn from the prepared studies, verified conceptions and technical programs will be developed for other regions of the country.

Within the framework of the activities related to the long-term development project for the Nitra region, the specialists of scientific and research institutes designed a set of planning, organizational, technological, investment, financial, and other measures aimed at creating conditions for reaching the required increase of the region's efficiency.

The proposed plan for the Nitra region calls for increasing the value of gross agricultural production from the current 12900 to 22600 Czechoslovak crowns per hectare of agricultural land. This objective is based on the anticipated income from higher crop yields, to be achieved after fertilizer use increases from the current 305 to 387 kg of pure nutrients per hectare of agricultural land, and on the anticipated effects of crop irrigation, which will be expanded from the current 2.9 to 6.0% of the total land area of the region.

As for crop production, the plan proposes increased yields of wheat from the current 5.4 to 6.0 t, of maize from 5.03 to 6.76 t, and of sugar beet from 42.5 t to 49.5 t per hectare of the production area. Similar increases in production were considered for other crops. In addition to better crop nutrition, there are also plans for better disease and weed control and, in particular, for the development of new varieties with genetic preconditions for higher yields under the conditions of the Nitra region.

Some structural changes will also take place in animal production, since the cattle density will be raised from the current 74.6 to 100 heads per hectare. In parallel, milk production will be extended to 1283/ha of agricultural land, and meat production raised from the current 468.0 to 558.5 kg/ha.

The solution concerns areas that exceed 100 000 ha worked by 20 agricultural enterprises, managed by an administrative center of the region.

The state management bodies influence the activities of agricultural enterprises of the region through:

(1) Setting the main targets of the state agricultural policy for the managed area.
(2) Specifying the volumes and structure of noninvestment expenses and providing the resources to cover these.
(3) Specifying the volumes and structure of the investment plans and providing their materialization through specialized suppliers, and ensuring material and financial resources.
(4) Providing better prices and subsidies to foster the implementation of the designed measures.

The state management bodies also allocate the necessary financial and material resources, and have the due power for the realization of the agreed development plans.

According to the development plan, several new specialized farms, provided with modern technology, should be constructed along with modern spacious buildings for approximately 40000 bovine animals (10000 of which should be cows), which will permit an increase in animal population. Similarly, buildings will be constructed for sheep, pigs, and other animals.

The development of the region will require a considerable increase in production intensity, labor efficiency, and the overall efficiency of the production activities of agricultural enterprises.

The plan will provide for investment in the workers, particularly in the form of machines and technological equipment, so that the current 60.6 Czechoslovak crowns per worker will be increased to 159.2, i.e., by 162%.

The plan contains proposals for interlinking individual agricultural enterprises via minicomputers, which, together with the large-size computers operating in the given region, will constitute a computer network able operatively to supply the managers with data on the achieved results. Simultaneously, the processing of optimization computations for the solution of certain production tasks, such as the optimization computations for the annual production plans, plans for animal or vegetable nutrition, traffic optimization, etc., will be done more frequently in the agricultural enterprises.

In the project, plants are designed to be grown at optimum sites; the variety and species structure are modified; and problems of early production of vegetables, fruit, and grapes are considered. Technical solutions to the problems of drying green forage in large-capacity drum driers (for the production of concentrated feedstuffs) are discussed.

In the model, traditional methods are used for balancing the requirements of animal and crop productions, the production and consumption of organic fertilizers in order to maintain high productivity in the areas, and the labor and energy supplies for the planned production.

The experimental plan for the agricultural development of the Nitra region should demonstrate that the cooperative attempts of scientists and engineers create the conditions for a considerable increase in regional agricultural production capacities.

This comprehensive program uses traditional computing methods, and contains no calculations for the effects of the planned production and production technologies on the agricultural natural resources, nor for their environmental effects.

For these reasons, the management bodies welcomed an alternative program, prepared in parallel with the original project, in cooperation with IIASA. The program will examine the impact of the new intensive production on the environment and will offer the possibility of choosing a production option that minimizes the negative effects on the soil and water systems – the most important agricultural production resources.

7.4. Production Conditions of the Nitra Region

Within the framework of the state management structure, the Nitra region represents an independent administrative and management unit. The whole region covers 101 042 ha of agricultural land and is heterogeneous, particularly in terms of land morphology and properties, and climatic conditions. Nitra is divided into several subregions, namely:

(1) *Lowlands* comprise 66.5% of the total agricultural land of the region. The ground is moderately undulating, at 150–350 m above sea level, and the average precipitation is 660–700 mm/year. Brown soil, chernozems, and plains prevail and provide suitable conditions for the majority of crops, particularly cereals, potatoes, sugar beets, and feeds.

(2) *Warm lowlands* represent 22.7% of the agricultural land of the region. The terrain, which is 150–200 m above sea level, has the properties of a lowland and an average precipitation of 500–600 mm/year.

(3) *Hilly country*, 9.5% of the agricultural land of the region, at 300–500 m above sea level, is predominantly undulating or sloping, with an average precipitation of 550–800 mm/year. The majority of the land is constituted of brown soils and luvisols, suitable for cereal and feed production.

(4) *Steep hills* make up 1.3% of the agricultural land of the region. The terrain is more sloping, typical of a mountain landscape, and individual land areas are thus more susceptible to erosion. The mean precipitation is 800–1000 mm/year. Brown soils, suitable for feed, cereal, and potato production, are prevalent.

7.4.1. Factors affecting production

Climate

The territory of the region is covered by four climatic zones. Approximately 31% of the agricultural land is in the climatic zone T1, 58% in zone T2, 8% in zone T3, and approximately 3% in zones T7 and T8. The respective climatic zones are characterized in *Table 7.3*.

Table 7.3. Climatic zones of Nitra.

Zone	*Properties*	*Annual total of daily temperatures above 10°C*
T1	Very warm, dry and warm	3000
T2	Slightly dry, lowland-like	3000 – 2800
T3	Warm, sightly dry, basin-like	2800 – 2400
T7,T8	Slightly warm	2400 – 2000

Soil

The region's soils are highly heterogeneous, falling into 26 soil subcategories and classes.

The majority of the soils originated over lime loess (55%), and loess and slope loam (10%). Clayish and alluvial sediments represent 14.7%, and loams and clayish sediments 8.3%, of the agricultural land. The rest is formed by deluvial loams, weathered hard rock, and sandy soils. "Skeletal" or "stony" soils are defined as containing 10% or more alluvial skeleton or eroded mother rock, respectively. The numeric soil representation is given in *Table 7.4*.

Table 7.4. Soil types of Nitra.

Soil type	*Area* (ha)	*% of total agricultural land*
Light soils	720	0.7
Moderately heavy soils	83095	82.2
Heavy soils	10371	10.3
Very heavy soils	2690	2.7
Heavy skeletal soils	379	0.4
Moderately skeletal soils	3787	3.7

Relief

The majority of the region's territory (89.7%) belongs to the hilly subregion of the Danube lowland, 3.4% to the subregion of the Danube plain, and 6.9% to the subregion of lower hills. The sloping lands of the region are as given in *Table 7.5*.

Table 7.5. Relief of Nitra.

Degree of slope	*Area* (ha)	*% of total agricultural land*
7 – 12	6956	7.0
12 – 17	1447	1.4
17 – 25	363	0.4
over 25	132	0.1

Soil and Ecological Evaluation

Of the region's total agricultural land, 60% belongs to the category of very productive areas, 32.5% to productive to moderately productive soils, 6.5% to less and little productive soils, and 1% to little productive soils.

Water erosion

According to soil erodibility (susceptibility to water erosion), and considering the geomorphological (land surface qualities), geological, pedological, and climatic factors, the soils were classified as follows:

(1) *Little to moderately erodible soils* suffer less than 1.5 mm washoff per year, plain with mild sloping of 1–7°, deep soils, nonskeletal or with skeletal content up to 25%. The soils of this category require antierosion arrangement of the territory, contouring, and special sowing technologies with contour-like distribution of crop varieties in the case of land with steeper slopes. These soils represent 21.8% (22000 ha) of the total agricultural land of the region.

(2) *Strongly erodible soils* suffer a yearly washoff of 1.5–5.0 mm of soil, with medium sloping of 7–12°, deep to moderately deep soils, skeletal 1–25%). The soils of this category require not only agrotechnical and biological antierosion measures (contour plowing), but also the construction of antierosion facilities. These represent 8.7% (8800 ha) of the total agricultural land.

(3) *Extremely erodible soils* suffer a yearly washoff of 5–20 mm, with sloping of 10–25°, deep to moderately deep soils, nonskeletal or medium skeletal (10–25%). These soils require the maximum antierosion measures, particularly technical ones. Row culture must be excluded, and the possibility of the terrace culture system may be considered. This type of soil covers 0.5% (500 ha) of the agricultural land of the region.

7.4.2. Classification of the soil and ecological factors

Because of its diversity – highly heterogeneous soil, climatic, and agrochemical conditions – the Nitra region has had to be grouped into smaller "homogeneous" units. This disaggregation was performed on the basis of data obtained largely from hydrometeorological stations, with the addition of agrotechnical production data.

The pedological examination of the region provided a comprehensive description of 6568 soil pits made in the Nitra region, and this was subsequently used for the soil and ecological unit (SEU) rating of the region's land (*Figure 7.2*).

The terms *soil* and *ecological unit* are applied to a limited territory, which, through the effects of a series of environmental factors, soil, climate, and relief, displays specific ecological properties and bioenergetic potentials. Each unit is characterized by genetic traits of the soil, soil building substratum, grading, climate, sloping, gravel, depth of the soil, and exposition according to the specified criteria. The Nitra region consists of 191 soil and ecological units described in this way. However, such a fine-grained disaggregation of a relatively small area (approximately 100 000 ha) was found to be impractical for the proposed model.

For the purposes of the regional model, the pedologists, agronomists, and economists recommended reclassifying the 191 soil and ecological units into 16 categories (logical units) without a continuous spatial delimitation in the map. The SEU selection/aggregation criteria were as follows:

(1) Climate.
(2) Soil subtype.
(3) Soil profile.
(4) Soil-building substratum.
(5) Sloping.

The model is based on the actual hypothesis that each of the 16 categories (described below) has approximately the same soil, climate, and production conditions for a certain set of differentially represented crops. Prevailing soil subtypes are according to FAO classification. Additional data concerning acreage, slope, and soil type can be found in *Table 7.6*.

Category 1

Climatic zone T1:

(1) Very dry, warm.
(2) Annual total of daily temperatures above 10°C: over 3000.
(3) Mean annual temperature 9–10°C.
(4) Mean annual precipitation 550–600 mm.

The prevailing soil subtype: fluvi-calcaris phaozems, haplic phaozems, fluvi-gleyic phaozems, eutric fluvisols.

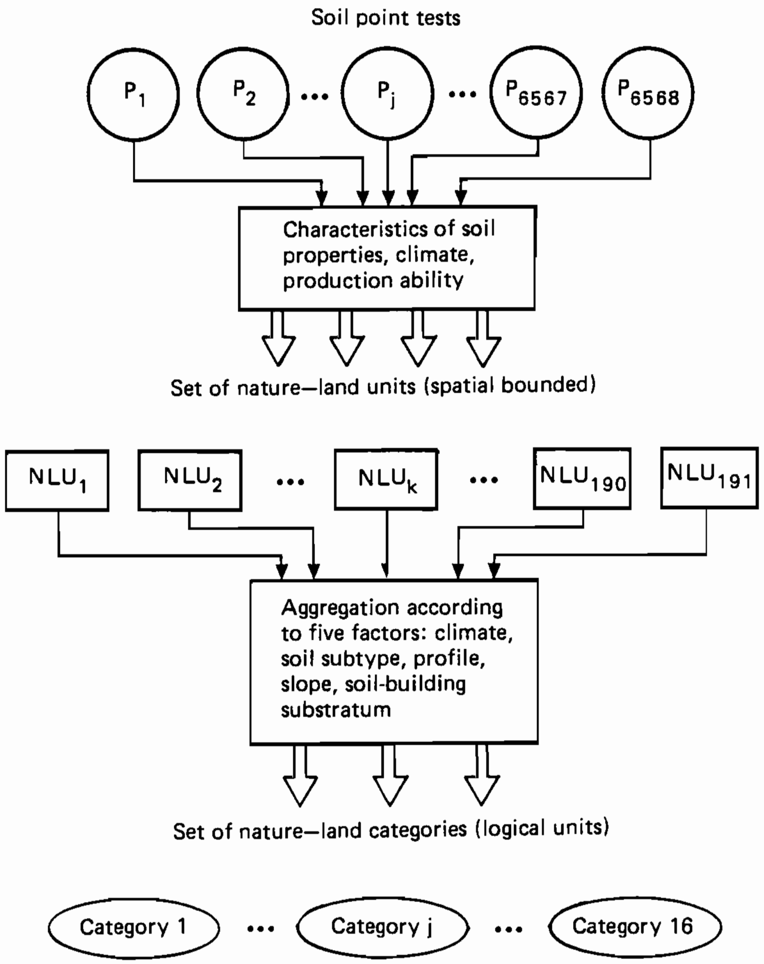


Figure 7.2. The system of aggregating natural and soil categories.

Category 2

Climatic zone T1.

The prevailing soil subtype: fluvi-eutric gleysols, fluvi-mollic gleysols, fluvi-calcaris phaozems, fluvi-gleyic phaozems, eutric fluvisols.

Table 7.6. The 16 soil categories of the Nitra region.

Category	*Size*	*Slope*	*Soil type*
1	4 662	Absolute plain, 0°	Predominantly moderately heavy, nonskeletal, some exceptionally light sandy soils
2	4 543	Absolute plain, 0°	Heavy to very heavy, nonskeletal
3	17 918	Plain to 3°, exceptionally up to 7° (approx. 200 ha)	Moderately heavy
4	2 781	60% up to 7°, 40% up to 12°	Moderately heavy
5	3 456	Absolute plain, 0°	Moderately heavy, sand, skeletal-free
6	3 284	Absolute plain, 0°	Heavy, nonskeletal
7	28 826	Plain up to 3°	Moderately heavy, nonskeletal
8	9 468	Slopes up to 7°	Moderately heavy, nonskeletal
9	3 624	Slopes up to 12°	Moderately heavy
10	5 375	Slopes up to 3°	Moderately heavy (50%), heavy (50%)
11	4 187	Prevailing slopes of 7°	Moderately heavy to heavy
12	1 069	Slopes up to 12°	Moderately heavy (50%), heavy (50%)
13	4 175	Slopes of 7–12° 33% over 12° (12–17°)	Moderately heavy, heavy (50%), with skeletal representing 25–30% of the topsoil
14	1 630	Slopes up to 7°	Moderately heavy, 50% containing 25–30% skeletal, 50% containing less than 10–25% skeletal
15	432	Slopes of 7–12°	Moderately heavy, 60% containing 10–25% skeletal, 40% having 25–30% skeletal
16	654	66% slopes of 12–17°, the rest 17–25°	Moderately heavy with 25–30% of skeletal

Category 3

Climatic zone T1.

The prevailing soil subtype: haplic chernozems, calcic chernozems, luvic chernozems, orthic luvisols.

Category 4

Climatic zone T1.

The prevailing soil subtypes: orthic luvisols, luvic chernozems, haplic chernozems, calcic chernozems.

Category 5

Climatic zones T2 and T3:

(1) Warm, rather dry, lowland and basin-like.
(2) Annual total of daily temperatures above 10°C: 2500–3000.
(3) Mean annual temperature 8–10°C.
(4) Mean annual precipitation 600–700 mm.

The prevailing soil subtypes: eutric fluvisols, fluvi-eutric gleysols, fluvi-calcaris phaozems.

Category 6

Climatic zones T2 and T3.

The prevailing soil subtypes: fluvi-eutric gleysols, eutric fluvisols, fluvi-mollic gleysols.

Category 7

Climatic zones T2 and T3.

The prevailing soil subtypes: orthic luvisols, luvic chernozems, haplic chernozems.

Category 8

Climatic zones T2 and T3.

The prevailing soil subtypes: orthic luvisols, luvic chernozems.

Category 9

Climatic zones T2 and T3.

The prevailing soil subtypes: orthic luvisols, luvic chernozems, haplic chernozems.

Category 10

Climatic zones T2 and T3.

The prevailing soil subtypes: orthic luvisols, stagno-gleyic luvisols.

Category 11

Climatic zones T2 and T3.

The prevailing soil subtypes: orthic luvisols, stagno-gleyic luvisols.

Category 12

Climatic zones T2 and T3.

The prevailing soil subtypes: stagno-gleyic luvisols, orthic luvisols.

Category 13

Climatic zones T2 and T3.

The prevailing soil subtypes: eutric cambisols, stagno-gleyic luvisols.

Category 14

Climatic zones T7 and T8:

(1) Moderately warm.
(2) Annual total of daily temperatures above 10°C: 2000–2400.
(3) Mean annual temperature 5–8°C.
(4) Mean annual precipitation 700–900 mm.

The prevailing soil subtypes: eutric cambisols, stagno-gleyic cambisols, rendzinas.

Category 15

Climatic zones T7 and T8.
The prevailing soil subtypes: eutric cambisols, dystric cambisols, rendzinas.

Category 16

Climatic zones T7 and T8.
The prevailing soil subtypes: eutric cambisols, rendzinas.

7.4.3. Production characteristics of the object categories

The possibilities of producing the respective crops are given in *Table 7.7*, together with the feasible cycles.

7.5. The Basic Methodology

The methodology of the Nitra case study was based on the general methodology designed at IIASA (Reneau *et al.*, 1981). The aim was to create a tool for analyzing the long-term effects of the interaction of agricultural technologies and natural resources under the given socioeconomic, soil, and climatic conditions.

This study defines *technology* as a sequence of a finite number of operations belonging to a certain set in which the input factors are combined, with the aim of providing a set of outputs (yields). Technology is thus seen as a process of transformation of the given (quantitative) inputs into outputs observing the logical time limits.

The output factors include not only the "required" acquisition targets at which the process is aimed, but also by-phenomena that may have negative impacts (such as soil erosion and nitrogen contamination of the underground water).

Table 7.7. Production percentages for selected crops, by Nitra land category.[a]

Land category	*Wheat*	*Barley*	*Grain corn*	*Sugar beets*	*Alfalfa + clover*	*Silage corn*	*Rape*	*Legumes*	*Mixture feed*	*Pastures*
1	20–29	18–25	12–20	5–7	10–16	8–12	–	3–5	10–16	86
2	22–30	10–18	15–20	6–8	13–17	7–12	–	–	9–14	82
3	22–30	12–18	12–20	7–11	14–18	8–12	3–5	1–3	8–14	87
4	25–33	15–20	12–20	1–2	13–19	7–13	1–5	3–7	10–16	87
5	23–32	18–24	12–18	7–11	15–20	6–10	1–3	2–5	5–8	89
6	22–32	17–22	12–18	5–7	15–20	6–10	1–3	2–5	5–9	85
7	22–32	17–22	12–20	1–3	16–20	6–10	1–3	1–3	5–9	81
8	22–32	17–22	12–20	4–7	16–20	6–10	1–3	1–3	5–9	84
9	22–30	18–25	11–16	–	16–20	6–10	1–3	1–2	7–10	82
10	24–32	16–22	7–11	–	13–20	10–14	2–4	2–4	8–12	82
11	27–32	15–22	6–10	–	15–22	10–14	–	–	8–12	81
12	25–32	15–22	6–10	–	16–22	10–14	–	–	8–12	80
13	28–35[b]	13–22[b]	–	–	16–24	9–14	–	–	8–12	76
14	28–36	16–20	–	–	18–26	10–16	–	–	10–16	82
15	26–36[b]	16–20[b]	–	–	18–26	10–16	–	–	10–16	80
16	26–36[b]	19–26[b]	–	–	18–26	10–15	–	–	10–16	83

[a] First value in each land category indicates minimum production; second number maximum production.

[b] Including rye + oats.

Individual operations may be specific to the respective plants, or they may have a more or less general character.

Operations can be defined as a set of partial interactions of several input factors. The set is further separated from the constraints of time and internal logic by acting as a one-shot transformation consuming no time. Summarizing all the inputs for all operations that constitute the respective process, a summary transformation is obtained, namely, the description (vector) ***alternative technology***.

Because crop production (CP) processes have a decisive impact on natural resources (soil, water), the development of concrete models was restricted only to this part of the agricultural production, as will become apparent in Section 7.5.2. Final output of crop production is obtained through biological material: plants. For that reason, a final set of plants is defined, each of which can be grown by means of several alternative technologies.

The input factors, which represent the technology description, are divided into two main groups:

(1) *Active* factors (i.e., those that influence the yield quantity of the required product by means of the biological material, namely, plants) include:

    (a) Water.
    (b) Organic fertilizers.
    (c) Other fertilizers.
    (d) The way in which the land is worked and agrotechnics.

    The above factors, together with the disposability of the natural factors and their quality, form the decisive basis for the potential yield of a plant in the given soil and climatic units. The expression of the main physical and biological principles that determine the potential yields, and the extent of their impact on the soil properties, represent the object of the system portion denoted ***crop module***.

(2) *Realization* factors (i.e., those that represent the inputs necessary for achieving the potential yields) are:

    (a) Supply of nutrients for active intake by the plant, in their optimum form and time.
    (b) Elimination of negative phenomena for growth and assimilation (pests, diseases, agrotechnics).
    (c) Production with minimum loss of yield at harvesting.
    (d) Soil preparation.
    (e) Optimum soil modification.

These types of input include manpower, energy (with the exception of solar energy), technical tools, chemicals (with the exception of fertilizers), and overhead costs including management. Their quantification, or specification, represents the object of the system portion called *technology module*.

As follows from the structure of the system of modules (*Figure 7.3*), the principal task of the respective sections is to generate the coefficients for the development of the main matrix of the decision module. A comprehensive (from the aspect of defining the details for the given study) description (vector) of separate alternative technologies is the output of both previously mentioned modules: a matrix of, e.g., $M \times N$ dimensions, where M is the number of the defined input and output factors, and N is the total number of technologies (for all crops, in all soil and climatic units, and all options).

The description of separate technologies is expressed through the input or output coefficients in the respective measurement units in relation to one hectare of land.

The selection of the most suitable combination of technologies, and the extent and distribution of crop production, are dealt with by the ***decision module***. The core of the module consists of the linear programming (LP) optimization procedure based on the previously mentioned matrix of alternative technologies, and the data that characterize the economic conditions and resources of both the regions under consideration and its surroundings.

The results of the activities of this module specify:

(1) Which technologies.
(2) For what plants.
(3) To what extent.
(4) At which soil and climatic units.

These results represent the most suitable (optimum) allocation of costs (see Section 7.5.2) from the aspect of the given constraints and object function.

Assuming that this optimum solution will be realized, its impact on the natural resources (i.e., soil) specifications, and on the economic specifications for the next period, can be assessed through the coefficients obtained from the crop module.

The first of the specified modifications represents the object of the *environment module*.

The next part is carried out by the ***adjustment module***, which also mediates the interaction with the economic environment (exogenously specified parameters).

Thus, one step of the recursive system operation is concluded for the time period of one year, and the primary data base is set to the condition at (t +1) time.

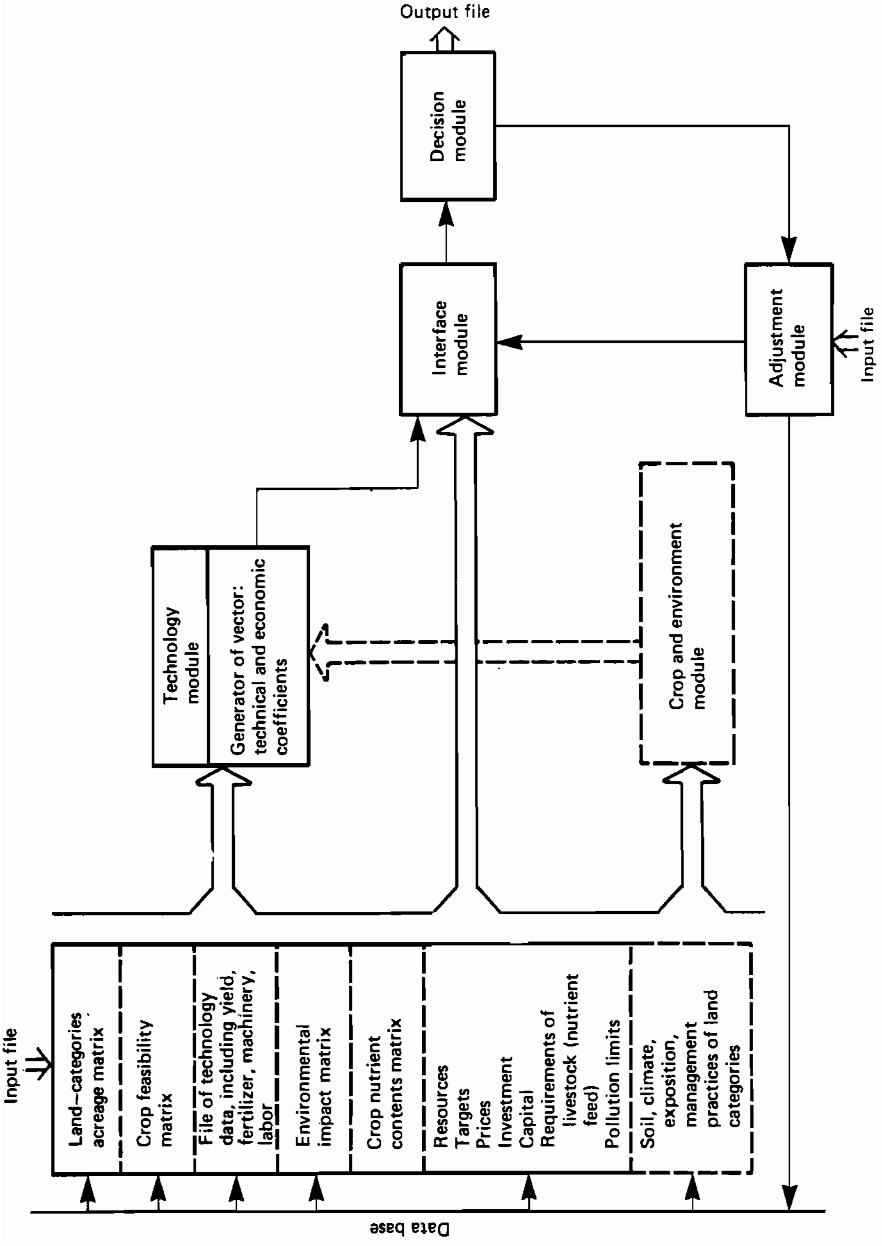


Figure 7.3. The considered structure of the system.

The dynamics of the data base are provided by the modules described, which modify the input parameters according to the specified principles and instructions. In this way the system responds flexibly to various scenarios for the economic development of the region.

7.5.1 Technology module

For the Nitra case study, all the actual technology vectors, which describe inputs and outputs for separate varieties in the 16 soil and climatic categories, were first set manually. This was done by professional estimations based on the practical experience in running 19 enterprises of the Nitra region, and on the consumption standards of separate inputs per one output unit, taking into account the conditions under which the production takes place. The module was constructed as follows:

(1) The set of technologies of the Nitra region was created on the basis of the crop feasibility matrix (*Table 7.8*). In the rectangular scheme, the coefficients (0,1) express the respective crops within the considered set of the 10 main plants in arable land of the respective category.
(2) Typical yields were specified for the main product (*Table 7.9*) on the basis of expert evaluations considering the position of the actual agricultural enterprises, climatic and soil factors, the terrain profile, etc. These data were linked with the inputs for determining the yields, namely those in the form of N, P, K, and manure. The yields of by-products, including the intermediate product (sugar beet pulp) that is returned for consumption within the framework of the fodder base, were specified.
(3) The other technology components represent inputs in kind or in value. On the basis of expert evaluations the costs of energy, fuels, human and machine work, and other expenses, denoted ***overhead costs***, were specified (*Table 7.10*).

On the basis of comprehensive evaluations of the production inputs in the Nitra region and expert estimation, the inputs and outputs were comprehensively evaluated and resulted in a set of technology vectors (in general) disaggregated into separate items as follows:

(1) Primary product.
(2) By-product.
(3) Application of pure nitrogen nutrients.
(4) Application of pure phosphorus nutrients.
(5) Application of pure potassium nutrients.
(6) Electric energy.
(7) Liquid fuels: soil preparation + sowing.
(8) Liquid fuels: treatment.
(9) Liquid fuels: harvest.

Table 7.8. Crop feasibility matrix for the Nitra region.

	Category															
Crop	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Wheat	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Barley	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Grain corn	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Sugar beets	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Alfalfa + clover	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Silage corn	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rape	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Legumes	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Mixed feed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Meadows + pastures	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

(10) Liquid fuels: post-harvest treatment.
(11) Thermal energy.
(12) Biocides, seeds, planting.
(13) Capital expenditures.
(14) Requirements for labor: soil preparation + sowing.
(15) Requirements for labor: treatment.
(16) Requirements for labor: harvest.
(17) Requirements for labor: post-harvest treatment.
(18) Tractors: soil preparation + sowing.
(19) Tractors: treatment + harvest.
(20) Lorries: soil preparation + sowing.
(21) Lorries: treatment + harvest.
(22) Lorries: post-harvest treatment.
(23) Cereal harvesters.
(24) Sugar beet harvesters.
(25) Corn grain harvesters.
(26) Feeds harvester.
(27) Other material expenditures: soil preparation.
(28) Other material expenditures: treatment and fertilization.
(29) Other material expenditures: harvest.

For model purposes, the comprehensive set of technology vectors for the Nitra region was divided into two subsets: the subset of *traditional* technologies, i.e., technologies currently used in production; and the subset

Table 7.9. Present crop yields within the 16 categories of the Nitra region (t/ha).

Land category	*Wheat*	*Barley*	*Grain corn*	*Sugar beets*	*Alfalfa + clover*	*Silage corn*	*Rape*	*Legumes*	*Mixture feed*	*Pastures*
1	4.3–5.9	4.0–5.3	4.8–6.7	41.3–46.4	7.3–10.5	32.5–38.4	2.2	1.2–1.4	22.5–27.5	6.2–8.0
2	5.4–5.7	4.0–4.7	5.0–6.0	36.0–37.0	7.4–8.8	30.0–36.0	2.0	1.0–1.3	21.0–24.5	6.3–7.5
3	5.3–5.6	5.0–5.4	5.4–5.9	41.3–45.3	8.0–9.1	32.5–37.0	2.2–2.4	1.9–2.0	25.0–28.7	6.5–7.6
4	5.0–5.4	4.6–4.8	5.2–5.9	38.0–41.7	8.2–8.9	30.3–31.0	2.1–2.3	1.7–1.9	25.3–26.5	6.6–7.3
5	4.9–5.3	4.5–5.1	5.3–5.9	40.8–44.8	8.7–10.2	33.1–34.8	2.2–2.4	1.2–1.4	23.4–28.0	6.7–7.8
6	4.8–5.3	4.6–5.0	5.2–6.3	40.0–46.6	8.2–10.3	33.7–37.8	2.0	1.0–1.2	24.2–26.2	6.4–8.0
7	5.1–5.3	5.0	5.2–5.4	42.0–44.0	7.5–8.3	33.7–39.6	2.1–2.3	1.3–1.4	23.0–25.0	6.3–7.2
8	4.8–5.0	4.6–4.8	4.8–5.0	38.6–40.6	7.2–7.4	32.5–37.6	2.1–2.3	1.3–1.4	23.5–24.5	6.1–6.6
9	4.6–4.7	4.4–4.7	4.5–4.7	–	7.1–7.3	29.7–35.6	2.0	1.1–1.3	21.8–25.8	5.8–6.0
10	4.9–5.1	4.3–4.6	4.7	37.4–38.5	7.5	36.5–37.8	2.0	1.1–1.3	23.4–25.4	5.4–5.3
11	4.7–4.8	4.4–4.5	4.5–4.7	35.4–36.0	7.2–7.5	39.2–35.9	–	–	21.2–23.2	5.2–5.5
12	4.3–4.5	3.5–3.9	4.1–4.3	–	7.1–7.3	31.3–34.9	–	–	21.0–23.4	5.1–5.3
13	4.1–4.2	3.1–4.1	3.6–3.8	–	5.6–6.6	25.0–28.0	–	–	21.1–23.1	4.6–5.6
14	2.9–3.6	2.8–3.2	–	–	5.8–7.0	22.0–24.7	–	–	21.0–23.0	4.7–5.8
15	3.1–3.4	3.0–3.1	–	–	5.3–5.9	22.5–23.9	–	–	17.5–19.5	4.4–4.7
16	2.5–2.8	2.4–2.6	–	–	5.4	–	–	–	17.5–18.5	4.4–4.4

Table 7.10. Values (per ha) for technologies specified, by primary crop and land category.

Crop	*Land category*	*Electric energy* (kWh)	*Fuels* (li)	*Pesticides, seeds* (Kcs)	*Tractors* (kWh)	*Lorries* (h)	*Harvester hours*		
							Cereal	*Sugar beets*	*Other*
Wheat	1–16	30–60	95–130	770–1040	820–1145	2.2–3.1	0.85–1.1	–	–
Barley	1–16	25–50	90–120	920–1205	705–985	2.1–3.0	0.85–1.0	–	–
Grain corn	1–13	40–60	170–230	960–1990	1450–1960	1.4–2.0	1.4–1.9	–	–
Sugar beets	1–11	–	250–330	1850–2555	2120–2750	13.9–16.2	–	3.9–4.0	–
Alfalfa	1–16	40–75	70–100	1820–2020	600–840	–	–	–	2.1–3.1
Silage corn	1–15	–	135–180	365–705	110–1430	3.5–4.7	–	–	1.5–2.1
Rape	1–10	15–20	95–120	785	800–1040	2.0–2.1	2.1	–	–
Legumes	1–10	50–90	100–130	2000–2135	850–1110	1.8–2.2	2.2–2.25	–	–
Mixture feed	1–16	–	70–100	355–380	780–1090	1.1–1.2	–	–	1.5–1.7

of *progressive* technologies, the use of which is expected in the process of intensified agricultural exploitation of the region. The notion of progressive technology is also based on the hypothesis that higher efficiency in utilizing the basic means – the land – will produce a higher output.

The previously presented detailed structure of the technology vector, split into discrete operations with numeric input parameters, was not practical for application to the Nitra case study. For this reason, it was decided to aggregate separate inputs into the following final form, where the middle column refers to items (1)–(29) listed above:

Final input form	*Original technology vector*	*Unit*
(1) Primary product	(1)	t
(2) By-product	(2)	t
(3) Electric energy	(6)	kWh
(4) Liquid fuels	(7+8+9+10+11) (see Note [1])	l
(5) Labor in crop production	(14+15+16+17)	h
(6) Financial expenditure	(12+27+28+29)	Kcs
(7) Manure		t
(8) Nitrogen	(3)	kg
(9) Phosphorus	(4)	kg
(10) Potassium	(5)	kg
(11) Tractors	(18+19) (see Note [2])	kWh
(12) Lorries	(20+21+22)	h
(13) Wheat harvesters	(23)	h
(14) Corn harvesters	(25)	h
(15) Sugar beet harvesters	(24)	h
(16) Feeds harvesters	(26)	h

The matrix of alternative technologies for the 16 categories of the Nitra region, for the 10 main crops under consideration, was constructed as previously described, which finally resulted in a complete set of 266 technology vectors.

7.5.2. Decision module

This module represents the core of the system in which the links are formally described as a system of linear equations and inequalities, which represent the framework of the economic activities of the region. The general structure of the decision module can be found later.

A linear programming approach is used, with objective functions to obtain the optimal set of agricultural technology vectors.

Description of the LP Model

The following symbols are used for the LP model:

(1) Indices:

i	Commodity (product) (i = 1,...,13), $I = \{i\}$, $I^1 = \{1,...,10\}$, crop production; $I^2 = \{11,...,13\}$, animal production.
j	Soil and climate category (j = 1,...,16).
l	Technology (l = 1,2).
ic	Crop (ic = 1,...,10).
IF	Feed (IF = 1,...,7).
IA	Group of animals (IA = 1,2).
s	Nutrients (nitrogen substances – proteins, starch units – energy, dry matter) (s = 1,...,3).
E	Starch units explicitly (E = 1).
N	Nitrogen substances (proteins) explicitly (N = 1).
b	Crop production by-product (b = 1,4).
m	Milk (m = 13).
L	Labor (L = 1).
M	Materialized work (M = 1,...,6).
o	Other inputs (o = 1,...,7).
r	Residual (nitrates, eroded material) (r = 1,2).
Z	$\{L,M,O\}$ – set of all inputs.

(2) Coefficients:

y^i_{ic}	Yield of i-commodity for the ic-crop (t/ha).
y^b_{ic}	By-product b of the ic-crop (t per ha).
$\alpha_{s,IF}$	Nutrients in feeds (% per t, starch units).
$\beta_{s,IA}$	IA nutrients required by the group of animals per year and head (t, starch units).
$\gamma^b_{IF,IA}$	Proportion of by-product as an IF feed for the IA group of animals (%).
y^i_{IA}	Utility in the ith commodity at the IA group of animals (t per head).
y^m_{IA}	Milk yield per cow (t per head).
RMI_{IA}, RMA_{IA}	Feasible protein/energy ratio, (min/max) (%).
LAB ...	Requirements for labor in CP (ic,l,j) and AP_{IA} (h per hectare or per head).
MA ...	Requirements for materialized work in CP (ic,l,j) and AP_{IA} (h or kWh per hectare or per head).
INP^o..	Requirements for other inputs in $CP(ic,l,j)$ and AP_{IA} (t, kg, kWh, l, or Kcs per hectare or per head).
$e^r_{ic,l,j}$	Volume of the technology residual of rth kind in CP (t per ha).

p_i	Price of product (commodity) unit (Kcs).
p_i	Price of external (purchased) input unit (Kcs).
c_i^{*}	Direct costs per unit of own input (Kcs).
k_i	Rate for unsatisfied social requirements for *i*th commodity (Kcs per t).
k_r	Rate of produced waste (residual) of *r*th kind (Kcs per t).

(3) The main variables:

$CP_{ic,l,j}$	Crop acreage (ha).
$AF_{IF,ic}^{i}$	Type of feed (t).
FC_{ic}^{i}	Required *CP* final product (t).
$AF_{IF,IA}$	Feeds for the group of animals (t).
$FNA_{s,IA}$	Demanded nutrients (in total) for the group of animals (nitrogen substances, starch units, dry matter) (t, starch units).
AP_{IA}	Herd size of the IA group of animals, AP_{IA}^{m} – number of cows (head).
FNA_{IA}^{E},FN_{IA}^{N}	Absolute quantities of starch units or protein (nitrogen substrates) (starch units, t).
FA_{IA}^{i}	Demanded final product of AP (t).
$PDIF_i$	Unsatisfied requirements for separate commodities (t).
F_i	Total output of separate commodities (t).
$INPT_i^{Z}$	Required inputs (t, h, l, kWh, kg, Kcs).
$EXINPT_i^{Z}$	External input (purchase) (t, hours, litre, kWh, kg, Kcs).
END_r	Residual differences compared to the standard admissible ones for the region in total (t).
UV	Required credit (Kcs).
RES	Current period savings (Kcs).

(4) Right-hand side variables:

TS_j	Total acreage of the *j*th land–climate category (ha).
$CMAX_{ic}^{j}$	Maximum crop acreage of the *j*th land–climate category (ha).
$CMIN_{ic}^{j}$	Minimum crop acreage of the *j*th land–climate category (ha).
$AMIN_{IA}$	Minimum herd size (heads).
$AMAX_{IA}$	Maximum herd size (heads).
DM_i	Required commodity output (t).
$INPL_i^{Z}$	Disposable capacities (resources) (t, h, l, kWh, kg, Kcs).
ES_r	Admissible pollution standards (t).

UVL	Disposable credit (Kcs).
RESR	Required level of accumulated means (Kcs).

Mathematical Formulation of the Task

(1) Land constraints:

$$\sum_{ic} \sum_{l} CP_{ic,l,j} \le TS_j \tag{7.1}$$

$$CMIN_{ic} \le \sum_{ic} \sum_{l} CP_{ic,l,j} \le CMAX_{ic} \tag{7.2}$$

(2) Crop production balance:

$$\sum_{j} \sum_{l} y^{i}_{ic}\, CP_{ic,l,j} - \sum_{IF} AF^{i}_{IF,ic} - FC^{i}_{ic} = 0, \qquad (i \in I - I^2) \tag{7.3}$$

(3) Balance of nutrients for animals and feasible protein/energy ratios:

$$\left.\begin{aligned} \sum_{IF} \alpha_{s,IF}\, AF_{IF,IA} - FNA_{s,IA} &= 0 \\ \sum_{IF} \alpha_{s,IF}\, AF_{IF,IA} - \beta_{s,IA}\, AP_{IA} &= 0 \\ AP_{IA} - 1/\beta_{s,IA}\, FNA_{s,IA} &= 0 \end{aligned}\right\} \tag{7.4}$$

$$\left.\begin{aligned} FNA^{E}_{IA} - RMI_{IA} - FNA^{N}_{IA} &\le 0 \\ -FNA^{E}_{IA} + RMA_{IA} - FNA^{N}_{IA} &\le 0 \end{aligned}\right\} \tag{7.5}$$

(4) Constraints on *CP* by-products:

$$\sum_{j} \sum_{l} y^{b}_{ic}\, CP_{ic,l,j} - \sum_{IA} \gamma^{b}_{IF,IA}\, AF_{IF,IA} \ge 0 \tag{7.6}$$

(5) Constraints on herd size (cattle, pigs – meat):

$$\left.\begin{aligned} AP_{IA} - 1/y^{i}_{IA}\, FA^{i}_{IA} &\ge AMIN_{IA} \\ AP_{IA} &\le AMAX_{IA} \end{aligned}\right\} \quad (i \in I - I^1) \tag{7.7}$$

(6) Constraints on milk production (number of cows):

$$AP^{m}_{IA} - 1/y^{m}_{IA}\, F^{m}_{IA} \geq 0 \tag{7.8}$$

(7) Constraints on the *CP* and *AP* output (commodities):

$$PDIF_i + F_i \geq DM_i, \quad (i \in I) \tag{7.9}$$

(8) Balance of *CP* and *AP* inputs (labor and other):

$$\begin{aligned}
-\sum_{tc}\sum_{j}\sum_{l} LAB_{tc,l,j}\, CP_{tc,l,j} + INPT^{L}_{i} &= 0 \quad (i \in I - I^{2})\\
-\sum_{tc}\sum_{j}\sum_{l} MA_{tc,l,j}\, CP_{tc,l,j} + INPT^{M}_{i} &= 0 \quad (i \in I - I^{2})\\
-\sum_{IA} LAB_{IA}\, AP_{IA} + INPT^{L}_{i} &= 0 \quad (i \in I - I^{1})\\
-\sum_{IA} MA_{IA}\, AP_{IA} + INPT^{M}_{i} &= 0 \quad (i \in I - I^{1})\\
-\sum_{tc}\sum_{j}\sum_{l} INP^{o}_{tc,l,j} CP_{tc,l,j} - &\\
\sum_{IA} INP^{o}_{IA} AP_{IA} + INPT^{o}_{i} &= 0 \quad (i \in I)
\end{aligned} \tag{7.10}$$

$$INPT^{Z}_{i} - EXINPT^{Z}_{i} \leq INPL^{Z}_{i} \quad (i \in I) \tag{7.11}$$

(9) Constraints on the generated residuals:

$$\sum_{tc}\sum_{l}\sum_{j} e^{r}_{tc,l,j}\, CP_{tc,l,j} - END_r \leq ES_r \tag{7.12}$$

(10) Financial balance:

$$\sum_{i \in I} p_i F_i - \sum_{i \in I} c^{*}_{i} INPT_i - \sum_{i \in I} p^{*}_{i} EXINPT_i + UV - RES = 0 \tag{7.13}$$

(11) Constraints on credit:

$$UV \leq UVL \tag{7.14}$$

(12) Accumulation restrictions:

$$RES \geq RESR \tag{7.15}$$

(13) Objective function – optimality criterion

$$\min z = \sum_i PDIF_i k_i + \sum_r END_r k_r \qquad (i \in I - I^2) \tag{7.16}$$

The Final Version of the Decision Module

The target of the decision module is to choose, according to a given criterion, the optimum technology combination from the available options for different productions, on separate types of land, in the respective year. The module variant comprises only the crop production (CP) sphere, since the relationship between production technologies and environmental effects is assumed only as far as nonpoint influence is concerned, particularly in crop production.

The animal production (AP) requirements are expressed indirectly through the given minimum extent of feed output, or nutrients contained in the feeds. The proper technologies of AP and their subsequent processing are not expressed as variables in this phase of the decision module. The module is expected to be further developed in this direction during the next phase.

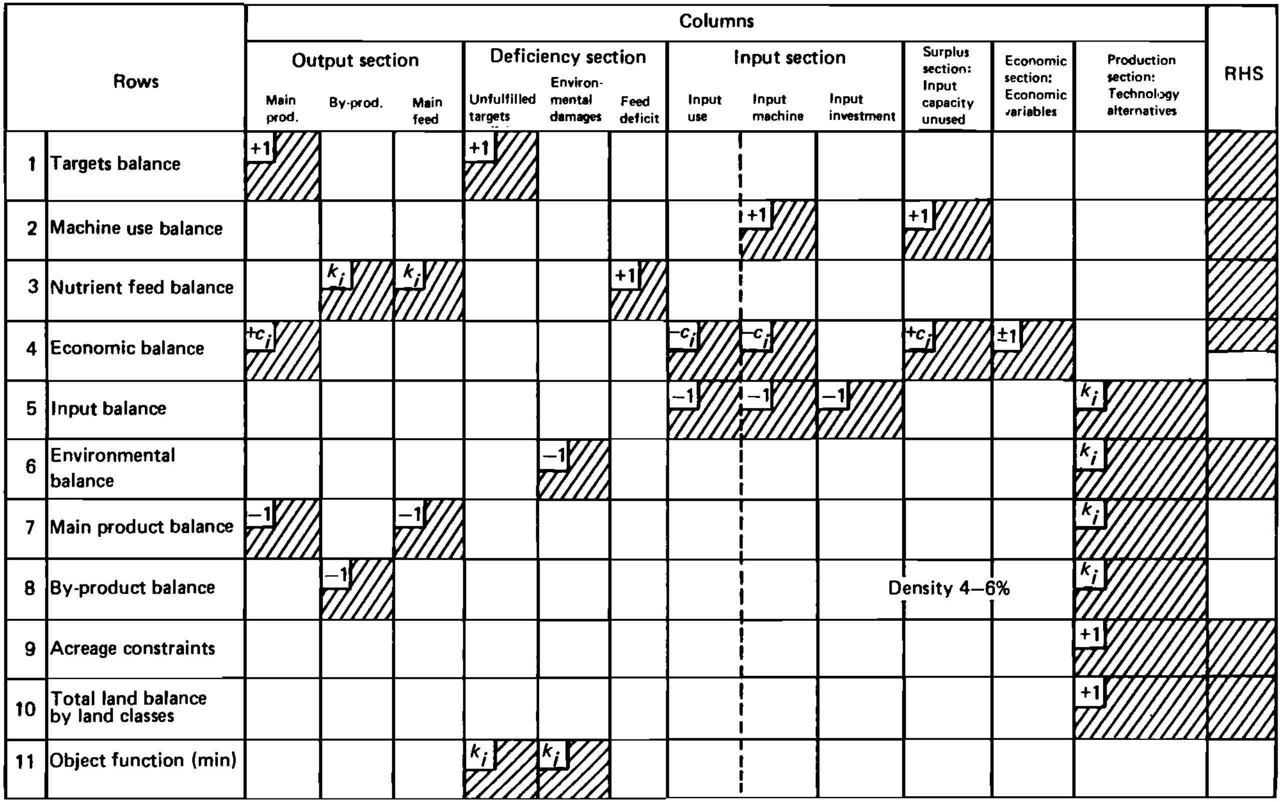
Linear programming is used as the mathematical procedure for the selection of the optimum technology combinations. The objective function is developed with the following aims:

(1) To minimize the difference between the actual output, which can be provided by means of the current technologies in the region, and the requirements of the society (fixed by targets in the region).
(2) Simultaneously, to minimize the extent of the negative environmental effects that may be caused by the implemented technologies. The model assumes certain limits to be set and their excess to be minimized.
(3) To minimize the extent of unsatisfied requirements for feed production, given the animal production targets.

The structure of the module is shown in *Figure 7.4*, from which it follows that the whole LP model is divided into a series of standard blocks defined by the sets of variables and constraints.

The row section consists of 10 blocks and can be divided into:

(1) *Block of the national economy requirements* (targets). The model assumes that requirements are set for all defined main products.
(2) *Machine use block.* From the total number of inputs specified for the model, a number of inputs can be specified and declared long-term (investment-like) inputs. The capacities balance is formulated so that the potential capacity of a certain type of machine is either processed



	Rows	Output section: Main prod.	Output section: By-prod.	Output section: Main feed	Deficiency section: Unfulfilled targets	Deficiency section: Environmental damages	Deficiency section: Feed deficit	Input section: Input use	Input section: Input machine	Input section: Input investment	Surplus section: Input capacity unused	Economic section: Economic variables	Production section: Technology alternatives	RHS
1	Targets balance	+1			+1									▨
2	Machine use balance								+1		+1			▨
3	Nutrient feed balance		k_i	k_i			+1							▨
4	Economic balance	$+c_i$						$-c_i$	$-c_i$		$+c_i$	±1		▨
5	Input balance							−1	−1	−1			k_i	
6	Environmental balance					−1							k_i	▨
7	Main product balance	−1		−1									k_i	
8	By-product balance		−1							Density 4–6%			k_i	
9	Acreage constraints												+1	▨
10	Total land balance by land classes												+1	▨
11	Object function (min)				k_i	k_i								

Figure 7.4. The Nitra linear programming component: hatched fields represent nonzero components of the matrix.

and used in the given year or, as a potential production reserve, it is shifted over to the following periods. The extent of the use variables for the given year is restricted by the top limit representing the yearly time fund for the respective means.

(3) *Nutrient balance block.* A balance is made for each of the specified feed types (in the Nitra model the feeds are expressed through the need of nutrients: proteins, energy, and dry matter). The balance calls for the requirements to be satisfied by the main products, namely, those declared usable as feedstuff, and by-products. If the given requirement cannot be fully or excessively satisfied under the current conditions, a variable is used that represents the difference (nonfulfillment) given by the respective prohibitive rates in the objective function.

(4) *Economic balance.* The financial balance is based on the incomes from the main product sales of the region, or on the evaluation of nutrients or feeds produced for the animal production. The direct costs for all inputs specified for the given region are summarized in a similar way. The negative difference that might arise may be covered from accrued funds, which could have been created thanks to the positive output results. The block also contains the investment balance, and total investments must not exceed the specified limits nor may they be extended through an investment credit. The investment credit variable is usually restricted by the top limit representing the maximum credit that can be taken in the respective year.

The model construction estimates the expected income for the output structure organization. In the objective function, any deviation from the estimate may again be expressed as a difference that has to be minimized. Since the construction of the LP matrix generator permits a direct specification of the extent and internal structure of the block, the solutions of its functions may be modified or extended for the respective regions or variant solutions.

(5) *Capacity balance block.* In this block, a balance is given for each output facility, including mechanization facilities in which the total extent of inputs used in the given year is equal to the sum of the separate inputs used by the respective technologies.

In the case of the investment-like inputs, the possibility of extending these by means of further investments is assumed. The purchase of a certain facility (machine) in the respective year assumes financial expenditures equal to the price of the machine, and its global potential capacity is distributed over the expected life cycle of the machine.

(6) *Environmental impact balance block.* The specification of the maximum extent of environmental impact (e.g., in tons of eroded soil) is assumed for each aspect that is specified and surveyed in the model, and which is still considered to be tolerable, i.e., exerting no long-term negative impact. Its excess is expressed by means of variables of

the respective difference, and constitutes a part of the minimized objective function.

(7) *Main product balance block.* The block provides for the correspondence between the total of the separate commodities produced by any alternative technology and their utilization, namely, as:

  (a) The final product intended for system consumption.
  (b) A feed resource for satisfying demand in the same year.

(8) *By-product balance block.* The constraints to this block are formulated simply as covering the volume of the by-products output necessary for feed production. The by-products output may exceed the necessary volume according to the extent of the used technologies and the production structure.

(9) *Acreage constraints block.* The current structure of the system of models contains no simulation of the impact of different or intended crop rotation technologies. The model, however, assumes the crop structure on the respective soils to be restricted (at least for selected plants) to certain limits. Therefore, the constraints to the given block are formulated only for those plants and soil categories to which a nonzero value is assigned by the feasibility matrix and, of these, only for the plants assigned nonzero minimum or maximum values.

(10) *Block of total land constraints.* This block contains simple limits to assure that the total crop of a certain land category does not exceed the total land acreage.

The column section of the activities consists of six blocks, which are as follows:

(1) *Output section*, containing:

  (a) Set of main products.
  (b) Set of by-products.
  (c) Feed set.

(2) *Deficiency section*, containing:

  (a) Set of unfulfilled requirements for products (commodities).
  (b) Set of activities quantifying their global environmental impact.
  (c) Set of deficiencies in nitrogen substrate, starch units, and dry matter.

(3) *Input section*, containing:

  (a) Set of activities – inputs (labor, energy, fertilizers, etc.).
  (b) Set of activities – machine capacities.
  (c) Set of activities – machine investments.

(4) *Block of unused machines* (surplus section).
(5) *Economic section.*
(6) *Production section*, containing set of all alternative technologies.

7.5.3. Adjustment module

The given module provides the dynamics and recursive operating ability of the whole model system. It actually carries out the functions that modify the input values for the next time horizon (t +1) either implicitly, keeping certain values in a permissible interval over the entire time horizon, or explicitly, providing the required trends in the (±) directions. The current possibilities are shown in *Figure 7.5*.

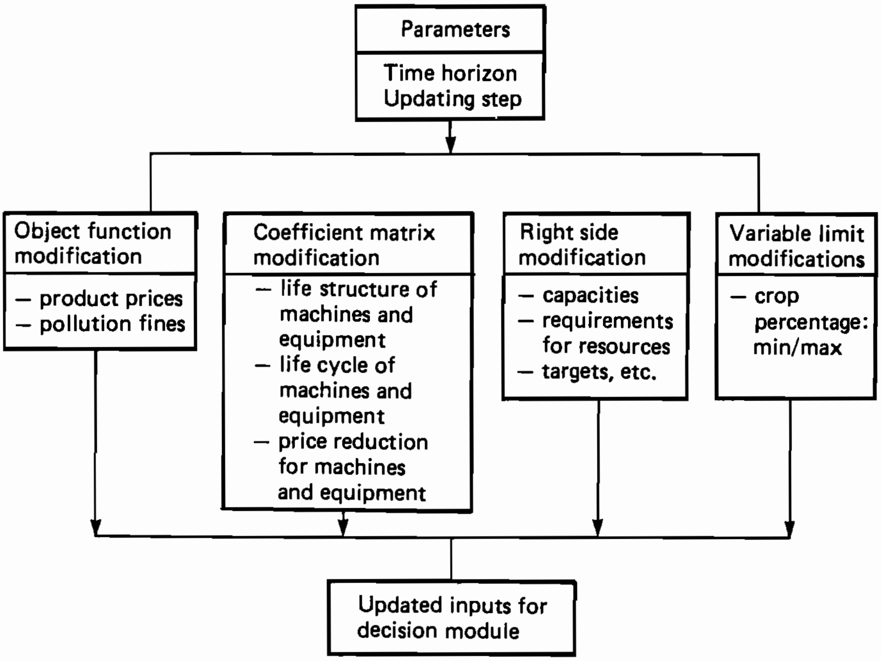


Figure 7.5. Functions of the actualization module.

7.5.4. Crop and environment module

This module is intended for the dynamics of certain input quantities of the technology vectors, namely, those that appear to be the most important from the aspect of the matter studied within the framework of the model (e.g., output, pollution). The module accepts both the environmental elements (soil, climate) and specific properties of the biological material in the vegetation period. Estimations of potential and actual crops at a given site are the final output of the first part of the module.

The other part of the module calculates the impact of agricultural production on the environment (soil), quantifying the volumes of the eroded matter and nitrates at the given site.

The module built and implemented at IIASA was tested at some sites and yielded promising results. In the case study, it was used as a dynamics procedure for the entire system; however, no practical linking has been carried out so far.

7.6. The Basic Scenario and Results

The basic scenario of the case study is obtained from the optimization of the agricultural output of the region by using existing technologies and considering their environmental (soil) impacts.

The case study is restricted to the area in which the agricultural production takes place, i.e., soil, climate, technological and economic conditions, considering their dynamics and the time horizon for which forecasting seems feasible. The natural (soil and climate) conditions of the Nitra region have been discussed in the previous sections.

7.6.1. The technical and economic framework

Products

The 10 main crops (commodities) produced on the majority of the region's soil are considered. We are concerned, namely, with winter wheat, spring barley, grain corn, sugar beets, alfalfa and clover, silage corn, rape, legumes, annual green feeds, and pastures with permanent grass stands. Crop rotation has not so far been considered in the basic scenario. An interval representation of the previously mentioned crops is assumed in the percentages (min/max) of areas at which the respective crops are produced. This crop production target level should cover the demand (purchase) of the society, feed consumption in the region, and sales for the surplus. The by-products output is incorporated into the region's feed base. The requirements for the feed base are specified by the need for nutrients, expressed globally in the dry matter, protein, and starch units (energy).

Sources

The input source items should be divided as follows:

(1) Fuels.
(2) Labor (human).
(3) Fertilizers (organic – manure + anorganic – N, P, and K).
(4) Mechanization (materialized work) – tractors, trucks, harvesters.
(5) Financial sources.

We are concerned solely with restricted sources bounded from above, which the region has at its disposal for the one-year output horizon.

Residues

So far, only the environmental deterioration caused by water erosion has been considered. The soil deterioration due to nitrate nitrogen has not yet been assessed.

Economy

In the model system, the interaction of production, source consumption, and investment requirements is represented through price relations and value categories as the total output value, total production costs, operation credit, investment credit, profit, and unused capital assets. The agricultural output efficiency of the region is reflected by the value of the objective function of the model, which may be formulated from various aspects (deficit minimization, profit maximization, etc.).

7.6.2. The basic scenario

The run of the model system was experimentally verified under the following conditions:

(1) The simulation time horizon is 10 years, starting from 1980.
(2) Crop rotation is not considered (although the acreage may be corrected, as preferred by the adjustment module).
(3) The set of alternative technologies is fixed (two technologies per crop and category).
(4) Product (commodity) prices are expected to increase by 2% a year, with base year 1980.
(5) Changes in requirements for the main product output are considered as constant annual increments or decrements, according to the expected demand in the target year.
(6) Soil decrements have been *a priori* specified for each crop and category per hectare.

7.6.3. Operating mode

The operating mode (*Figure 7.6*) of the current version of the model system for the Nitra case study is characterized by the following attributes:

(1) The decision module is linked with the recursive cycle with an optimization to an optional time horizon.
(2) The adjustment module is serially linked to the decision module outputs.
(3) The technology module so far consists of isolated conventional files as external inputs into the whole system.

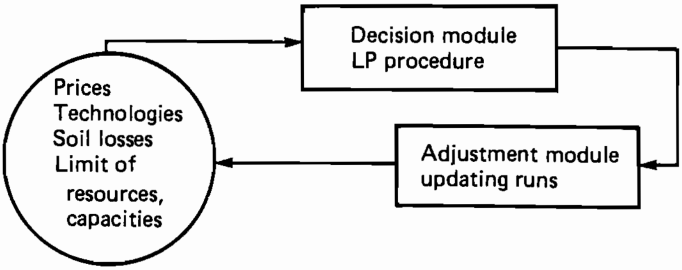


Figure 7.6. Operational chart of the developed system.

The crop and environment module is not linked to the current solution.

The operating mode is determined by software in the FORTRAN 77 language, with implicit use of the MINOS software package on the VAX 11/780 computer.

7.6.4. A brief presentation of the results

A test run (simulation) of the optimization of the agricultural output in the region, with selected technologies of crop production in the respective categories, was carried out according to the specified scenario. The solution corresponds to the 10-year time horizon, 1980–1990. The achieved results demonstrate that the model system is functionally valid in the recursive mode. The computation of the numeric values was correct from the formal aspect.

Independently from the case study, a group of experts have recently worked out a qualified estimation of the agricultural production for the

Nitra region, for the time horizons 1980–1985–1990. The experts mainly considered material (seeds), probably used by the agricultural enterprises of the region, along with the effects of other production-intensifying inputs. These estimated production volumes may be regarded as guiding variables in forecasting the production development for the above-mentioned periods.

We then compared the results obtained by our simulation with the future agricultural production estimates made by the experts who worked independently from the case study. The comparison has, to a great extent, proved the general validity of our model and its ability to express the agricultural production possibilities in the region.

Figure 7.7 shows the comparison of the estimated production volumes with the results of our computations for three main crops of the region: winter barley, spring barley, and sugar beets.

According to these graphs, the level of the winter wheat yearly production, as well as that of sugar beets, is significantly lower than the level recommended by the experts. Their recommendations were influenced by the general requirements of intensifying the agricultural production in accordance with the goals of the national economic development. On the other hand, the production of spring barley in our computations is much higher than the volume considered by the experts.

As for the other crops, which are not dominating in the region, the results obtained by the model mostly correspond to those of the experts' estimations. The only exception is the production of legumes, where a deficit was computed for all of the given time periods.

The feed base consists of the feeds (alfalfa, silage corn, feed mix, and pasture hay) and by-products, namely, cereal, corn straw, and sugar beet tops. The computations indicated that the base is inadequate to meet the requirements of animal production for proteins and starch units (energy). Some relationships should be sought in the underuse of the land (approximately 7000 ha yearly have not been used), which has to do with a shortage of tractors: the available tractors are fully used each year. The results indicate too few corn and feed harvesters and support a call for investments in these variables, namely, purchase of new machines. In the case of trucks, the situation is completely different as there is a surplus of them. There is also a slight surplus of cereal harvesters and sugar beet harvesters.

According to the scenario, in the case of the other inputs, only the data concerned with the demand for electric energy, fuels, labor, other expenditures, manure, and N, P, and K are considered.

The data base concerned with the deterioration of the agricultural soil of the Nitra region, caused by water erosion, was constructed on observations made by the scientists from various regions with similar soil and morphological conditions. For every soil and ecological unit, as well as for each of the 10 main crops, an evaluation was made of the amount of the soil-building substratum that is washed off from one hectare. This washoff

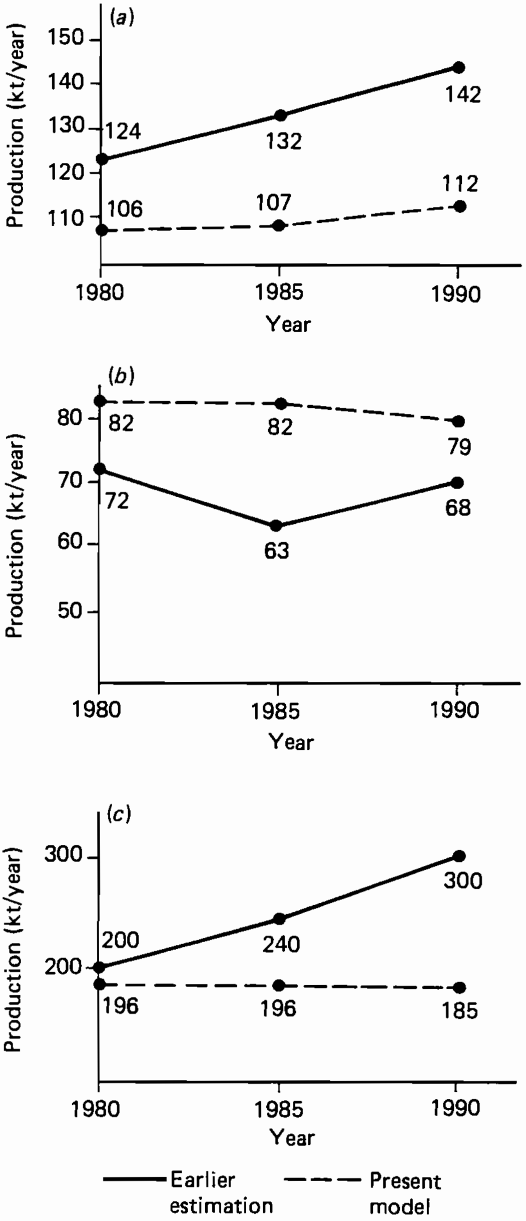


Figure 7.7. Comparison of annual production estimates of the main crops in the Nitra region: (*a*) winter wheat; (*b*) spring barley; (*c*) sugar beets. Solid line indicates earlier estimation; broken line indicates present model.

varies from 0 to 62 t/ha per year, depending on the crop, applied technology, sloping, soil type, and frequency of rainstorms.

The amount of the washed-off soil in the whole region was computed for the time periods considered with our model, in accordance with the considered plant production structure. The results are shown in *Figure 7.8*. The results showing the amount of possible annual soil erosion are alarming, indicating the extent of the detriments to the crop-building layers of soil prevailing in the morphologically heterogeneous parts of the region.

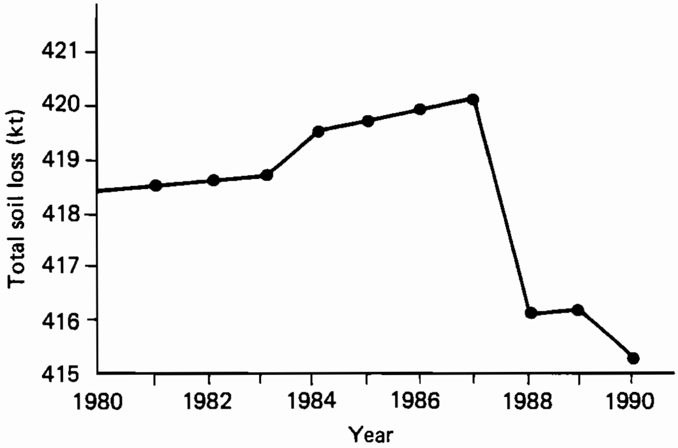


Figure 7.8. Eroded soil losses in 1980 (418 580t), 1981 (418 715t), 1982 (418 820t), 1983 (418 917t), 1984 (419 424t), 1985 (419 874t), 1986 (419 973t), 1987 (420 165t), 1988 (416 176t), 1989 (416 266t), and 1990 (415 081t).

The sudden break of the curve between the years 1987 and 1988 can be explained partly by a decrease in the sugar beet-growing area computed by our model, and partly by the increase in the growing area of the densely seeded cereals, mainly wheat and oil-bearing crops (rape). Consequently, the production of sugar beets is to be decreased, while that of wheat is to rise. The decrease in the amount of the eroded soil substratum is also caused by a general change in the structure of the crops, and by their allocation in the appropriate soil units.

The level of water pollution caused by agrochemical materials to the agricultural production resources was not considered in our simulation computations.

The results of a comprehensive analysis may consequently lead to the generation of other scenarios that could be used for simulating the future alternative strategies. The following scenario designs may be presented as examples:

(1) Requirements for feeds (dry matter, nitrogen substances, starch units) according to the considered animal populations in the respective time horizons.

(2) Valuation (fines) of nonfulfillment of the respective requirements, i.e.:

    (a) Unfulfilled demand for the main product output.
    (b) Unfulfilled requirements for feed production.
    (c) Disobedience (excess) of standards and limits related to environmental pollution.

(3) Design of the differential price changes concerning the main and by-products or input factors.

(4) Changes of the disposable sources, e.g., in accordance with world trends.

On the grounds of these deliberations, other scenarios may be generated, which can be used as the basis for simulation conversions of variant solutions of the trends for further economic development of the region.

7.7. Summary and Conclusions

The intention of the Nitra case study was to provide the management bodies with a rigorous apparatus for modeling the optimum structure of agricultural production, at the regional level, which would have the minimum possible negative impact on the ecology of the country.

The Nitra region was considered, using the general methodology developed at IIASA in 1981. The model was built on the basis of dynamic elements of the linear programming module, with the hope of creating a recursive system of models that would permit conversions, over the specified time horizon and in different scenarios of economic development, for price changes in particular, and for changes in the disposability of resources, and modifications of the soil pollution limits.

Given Nitra's heterogeneous morphology, different soil types, and various climatic and agrochemical conditions, the chosen region was disaggregated into 16 units with approximately similar soil, climatic, and production conditions, suitable for growing a limited set of crops. The units are continuous and are denoted as soil and climate categories with specified properties. In the case study, 10 main crops were considered, for which intervals of their specific representation over the arable land of a given category were defined. For the experimental run of the model, the yields of the respective crops were specified on the basis of expert judgment of the agricultural enterprises. Similarly, the inputs for the activities, which are a part of the vectors of technologies, were obtained from practiced observations, while estimations were made for the progressive technologies.

Animal production and its relevant technologies have not been included in the experimental model; the possibilities of their development are implicitly reflected through the nutrients/dry matter, energy, and protein/number of animals.

It was necessary to disaggregate the region into smaller areas, not only with respect to the different natural and production conditions but also from the aspect of the economic power of the enterprises. The state is interested in economically supporting the "weaker" enterprises of the region, increasing the intensity of their production, making efficient use of the resources, and protecting the soil against water erosion. This region does not suffer much from nitrate pollution, although this is a general menace to the living environment of the state.

We consider the economic and mathematical model built up within the framework of our case study to be just a basis for further understanding. The model formalizes the main relationships that describe the region's conditions and make validation possible, i.e. it permits us to verify the model in terms of reality at the first stage, and then to use it for designing the region's agriculture including its negative impact. The obtained results are just for orientation and merely validate the framework of the first phase. The agricultural production of the region over 10 years (starting from 1980) is considered, on the assumption of a rising trend of prices of products, resources, energy, and requirements for the final outputs in the target year 1990. It can be stated that the results of the simulation are in accordance with the real statistical data recorded in the starting year 1980. Soil losses are represented by the values taken from the sowing structure, indicating a considerable loss of the soil substrate. Disproportions can be found between the requirements for fodder and the inadequate machine capacities.

The problem of soil exploitation remains an open question in the case study, since the practical recalculation did not result in a confrontation of the effects of all three quantities, namely: output, exploitation of the supplies, and observation of the pollution limits. These relationships were formulated, but their analysis has not been concluded.

The linking of the crop and environment modules into a model system, and the incorporation of the adjustment module so that a fully automated recursive operation mode can be reached, still remain pending, as do other suggestions.

Notes

[1] Item (11) is converted by coefficient 1 litre of fuel oil = 0.83 tons of measurement fuel, and 1 litre of petroleum = 0.74 tons of measurement fuel.

[2] The average tractor power is 50 kW.

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CHAPTER 8

Japan's Suwa Basin: A Regional Agricultural Model

T. Kitamura, R. Nakamura, S. Ikeda, H. Tsujii,
M. Matsuda, S. Hoshino, Y. Matsuo, and M. Nakayama

Abstract

The most important agricultural problem for densely populated Japan is to find a system of agriculture in a regional framework that is supported by the ordered use of agricultural land, makes the most of limited natural resources, and is balanced with regional environments.

A recently developed recursive LP model considers the farm household to be the fundamental unit of not only agricultural production but also land management. Thus, the variables in the model are the numbers of farm households engaging in specified types of agricultural management. Resources and environmental capacity in the area are taken as the constraints. The objective function of the model maximizes agricultural gross receipts in the whole area.

The Suwa Lake basin in central Japan was chosen as a case study area. Activity coefficients used in the LP calculations are calculated from the Japanese census of agricultural statistics. Principal component analysis is used to categorize farm households into four typical types of management. Water resources are estimated by a runoff simulation model. Water pollution is estimated by systems analysis; flow rates of pollutant materials in the basin are calculated.

Several future policy alternatives are examined by recursive runs of this LP model. Water pollution from nonpoint sources is the main limiting factor, although water resources are relatively abundant. Pollution of the Suwa Lake region has already exceeded maximum allowable values. The development of a new type of farm household, which produces less pollution within a large management area and is less dependent on rice crops, is the most crucial issue for sustaining agricultural productivity in this region in future.

8.1. Introduction

Environmental problems relating to food production are urgent issues in some countries. It is necessary to increase the productivity of agriculture to satisfy food requirements, while simultaneously balancing the environmental conditions in each region where agriculture is conducted. To understand these problems, the structure of regional agriculture in each region should be analyzed macroscopically, and regional agricultural production planned according to environmental conditions.

From this point of view, agriculture is not only an activity for the production of food and timber, but also one of the most important activities for the management of land, which is a basic of human existence. Thus, agriculture considered in a regional framework depends on the natural and social conditions of the regions involved, and is a basic activity that generates the regional structure.

Before discussing the Task 2 case study in Japan, it is better that we describe the features of Japanese agriculture, which has for a long time been controlled by severe natural and social conditions, in particular:

(1) Population pressure. In Japan, population density per square kilometer is 299 for the total area, but 921 for the habitable areas, including agricultural areas. This means that Japan has one of the highest population densities in the world.
(2) Regionally different climatological conditions. Most, but not all, of the archipelago lies in the humid Asian monsoon zone and so has plenty of rainfall. Narrow flat areas, which are only 30% of the total land, are surrounded by the mountainous areas that accompany the geographic conditions of a volcanic archipelago.

Historically, these conditions have brought the following special characteristics to Japanese agriculture:

(1) Agricultural production based on rice cultivation by gravitational irrigation systems.
(2) Agricultural production by family farms whose land holdings are only about one hectare per household on average.
(3) Farm management that often combines rice production with nonagricultural activities such as not only forestry and fisheries, but also rural industry.
(4) Low level of self-sufficiency in agricultural products owing to geographical conditions.
(5) Regionally combined agriculture based on agricultural settlements that have been established by farmers not only for producing rice, but also for conservation, disaster prevention, joint control of irrigation systems, etc.

In order to improve the circumstances of Japanese agriculture, modernization and mechanization of agricultural production systems have been taking place. As a result, many aspects of Japanese agriculture use highly developed technologies, some of which have reached a highly mechanized production system. However, such a development does not necessarily give farmers high income from agricultural production; because their farm sizes are small they have to purchase many expensive machines and do off-farm work in order to pay for them. Therefore, only old farmers, wives, and children remain in many rural regions the year around, as the younger and more highly skilled leave for urban areas and the rural community gradually deteriorates. The agricultural structure in rural regions has already lost much of its function not only in agricultural production, but also in land management. Modernized agriculture, together with prevailing part-time farming, has not always made effective use of land. Moreover, deterioration of soil and water quality are caused by the inputs of oil, chemical fertilizers, and pesticides due to agricultural modernization.

Thus, in order to achieve highly productive systems in agriculture, policies for improvement of the rural living environment and of land management are necessary. The key question, therefore, is how to find regional agricultural systems that are balanced with regional environments.

That is why integrated rural development is necessary for the functioning of stable and balanced agricultural production systems in Japan, as well as for the introduction of modernized systems of agricultural production.

However, we should not forget that "agriculture" in a regional framework means the macroscopic agricultural systems incorporated in the regional structure, not the behavior of each farmer.

Thus, the objectives of Task 2 in the case of Japan are as follows:

(1) To understand the major elements of the structure of regional agricultural systems.

(2) To find a planning method for agriculture in a regional framework that will improve the structural deficiencies of regional agricultural systems.

8.2. Study Region and Method of Data Analysis

8.2.1. Study region

The Suwa basin in Nagano Prefecture was selected as the case study region. It is situated in the central part of Japan, latitude from 35°48′ to 35°10′ N, and longitude from 138° to 138°24′ E. It lies at an altitude of between 760 and 2900 m, is situated about 200 km west of Tokyo, and has an area of about 700 km^2, extending 35 km from east to west and 41 km from north to south. This area is surrounded by mountains, has three kinds of topographic divisions, and is on the median dislocation line (*Figure 8.1*).

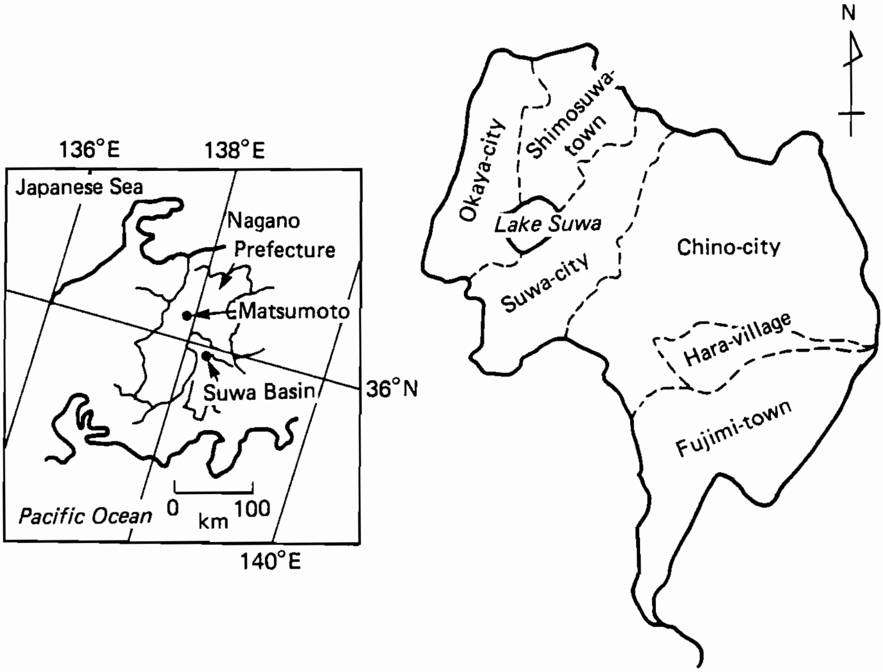


Figure 8.1. Situation of the Suwa Basin.

The basin is divided into four groups by land-use. There are 2591 ha of residential land, 9391 ha of agricultural land, 19117 ha of mountain and forest, and 38919 ha of wasteland and others. Mountain, forest, and wasteland account for 83% of the total, agricultural land 13.3%, and residential land 3.7%. In Chino-city, Fujimi-town, and Hara-village, agricultural land still remains. About 37% of the total agricultural land in this basin is concentrated in Chino-city. The number of farm households is 11706: a comparatively high 19.4% of total households. Chino-city and Hara-village produce mainly vegetables, while in Fujimi-town, agricultural activity is mainly livestock raising. Land in these parts of the region is largely utilized for farming. On the other hand, in Okaya-city, Suwa-city, and Shimosuwa-town, agricultural land is decreasing because of urbanization, and the rate of growth of secondary and tertiary industries is high in these districts.

In the western part of the basin lies Lake Suwa, a tectonic lake that covers an area of 13.3 km^2 and has a maximum depth of only 6.8 m. Lake Suwa is now being severely affected by heavy alluvial deposits from the land nearby, where intensive agriculture is conducted. Eleven rivers flow into the lake, carrying many fertilizers and wastes which cause serious water pollution. These pollutants are produced not only by wastes from industries and cities, but also by chemical fertilizers used in the intensive agricultural region, which covers 94 km^2 of the basin. This phenomenon results from the fact that chemical fertilizers, such as nitrogen (N), phosphorus (P), and potassium (K), can be cheaply obtained in Japan due to the development of the chemical industry. Thus, there is an intensive use of machinery and fertilizer. Waste water from cities flowed into the lake without any treatment. Canalization and construction of a sewage disposal plant are almost completed, and it is expected that the ecological conditions of the lake will greatly improve after the completion of these projects.

The Suwa basin has a population of 203 491 (*Table 8.1*). Figures for the basin population in 1960, 1970, and 1980 show that it increased remarkably during the period 1960–1970 in Okaya-city, Suwa-city, and Shimosuwa-town, while it decreased in Fujimi-town and Hara-village. In Chino-city, during the 10 years from 1970 to 1980 population swelled rapidly, and for the five years from 1975 to 1980 this amounted to a 10.6% increase. This phenomenon illustrates urban sprawl in the area, because population increases in Okaya-city, Suwa-city, and Shimosuwa-town are limited by their narrow geographical structures. Chino-city is becoming a dormitory town

Table 8.1. Population, households, employment status, and land use in the Suwa region, 1980.

Indicator	*Okaya-city*	*Suwa-city*	*Chino-city*	*Shimo-suwa-town*	*Fujimi-town*	*Hara-village*	*Total*
Population	62 210	50 558	43 942	26 575	14 081	6 125	203 491
Households	18 313	15 879	12 326	8 228	3 924	1 597	60 267
Farm households:							
Total	1 585	2 073	4 396	528	1 966	1 158	11 706
Full-time	100	150	551	36	238	220	1 295
Mainly farming	89	270	697	37	441	382	1 916
Mainly other jobs	1 396	1 653	3 148	455	1 287	556	8 495
Employment (%):							
Primary industry	3.8	8.3	26.0	3.7	30.6	51.8	13.2
Secondary industry	58.6	45.7	38.3	58.7	39.7	27.1	48.7
Tertiary industry	37.6	46.0	35.7	37.6	29.7	21.1	38.1
Area (ha):							
Paddy field	281	912	1 961	162	1 280	694	5 290
Upland field	382	424	1 537	113	1 022	623	4 101
Residential land	680	537	701	238	315	120	2 591
Mountain and forest	2 257	3 911	5 276	3 588	3 862	283	19 177
Wasteland	1 090	1 498	8 977	1 641	4 375	1 027	18 608
Others	3 229	3 207	8 136	587	3 583	1 569	20 311
Total	7 919	10 489	26 588	6 329	14 437	4 316	70 078
Population density (persons/km^2)	786	482	165	420	98	142	290
Cultivated land[a] (m^2/person)	107	264	796	103	1 635	2 150	461

[a] Cultivated land = paddy field + upland field.

for the cities. Such changes in population bring new problems related to effective use of land.

A general comparison between the Suwa basin and Japan as a whole is given in *Table 8.2*. As the table shows, the conditions and problems of the Suwa basin are similar to those of the whole country. So the basin could be considered a micro-Japan, which is one of the main reasons why we selected the area for our case study.

Table 8.2. Comparison between the Suwa basin and Japan as a whole.[a]

	Suwa basin		*Japan*	
Indicator	*Millions*	*Percent*	*Millions*	*Percent*
Population	197 552		111.94	
Households (in thousands)	55 313	(100)	31 271	(100)
Farm households:	12 336	(22.3)	4 953	(15.8)
Full-time	1 198	(2.2)	616	(2.0)
Mainly farming	2 073	(3.7)	1 259	(4.0)
Mainly other jobs	9 065	(16.4)	3 078	(9.8)
Employed persons by:	104 893	(100)	52.13	(100)
Primary industry	13 846	(13.2)	6.61	(12.7)
Secondary industry	51 083	(48.7)	18.41	(35.3)
Tertiary industry	39 964	(38.1)	27.11	(52.0)
Area (km^2):	700.78	(100)	377 619	(100)
Paddy field	53.01	(7.6)	30 527	(8.1)
Upland field	41.23	(5.9)	25 825	(6.8)
Residential land	26.77	(3.8)	10 302	(2.7)
Others	579.77	(82.7)	310 965	(82.4)
Population density[b]	282		296	
Cultivated land[c]	477		503	

[a] There is a slight data variation between *Tables 8.1* and *8.2* owing to different statistical sources. [b] Persons/km^2. [c] Cultivated land (m^2/person) = paddy fields + upland fields.

8.2.2. Data collection

The basic agricultural data for each community are available from the Agricultural Census, Agricultural Settlement Card, in which all the data for agriculture related to each community are listed every five years. Thus, the Agricultural Settlement Card data for 1970 and 1975 were used in this study. From these data, 17 factors were selected and used for the calculation of activity analysis. The data for resources, except those related to water resources and pollution, were also obtained from these census data. Hydrological data for water resources were obtained from meteorological observations, and river discharge data were gathered from the observation station at Lake Suwa.

8.3. Model Development

8.3.1. Normative model development of regional agriculture

We consider a recursive linear programming (LP) model as the fundamental tool, and develop a macroscopic model of regional agriculture with special attention to the situation of Japanese agriculture.

A farm household for agricultural production is normally considered one of the smallest units of management in systems of agricultural production. Here, it is noteworthy that a farm household is considered not only a production unit, but also a unit of environmental management in its region. This is a basic point in considering regional agriculture as something complex, including agriculture in the narrower sense, and, in the wider sense, such nonagricultural activities as small-scale industry, rural commerce, land management, and so forth.

The environmental problems emerging in rural regions are mainly caused by the highly mechanized production systems in agriculture, which lose sight of land management functions. It is clear that since agricultural activity, which is oriented only to production, has grown, regional environmental imbalance has also emerged. We made a conscious decision to consider farm households as the basic activity units which bring about the balanced use of land in rural regions through agricultural land management.

There are the following aspects to considering agricultural activities in a regional framework:

(1) Regional agricultural systems are surrounded mainly by natural, but also by cultural, environments.
(2) Farm activity uses technologies, produces various outputs by using resources, and earns income.
(3) Farm activity not only earns income, but also manages its environs.
(4) Resources are used for farm activity.
(5) Such resources are, in a wider sense, commodities produced by one activity and used by other activities; that is, regional agricultural activities are interrelated.
(6) Thus, if we consider a complete linkage system of activities in one region as accomplishing a balanced human society, it is necessary that each activity distribute income equally and maintain a good balanced use of resources that conserves the environment.
(7) To create a balance among activities and resources, the technological development of agricultural production is required. But technological development should be oriented to a target that balances agricultural production and environmental sustainability.
(8) A region cannot exist by itself, but depends on linkages to other regions. Only through such linkages is sustainable agricultural development possible.

An integrated system for agricultural production in a regional framework is fundamentally constructed of *Resources* and *Activities*, which are supported by *Technologies* in each *Environmental* condition. Therefore, the integrated agricultural system in a regional framework could be called a *RATE system*, instead of an R-T-E system.

Technology in a RATE system is considered as a background to activities, but it is also produced by activity. So technology has an effect on environment, and creates activity and resources. Environment is all the surrounding conditions, circumstances, and influences that give a regional context to agricultural production; conditions such as climate, land slope, soil, and economic relations with other regions belong to this environment. In a case where we control resources, such as soils that have eroded in the region or a quantity of waste water, such soils and water are taken as resources in our model. However, if the amount of soil in water is considered to be a criterion function, such an environmental factor is treated as a means of environmental assessment. This model is schematically expressed in *Figure 8.2*.

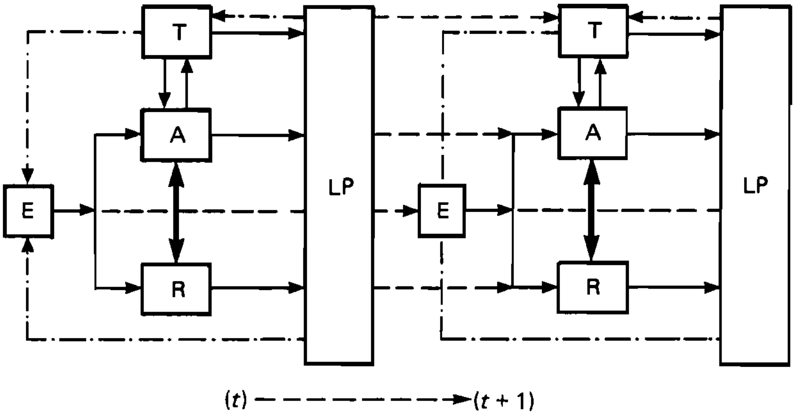


Figure 8.2. The development of the RATE system. R = Resource module; A = activity module; T = technology module; E = environment module; LP = linear programming module; t = the starting point; $t + 1$ = the next time unit; thin arrow = orientation of relations among modules; crossed arrow = feedback relations among modules; thick arrow = balancing relations between resource and activity; broken arrow = time series.

As *Figure 8.2* shows, our model is divided into five modules:

(1) Environmental module.
(2) Technology module.
(3) Resource module.
(4) Activity module.
(5) LP module.

We start off by checking technological possibilities through the technology module, as well as by examining external and internal conditions of regions through the environmental module. These processes are analyses of all the prerequisites for analyzing regional agriculture.

After analyzing these modules, the analysis of resources and activities of regions starts. The resources here include not only water, land, and other physical resources, but also other inputs, such as labor, capital, nutrients, commodities, etc. Through this analytical process, a normative model, income coefficient of objective function, activity coefficients, and resources (right-hand side, RHS), are determined. The recursive LP model is applied to the description of regional agriculture. The results of LP calculations give the specified region an orientation in the development of regional agriculture. The orientation – namely, the impact on the agricultural systems – has an effect on the balance of regional agriculture and creates the next step toward balance.

8.3.2. Model description

In general, the basic equation for an LP model is given in the following form:

$$Y = CX \rightarrow \max \tag{8.1}$$

subject to

$$AX \leq R \tag{8.2}$$

where C is the income coefficient vector, A is the matrix of activity coefficient, X is the variable vector, and R is the resource vector.

However, the practical model that enables us to solve real problems for the regional agricultural problems, mentioned in Section 8.3.1, takes the gross income coefficient as the income coefficient vector, number of farm activities as the variable vector, and resource constraints as the resource vector – namely, RHS – and can be constructed by introducing the following two aspects of the model:

(1) Disaggregation of regions.
(2) Time series factors.

In order to consider time series factors, the LP model applies recursive linear programming to data for two years. It estimates the number of activities for each year and allocation of resources for the second year, the activity coefficients and elasticity coefficients by region each year, and the constraints on resources for the first year. In other words, the regional structure, expressed using coefficients and the allocation of resources for the first year, gives a basis for estimating the resources of the second year. Thus, repeating this process, the resource allocation of the second year can estimate that of the third year. So the model can be used practically in allocating resources and activities for the future.

The recursive model in this study is applied to two districts in two years, but the case of more than three districts could be easily considered, The recursive linear programming for the case of two districts in two years is shown as follows, with normal description:

$$Y = \sum_{t=1}^{2} \sum_{k=1}^{2} \sum_{j=1}^{4} C_j^{kt} \cdot x_j^{kt} \rightarrow \max \tag{8.3}$$

subject to

$$\sum_{j=1}^{4} a_{ij}^{11} \cdot x_j^{11} \leq R_i^{11} \quad \text{1st district resources in the first year } (i = 1,\ldots,s) \tag{8.4}$$

$$\sum_{j=1}^{4} a_{ij}^{21} \cdot x_j^{21} \leq R_i^{21} \quad \text{2nd district resources in the first year } (i = 1,\ldots,s) \tag{8.5}$$

$$\sum_{k=1}^{2} \sum_{j=1}^{4} a_{ij}^{k1} \cdot x_j^{k1} \leq R_i^{1} \quad \text{common resources for the 1st, 2nd districts in the first year } (i = s+1,\ldots,ie) \tag{8.6}$$

$$\sum_{j=1}^{4} a_{lj}^{11} \cdot x_j^{11} \cdot e_l^{1} - \sum_{j=1}^{4} a_{lj}^{12} \cdot x_j^{12} = 0 \quad \text{1st district resources in the second year } (l = 1,\ldots,le) \tag{8.7}$$

$$\sum_{j=1}^{4} a_{lj}^{21} \cdot x_j^{21} \cdot e_l^{2} - \sum_{j=1}^{4} a_{lj}^{22} \cdot x_j^{22} = 0 \quad \text{2nd district resources in the second year } (l = 1,\ldots,le) \tag{8.8}$$

where C_j^{kt} is the income coefficient of the j type of farm activity in k district at t year, a_{ij}^{kt} is the activity coefficient of i resource of the j type of farm activity in k district at t year, e_l^k is the elasticity coefficient of l resource in k district between 1st and 2nd years, x_j^{kt} are variables, (the numbers of the j type of farm activity in k district at t th year, $(i = 1,\ldots,s)$ are resource subscripts for individual districts in the first year, $(i = s+1,\ldots,ie)$ are common resource subscripts for each district in the first year, l is the resource subscript for the second year, j is the farm type subscript for farm activity, k is the district superscript ($k = 1,2$, but easily expanded), and t is the year superscript ($t = 1,2$).

A simplex tableau of this model is shown in *Table 8.3*. In this tableau, the first and second rows show resource constraints by district in the first year, and the third row shows the common constraints for each district. The fourth and fifth rows are the constraints for the second year, which result from the elasticity coefficients of resources between the first and second years.

Table 8.3. The simplex tableau.

	First year		*Second year*		
	1st district $x_1 \ldots x_4$	*2nd district* $x_1 \ldots x_4$	*1st district* $x_1 \ldots x_6$	*2nd district* $x_1 \ldots x_6$	*Resource constraints*
1st district, first year	a_{ji}^{11}	0	0	0	$\leq R_i^{11}$
2nd district, first year	0	a_{ij}^{21}	0	0	$\leq R_i^{21}$
Common, first year	a_{ij}^{11}	a_{ij}^{12}	0	0	$\leq R_i^{1}$
1st district, second year	$a_{ij}^{11} \cdot e_i^1$	0	$-a_{ij}^{12}$	0	$= 0$
2nd district, second year	0	$a_{ij}^{21} \cdot e_i^2$	0	$-a_{ij}^{22}$	$= 0$

Accordingly, if there are data for two years, the resource constraints of the second year are calculated using the result of the first year and checked with the second year value. Moreover, the performance of the model will be checked against actual data. Thus, when we set up the objective function, the model will be calculated for the future. *Figure 8.3* shows this calculation process.

8.3.3. Resources

Resource types

The resources for regional agriculture in this chapter are taken in the sense of the LP framework. Under this definition, the resources of rural regions will be divided into two categories: basic resources and nonbasic resources.

Basic resources, which are essential not only to agricultural production but also to the sustainable development of environments, are land, water, and labor. It is very clear that no agricultural products can be expected without *land, water,* and *labor,* but they need also to sustain the environments involved.

Nonbasic resources in a wider sense are region-specific and depend on the political targets to which agricultural production in the specified region is oriented. These targets of regional agricultural policies are also linked, in turn, to national economic policies, such as price control, production control, international trade, and so forth.

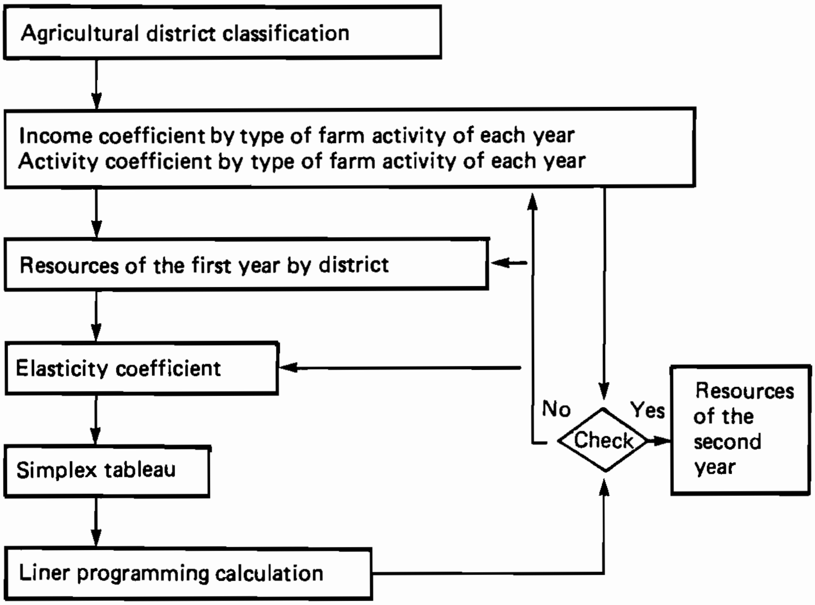


Figure 8.3. The calculation process of the model.

From the application-oriented point of view, nonbasic resources can be divided into the following four categories:

(1) Financial capital.
(2) Commodities (variable inputs and outputs).
(3) Capital assets (fixed capital).
(4) Transportation.

Financial capital means constraints by actual money flow. Secondary or intermediate products are commodities. Input commodities, such as energy, fertilizer, etc., are necessary for agricultural production. As output commodities, various agricultural products can be found in each region. These resources [categories (1) and (2)], are called *economic* resources. The capital assets include farm buildings, large plants, and livestock. Transportation is also considered a very important type of resource. Thus, the third and fourth categories can be called *infrastructural* resources.

Nonbasic resources are classified in the above-stated manner because of the practical nature of the modeling of regional agriculture. It is very important in systems analysis that a proposed model is simulated and applied in practice, for which resources should be measurable. The measurable resources will differ from case to case, but their main importance in theory is to make clear the conceptual categories of resources. So the above-stated categorization of nonbasic resources will be enough, theoretically, to classify nonbasic resources.

Thus, these various resources, which are constraints (the RHS in the LP model), are estimated by the resource module. This module also includes the module for feedback modification. The resources are also dependent on time, so are expressed as:

$$R = fr(E,T,t) \tag{8.9}$$

where $fr(E,T,t)$ is a resource function of a certain technology (T), environment (E), and time (t).

Estimation of Water Resources

Most of the resources could be estimated from actual data. However, water resources are estimated by the following methodology, the ***tank model***.

The tank model method of Sugawara (1961), also known as the reservoir model, which is widely used in Japan, is employed to estimate water resources. The tank model has quite a simple structure, as shown in ***Figure** 8.4*, and is composed of several tanks, each of which is considered as a separate catchment area, as are reservoirs and pipes leading to rivers and canals attached to them. Such a framework is based on the idea that a basin can be regarded as a system that comprises several types of water storage.

Outlets (pipes) attached to the side wall of a tank produce an outflow to rivers in the catchment area. Outputs from the upper stages correspond to direct runoff, and those from lower tanks represent base flow. Outlets on the bottom are for the downward flow into the ground. The position and diameter of these pipes have to be adjusted by trial and error in order to obtain good agreement between the output of a model and the actually measured discharge. Thus, the model could be written as follows:

$$y = \sum_{q=1}^{qe} y_q \tag{8.10}$$

$$y_q = A_q \cdot H_q$$

where y is the total discharge of outlets, q is the number of outlets ($= 1,\ldots,qe$), y_q is the discharge of outlet q, H_q is the water head of outlet q, and A_q are coefficients of outlet q.

The highly nonlinear nature of the model does not assure the presence of a unique set of coefficients as a solution, i.e., there exists the possibility that more than one set of coefficients could produce approximately the same output. However, intensive use of the tank model in various districts of Japan has led to guidelines for obtaining a nearly unique set of coefficients.

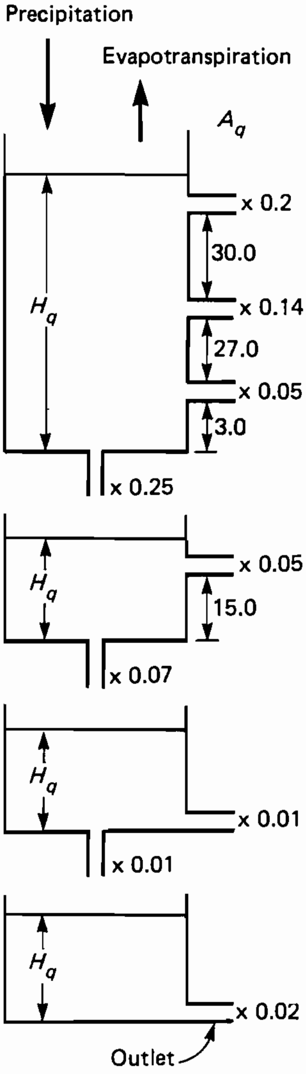


Figure 8.4. The tank model.

8.3.4. Activity

Activity Coefficient Matrix

Agriculture considered in a regional framework is supported by various groups of activities which contribute to both agricultural production and land management. Activity variables defined here in the LP framework only include the number of farm activities and exclude nonagricultural activities, such as schools, local authorities, etc. An LP model of this kind is used in the field of regional science (Isard, 1960). The coefficients of activity explain technologies related to the management of farm activities which could exist in a given environmental condition. Obviously, they depend on time. Thus, the matrix of activity coefficients is given by the activity function $fa(E,T,t)$ of technology (T), environment (E), and time (t), as follows:

$$A = fa(E,T,t) \tag{8.11}$$

Accordingly, activity coefficients are determined by farm activities in the region. LP being a planning model, activity coefficients are usually designed for ideal or model farm activity. Such designed activity coefficients are not checked carefully to see whether the total resources in the region keep a balance with resources that are used by the designed activities. So it is very difficult to grasp the actual number of activities that are allocated by the estimated results of LP calculation for the future.

Moreover, in Japan, individual farm activity is very small (about one hectare), so it is not suitable that the activity coefficients of the model be set up by each farm's activity in the region. Thus, in this study, activity coefficients were determined as an average value of agricultural settlements from existing data, presuming that each agricultural settlement in a uniform district should have the same farm activities of a standard type. The method of determining the types of farm activity and each activity coefficient from actual data was pursued and is roughly shown in ***Figure 8.3*** (Section 8.3.2).

The existing structure of farm activities, that is, their coefficients, were determined as follows:

(1) Agricultural settlements, as the smallest regional unit, were classified into four types of district by various agricultural criteria, and the average structure of each district was considered as its structure of farm activity.

(2) The average levels of resource-use per farm activity in each district were found and used as activity coefficients.

Fortunately, data on each agricultural settlement, which are compiled by the Japanese agricultural census, are available for analyzing activity coefficients. An agricultural settlement can be considered not only as a management unit of farm activity, but also as a regional unit. Using the data, agricultural settlements are classified into four types using the method of principal component analysis (PCA). Average resources per farm activity of an agricultural settlement are considered as activity coefficients.

The method of classifying regional agriculture by district has been developed from the method of economic land classification, known in Japan as the Cornell method (Kanasawa *et al.*, 1973). Each agricultural settlement is used as the unit of classification, instead of each farm business as in the USA. Thus, because the agricultural settlement is considered the smallest regional unit, the concepts of economic land classification have changed, to some extent, for district classification.

Expected agricultural income of the agricultural settlement is chosen as a criterion for district classification. However, as the agricultural settlement census has no index to indicate directly the income of an agricultural settlement, gross income was chosen as the income index from the census.

The principal component analysis (PCA) method is applied to classify the districts. The factors that explain the characteristics of agricultural production, such as the areas of paddy fields, upland areas, and the number of full-time farmers, are selected. Thus, the score of the *m*th principal component (Z_m) is calculated as follows:

$$Z_m = \sum_{p=1}^{pe} l_{mp} \cdot X_p \tag{8.12}$$

where p is the number of factors ($p = 1,\ldots,pe$), m is the number of principal component, and l_{mp} is the *m*th coefficient factor p (l_{mp} is determined by the rules of PCA).

The 16 factors used in this analysis are divided as follows:

(1) Factors for agricultural income level:

  (a) Total agricultural product per farm household.
  (b) Number of farm activities producing more than ¥1 000 000 output.
  (c) Number of farm activities producing less than ¥30 000 output.

(2) Farm activity structure:

  (a) Number of full-time farm activities.
  (b) Number of mainly farming activities.
  (c) Number of part-time farm activities.

(3) Labor conditions:

  (a) Number of main laborers per farm activity.

(4) Farm size:

  (a) Total cultivated land per farm activity.
  (b) Paddy field per farm activity.
  (c) Upland field per farm activity.
  (d) Vegetable-planted land per farm activity.

(5) Land-use pattern and others:

  (a) Rate of paddy field.
  (b) Rate of upland field.
  (c) Rate of orchard.
  (d) Agricultural output per unit area.
  (e) Rate of fallow upland field.

Each type of farm activity discussed here does not express the existing farm activities, but merely an average picture of farm activity. An activity coefficient is an average resource utilized by each farm activity. Thus, if the farm activities by type are counted, the total resources utilized can be estimated to understand the relations between incoming and outgoing resources.

Activity Coefficients Related to Water Resources and Water Pollution

Water requirements for each farm activity depend on the cropping pattern of minor land-use, and are estimated by the following equation:

$$a_{wj}^{kt} = \sum_{r=1}^{re} w_r^{kt} \cdot a_{yj}^{kt} \tag{8.13}$$

where w_r^{kt} is the water requirement for crop r (or livestock r) in k district at tth year, a_{yj}^{kt} is the area (or heads) for crop r (or livestock r) of the j type of farm activity in k district at t year, a_{wj}^{kt} is the water requirement of the j type farm activity in k district at t year, r is the crop or livestock subscript ($r = 1,\dots,re$), and subscript w is equivalent to subscript i (resource subscript) in equations (8.4.) through (8.8), because we cannot obtain the data on water requirements from the census data for agricultural settlement.

Water pollution caused by agricultural production is one of the major environmental constraints to agricultural production. The model of water pollution is composed of the following eight subsectors, which discharge such nutrients as nitrogen and phosphorus into the water basin area:

(1) Paddy fields.
(2) Crop fields.
(3) Orchards.
(4) Domestic animals.

(5) Village population.
(6) Forests.
(7) Industrial output.
(8) Urban population.

The conceptual structure of this model is illustrated in *Figure 8.5*.

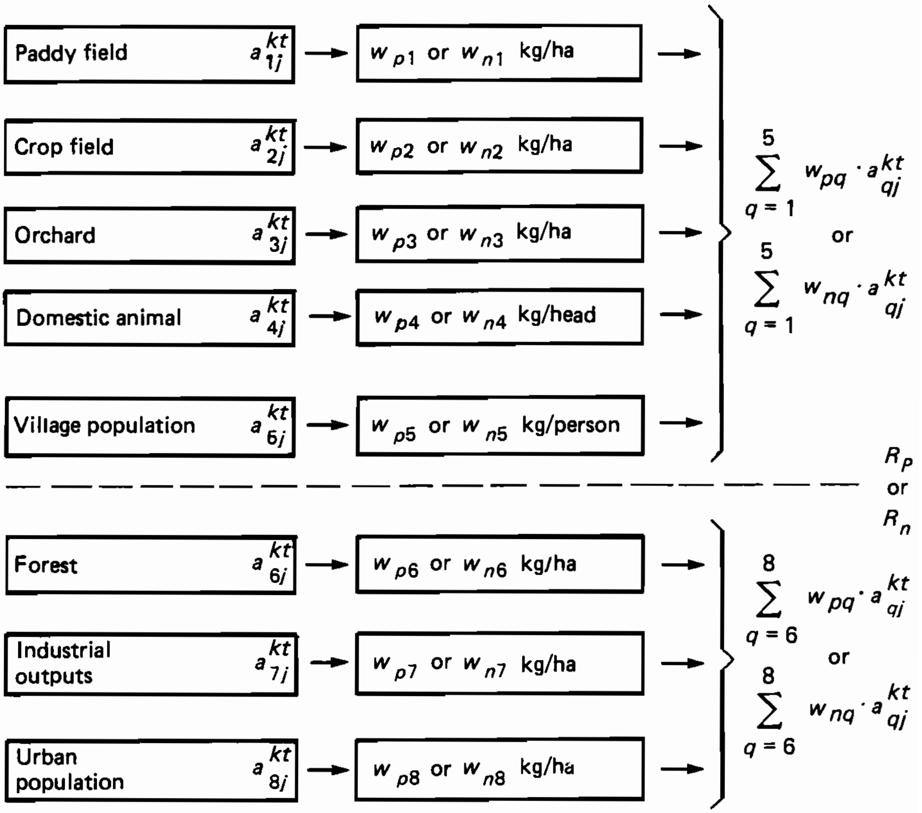


Figure 8.5. A nutrients emission model from nonpoint sources.

The calculated activity coefficient related to the water pollution load, a_{pj}^{kt} (for phosphorus) or a_{nj}^{kt} (for nitrogen), is as follows:

$$a_{pj}^{kt} = \sum_{q=1}^{5} w_{pq} \cdot a_{qj}^{kt} \tag{8.14}$$

$$a_{nj}^{kt} = \sum_{q=1}^{5} w_{nq} \cdot a_{qj}^{kt} \tag{8.15}$$

where a_{pj}^{kt} (or a_{nj}^{kt}) is the phosphorus (or nitrogen) activity coefficient of the j type of farm activity in k district at tth year, w_{pq} (or w_{nq}) is the phosphorus (or nitrogen) load of the related resource q, a_{qj}^{kt} is the activity coefficient of q resource of the j type of farm activity in k district at tth year, q(1–5) are resource subscripts ($q = 1,\ldots,5$ are paddy field, crop field, orchard field, domestic animal, and village population), and subscript p or n is equivalent to subscript i (resource subscript) in equations (8.4) through (8.8).

Hence, given a policy figure for the total nutrient loads R_p or R_n that is presumed to prevent the eutrophication phenomena in lake water, we have the following constraint equations in the RHS of the LP model:

$$\sum_{k=1}^{2} \sum_{j=1}^{4} a_{pj}^{kt} \cdot x_j^{kt} \le R_p \qquad \text{(phosphorus)} \tag{8.16}$$

$$\sum_{k=1}^{2} \sum_{j=1}^{4} a_{nj}^{kt} \cdot x_j^{kt} \le R_n \qquad \text{(nitrogen)} \tag{8.17}$$

8.4. Discussion of Results

8.4.1. Estimation of activity coefficients

Types of Farm Activity

As explained in the previous section, PCA is used as the method for district classification. The factor loadings and the proportions of PCA are shown in *Table 8.4*. From this table, the first principal component (PC) represents the farming scale in agricultural production. The first PC, which represents agricultural superiority of settlements, is useful for the district classification of agricultural production. The second PC can be recognized as something like a farming pattern component; it is, however, not clear whether or not this component is available for district classification.

Thus, the settlements are classified into three types by the scores of the first PC. The thresholds among the three types are set up, considering not only natural conditions, such as topography, but also the spatial continuity of each type. However, in the center of the Suwa region, there is a paddy-dominant part where farmland is already consolidated. This part can be distinguished by the rate of paddy field. The dominance of paddy field in the region is used for a secondary classification criterion. Using these two criteria of district classification, as shown in *Table 8.5*, agricultural settlements are classified into four types. *Figure 8.6* illustrates the results of district classification.

In the process of this classification, it is noted that some settlements are peculiar. Their farm sizes are much larger than the average. Thus, the settlements where agricultural land area under management per farm

Table 8.4. Factor loadings and the proportions of principal component analysis.

	Factor No.[a]	*PC-1*[b]	*PC-2*[c]	*PC-3*[d]
Agricultural income level	1a	0.95	−0.02	−0.04
	1b	0.95	0.12	−0.06
	1c	−0.80	−0.48	−0.03
Farm activity structure	2a	0.80	−0.13	−0.02
	2b	0.73	0.41	0.16
	2c	−0.93	−0.20	−0.10
Labor condition	3a	0.86	0.28	0.01
Farm size	4a	0.74	−0.31	0.20
	4b	0.18	0.84	0.37
	4c	0.68	−0.51	0.15
	4d	0.69	−0.25	−0.12
Land-use pattern	5a	−0.65	0.57	0.23
	5b	0.66	−0.61	0.11
	5c	−0.10	0.15	−0.76
Others	5d	0.53	0.49	−0.44
	5e	−0.26	−0.09	0.50
Proportions (%)	–	49.8	16.5	8.4
Accumulated proportions (%)	–	49.8	66.3	74.7

[a] Factor numbers are as listed in Section 8.3.4. [b] PC-1 = first principal component. [c] PC-2 = second principal component. [d] PC-3 = third principal component.

Table 8.5. Thresholds of each type of farm activity.

	Type 1	*Type 2*	*Type 3*	*Type 4*
Score of the first PC	1.0 (highest)	1.0 to 0.5	1.0 to 0.5	0.5 (lowest)
Rate of paddy field	–	>0.79	<0.79	–

activity is larger than 2.0 ha, which is almost equal to the average size plus double standard deviation, are excluded.

Activity and Income Coefficients

As a result of the district classification mentioned above, agricultural settlements are categorized into four types; i.e., the number of farm activity variables is four. Thus, the coefficient of farm activity, $A(a_{ij})$, for average resource utilization per farm activity, can be computed by dividing the resources available in each classified agricultural type by the number of farm activities. In a case where the farming patterns of the same types of settlement are similar, the average farm activity of each type is regarded as a typical farming pattern for that region. Characteristics of each type are shown in *Table 8.6.* However, activity coefficients related to water resources and pollution are calculated separately, as described in Sections 8.4.2. and 8.4.3.

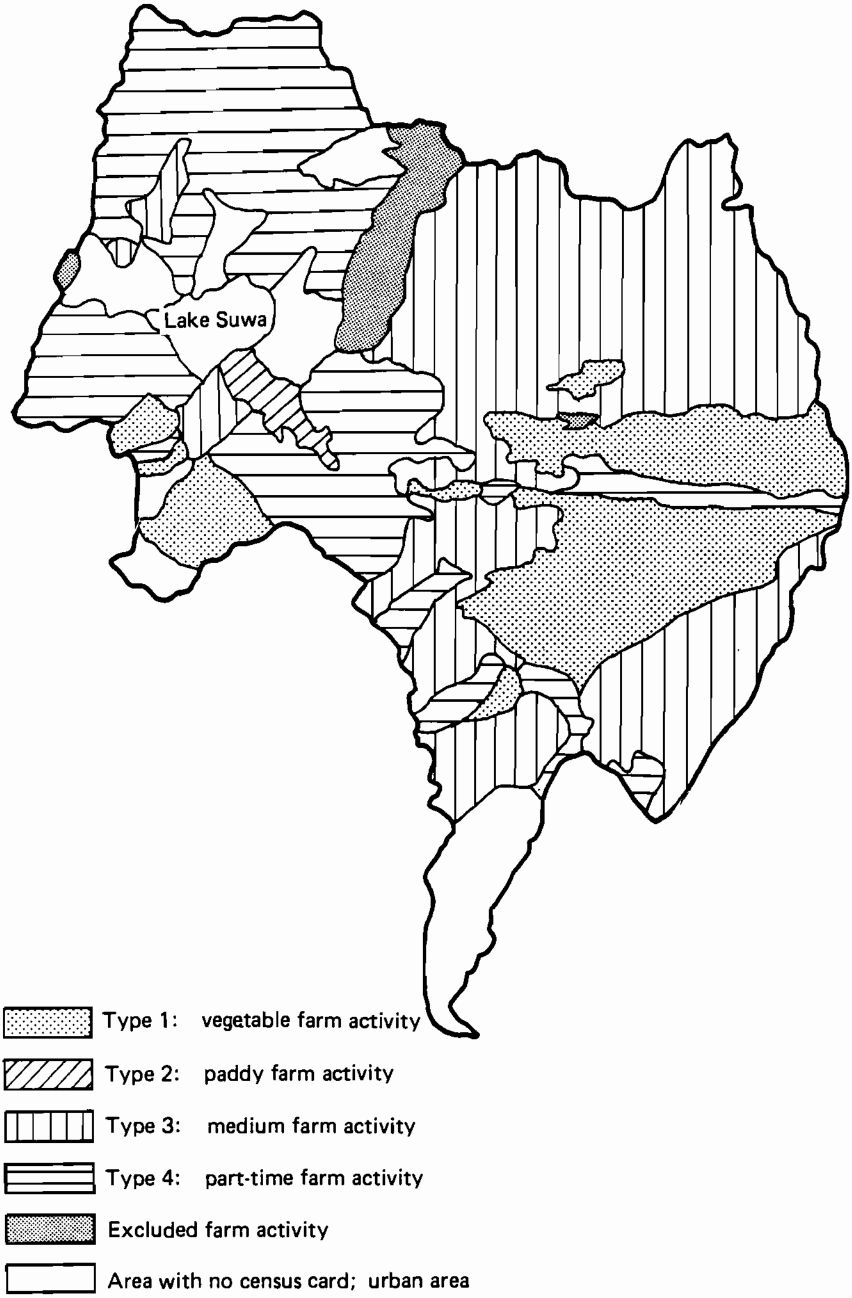


Figure 8.6. **Agricultural settlement classified by four types of farming, Suwa region.**

Table 8.6. Average farm activity.

		Type of farm activity			
Year	*Factor*	*1 Vegetable farm*	*2 Paddy farm*	*3 Medium farm*	*4 Part-time farm*
1970	No. of activities:				
	District I (6403)[b]	1362	88	3439	1514
	District II (3056)[b]	0	619	661	1776
	Total (9459)[b]	1362	707	4100	3290
	Annual sale of agricultural products (1 000 000)[c] ¥	1.114	0.827	0.661	0.289
	No. of agricultural laborers	1.820	0.977	1.385	0.766
	Paddy field (10a)[c]	6.036	6.008	4.518	2.656
	Upland field (10a)[c]	4.426	0.593	2.352	1.080
	Orchard (10a)[c]	0.657	0.386	0.954	0.514
	Dairy cattle (head)[c]	0.679	0.000	0.202	0.031
	Beef cattle (head)[c]	0.183	0.000	0.100	0.020
	Pig (head)[c]	1.370	0.652	0.507	0.445
	Rice (10a)[c]	5.550	5.731	4.193	2.452
	Vegetables (10a)[c]	2.375	0.321	0.814	0.457
	Flower plants (10a)[c]	0.190	0.085	0.109	0.027
	Grass (10a)[c]	0.997	0.000	0.269	0.039
1975	No. of activities:				
	District I (6116)[b]	1314	81	3287	1434
	District II (2850)[b]	0	598	623	1629
	Total (8966)[b]	1314	679	3910	3063
	Annual sales of agricultural products (1 000 000)[c] ¥	1.432	0.778	0.683	0.258
	No. of agricultural laborers	1.413	0.685	0.995	0.445
	Paddy field (10a)[c]	6.267	5.267	4.438	2.450
	Upland field (10a)[c]	4.767	0.657	2.271	1.012
	Orchard (10a)[c]	0.165	0.218	0.452	0.243
	Dairy cattle (head)[c]	0.583	0.000	0.135	0.017
	Beef cattle (head)[c]	0.148	0.000	0.074	0.006
	Pig (head)[c]	0.977	1.361	0.584	0.337
	Rice (10a)[c]	5.310	4.929	3.972	2.188
	Vegetables (10a)[c]	2.780	0.303	0.897	0.481
	Flower plants (10a)[c]	0.284	0.091	0.174	0.021
	Grass (10a)[c]	0.873	0.003	0.173	0.013

[a] Each value in this table, except number of activities, is presented as per farm activity. [b] Value in parenthesis = total number of activities. [c] Value in parenthesis = unit of each factor.

On the assumption that the more agricultural income a settlement earns, the higher is its level of farming pattern, type 1 farm activity has the highest level and type 4 the lowest, excluding the peculiar settlement mentioned above. The average annual sales per farm activity, for each of the four classification districts, are used as the income coefficients for the objective function of our LP model. Type 1, which has a large area for vegetables and is supposed to support the management of highland vegetables, represents the leading pattern of farm activity in this region, and is called vegetable farm activity. The paddy field is more dominant in type 2 than in the other types; thus, type 2 is called paddy farm activity. It has the highest productivity of labor among all the types. Type 3, which is better called medium farm activity, has less paddy field per farm activity than type 2, but has some uplands. This makes the income of type 3 a little lower. The settlements of type 4 are situated around Lake Suwa, where population density is very high. This type is regarded as a typical part-time farming pattern of weekend agriculture in urban areas of this region, so it is called part-time farm activity.

Resource Constraints

The RHS is based on the classification of the Suwa region by watersheds. The region is classified into two districts, of which the first has the more rural characteristics. District I, east of Lake Suwa, is the upper watersheds of two major rivers, the Kami and the Miya, which flow into Lake Suwa. By contrast, district II, around Lake Suwa, contains the lower reaches of the two rivers and an urbanized area. The two subregions are demarcated by the administrative boundary between Chino-city and Suwa-city (see *Figure 8.1*), but the areas in the Suwa region that do not belong to the watershed of Lake Suwa are excluded from the subregions, as shown in *Figure 8.7*.

Most of the resource constraints for the two subregions are computed by combining the resources estimated by the Agricultural Settlement Census (1975), but water resources and the constraints of water pollution are calculated separately, as shown in the following sections. The values of the RHS are shown in Appendix 8A.1.

8.4.2. Constraint of water resources

Limit of Water Resources (RHS)

A drought year, with the probability of occurring once in 10 years, is used to give the design criteria for water resources in this model. As a drought year, the year 1963 is selected. The validity of the tank model is checked by comparing output values with observed data, shown in *Figure 8.8*. The basin of Lake Suwa in this model is divided into the five sub-basins shown in *Figure 8.9*, but aggregated to form two districts, namely, district I with basins B + C, and district II with basins A + B + E.

To estimate the steadily available amount of groundwater flow in the catchment area, the tank model is used. Taking the geographical and hydrological characteristics of this area into consideration, the outflow from the fourth vessel (tank) in the model could be regarded as groundwater flow. Through the simulation of trial and error it was found that the amount of

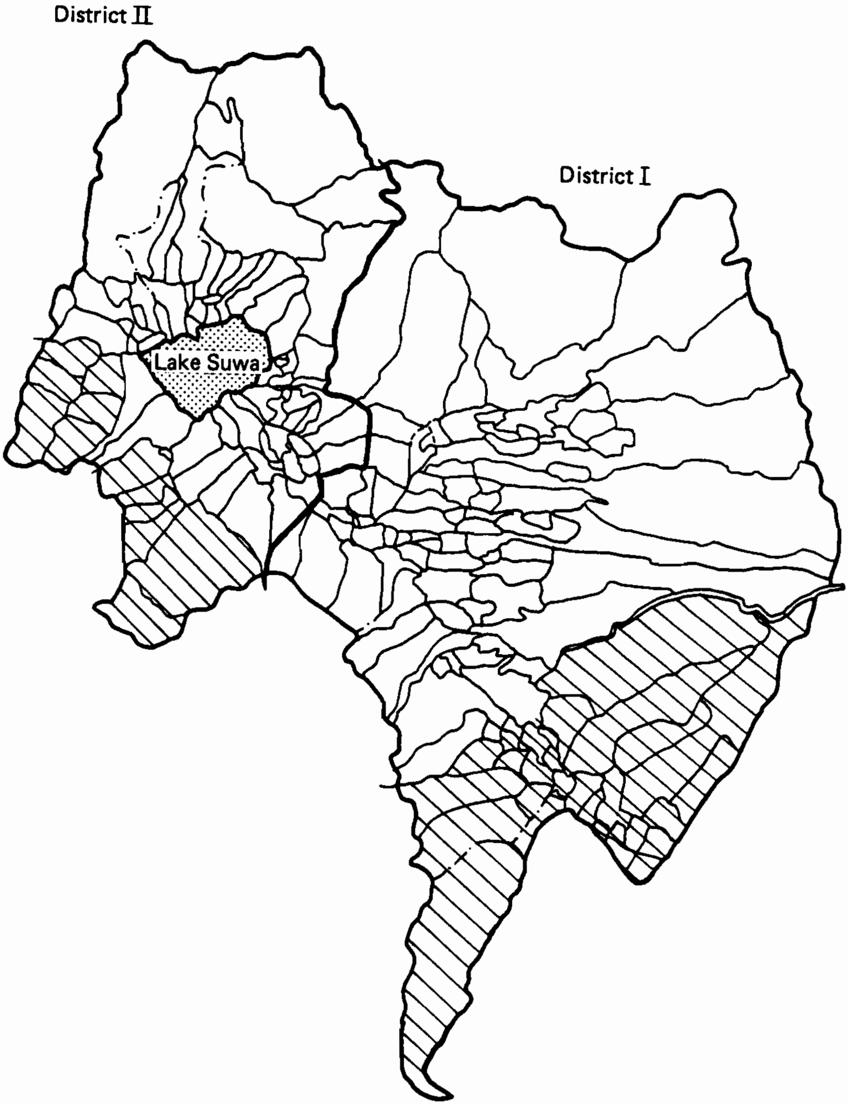


Figure 8.7. Dichotomy of Suwa region for calculation of RHS. Hatched area = excluded area outside watershed of Lake Suwa.

pumping, namely from the fourth vessel, is up to 0.5 mm/day, which is equivalent to groundwater storage.

In order to prevent environmental deterioration of water resources, the amount of pumped water is limited to the extent that the minimum discharge of a river in a given year should not be less than half of the original value, when there is no pumping of groundwater. Minimum daily

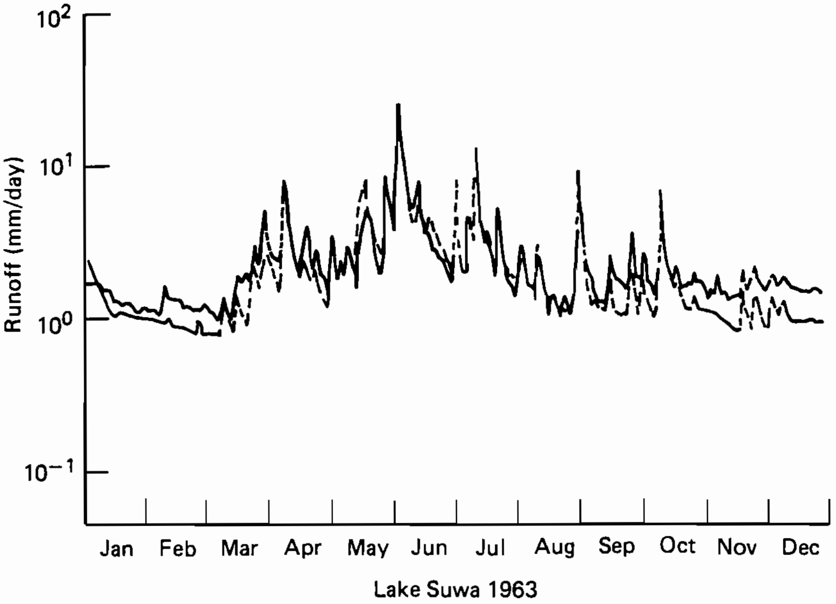


Figure 8.8. Simulated discharge in 1963. Solid line = observed; broken line = calculated.

discharge per annum, in the year 1963, was calculated as 0.78 mm/day. But, in the above case in which groundwater flow is 0.5 mm/day, minimum discharge was 0.37 mm/day.

Thus, the value of 0.5 mm/day is to be used as the input for water resources, i.e., RHS. The values of the RHS are thus determined to be 20 million and 15 million m^3/year for districts I and II, respectively. From the technological point of view, this amount is regarded as very large; this might be due to the volcanic configuration of the geology in these regions.

Activity Coefficient of Water Resources

For upland (nonpaddy) field irrigation, the maximum water requirement for celery and parsley has been shown by experiments to be 4.0 mm/day. This value has been used in this area for years, and neither surplus nor shortage has been observed, so it will also be used in future projects.

For paddy field irrigation, the maximum value of water requirement has been fixed at 25 mm/day. But in this area, surplus water carried to paddy fields always returns to nearby drainage channels and then to the lake. Paddy field irrigation in this area has some 100 years of development history; the canals have been finely constructed to make full use of return flow. Thus, it is assumed that the net amount of water consumed in paddy fields is the amount of evapotranspiration, which is estimated at 7 mm/day.

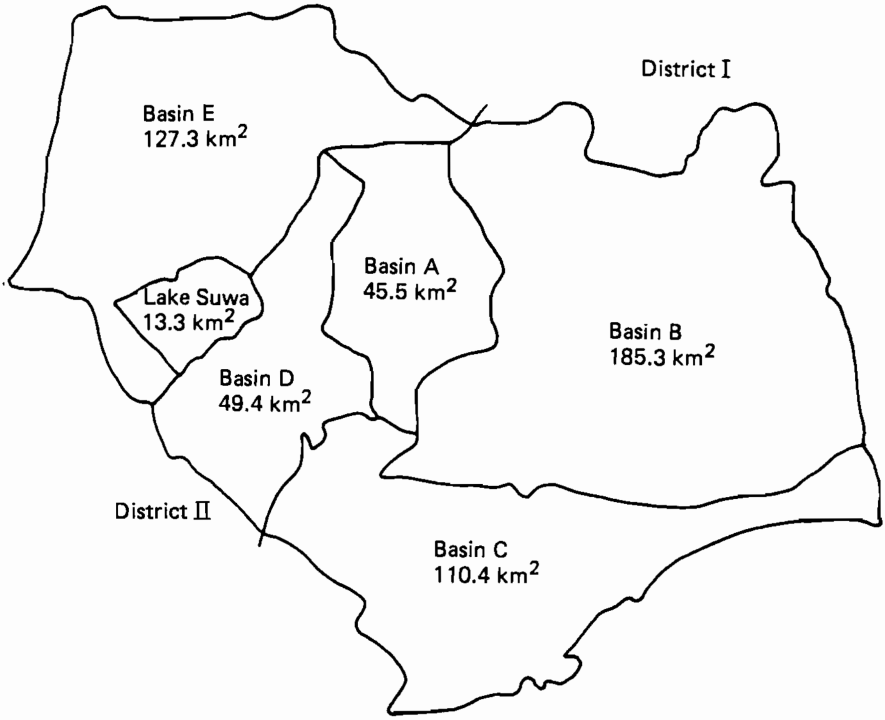


Figure 8.9. Sub-basins in the Lake Suwa region.

In the next step in both cases, as mentioned above, the amount of effective rainfall is subtracted from these requirement values to obtain the amount of consumptive use, also on the basis of "once-in-ten-years probability" drought conditions. This 1/10 condition is customarily used in Japanese standards for the design of water requirements in irrigation.

As there is a considerable amount of rainfall in this region, two types of upland farming can exist: one with irrigation and another without. According to the activity analysis, the activity coefficients of water resources were estimated as the averaged values for the demand of each type. The average areas of paddy and nonpaddy fields for each type of farm activity were obtained from *Table 8.6*. Based on the values shown above, the demands for water of each type were calculated. From the results of an actual survey in the area, the most intensive farm activity of type 1 was found mainly in district I. Thus, from the results of surveys, it was estimated that nonpaddy fields were irrigated most heavily in type 1 farm activity, where half of the nonpaddy fields are irrigated, and additionally in type 2 farm activity, where a quarter of the nonpaddy fields are irrigated.

The values in *Table 8.7* were calculated as the activity coefficients of water resource per year for each farm activity. The values obtained in the above analysis are in a form that allows their ready use for the LP calculation.

Table 8.7. Activity coefficients of water resource by type of farm activity (m^3/year).

Type	*Paddy*	*Nonpaddy*	*Total*
1	2900	1020	3920
2	2885	90	2975
3	2170	0	2170
4	1277	0	1277

In the process of this analysis, the following facts are also made clear:

(1) Most of the surface-water resources have already been used by paddy field irrigation for rice crops and by other industries.

(2) A large future increase in water demand is expected to be caused mainly by the expansion of irrigation for intensive agriculture in highland fields. If a new labor-saving technology in upland irrigation is developed, this tendency will be even more accelerated, and water resource problems are foreseen.

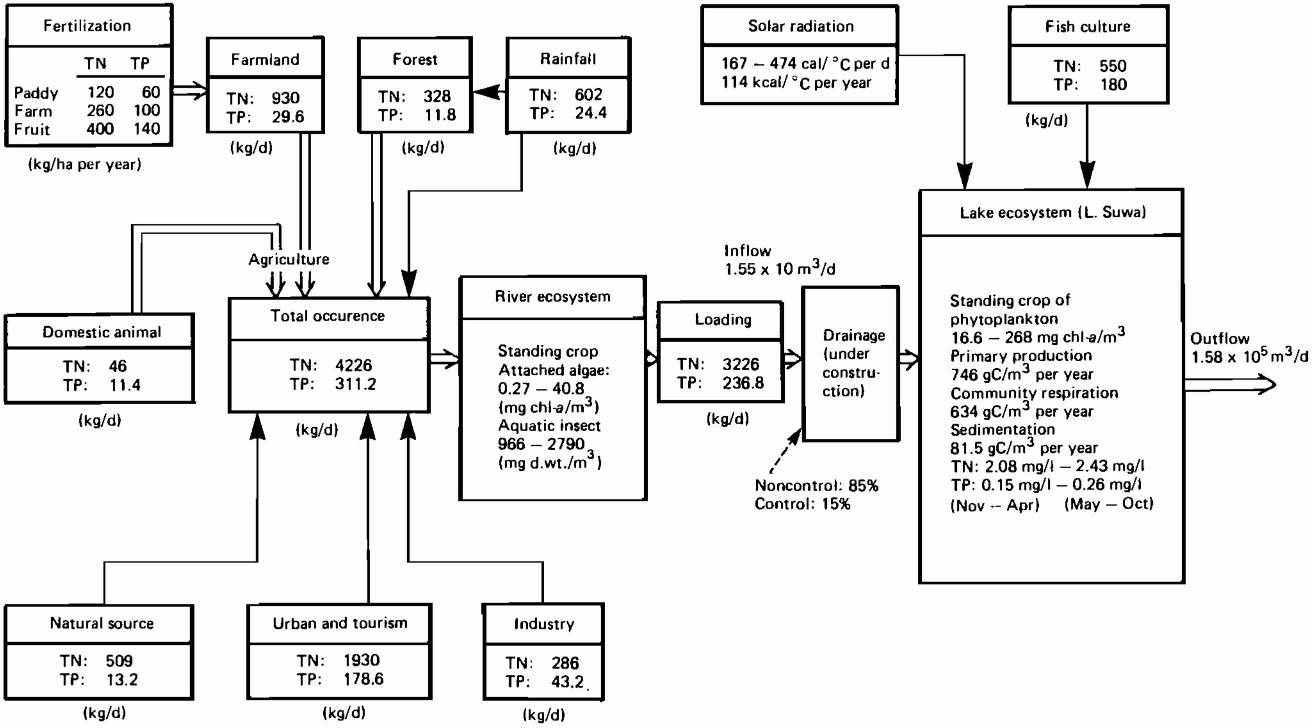
(3) Groundwater is the only possible water resource to be acquired in the future.

(4) Preservation of the quantity and quality of groundwater, therefore, is the most crucial problem in this region.

8.4.3. Estimation of water quality from nonpoint nutrient loadings

The estimation of the overall material balance for the nutrients nitrogen and phosphorus, in the Suwa Lake basin, was carried out in 1979 by the local authority (*Figure 8.10*). The share of the agricultural sector amounts to approximately 30% of the total nutrient emission load, although the actual nutrients flowing into the lake are less than estimated because of natural decay and absorption on their way to the lake due to the hydrological and topographical conditions.

Table 8.8 shows the calculated unit nutrient load and activity coefficients of nitrogen and phosphorus, a_{pj}^{kt} and a_{nj}^{kt}, for each type of farm activity in k district at tth year in the Suwa basin area, on the basis of 1975 agricultural census data for Japan. In this estimation, primary generation factors for unit resource utilization, shown in *Table 8.9*, are used.



ure 8.10. Material balance of nutrients TN (total nitrogen) and TP (total phosphorus) in Lake Suwa region, 1975 rasawa, 1979): chl-*a* = chlorophyll *a*; d.wt. = dry weight.

Table 8.8. Activity coefficients of water quality by type of farm activity (kg/year).

Type	*Nitrogen (N)*		*Phosphorus (P)*	
1	a_{n1}^{kt}	64.89	a_{p}^{kt}	4.78
2	a_{n2}^{kt}	28.00	a_{p2}^{kt}	2.52
3	a_{n3}^{kt}	45.78	a_{p3}^{kt}	3.12
4	a_{n4}^{kt}	26.27	a_{p4}^{kt}	2.17

Table 8.9. Primary generation factors of water pollution.

Resource field (q)	*Nitrogen* (w_{nq})	*Phosphorus* (w_{pq})	*Unit per year*
Paddy field (a[a])	20.28	1.26	kg/ha
Crop field (a_2)	72.28	2.10	kg/ha
Orchard (a_3)	111.20	2.94	kg/ha
Domestic animal (a_4)	6.31	1.10	kg/head (cattle)
	6.62	1.14	kg/head (pig)
Village population (a_5)	0.945	0.593	kg/person

[a] aq ($q = 1, \dots, 5$) is equivalent to aq_j^{kt} in equations (8.14) and (8.15).

8.4.4. Overall results

Simplex Tableau

As for the results of the section above, a simplex tableau of the LP calculation was constructed. The table, which is given in the Appendix, is written for a two-year period. Based on this, several calculations of model analysis were executed.

Agricultural Management and Water Use in the Suwa Region

Based on the 1970 analysis. The relationship between agricultural management and water use in the Suwa region is analyzed using the following procedures.

For *case 1*, the RHS is set as a nominal case of the analysis, using actual observed values. The results will indicate the same values as the actual number of farm activities, x_j^{kt}, if the LP calculations are carried out for the values of these matrices. In this step, the constraints on pollution and water resources are not yet taken into consideration.

The next step, *case 2*, is to see how the state of agriculture tends to change if the constraints are slightly slackened. Thus, the RHS is increased by 1.0% of the original values.

According to the results of optimal solution (*Table 8.10*), the number of farm activities in district I change. Type 1 and type 2 activities increase, as a result of the larger values for the income coefficient, compared to the other types.

Table 8.10. Results of LP analysis for 1970 (unit: number of farm activities for each type).

	District I[a]					*District II*[a]					
Case	*1*	*2*	*3*	*4*	*Subtotal*	*1*	*2*	*3*	*4*	*Subtotal*	*Total*
1	1362	88	3439	1514	6403	0	619	661	1776	3056	9459
2	1380	97	3517	1407	6401	0	631	695	1728	3054	9455
3	1331	97	3558	1415	6401	0	681	595	1780	3056	9457
4	1454	97	3232	1619	6402	0	654	595	1806	3055	9457

[a] Numbers 1 through 4 refer to the type of farm activity.

Next (*case 3*), the constraints on quality and quantity of water, namely, pollution and water resources in this region, were taken into account. These two terms are not based on actual values observed in the year 1970, but on an independent analysis (Sections 8.4.2 and 8.4.3) of the limit of these "resource terms".

The results for district I show that the increment of type 1 farm activity is reduced in this case, but the distribution in district II shows a different result: the number of type 2 farm activities increases. Type 3 decreases owing to the high value for the pollution coefficient for that type. These facts mean that the constraints caused by water pollution, which is mainly brought about by intensive upland field cultivation, have already passed beyond the limit. The water resources, however, had no effect on the calculated consequence. The output of the LP result indicated slackness in resource use.

In *case 4*, it is likely that a proportion of the paddy fields in this region will be converted into nonpaddy fields in the future. Japan has been suffering from a surplus of rice production in the last decade, and the government has strongly promoted a policy for an increase in nonpaddy agriculture.

To establish a limit on the expansion of nonpaddy fields in the near future, it was supposed in the analysis that paddy fields are converted into nonpaddy fields. Generally speaking, converting paddy fields into nonpaddy fields is much easier than converting in the reverse direction, because nonpaddy fields need neither flattening nor extensive water-use systems, except for wet land where complete drainage systems are indispensable.

The result shows that the increases in types 1 and 2 were smaller than normally expected. In order to increase drastically the conversion of paddy fields, into nonpaddy fields, a new type of farm activity, which is not too dependent on rice crops, has to be created.

Based on the 1975 analysis. The results of the analysis on the year 1975 are shown in *Table 8.11*. Clearly, the tendencies of the results of the 1975 calculations are the same as those for 1970.

Table 8.11. Results of LP analysis for 1975 (unit: number of farm activities for each type).

	District I[a]					*District II*[a]					
Case	*1*[a]	*2*	*3*	*4*	*Subtotal*	*1*	*2*	*3*	*4*	*Subtotal*	*Total*
1	1314	81	3287	1434	6116	0	598	623	1629	2850	8966
2	1445	89	3155	1426	6115	0	605	663	1581	2849	8964
3	1387	89	3062	1577	6115	0	658	561	1631	2850	8969
4	1396	89	3053	1577	6115	0	641	561	1647	2849	8964

[a] Numbers 1 through 4 refer to the type of farm activity.

Alternative Scenarios for Resource and Environmental Policies

According to the results of the above analysis, alternative scenarios are considered. The analysis was based on the observed data for the years 1970 and 1975. The main results were as follows:

(1) The potential amount of irrigation water is sufficient to maintain the current level of production activity in the region as a whole for rice cropping and for highland vegetable cropping.

(2) The nutrient loads originating from agricultural nonpoint sources (fertilizer and cattles) have rather severe constraints R_i set by local government on the agricultural activities in the region.

Generally speaking, water resources are regarded as a possible limiting factor. In the Suwa region, however, water resources are abundant because of the volcanic nature of the geography.

From the viewpoint of preventing the eutrophication of Lake Suwa, it is important to have a target figure for nutrient loading from agricultural nonpoint sources. The constraints of the nutrient loads in the RHS of this LP calculation are therefore set to meet the prescribed targets planned by local government when the construction of sewage works, located near the lake, was begun in 1976. The total loads for the agricultural sector were:

(1) Nitrogen: 355 875 kg/year.

(2) Phosphorus: 14 965 kg/year.

Figure 8.11 shows the share of each nutrient, (*a*) total nitrogen and (*b*) total phosphorus, originating from agricultural activities in districts I and II. District II makes a much greater contribution to the total nutrient loads in terms of agricultural nonpoint sources, both in share and in volume, as illustrated by the hatched parts in *Figure 8.11*.

The most important decision for agriculture based on rice cropping is to what extent the land is to be used as paddy or upland crop fields. The

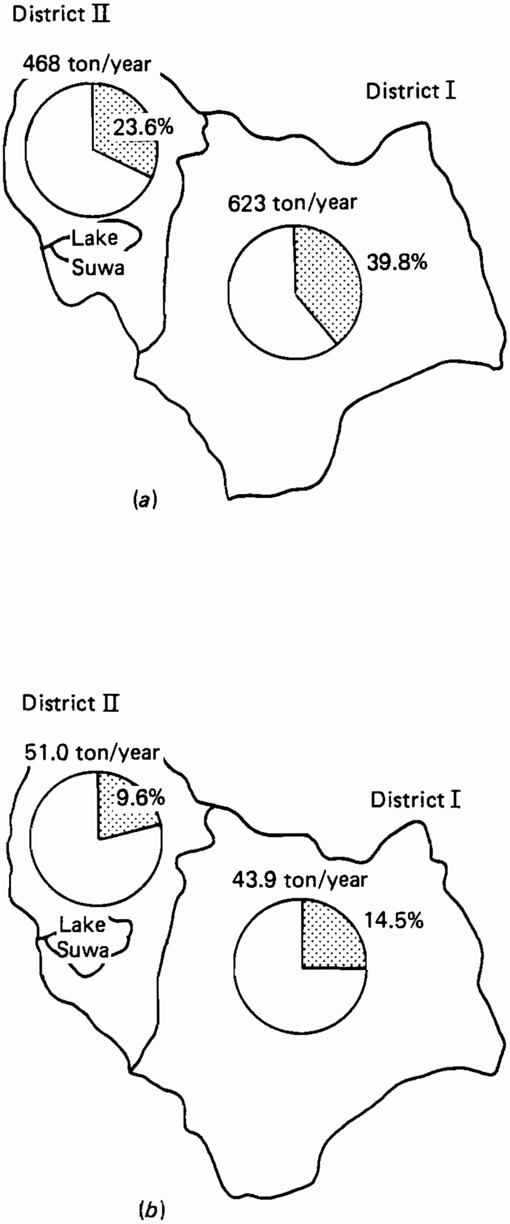


Figure 8.11. Estimated nutrient loads from agricultural nonpoint sources. (*a*) Total nitrogen; (*b*) total phosphorus.

coefficients of the objective function indicate that the type of farm activity with the largest proportion of upland crop field has the largest income coefficient. In the Suwa basin, type 1 farm activity has a larger share of upland field and gross production than the other three types (*Tables 8.10* and *8.11*). This reflects the fact that the Suwa region is famous as the supply area of highland vegetables during the summer season.

These upland crop fields do not use as much water during their production process as do paddy fields. However, they have a much greater influence on the pollution of Lake Suwa than do paddy fields because of intensive use of fertilizer in modernized technology for upland crops.

Thus, we focus on the problem of fertilizer use in rice cropping and highland vegetables, and its impact on the eutrophication of lake water. The following four policy alternatives are examined using our LP models:

(1) *Case 5*: No specific constraints on the nutrient loading from agricultural sectors.
(2) *Case 6*: Standard case of attaining the target values assigned by local government.
(3) *Case 7*: Reinforcement of target values by a 10% reduction.
(4) *Case 8*: Relaxation of the prescribed target values by a 10% increase.

This analysis starts at the same point as does the preliminary study shown in case 1, namely, 1970. The results are shown in *Table 8.12* in terms of number of farm activities allocated to each type. The results of the four cases are as follows.

Table 8.12. Results of the Suwa LP model under nutrient loading from agricultural nonpoint sources (unit: number of farm activities for each type).

	District I[a]				*District II*[a]				*Pollution*			*Slackened*
Case	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*TN*[b]	*TP*[c]	*Total sales*	*labor force*
Orig.[d]	1362	88	3439	1514	0	619	661	1776	382	28.2	575.5	0
5	2745	593	0	3067	266	717	0	2074	367	28.8	592.0	675
6	2735	600	0	3067	0	984	0	2071	357	28.2	584.3	905
7	1485	1861	0	3057	0	984	0	2071	310	25.4	548.9	1956
8	2743	593	0	3067	116	867	0	2072	367	28.5	587.8	800

[a] Numbers 1 through 4 refer to the type of farm activity. [b] TN = total nitrogen; [c] TP = total phosphorus. [d] Orig. = case 1, 1970

In *case 5*, the distribution of farm activity in the optimal solution in both regions is changed. Types 1, 2, and 4 increase, while type 3 disappears. This is caused by the large values of income coefficients for types 1 and 2, and we have higher total sales than in the original case. Instead, we have a slackened (unemployed) labor force of 675 persons, since type 4 needs less labor than type 3 (type 3: 0.995 person/farm activity; type 4: 0.445 person/farm activity).

Case 6, with water pollution as a main constraint, shows a drastic structural change in district II from *case 5*. Type 1 farm activity has disappeared in exchange for an increase in type 2. This case shows that the phosphorus load from type 1, which is presumed to discharge the greatest amount of nutrients partly due to the intensive use of chemical fertilizers in vegetable production, will become a severe constraint in promoting the change of agricultural structure in this region.

Case 7 imposes a more severe constraint on the phosphorus load, from 28.2 to 25.4 ton/year. Then, in addition to the structural change in district I, district II also shows a great decrease in the number of type 1 farm activities (about 1300).

For *case 8*, the relaxation of the water pollution constraint from the standard *case 6* results in almost the same output as *case 5*, with no constraints. This means that the agricultural structure in 1970 has a slightly higher level of nutrient discharge than the level estimated by local government.

Recursive Application of the LP Model from 1970 to 1975

The basic method used in this recursive analysis, as shown in Section 8.3, is further explained as follows by forming a one-constraint matrix. Put:

$$a_{i1}^{kt} \cdot x_1^{kt} + a_{i2}^{kt} \cdot x_2^{kt} + \cdots + a_{in}^{kt} \cdot x_n^{kt} = R_i^{kt}$$

where left-hand side coefficients are those of the constraint matrix and R^{kt} denotes the amount of resources actually consumed by calculated activities $x_1^{kt}, x_2^{kt}, x_3^{kt}, x_4^{kt}$.

The idea of recursiveness is then expressed as:

$$\varepsilon \cdot R_i^{k(t-1)} \geq R_i^{kt}$$

Therefore,

$$\varepsilon R_i^{k(t-1)} - R_i^{kt} \geq 0$$

where t is the time of the application of LP. For ε, the value of 1.1 has been used.

The matrices for two time periods, $t-1$ and t, have been combined into one matrix to be solved simultaneously in one LP run (*Table 8.13*). The equation means that the "resources term" in the time period t is the "resources" used in the previous time period, $t-1$, multiplied by *epilson*. This method implies that the resources left unused in the first time period will be diverted to other industries and cannot be regained in the second time period.

In this Suwa region, the number of laborers in agriculture decreased in the period from 1970 to 1975, and the agricultural land cultivated was also

Table 8.13. Result of recursive run of LP by one-constraint matrix (unit: number of farm activities for each type).

	District I[a]				*District II*[a]			
Year	*1*[a]	*2*	*3*	*4*	*1*	*2*	*3*	*4*
1970	1362	88	3439	1514	0	619	661	1776
1975	3701	1098	0	0	630	1244	0	0

[a] Numbers 1 through 4 refer to the type of farm activity.

reduced in that period. Thus, the result showed much unused resources within constraints generally.

There are various ways of making the models recursive, which may produce different results. In order to assure the validity of the result, it is necessary to pay special attention to the construction of a recursive model.

Essentially, in the process of making a recursive LP model, the activity coefficients used for the LP calculation for a particular year have to be connected with the result of the calculation for another year in a previous period. The means of connection will vary according to the method adopted. In the last stage of analysis, however, the correctness of the connecting method should be validated. The proof is normally made by comparison of the values obtained for recursive iterations for some period with the values from actual observations at that time.

Using the data for 1970 as a starting time, recursive calculations for five years, from 1971 to 1975, were executed. The results can be compared with the measured actual data for 1975.

According to the detailed recursive model, all the activity coefficients of the LP matrix would vary in connection with the results of a preceding year period. Although variations would not necessarily be linear with time, a linear-increment relationship was assumed in this analysis as the first approximation.

On the basis of this assumption, six calculations were performed: each calculation was for one year, from 1970 through 1975. The values of RHS for 1970 and 1975 were known from the observed data for these two years. For the linear approximation, the RHS for intervening years are interpolated with equal spacings between each year, and they are given exogenously. For example, the values of the RHS for labor in the first district, Labor 1, are 8488 persons for the year 1970 and 5820 persons for the year 1975. The values for each year from 1970 through 1975 are then 8488, 7954, 7421, 6887, 6354, and 5820, respectively, with the same increment of -534 for each interval.

The results of the six calculations are shown in *Tables 8.14* and *8.15*. In the course of these calculations, it was found that the solution became infeasible in the calculation for 1972 through 1975. The cause of this infeasibility is that there was a large reduction of labor resources during the five years between 1970 and 1975. This large and quick reduction is very difficult to follow in this type of calculation.

Table 8.14. Estimated RHS by linear interpolation in the years 1970–1975.

RHS[a]	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*
Labor1	8 488	7 954	7 421	6 887	6 354	5 820
Riceland1	28 265	27 964	27 664	27 363	27 063	26 762
Upland1	15 804	15 690	15 576	15 461	15 347	15 233
Orchard1	4 988	4 404	3 820	3 237	2 653	2 069
Farm1	6 403	6 346	6 288	6 231	6 173	6 116
Labor2	2 880	2 655	2 430	2 204	1 979	1 754
Riceland2	11 417	11 115	10 813	10 510	10 218	9 906
Upland2	3 840	3 767	3 693	3 620	3 546	3 474
Orchard2	1 782	1 587	1 392	1 198	1 003	808
Farm2	3 056	3 015	2 974	2 932	2 891	2 850
Waternn	382 300	369 403	356 506	343 610	330 713	317 816
Waterpp	28 220	27 562	26 903	26 245	25 586	24 928
Waters	3 500	3 220	2 940	2 659	2 379	2 099

[a] See Appendix 8A.3 for definition of these symbols.

Table 8.15. Calculated activity with "structure" in 1975, and RHS in 1970–1975.

RHS[a]	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*
Value	6 832	6 725	6 618	6 511	6 405	6 297
Labor1	5 576	5 525	5 475	5 423	5 373	5 322
Riceland1	28 265[b]	27 964[b]	27 664[b]	27 363[b]	27 063[b]	26 762[b]
Upland1	15 804[b]	15 690[b]	15 576[b]	15 461[b]	15 347[b]	15 233[b]
Orchard1	1 331	1 319	1 307	1 296	1 283	1 271
Farm1	6 403[c]	6 346[c]	6 288[c]	6 231[c]	6 173[c]	6 116[c]
Labor2	1 881	1 836	1 792	1 748	1 703	1 660
Riceland2	11 417[b]	11 115[b]	10 813[b]	10 510[b]	10 208[b]	9 906[b]
Upland2	3 840[b]	3 767[b]	3 693[b]	3 620[b]	3 546[b]	3 473[b]
Orchard2	659	687	680	672	664	657
Farm2	3 056[c]	3 014[c]	2 974[c]	2 932[c]	2 891[c]	2 850[c]
Waternn	328 648	324 919	321 177	317 430	313 687	309 958
Waterpp	27 154	26 811	26 469	26 126	25 783	25 442
Waters	2 577	2 539	2 501	2 464	2 426	2 388
x11	2 575	2 577	2 539	2 521	2 503	2 485
x12	975	942	910	878	846	813
x13	0	0	0	0	0	0
x14	2 852	2 846	2 837	2 831	2 823	2 817
x21	289	275	262	249	235	221
x22	1 003	949	897	844	790	737
x23	0	0	0	0	0	0
x24	1 763	1 789	1 815	1 839	1 865	1 890

[a] See Appendix 8A.3 for definition of these symbols. Note that *xij* denotes number of type *j* farm activities of *i* district. [b] Upper limit. [c] "Fixed" to the RHS.

The problem is how could this large decrease in the labor population have come about? If it were true, the productivity per laborer in farming would have been increased dramatically, because the gross agricultural income for the whole area did not show a considerable decrease during that five-year period. This was impossible. The fact was that the number of agricultural laborers is not reflected exactly in the statistics.

The analysis of the cause of this slippage leads to the following conclusion. It is true that a large decrease of labor resources had occurred as a result of the introduction of electronic industries in the Suwa region. Many male laborers became factory workers. The productivity of farms, however, did not decrease, because the greater part of the farming was done by part-time farmers or with the help of other members of the family. This conclusion agrees well with observations in this region. Thus, it is clear that the actual situation in agriculture in this region is well reflected in this analysis rather than in the agricultural statistics.

It has to be noted, here, that the result was obtained without detailed modeling with a recursive method. Whatever the adopted method might be, this result would have been obtained sooner or later. The result was, so to speak, indifferent to the types of recursive models in the LP analysis.

The problem remains, however, of whether this tendency will continue in the future. The answer cannot be given at this stage of the analysis, but will be with the use of more detailed and more micro-oriented modeling of the whole region.

The left-hand side of the matrix for 1975 is made to fit for this all-reducing condition. The application of this recursive method would imply that the constraints of this LP model seem to tighten for 1975.

The calculated result showed more concentration of farm activity in types 1 and 2. Both are characterized by intensive upland agriculture and a large area of paddy fields for rice crops, respectively. The agriculture of the Suwa region would tend toward these traditional types of farm management, if constraints or nonpoint pollution could be relaxed.

8.5. Conclusion

The main points of the analysis are as follows:

(1) The Suwa region is divided into two districts by the characteristics of watershed and type of farm activity. Using principal component analysis, farm activities are classified into four standard types of management. For each district and type of farm activity, activity coefficients of the LP matrix (except for water resources and pollution) are calculated from agricultural census data.

(2) Water resources are evaluated by a simulation model (the tank model), and the limitation and consumption of resources are obtained by a simulation run of the model.

(3) The pollution factor is examined by systems analysis. The movement of each element in the region is expressed in a flow chart, and all flow rates are calculated for each path.

(4) LP analysis is performed using data obtained as above. In the first step of analysis, the variation in type of farm activity is examined. In Japan, most farm activities are based on rice crops in paddy fields. To increase food production in future in this region, a new type of farm activity, which does not depend completely on rice crops, is necessary.

(5) Alternative scenarios for resources and environmental policies are analyzed by LP. While water resources are relatively sufficient, water pollution has already exceeded the standard limit fixed by the Japanese government. Several scenarios for the improvement of agricultural nutrients from nonpoint sources are examined, reflecting a significant increase in the most profitable type of farm activities.

(6) Recursive LP analysis is performed by using one matrix for some period of calculation. The result indicated that if the number of farm activities and the source of high-intensity pollution were reduced, the most profitable type of farm activity could increase.

(7) Discussion on the general problem of recursive model application makes it clear that the factor of part-time farmers (so-called Sunday farmers) is very important.

The overall results show that the constraints imposed by water pollution, which is mainly brought about by the intensive use of fertilizers in upland field cultivation, have already passed the limit of safety. It is likely that a large proportion of the paddy fields in this region will be converted into nonpaddy fields in the future. Japan has been suffering from surplus rice production in the last decade and a half, and the government is strongly recommending the increase of nonpaddy agriculture. However, the policy implication of these results is that extensive conversion of paddy fields into nonpaddy fields cannot be attained without some policy instruments, either to limit nutrient loadings from agricultural nonpoint sources or to promote a recycling of nutrients before they reach the lake water. In general, water resources are a possible limiting factor in regional agriculture. However, in the Suwa region, it has been found that groundwater is abundant enough to fulfill current needs, and no shortage of water is foreseen in this region. The volcanic characteristic of the geology of this region is the cause of this abundance of groundwater. The conservation of the quantity and quality of groundwater will also be a crucial factor for the development of this region over the long term.

Appendix 8A.1. Coefficients of activity: First year (1970)

	District I				*District II*			
	X111	*X121*	*X131*	*X141*	*X211*	*X221*	*X231*	*X241*
1	1.114	0.827	0.661	0.289				
2	1.820	0.977	1.385	0.766				
3	6.036	6.008	4.518	2.656				
4	4.426	0.593	2.352	1.080				
5	0.657	0.386	0.954	0.514				
6	0.679	0.0	0.202	0.031				
7	0.183	0.0	0.100	0.020				
8	1.370	0.652	0.507	0.445				
9	5.550	5.731	4.193	2.452				
10	2.375	0.321	0.814	0.457				
11	0.190	0.085	0.109	0.027				
12	0.997	0.0	0.269	0.039				
13	1.0	1.0	1.0	1.0				
2					1.820	0.977	1.385	0.766
3					6.036	6.008	4.518	2.656
4					1.126	0.593	2.352	1.080
5					0.657	0.368	0.954	0.514
6					0.679	0.0	0.202	0.031
7					0.183	0.0	0.100	0.020
8					1.370	0.652	0.507	0.405
9					5.550	5.731	4.193	2.452
10					2.375	0.321	0.814	0.457
11					0.190	0.085	0.109	0.027
12					0.997	0.0	0.269	0.039
13					1.0	1.0	1.0	1.0
14	64.89	28.00	45.78	26.27	64.89	28.00	45.78	26.27
15	4.78	2.52	3.12	2.17	4.78	2.52	3.12	2.17
16	0.39	0.29	0.22	0.13	0.39	0.29	0.22	0.13
2	1.299	0.698	0.989	1.547				
3	5.638	5.611	4.220	2.481				
4	4.687	0.628	2.491	1.144				
5	1.250	0.147	0.363	0.196				
6	0.614	0	0.183	0.028				
7	0.139	0	0.076	0.015				
8	1.271	0.605	1.470	0.413				
9	5.045	5.309	3.811	2.229				
10	2.876	0.387	0.986	0.553				
11	0.277	0.124	0.159	0.039				
12	0.805	0	0.217	0.031				
13	0.955	0.955	0.955	0.955				
2					1.037	0.557	0.789	0.437
3					5.046	5.023	3.777	2.220
4					6.551	0.536	2.126	0.976
5					0.371	0.218	0.539	0.290
6					0.177	0	0.053	0.008

Appendix 8A.1. (*Cont.*)

	District I				*District II*			
	X111	*X121*	*X131*	*X141*	*X211*	*X221*	*X231*	*X241*
7					0.044	0	0.024	0.005
8					0.041	0.519	1.459	1.403
9					1.523	4.671	3.417	1.998
10					0.301	0.311	0.789	0.443
11					1.180	0.080	0.103	0.026
12					0.118	0	0.032	0.005
13					0.933	0.933	0.933	0.933
14								
15								
16								

Appendix 8A.2. Coefficients of Activity: Second year (1985)

	District I				*District II*			
	X112	*X122*	*X132*	*X142*	*X212*	*X222*	*X232*	*X242*
1	1.440	0.683	0.258	1.440	0.778	0.683	0.258	
2	-1.421	-0.685	-0.955	-0.455				
3	-6.301	-5.267	-4.438	-2.450				
4	-4.793	-0.657	-2.271	-1.021				
5	-0.165	-0.218	-0.452	-0.243				
6	-0.586	-0.0	-0.135	-0.017				
7	-0.149	-0.0	-0.074	-0.006				
8	-0.983	-1.316	-0.584	-0.337				
9	-5.338	-4.929	-3.972	-2.188				
10	-2.795	-0.303	-0.897	-0.481				
11	-0.286	-0.091	-0.174	-0.021				
12	-0.878	-0.003	-0.173	-0.013				
13	-1.0	-1.0	1.0	-1.0				
2					-1.421	-0.685	-0.955	-0.445
3					-6.301	-5.267	-4.438	-2.450
4					-4.793	-0.657	-2.271	-1.012
5					-0.165	-0.218	-0.452	-0.243
6					-0.586	-0	-0.135	-0.017
7					-0.149	-0	-0.074	-0.006
8					-0.983	-1.361	-0.584	-0.337
9					-5.338	-4.929	-3.972	-2.188
10					-3.795	-0.303	-0.897	-0.481
11					-0.286	-0.091	-0.174	-0.021
12					-0.878	-0.003	-0.173	-0.013
13					-1.0	-1.0	-1.0	-1.0
14	61.42	25.81	38.91	22.02	61.42	25.81	38.91	22.02
15	4.38	2.81	2.88	1.96	4.38	2.81	2.88	1.96
16	0.49	0.29	0.22	0.13	0.49	0.29	0.22	0.13

Appendix 8A.3. RHS values and constraints

Symbol	*Value*	*Unit*	*Abbreviation*
L	8488	1 person	LABOR11
L	28265	10a	RICELD11
L	15804	10a	UPLAND11
L	4988	10a	OCHARD11
N	17823	1 head	MILK11
N	6409	1 head	MEAT11
N	51272	1 head	PIG11
N	34606	10a	RICE11
N	8684	10a	VEGETB11
N	884	10a	FLOWER11
N	2353	10a	GRASS11
E	6403	N	FARM11
L	2880	1 person	LABOR21
L	11417	10a	RICELD21
L	3840	10a	UPLAND21
L	1782	10a	OCHARD21
N	30	1 head	MILK21
N	65	1 head	MEAT21
N	2599	1 head	PIG21
N	12844	10a	RICE21
N	2104	10a	VEGETB21
N	247	10a	FLOWER21
N	44	10a	GRASS21
E	3056	N	FARM21
L	382300	kg/year	WATERMM1
L	28220	kg/year	WATERPP1
L	3500	10^5m^3	WATRES1
L	5831	1 person	LABOR12
L	26807	10a	RICELD12
L	15397	10a	UPLAND12
L	2069	10a	OCHARD12
N	0	1 head	MILK12
N	0	1 head	MEAT12
N	0	"	PIG12
N	0	10a	RICE12
N	0	10a	VEGETAB12
N	0	10a	FLOWER12
G	6166	N	FARM12
L	1754	1 person	LABOR22
L	9906	10a	RICELD22
L	3456	10a	UPLAND22
L	808	10a	OCHARD22
N	0	1 head	MILK22
N	0	1 head	MEAT22
N	0	1 head	PIG22

Appendix 8A.3. (*Cont.*)

Symbol	*Value*	*Unit*	*Abbreviation*
N	0	10a	RICE22
N	0	10a	VEGETB22
N	0	10a	FLOWER22
N	0	10a	GRASS22
G	2850	N	FARM22
N	317800	kg/year	WATERNN2
N	24900	kg/year	WATERPP2
L	3500	$10^5 m^3$	WATRES2

Appendix 8A.4. Other definitions for the model

Factor	*Definition*	*Unit*
x_{kjt}	Variables – numbers of the *j* type of farm activity in *k* district at *t*th year	
Value	Annual sale of agricultural products	1,000,000
LABOR *kt*	No. of agricultural laborers in *k* district at *t*th year	
RICELD *kt*	Paddy field in *k* district at *t*th year	10a
UPLAND *kt*	Upland field in *k* district at *t*th year	10a
OCHARD *kt*	Orchard in *k* district at *t*th year	10a
MILK *kt*	Dairy cattle in *k* district at *t*th year	head
MEAT *kt*	Beef cattle in *k* district at *t*th year	head
PIG *kt*	Pigs in *k* district at *t*th year	head
RICE *kt*	Rice in *k* district at *t*th year	10a
VEGETB *kt*	Vegetables in *k* district at *t*th year	10a
FLOWER *kt*	Flower plants in *k* district at *t*th year	10a
GRASS *kt*	Grass in *k* district at *t*th year	10a
FARM *kt*	No. of farm activities in *k* district at *t*th year	
WATERNN *t*	Water quality related to nitrogen at *t*th year	kg/year
WATERPP *t*	Water quality related to phosphorus at *t*th year	kg/year
WATERS *t*	Water resources at *t*th year	$10^5 m^3$

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CHAPTER 9

Hungarian Agriculture: Development Potential and Environment

C. Csáki, Z. Harnos, K. Rajkai, and I. Vályi

Abstract

Two comprehensive research projects were recently completed by the Hungarian Academy of Sciences on the development problems of the Hungarian food and agricultural sector. In these studies agroecological factors were stressed.

Using the models developed in these projects, results could be easily produced to answer questions raised within IIASA's Task 2 effort. Thus, information could be obtained about technologies that provide for a rational, sustainable utilization of land potentials. This chapter, therefore, gives only a brief outline of the methodology and offers an overview of the findings, with less detail with respect to the results published under the two original projects and more to those obtained in the IIASA Task 2 reruns. Finally, the most important policy-related conclusions are briefly reiterated.

The study supports the view that a substantial part of the ecologically available production potential is yet to be used, but at the same time draws attention to measures that seem to be indispensable if productivity is to be maintained or increased.

9.1. The Present State of Hungarian Agriculture

Agriculture traditionally plays an important role within the Hungarian national economy. The per capita value of agricultural production is higher in Hungary than in any other centrally planned European country. In addition to satisfying the demands of the population at a higher level of consumption, Hungarian agriculture is also a regular supplier of considerable quantities of produce for export. It is not surprising that the elaboration of agricultural policies, the analysis of future potentials in agriculture, and the study of options for utilizing these potentials has always been a crucial element of national planning.

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

9.1.1. The major characteristics of agricultural production

Despite a total increase in agricultural production, the percentage of agriculture in gross and net national production has decreased. (In 1983, agriculture contributed 19.2% to the total net national production of the country.) Between 1961 and 1965, total agricultural production increased at a rate of 1.4% annually, compared to the average rate of the preceding five years; in 1966–1970, the increase was 3%; in 1971–1975, 3.5%; in 1976–1980, growth occurred at a rate of 2.9%, while it was 3.6% in 1981–1983. According to data from the World Bank, Hungary ranked second after the Netherlands in the growth of per capita food production during the 22-year period of 1961 to 1983.

With a few exceptions, the production of major agricultural products has increased significantly (*Table 9.1*). Substantial results have been achieved, especially in the growth of wheat and corn production. Twenty years ago, an agricultural worker produced food for 5–6 persons; now he produces enough for 12–14 people at a much higher level of consumption (*Table 9.2*), 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 1983, approximately 23% of the total exports from Hungary were of agricultural origin, whereas the same type of products made up only 8% of the total value of imports.

The 1970s brought considerable changes to the technologies used in agricultural production. Highly mechanized crop production methods

Table 9.1. Main indicators of agricultural production in Hungary (Central Statistical Office, 1984).

Activity/Indicators[a]	*1938*	*1950*	*1960*	*1970*	*1980*	*1983*	*Average annual growth rate 1970–1983* (%)
Total gross output[b]	113	100	120	146	206	218	3.1
Plant cultivation	121	100	121	135	190	191	2.7
Livestock raising	101	100	118	162	230	255	3.6
National income[b]	106	100	102	98	114	116	1.3
Wheat	2688	2085	1768	2723	6077	5985	6.3
Corn	2662	1820	3543	4072	6673	6426	3.6
Sugar beets	969	1640	3370	2175	3941	3783	4.4
Fruit	310	587	737	1308	1451	1682	2.0
Grapes	495	611	491	743	837	812	0.7
Slaughter animals	751	839	1104	1360	2066	2335	4.3
Milk (million litres)	1525	1403	1899	1807	2470	2689	3.1
Eggs (million)	844	955	1848	3280	4384	4481	2.4

[a] Measured in 1000 tons, except where noted. [b] Index value.

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, feedlots, and dairy farms. Due to large-scale mechanization in Hungarian agriculture, the overall power capacity of machinery reached the 1000 W/ha level in 1978. Most of the operations in field crop production are fully mechanized and use 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 in the West.

Cooperative farms play a determining role in Hungarian agriculture (*Table 9.3*). 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 fulfill their obligations toward society, while the socialist state guarantees their independence in a legal framework, helping and controlling them in their activities. State enterprises and cooperatives possess equal rights, and their relationship is based upon mutual advantages and risks.

In Hungary, large-scale agricultural farming is integrated with 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 became a form of small-scale farming. Now this is indispensable in Hungarian agrarian development in general, and in providing the population with food and in utilizing the capabilities and

Table 9.2. Per capita consumption of food and nutrients (Central Statistical Office, 1984).

Product[a]	*1970*	*1975*	*1980*	*1984*
Metal total	60.4	71.2	77.0	77.6
Milk and dairy products[b]	109.6	126.0	180.0	185.0
Eggs (number)	247.0	274.0	320.0	328.0
Fats, total	27.7	29.1	29.1	32.7
Butter	2.1	1.7	2.0	2.4
Cooking oil, margarine	2.8	4.6	8.0	10.2
Flour	124.1	117.9	109.0	106.0
Rice	4.1	4.3	3.6	3.5
Potatoes	75.1	66.8	60.0	58.0
Sugar	33.5	39.4	36.0	35.0
Coffee (dkg)	164.5	261.4	300.0	280.0
Tea (dkg)	7.2	8.1	9.4	11.2
Wine (litre)	37.7	34.2	33.0	30.0
Beer (litre)	59.4	72.3	89.0	87.0
Spirits[c] (litre)	5.4	7.2	9.6	10.1
Tobacco	2.2	2.3	2.0	2.2

[a]Measured in kg, except where noted. [b]Excluding butter. [c]Converted into 50% proof spirit.

Table 9.3. Number and average size of Hungarian state farms and cooperative farms (Central Statistical Office, 1984).

	State farms			*Cooperative farms*		
Indicator	*1960*	*1976*	*1983*	*1960*	*1976*	*1983*
Number of farms	333	141	218	4507	1425	1302
Agricultural hectarage	2597	5826	7244	765	3120	4092
Value of fixed assets (MFt)	48	286	377	2	73	108
Employment (heads)	518	999	1150	212	420	510
Gross value of agricultural production (MFt)	27	115	317	6	41	91
Value added (MFt)	13	46	125	4	24	51

initiatives of the farmers in particular. Since that time, agrarian policy has considered household farming as an integrated 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. (About 30% of total agricultural output was produced by small-scale farms in 1983.) The main point is that socialist agricultural production relies on both small- and large-scale production and, though large-scale farms have the bigger share, small farms also play an indispensable role (Csáki, 1983a, b).

9.1.2. Natural conditions for Hungarian agriculture

The area of Hungary is 9303.6 kha, with the following land use structure in 1980:

Category	*kha*
Plowland	4734.7
Meadows and pastures	1294.2
Vineyards, orchards	306.2
Gardens	291.4
Forests	1610.3
Other (settlements, infrastructure, etc.)	1066.8

On the whole, 72.3% of the territory of Hungary is utilized by agricultural production. A significant part of nonagricultural areas has been afforested – this amounts to some 5000 kha over the past 35 years – bringing the share of forests in total to 18%. Continued afforestation seems to be justified on steep slopes and on low-quality plowlands and pastures. The process of industrialization and urbanization necessarily involves a decrease in the area under agricultural cultivation. The rate of this process must be slowed down, and the extraction of land from agriculture should be limited to the less valuable areas.

The fertility of the soils of Hungary can be characterized as follows:

(1) Of the arable area, 27.2% is of the high-fertility chernozem type, with rich humus content, and good water- and nutrient-holding capacity.
(2) The share of brown forest soils, often subject to acidification with unfavorable nutrient budget and physical characteristics, is 30%. These soils are in general of good or fair fertility.
(3) Meadow and alluvial soils, with medium nutrient and humus content, and good or fair productivity, represent 23%.
(4) The rest is in general of low fertility.

Agricultural use might impact unfavorably on soil fertility. Acidification of soils has emerged during the past decades , with one of its principal causes being the high fertilizer application. About one third of Hungary's arable area, namely, the hilly regions with strong relief, are endangered by erosion. On 25% of the arable area with sandy and silty soils of light mechanical composition, deflation (or wind-borne erosion) appears with its damage. Salinization occurs on a significant part of the Great Hungarian Plain.

Hence, a conflicting picture of soil conditions emerges in Hungary. On the one hand, we can establish that soils with high fertility have a favorable share, while on the other hand it appears that more than half of the arable area is endangered by detrimental processes. We also have to reckon with the ambitious plans, which envisage substantial increases in agricultural production. This, in general, means the intensification of technologies, which will eventually contribute to the aggravation of undesired processes.

There are also indications of unfavorable soil properties (*Figure 9.1*), showing that 46% of soils are of unfavorable water budget, 13% are strongly acidic, and on 16% serious erosion-borne damage limits fertility. A smaller proportion of these unfavorable properties are unreclaimable, or practically unchangeable, natural endowments. The rest, however, can be eliminated or at least alleviated by ameliorative interventions.

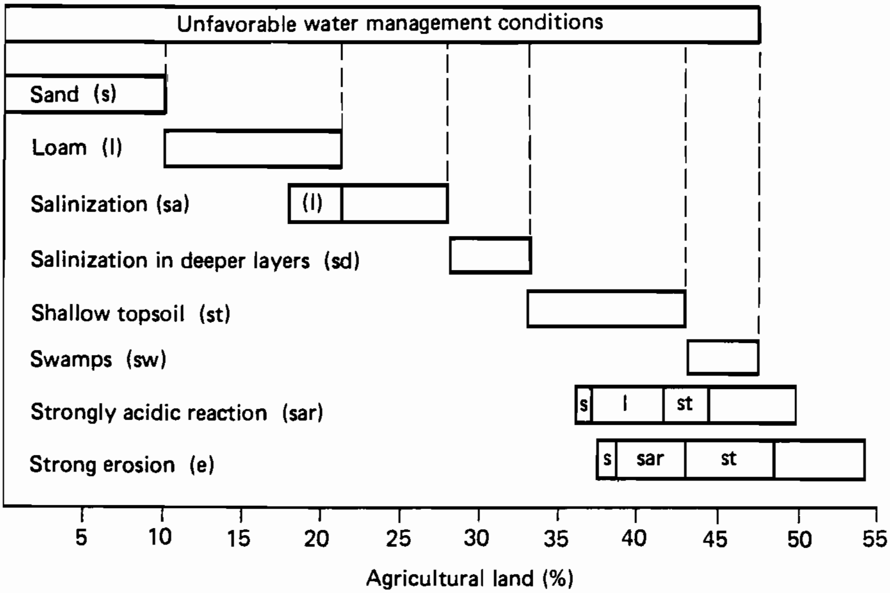

Figure 9.1. The distribution of unfavorable soil characteristics in Hungary.

Temperature conditions are, in general, favorable for the production of most crops cultivated in the temperate zone. The amount of solar radiation cannot be regarded as a limiting factor in substantially increasing biomass production. According to computations based on the amount of solar radiation that reaches the area of Hungary, and the share of energy that can be fixed by way of photosynthesis, the maximum possible production amounts to 30 ha in terms of dry weight. The present average is 7 ha. Even record yields are not higher than 15–16 t/ha.

The yearly average precipitation in the country is between 565 and 715 mm. The relatively warm climate involves increased evaporation losses.

According to agrometeorological estimates, only about half of the total precipitation is utilized in the course of life processes of the vegetation. Some 5% of this amount of water is additionally supplied to the plants in the form of irrigation. Hence, it is basically the natural precipitation that is utilized by Hungarian agriculture.

Climatic conditions are favorable for plant production, as is illustrated in the comparison of the climatic productivity of the country with respective data for others. If the climatic productivity of the European territory of the Soviet Union south of the 60th latitude is rated 100, the relative climatic productivity in the rest of the CMEA countries is as follows:

Poland	105
GDR	113
Czechoslovakia	118
Romania	126
Hungary	139
Bulgaria	145

Besides the favorable endowments, damaging phenomena that arise from the random nature of weather must also be mentioned. Yield is most endangered by drought and frost. For example, in corn production average drought losses exceeding 5% of the harvest can be expected in every fifth year. There are 3 drought years in every 15-year period, with an expected loss of 5–10%, 10–15%, and greater than 15% on one occasion. Production of maize is endangered also by early autumn frosts and excessive rainfall in the harvest period. It is grape and fruit production that is mainly affected by frost damage. These dangers can be decreased substantially by considering the ecological requirements of the individual crops.

9.2. Objectives and Scope of the Study

The objectives of the study include a whole range of problems, with the main emphasis laid on investigations of the impacts on:

(1) The level of production and production growth.
(2) Energy, especially energy requirements of nonagricultural support.
(3) The natural environment, especially agricultural production potentials.

As major objectives of the study, the following questions were investigated:

(1) How can the productivity and efficiency of Hungarian agriculture be increased by using more rational combinations of existing technological alternatives?

(2) What are the production potentials of the existing soil resources, and how can these be increased and utilized?
(3) How efficiently are existing biological resources being used?
(4) How efficient is energy transformation in Hungarian agriculture?
(5) What are the economic consequences of an environment-protection oriented agricultural development?
(6) Can increasing needs to protect the environment limit the growth of agricultural production?
(7) What possibilities do we have to introduce technologies based on the higher-level utilization of the potential of the original biological processes?

The scope of the whole study was extended over the entire vegetation of the country; however, our case study is related only to plant production in Hungary. More than 80% of the total plowland in Hungary is covered by the crops taken into consideration, which are as follows:

(1) Wheat.
(2) Winter and spring barley.
(3) Rye.
(4) Rice.
(5) Corn.
(6) Sugar beets.
(7) Potatoes.
(8) Sunflowers.
(9) Soybeans.
(10) Peas.
(11) Alfalfa.
(12) Red clover.

The study is based on the following agroecological parameters and geographic units:

(1) The territory of Hungary is divided into 35 agroecological regions (*Figure 9.2*) which, according to their climatic characteristics, can be regarded as homogeneous.
(2) From the point of view of soil fertility, 31 soil types are formed. For reasons of computability, these soil types are aggregated into five soil (productivity) categories. Model parameters and results are formulated in these terms (see Section 9A.1; for further details see Harnos, 1982; Harnos and Györffy, 1982). Their distribution within the regions led to a division of 205 habitat types.

Although the basic investigations were carried out on a soil type–region–crop basis, the whole country was covered in that way and conclusions are drawn on the national level as well.

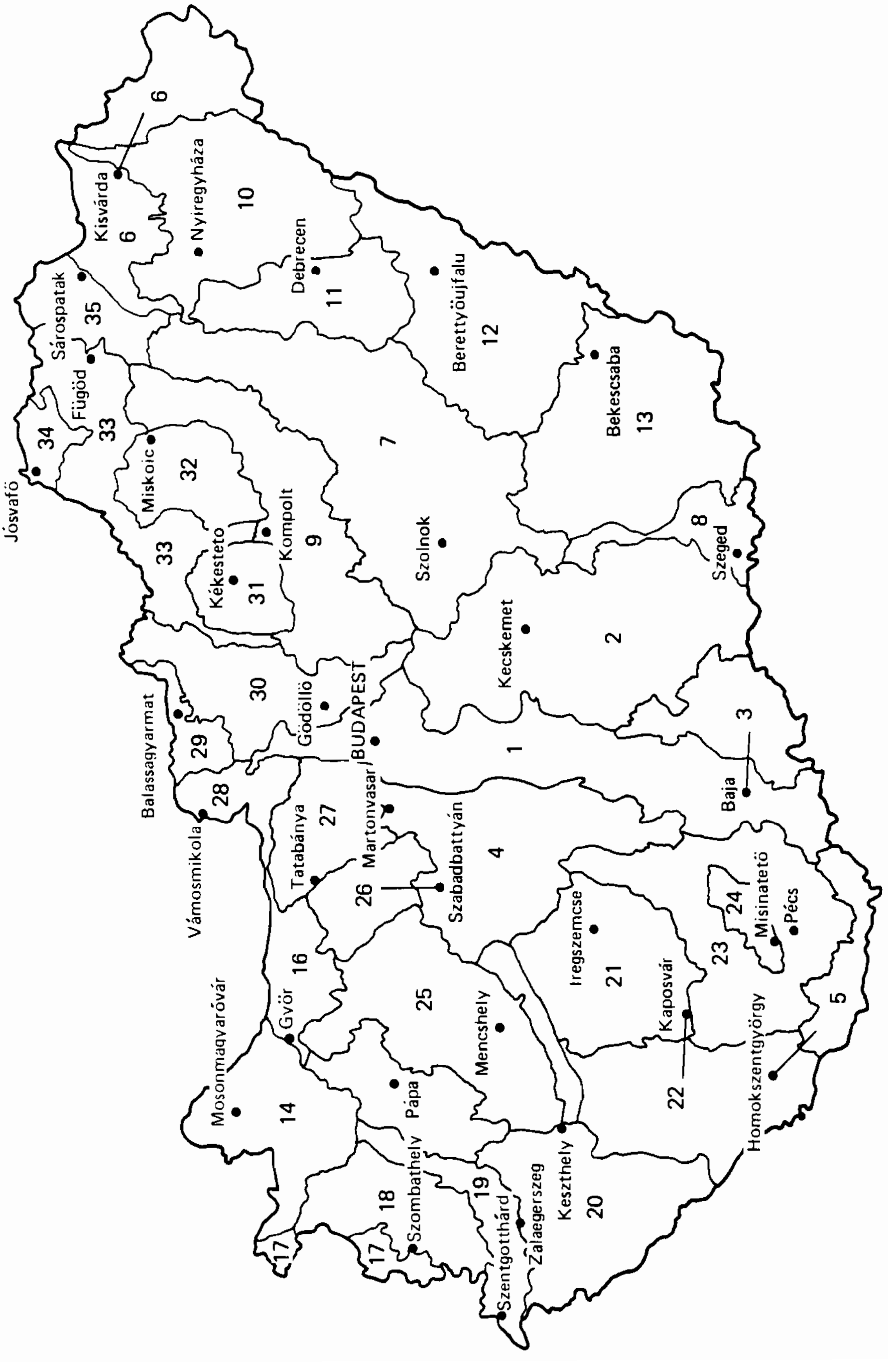

Figure 9.2. **The ecological regions of Hungary.**

9.3. The Methodology of the Study

The nature of the study requires an analysis of the processes of production, of land use, and of technological change over a long-term period, i.e., of about 20–25 years. Therefore, a two-level model system was elaborated in order to describe the major physical, biological, agrotechnical, and economic processes of Hungarian agriculture.

The modeling methodology, taken over from the two research projects by the Hungarian Academy of Sciences and its relationships to IIASA's conceptual framework, is described in Csáki *et al.* (1982).

The main goal of the model development is not merely optimization, but also 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. Use of the model might also allow for the calculation of optimal states of some of the subsystems. The overall methodology used by the model system is a simulation technique. The time horizon of the analysis is 20–30 years.

The model system consists of two submodels, with the first discussed here in more detail. For the second, we refer the reader to the already mentioned publications.

(1) The *plant soil* (PS) model is used to describe the major plant–soil–agrotechnology relationships.
(2) The *plant production* (PP) model is designed to integrate soil and crop-specific subsystems into a national plant production system and to draw conclusions, on a national level, on optimal resource allocation in land use and development.

9.3.1. Plant soil model

In describing the relationships between the plant and its environment, we sought the answer to the following questions:

(1) How will the output of plant production develop in the case of given soil quality and agricultural technology?
(2) How does the state of the habitat change as a consequence of the applied agricultural technology?

The separation of the questions is justified by the prevalence of "instantaneous" versus delayed effects, such as those of actual land quality and the agricultural technology applied on output versus those of the technology on land quality.

The PS model simulates the major interrelationships among plant growth, soil conditions, and agricultural technologies. Each run of the model is related to a given crop, on a given soil type, assuming the use of a given agrotechnology. The main relationships considered in the PS model are shown in *Figure 9.3*.

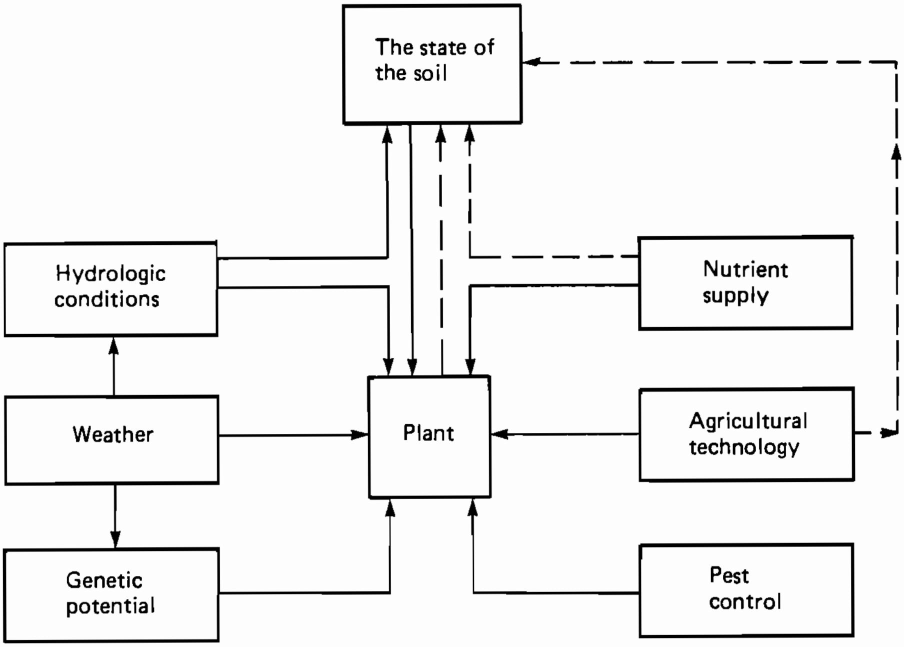

Figure 9.3. Major interrelationships in the plant–soil model. Solid arrows = effects on the production; broken arrows = effects on the habitat.

The PS model includes two major modules:

(1) Generation of yield.
(2) Modeling of impacts on habitat conditions.

Yield Generation

The formation of the yield is given in the PS model as a function of:

(1) Genetic potential.
(2) Habitat conditions.
(3) Applied agricultural technology.

Based on an extensive inquiry of the experts' opinion, a detailed data base of yield potentials was available from the Agroecological Survey project (Harnos, 1982; Harnos and Györffy, 1982).

As the long-term dynamics were investigated, the time factor also had to be taken into account, and the gap between the period covered by historical data and that covered by forecasts had to be filled. For the description of the effect of genetic progress on the average yields of the different field crops, we used the logistic function:

$$f(t;a_1,a_2,a_3,a_4) = a_1 + \frac{a_2 - a_1}{1 + \exp a_3(t - a_4)} \tag{9.1}$$

where a_1 is the level prior to the development period, a_2 is the level to be achieved after the development period, a_3 is proportional to the maximal growth rate, and a_4 is the point in time when maximal growth takes place. The graph of the function is shown in *Figure 9.4*.

Formally, this method is similar to that used for checking the consistency of the experts' estimates in the Agroecological Survey project. To illustrate the relevance of the logistic model in an international context, we quote here some of the numerical results of these consistency checks. The following terminology was used.

In the case of constrained development curves, the regression was based on data for the periods 1901–1977 and 2001–2010; in the latter period, the values used were those estimated by the experts. For the unconstrained development curves, only past statistical data, for the period 1901–1977, were used. To provide for a possibility of international comparison, we computed the unconstrained development curves for some countries with a developed agriculture (and found surprisingly good fits). For more of the background, see Vályi (1982) and Csáki *et al.* (1984).

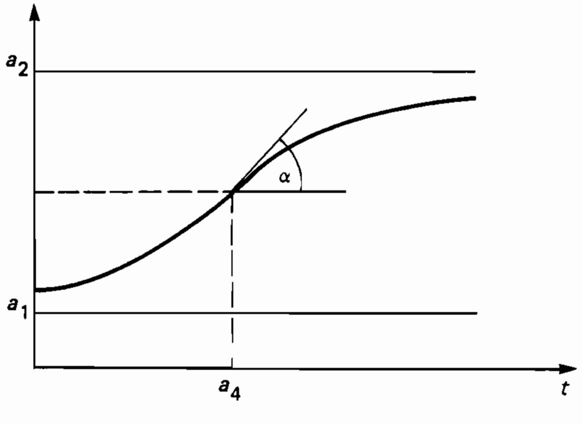

Figure 9.4. Logistic function used to describe genetic development.

Based on the distribution of the experts' opinion, three levels were determined: the pessimistic, average, and optimistic estimates. (The interval between the pessimistic and optimistic estimates contained about two-thirds of the opinions.)

In the case of wheat and maize, a remarkable coincidence of the experts' opinions and the unconstrained development curve could be observed, while in other cases, e.g., for the yield of sugar beets, even the "pessimists" forecast significantly higher yields than the logistic model. Some of the results can be seen in *Tables 9.4* and *9.5*, where the following additional notations are used:

F	is relative value of the yield in 1977, between the lower and upper levels of stagnation (%).
max ΔY	is growth of the yield in year a_4.
δ	is estimated variance around the development curve.

Table 9.4. Development curves for the yield of maize.

Type of constraint	F(%)	a_4	a_1	a_2	max ΔY	δ
Pessimistic	70	1971	1.56	5.82	0.13	0.36
Average	60	1974	1.54	6.79	0.15	0.36
Optimistic	50	1977	1.53	7.93	0.16	0.36
None	65	1974	1.56	6.34	0.14	0.36

Table 9.5. Development curves for the yield of wheat.

Type of constraint	F(%)	a_4	a_1	a_2	max ΔY	δ
Pessimistic	85	1970	1.26	4.45	0.14	0.22
Average	70	1973	1.25	5.26	0.17	0.22
Optimistic	60	1975	1.24	6.06	0.19	0.22
None	65	1974	1.25	5.61	0.17	0.22

Habitat conditions represent the second major factor to determine yields. The genetically possible yield can be obtained at habitats best suited to the crop, while actual yields are determined by the actual characteristics of the given habitat. Of these, the following are considered in the model:

(1) Soil characteristics.
(2) Meteorological effects.
(3) Hydrological conditions.

The productivity of the soil was determined on the basis of its state at present, which can be modified by the production technology. The state of the soil is expressed in terms of:

(1) The extent of erosion.
(2) The extent of compaction.
(3) The soil pH.
(4) The nutrient level of the soil.

These modifying effects on the yield are shown in *Figure 9.5*.

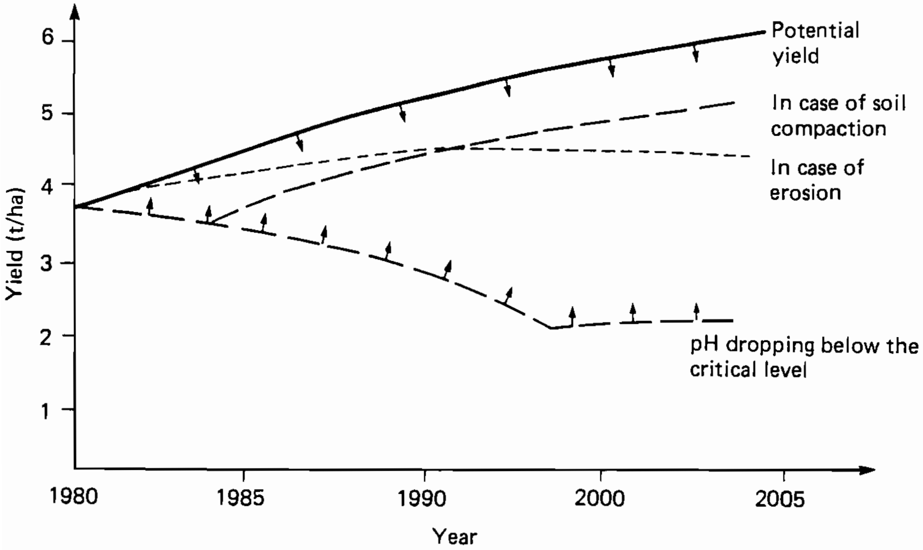

Figure 9.5. Impact of soil conditions on the utilization of genetical potentials. Arrows indicate the range of possible yield.

Weather is described by a random variable, its role in the model being mainly related to the natural water supply for the plant. Based on the observed meteorological parameters, climatic year types were developed, which we characterized by the expected amount of precipitation, its distribution, and the frequency of occurrence of the year type.

We assumed that the growth of the plant is mainly determined by the amount of available water. In a given period, this consists of:

(1) The precipitation.
(2) The water content of the soil that is available to the plant.
(3) The capillary supply of groundwater.
(4) The amount of irrigated water.

The value of these parameters is determined by natural conditions and production technology. These relationships were combined into a hydrological submodel.

Agricultural technology affects the growth of the plant by way of mechanical operations on the soil and by the nutrient supply. The selection of the mechanical operation is of special importance on slopes, being determinant for the extent of erosion. When computing the amount of nutrients available, we supposed that the specific nutrient content of the crop and nutrient requirements must be in a state of equilibrium. Nitrogen supply is determined by the humus content, while the supplies of potassium and phosphorus are a function of the amount stored.

Modeling Effects on Soil Conditions

The second major block in the PS model is devoted to the description of the effects of plant cultivation on soil characteristics. In our model, among the rather complex soil–agrotechnology interrelationships, six major environmental effects of agricultural production are considered, represented by six indicators. *Table 9.6* gives an overview of the environmental effects treated in the study. The data base for developing this model block included experimental data and the results of a field survey.

The treatment of the individual environmental effects is indicated under the following subheadings.

Erosion. About one third of the territory in Hungary is hilly. This fact involves the possibility of erosion. The relevant agrotechnical effects of erosion are: a decrease in the fertile layer of soils, nutrient loss, and accumulation of eroded material. A general consequence is the decrease of the agricultural territory and environmental pollution. The magnitude of erosion was computed or estimated for each soil type. Here, the erosion part of the CREAMS model system was tried with Hungarian data. In case of certain, rather regularly appearing misfits, experts' estimates were used as indicated in *Table 9.7*.

Acidification (decrease in pH). As an unfavorable environmental effect, the decrease of pH occurs as a consequence of agricultural activity. This acidification may occur on soils (especially when they have light texture) with a calcium carbonate level below 1% after the application of "acidifying" fertilizers such as ammonium sulfate, potassium sulfate, or superphosphate. According to the literature, acidification up to pH 5.5 is favorable for most plants. Generally, all plants suffer in situations where the pH value is less than 4.5–4.8, because in this range the release of toxic manganese and aluminate compounds can be observed – a process which leads to a reduction in yields. In the model, the pH sensitivity of plants was represented as shown in *Table 9.8*.

The sensitivity threshold is the given range of pH 4.8–4.5, depending on the actual soil phosphorus content. If the soil P content is very poor, the effect of pH appears at pH 4.8; and in case of higher soil P content (above medium level), at pH 4.5.

Table 9.6. Environmental processes: their causes and indicators, as represented in the model.

Variable	*Environmental effects*	*Causes*	*Indicators*
Depending on land site characteristics	Erosion	Relief	Depth of top soil
	Acidification	Noncalcareous sands	pH ranges
	Secondary salinization	Salinization potential	Critical ground-water level
Depending on agrotechnics applied	Degradation of the physical structure of the soil	Improper application of heavy machinery	Bulk density
	Disturbances in the soil nutrient balance	Inadequate nutrient supply	Nutrient levels

Table 9.7. Effects of erosion on soil productivity (expected yield, %).

		Erosion categories[a]			
Plant	*Soil*	*None*	*Medium*	*Strong*	*Reference*
Winter wheat	Chernozem	100	76	59	Duck (1969)
	Forest soil	100	86	64	
Barley	Chernozem	100	81	67	
	Forest soil	100	78	60	
Maize	Chernozem	100	72	44	
	Forest soil	100	76	46	
Winter wheat	Chernozem	100	91	62	Duck and Máté (1973)
Barley	Chernozem	100	77	63	
Average values	Degr. chernozem	100	70	50	Sobolev (1973)
	Chernozem	100	50	20	
	Chestnut soil	100	60	30	
Barley	Chernozem	100	79	–	Skhorodumov (1970)
Pea	Chernozem	100	68	43	
Maize	Chernozem	100	78	63	
Barley	Forest soil	100	50	–	Pusztai and Kudeiarov (1973)
Barley	Forest soil	100	40	22	

[a] Erosion categories (in terms of % of topsoil lost): none, 0%; medium, 60%; strong, 70%.

On about a quarter of the total agricultural area of Hungary, the natural conditions allow for lowering the pH by way of inappropriate fertilizer application. We have to note that the acidification of these territories due to fertilization can be compensated for by adding a suitable quantity of

Table 9.8. The pH sensitivity of plants.

Level	*Plant*	*Reduction of yield*
Nonsensitive	Potato, rye	None
Moderately sensitive	Corn, wheat, grass	About 25%
Highly sensitive	Sugar beet, sunflower, barley, alfalfa	More than 50%

lime. In considering the effects of liming, we used data from Sarkadi (1975).

Salinization. The Great Hungarian Plain has a negative water balance. This property, together with its basic characteristics and geological composition, are conducive to salinization and alkalinization processes.

A map of this area was constructed for irrigation planning purposes at the scale of 1:100 000 at the Research Institute for Soil Science and Agricultural Chemistry. Four soil categories are distinguished on the map:

(1) Freely irrigable territories.
(2) Conditionally irrigable territories.
(3) Nonirrigable territories:
    (a) Because of secondary salinization.
    (b) Because of secondary peat formation.
(4) Hilly areas.

Secondary salinization, alkalinization, and peat formation may occur as direct consequences of irrigation. There is a possibility of predicting these unfavorable processes, based on the notion of critical groundwater depth. The principles for the construction of this map can be found in Szabolcs *et al.* (1969). Critical groundwater depths are summarized in *Tables A9.1* and *A9.2* of the *Appendix*. These depend on the salt content of the groundwater, the average salt content of the soil profile, and on soil water management categories (see *Table A9.3*). The critical groundwater depth refers to salt balance in the soil profile, which extends from the surface to the groundwater level. Using the irrigability map for the ecological regions, the necessary information for our model about the conditions could be derived.

Degradation of soil structure. It is well known that during intensive agricultural activity, different changes occur in the soil structure (the ratio of microaggregates to macroaggregates increases, etc.). A serious problem is the compaction of the soil, a consequence of using heavy machinery on plowed land if the soil moisture state is close to field capacity or above. In this case the compaction can be so excessive (bulk density reaching 1.8 g/cm^3) that amelioration is required to avoid decreases in the yield. These degradation procedures are independent of soil type. Their occurrence is a function of climatic conditions and the applied agrotechnics only.

Relationships between yield and applied agrotechnics. The basic assumption is that the appropriate yield–fertilizer doses are dependent on the soil properties or, more precisely, on the actual nutrient state. In order to formulate this function of three variables, the yield has to be planned for a certain fertilizer quantity and soil nutrient state. The function is given in the form of multiplicative factors for three crops in *Tables A9.4*, *A9.5*, and *A9.6*. By multiplying the planned yield value with these factors, we obtain the necessary quantity of fertilizers. Here only one parameter is necessary, namely, the actual value of soil nutrient state. This value was obtained from the information system of the Hungarian Ministry for Agriculture and Food.

The above procedure is modified in some of the calculations, bearing in mind the long-term effects of fertilizers. These are dependent on the type of fertilizers used:

(1) Nitrogen (N): if for some reason in a given year the planned yield is not achieved, then about 50% of the unused nitrogen remains in the soil and is available for the next crop.
(2) Phosphorus (P) and potassium (K): here the model uses the assumption that phosphorus and potassium are fixed in the soil and serve as a nutrient pool for the plants over the whole time horizon of the model. The actual available amount of P and K is determined from the amount fixed in the soil, through a function fitted to experimental data.

Organic matter content of the soil. To follow the development of organic matter content of the soil, in addition to the losses caused by erosion, natural decay had also to be considered. Assessment of current status and estimation of rates of change were carried out using questionnaires.

9.3.2. National plant production model

The second submodel of the model system describes the national plant production system. The results of the PS model are used as inputs for setting the variables in the plant production model. This model is focused on the dynamic interrelationships between the state and transition of production and habitat on the national level. While the economic background of the Hungarian agriculture is described by the Hungarian Agricultural Model (HAM; see Csáki, 1981), in selecting the mathematical model to describe ecological relationships, the following viewpoints had a determinant role:

(1) Changing the behavior of the system is possible over a longer period only, a fact explained partly by the inertia of the system and partly by the limited nature of the resource. Changes in the state of the soil are a function of agricultural technology and amelioration. The effects

of these are delayed and prevail, normally, over longer periods. These observations justify the need for studying the system's dynamics and for analyzing the production of different periods in their interrelation and not separately.

(2) The operation of the plant production system is influenced, among a number of other factors, by the productivity of the soil and the level of nutrient supply. The benefits of investments enhancing the productivity of the soil – such as amelioration, the construction of irrigation works – come into effect over long periods, and the recovery of costs is a relatively slow process. On the other hand, nutrient inputs directly influence the level of production. Nutrient supply and ameliorative investments are controlled by the allocation of financial resources. The system is described as a control problem, with the allocation of resources playing the role of control. To explain the structure of the system, we shall use the terminology of this modeling technique.

The cultivation branches within plant production were divided into two groups:

(1) Field crop production and grassland management.
(2) Fruit and grape production.

This grouping is justified by the fact that field crops and grasslands occupy some 6 million hectares in Hungary. The product structure and the inputs within these cultivation branches can be changed in a relatively flexible way. The area required by orchards and vineyards changes very slowly due to their plantation character. Here, no expansion of area was considered, and possibilities for a quantitative increase of production can be foreseen with a large degree of certainty.

In describing plant production during one period, the effects of the following were accounted for in the PP model:

(1) The conditions of the habitat.
(2) Economic conditions.
(3) The level of nutrient supply.
(4) The yields.
(5) The constraints on the sowing structure.
(6) The constraints on the product mix.

State variables of the system represent the habitat conditions of plant production (area available for cultivation and its composition according to soil fertility).

In describing qualitative and quantitative changes in the arable area, the effects of the following were considered:

(1) Decreasing area.
(2) Natural conditions.
(3) Investments (economic conditions).
(4) The applied agricultural technology.

The changes of state variables were controlled by the amount and allocation of resources as controlling conditions.

The model describes the utilization of resources in two ways:

(1) Ameliorative investments and construction of irrigation works, resulting in increased productivity.
(2) Providing for nutrient supply and technology, improving the conditions of production in the given period.

This type of linking of factors that influence the productivity level in the short and the long run, made it possible to study issues such as:

(1) Whether it is expedient to strive for achieving outstanding yields in the short term, considering the eventual necessity to compensate for deteriorating soil fertility by additional investments in the future, if possible at all.
(2) In caring for the future, resources should be divided in such a way that the conservation or even improvement of productivity is stressed, paying out in the form of a gradual increase of yields in the future.

Static or recursive optimization models always seek to achieve local optima, meaning, in the case of the present model, that resources have to be devoted entirely to achieving the production goals of the current period. The answer over the long run is not equivocal, especially when taking into consideration the fact that a significant proportion of Hungarian plowland needs amelioration. Such measures, in turn, might substantially boost plant production.

The dynamic relationships between the state of the habitat, investments, and land use are represented in *Figures 9.6* and *9.7*. The parameters and constraints influencing the production of individual periods in the plant production model are:

(1) The yields, with their development as determined by the PS model.
(2) The nutrient supply of crops, provided in the following possible ways: the application of chemical fertilizers, manure, plant residues, and other organic materials; and nutrient flow from the air and soil. These nutrient sources have different roles in the model:
    (a) The amount of chemical fertilizer is constrained by the available inputs during the given period.

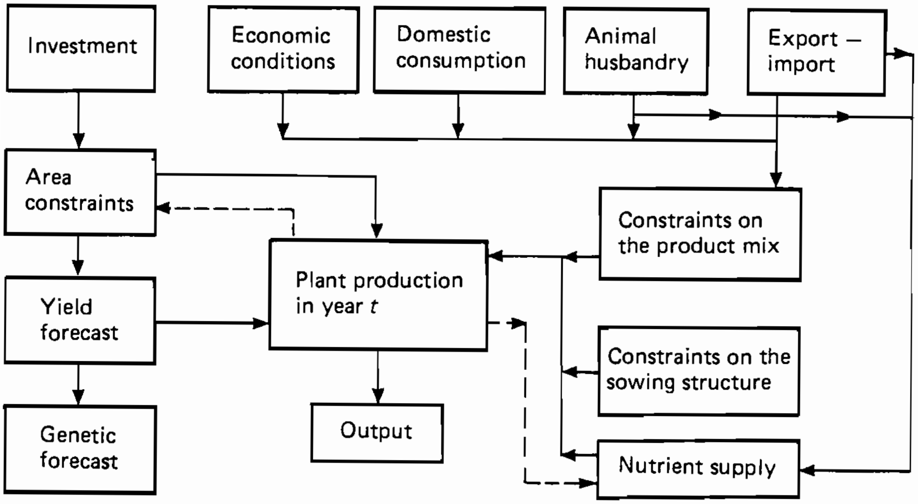

Figure 9.6. Conditions of plant production.

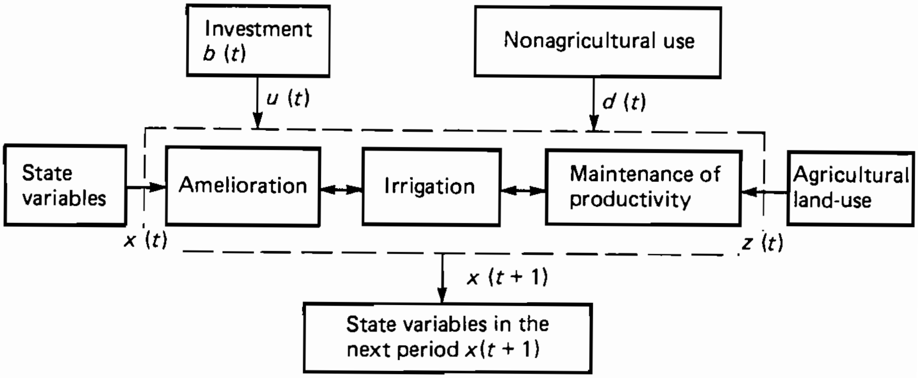

Figure 9.7. The dynamic relationships between agricultural land use and the state of the habitat. $Bu(t) = b(t)$ and $x(t+1) = Dx(t) + Ez(t) + Cu(t) - d(t)$, $t = 1,2,\ldots,T$ where $x(t)$ is state variable, $u(t)$ is control variable (investment), $z(t)$ is sowing structure, and $d(t)$ is extraction of land from agricultural use.

(b) The use of organic materials for fertilization decreases the need for chemical fertilizers and, at the same time, hinders the processes that lead to the deterioration of soil fertility, related to later requirements for ameliorative investments.

(3) Proportions and limitations in the cultivation area of the individual crops, or group of crops, representing biological or environmental considerations. Product mix is mainly controlled by:

   (a) Domestic consumption.
   (b) Fodder requirements of animal husbandry.
   (c) Processing capacity of the food industry.
   (d) Plant-based raw material needs of the different industrial sectors.
   (e) Export/import options.

(4) Economic conditions, i.e., the allocation of available resources and their role as a control in the model. The resources can be devoted to ameliorative investments, construction of irrigation works, and investment in technology.

From the exposition of the subject, it is clearly seen that the process of plant production is a ramifying, complex system that also contains stochastic elements such as the weather, and nonlinear relationships such as those between soil, nutrient supply, and the crop. The exact description of some of the interrelationships is not solved even at the theoretical level. For these reasons, and for the sake of constructing an operational model, extensive simplifications had to be made. Of these, we should like to point out two:

(1) Problems arising from the scale were solved by way of aggregation.
(2) Nonlinear relationships were approximated by linear ones.

In the end, a large-scale linear model was developed as a framework for the national level investigations (discussed in more detail in Harnes, 1981; Csáki *et al.*, 1982), which can be formulated analytically as follows:

(1) Control conditions:

$$B\underline{u}_N(t) \le \underline{u}_N^0(t)$$

$$\underline{u}_N(t) \ge 0$$

(2) State equation:

$$\underline{x}_N(t+1) = D \cdot \underline{x}_N(t) + E \cdot \underline{z}_N(t) + C \cdot \underline{u}_N(t) - \underline{d}(t)$$

$$\underline{x}_N(t_0) = \underline{x}_N^0$$

where $\underline{x}(t)$ is composition of land area according to quality classes, $\underline{z}(t)$ is actual sowing structure, implicitly including nutrient levels and the agrotechnology applied, E is the effect of the applied agrotechnology on the land, C is qualitative changes due to amelioration, and $\underline{d}(t)$ is decrease of agricultural area.

(3) Equations that describe the functioning of the system:

$\underline{x}_N(t) = F \cdot \underline{z}_N(t)$ (utilization of the available area)

$A \cdot \underline{z}_N(t) \leq \underline{b}(t)$ (sowing structure)

$\underline{H}_N(\underline{z}_N(t), y_N(t), \underline{u}_N(t), \underline{s}(t)) \leq 0$ (relationship between nutrient supply and product mix)

Nutrient supply includes the utilization of organic matter of different origins and chemical fertilizers. The output of the system (i.e., the product mix) is computed from the sowing structure and average yields, according to the equation:

$$\underline{y}_N(t) = G(t) \cdot \underline{z}_N(t)$$

constrained by the inequalities

$$\underline{y}_N^0(t) \leq \underline{y}_N(t) \leq \underline{y}_N^1(t) .$$

The product mix $\underline{y}_N$ is controlled by the factors listed above in conjunction with *Figures 9.6* and *9.7*.

The matrix $G(t)$ represents the development of yields. Its entries were determined on the basis of the forecasts and development curves that had been elaborated in the Agricultural Survey project. These values depend on the type of habitat and the level of nutrient supply.

The meaning of the individual groups of conditions is as follows. Production site conditions for plant production are represented by the state variables of the system, i.e., the area of available land together with its composition according to productivity classes.

When describing the qualitative and quantitative changes of the land, the following factors were considered:

(1) Decrease of agricultural area.
(2) The natural conditions.
(3) Investments (economic conditions).
(4) The applied agrotechnology.

Changes of the state of the system were controlled by means of the distribution of resources. Resource use can be divided into two groups:

(1) Ameliorative investments and the construction of irrigation works, improving productivity.

(2) Nutrient supply and technology, improving the conditions of production in the given period.

9.4. Potentials and Limits in the Use of Hungarian Land Resources

A great number of calculations have been completed, both by using the whole model system and by using its two major components. The detailed discussion of the results exceeds the scope of this study; for reference, see Csáki *et al.*, (1984) and Hungarian Academy of Sciences (1985). Here, we present only the main conclusions regarding production potentials, energy transformation, and the environmental limits on further growth.

From results concerning production potentials, we present some conclusions on yields as well as spatial allocation of field crops.

9.4.1. Yield potentials

By using the methodology described in the previous section, projections have been made for all the major crops. Some of the conclusions are as follows.

Cereals

According to the study, a period of substantial growth could be expected for the production of cereals. On average, during the period 1979–1981, 12.8 Mt of cereals were harvested in Hungary. By the end of the century, a growth in cereal production to 20–22 Mt seems feasible:

(1) The production of corn represents the largest volume. The present annual production is 7–8 Mt. Among the CMEA countries, Hungary occupies a distinguished position with a share of 23% percent. According to the study, by the year 2000 a national average yield of 7.5 t/ha can be attained.
(2) Wheat is less sensitive to the changes of ecological conditions than corn. Yield differences between the individual regions are considerably smaller. The highest wheat yield up to now is 4.76 t/ha (1980). By the turn of the century, a national average of 6.1 t/ha seems to be attainable.

Legumes

These crops may significantly contribute to the protein balance of the animal husbandry sector.

(1) Peas are currently produced over roughly 50 kha, with yields in the range of 2.3–2.5 t/ha. The study indicates that they may reach the level of 3.6 t/ha by the end of the century.

(2) Soybeans play a key role in world plant production, and in pig and poultry farming. Hungarian soybean production has a history of alternating successes and failures. Sowing area is around 20 kha and yields are in the range of 1.4–1.8 t/ha, namely, around the break-even level. The prognoses foresee an increase to 2.6–3.0 ha yield by the end of the century.

Industrial Crops

The production of sugar beets is necessary only to the extent required by internal demand because in the CMEA countries to the north of us, with a cooler and wetter climate, the crop is cultivated with substantially higher productivity. Domestic yield averages are around 30–34 tons/ha. The projections state that for the year 2000, 45 t/ha is a realistic target. Sugar beets show an especially good response to favorable physical and chemical conditions in the soil. On irrigated fields, even a 57 t/ha yield can be attained.

The cropping area of sunflowers is on the increase. Demand for vegetable oils is rising on both the international and the domestic markets. Hungary has favorable natural conditions for producing sunflowers. Highest yields so far are 1.8–1.9 t/ha. By the end of the century the national average on ameliorated areas may rise to 3.3 t/ha.

Meadows and pastures

Of the 1290 kha of grassland in the country, 600 kha can be transformed into intensively managed grassland by way of hydromelioration, fertilizer application, irrigation, and other modern technologies, so that even before the end of the century the present hay yields can be doubled. The rest is to be handled as unconditional grassland where no significant production increase is expected as a result of intensification, but hay yields can be doubled even here through rational management practices. The study also shows that the increased harvest obtainable in this way can only be utilized by an increased stock of ruminants. The larger production of the intensive grasslands provides the possibility of decreasing the plowland area used for producing fodder. Low-productivity grasslands play a significant role in the protection of the environment, and should therefore be maintained and cared for. The rest can be used for afforestation and supporting wildlife.

Fruit production

The territory of Hungary is suitable for the cultivation of every fruit species of the temperate zone. Requirements of the national economy at the turn of the century can be met by the production of 2.2 Mt of fruit.

Relative to the present yields in the large-scale plantations, the yield of apples can be increased by 50–80% and that of the other fruits by 100–150%. The precondition for achieving this goal is that 95–110 kha of orchards need to be planted, and existing ones reconstructed. This area may be expediently shared between a smaller number of specialized enterprises, according to the habitat requirements and the ecological endowments. The climatic conditions of the country require the substantial extension of the area of irrigated orchards.

Vine Growing

Ecological conditions in our traditional vine-producing regions are favorable for the production of grapes for table wines of special or good quality, rich in bouquet. Extreme weather conditions such as winter or spring and early autumn frosts, however, may endanger safe production. The present, in international comparison rather low, average national yield of 4–5 t/ha can be doubled by the turn of the century if:

(1) Some 130–140 kha of vineyards, capable of produce 1–1.2 Mt of grapes, are planted in protected slopes of favorable microclimate in hilly areas, providing for greater production security.
(2) The rate of planting is increased during the coming 15 years in order to develop an optimal age structure.

9.4.2. Spatial allocation potentials

Our calculations show that the output of the plant production sector may reach a 40–50% higher level than in the late 1970s. The rate of growth, however, depends on a number of different economic conditions, of which the following are a few considered in the study:

(1) The choice of an ecologically based sowing structure.
(2) The conservation of soil productivity by applying ameliorative agricultural technologies and additional ameliorative investments.
(3) The expansion of the share of irrigated areas.
(4) The insurance of a sufficient nutrient supply, the spreading of modern agricultural technologies.

According to presently accepted conceptions, a 50% increase in overall plant production is envisaged. The growth potential does, however, vary from crop to crop. In some areas, no growth is planned because the aim is only to meet domestic demand, which has already been reached. There are other commodities, such as protein feeds, where output may multiply relative to the present level. The greatest increase in volume is expected in grain production (including corn). An annual 19–20 Mt of total production seems to be a realistic target around the turn of the century. According to the computations, by using a sowing structure that is optimally suited to ecological conditions:

(1) The productivity of plant production can be boosted by 10–15%.
(2) The risk of deficiencies due to random weather effects can be substantially reduced.

Figures 9.8 and *9.9* indicate the cultivation areas of maize and cereals according to one computation variant. From a comparison of the figures, it is clear that the cultivation areas of the two crops are strictly separated, caused mainly by climatic effects.

The extent of the risk due to the variability of weather in the case of the optimal sowing structure is, according to the calculations:

Cereals (wheat + barley)	5-7%
Maize	10-15%
Sugar beets	13-18%
Sunflowers	10-20%
Alfalfa	21-23%

These figures are substantially lower than those experienced up to the present, indicating another beneficial effect of adapting a sowing structure that is better suited to ecological conditions.

The effects of amelioration were investigated according to three aspects:

(1) The relationships between amelioration and sowing structure.
(2) The relationships between the extent of amelioration and total production.
(3) The time order and location of ameliorative interventions under fixed levels of total investment.

Ameliorative investments have a major influence on the total volume of production. In the case of maximal ameliorative efforts, a production surplus of 10% can be achieved relative to the analogous variant without amelioration. This increase in terms of grain production corresponds to more than 3 Mt annually. The total amount of resources that can be devoted to ameliorative investments was set to different levels, and on this basis the individual investments were selected by the model according to their efficiency. From the resulting consecutive ameliorative levels, the curve of diminishing returns, in terms of production increase, is estimated. It needs to be pointed out that, according to the calculations, it seems to be more expedient to carry out ameliorative interventions in areas of higher base productivity than in those of lower productivity.

The following comparison of computation results is to illustrate the significance of amelioration. The two variants use identical bounds on the production of field crops (4.61 Mha).

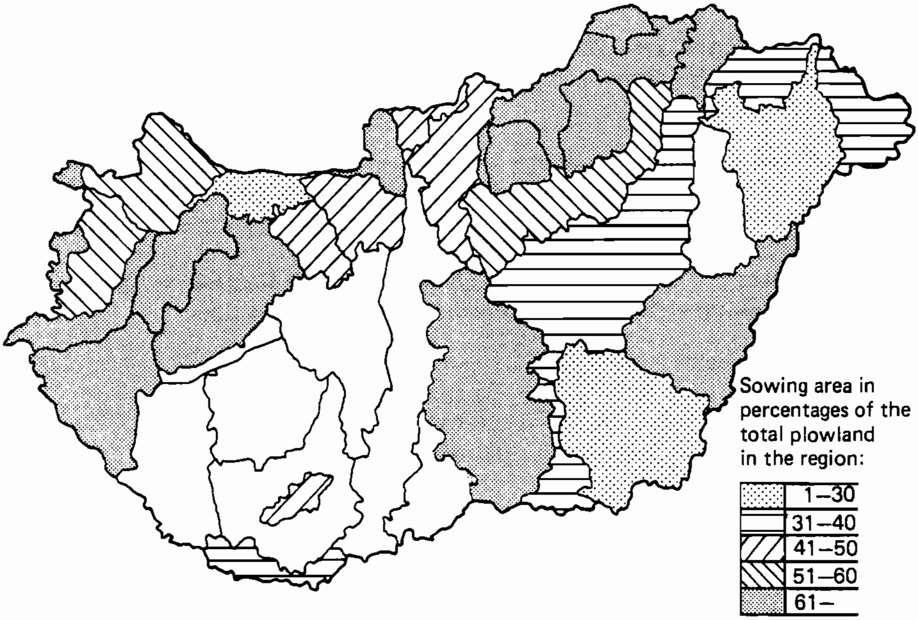

Figure 9.8. Computed sowing area of cereals.

The first version is based on supposing that 300 kha are ameliorated in each five-year period, and that the productivity of the rest does not change. The second version does not account for changes in productivity. The difference, in terms of grain production, is shown in *Table 9.9*.

The amelioration of 300 kha of land costs about 4.5–5 billion Hungarian Forints in each five-year period, but this means, of course, higher yields. According to the computations, if the amelioration is not carried out, the volume of grain produced around the year 2000 will have decreased by about 1 Mt, and the difference already exceeds 0.5 Mt by 1990.

The price of grain at present is 3-4 thousand Hungarian Forints per ton, i.e., by amelioration an additional income of 3–4 billion Hungarian Forints can be achieved each year.

Table 9.9. Grain production (in kt).

Year	*First version*	*Second version*	*Difference*
1990	18008	17473	535
2000	19930	18978	952

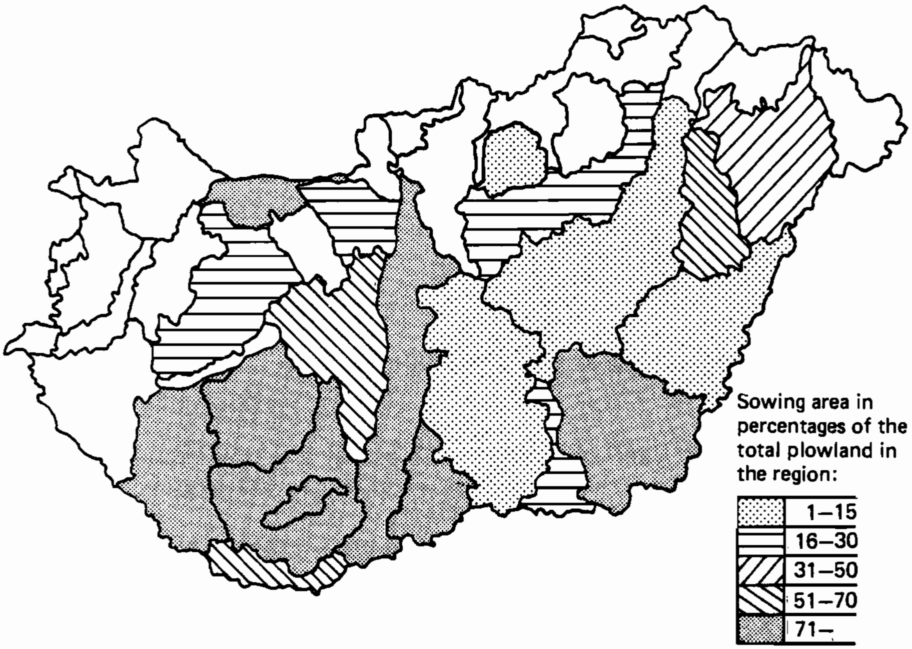

Figure 9.9. Computed sowing area of maize.

Nutrient supply

Two questions were considered in connection with the nutrient supply:

(1) What is the role of the different nutrient sources in the total nutrient supply?
(2) How are the sowing structure and product mix related to nutrient input quantities?

Nutrients are available for the crops from the following sources:

(1) Chemical fertilizers.
(2) Manure.
(3) Plant residues.

(4) Nitrogen-fixation by phaseolus crops.
(5) Precipitation and air.

According to our calculations, the percentage shares of the N, P, and K sources in 1980 were as given in *Table 9.10*.

Table 9.10. Sources (in %) of nitrogen, phosphorus, and potassium in 1980.

Nutrient	*Fertilizers*	*Manure*	*Residues*	*N-fixation*	*Air*
Nitrogen	66	9	13	5	7
Phosphorus	74	11	15	–	–
Potassium	69	12	27%	–	–

Based on these figures, one is led to three main conclusions regarding future plans and actions:

(1) Sources other than chemical fertilizers play a significant role, with their combined shares ranging between 26 and 34%, depending on the type of nutrient.
(2) The application of manure not only results in saving chemical fertilizers, but also increases the organic matter content of the soil, thus affecting the soil's structure, water-holding capacity, etc., slowing down acidification processes, and contributing to a large extent to the supply of soil microelements.
(3) While planning the nutrient balance, the consideration of materials other than chemical fertilizers constitutes a part of environmentally beneficial agrotechnologies, by reducing such processes as nutrient leaching and nitrification of subsurface and surface waters.

The following could be established about the relationship between nutrient supply and sowing structure. An eventual reduction of N-fertilization by 15% involves a decrease in yields, changes in the sowing structure, and also a lower demand for phosphorus and potassium fertilizers (by 10–15%). The increase of the share of phaseolus crops can be observed in this case, with the wheat:corn ratio significantly modified in favor of wheat. In the runs without limitation on N-fertilizer inputs, this ratio was 40:60, while it was 52:48 in a constrained variant.

9.4.3. Material and energy flows in Hungarian agriculture

We now turn to the exposition of those findings of the biomass study that we found relevant in the context of the case study. Biomass production is basically determined by plant production, constituting a precondition for animal husbandry (secondary biomass), and these two together meet the needs of the population, the food processing industry, and other consumers, as well as serving as a raw material resource for the production of tertiary biomass. These material flows are discussed here under Hungarian circumstances, as reflected by the extensive survey of the situation in 1980, carried out by the Central Statistical Office (1983).

Material Flows

We speak of biomass as a renewable natural resource. The transformation and utilization processes, complemented with that of renewal, constitute a material cycle. The material cycle consists of the movement of the biomass produced in the process of renewal. Biomass is constituted mainly of carbonic compounds, and therefore is an energy carrier. For this reason, the cycle of materials and energy will be used in representing the biomass cycle. We shall concentrate our attention on agricultural biomass excluding forests.

Dry matter cycle

The utilization of *primary biomass* is determined quantitatively by two items:

(1) Nearly two-thirds of main products, or 34% of the total agricultural plant production, is used as fodder.
(2) Litter represents an additional amount of 3.5%.

These two constitute the inputs to animal husbandry. Nearly 35% of the total biomass, or up to 43% if stalks and roots are added (i.e., nearly 80% of by-products), remains on the field, and even in the best case only participates in the restoration of the nutrient content of the soil. These two items point out the decisive importance, from the point of view of biomass utilization, of the efficiency of fodder conversion and the implementation of a rational, complex utilization of by-products and wastes. The remaining part of primary biomass exits the cycle. Nearly half (8.2% of the total) was used in 1980 to build up stocks and for exports. Almost the same amount was used as fodder. A minor share of the last returns to the cycle in the form of communal waste.

The production of *secondary biomass* can be identified with animal husbandry. The significance of this sector arises both from its role of a producer and that of a transformer.

From the amount of fodder used by animal husbandry, it can be established that transformation efficiency is relatively low. Not more than 5.4 Mt of secondary biomass are produced in the sector from fodder, with a dry matter content of 16.4 Mt, i.e., the input–output ratio is roughly 3:1.

This ratio further deteriorates to 11:1 if only useful production is considered. More than 80% of the main products of animal husbandry serves directly, or indirectly, the goals of feeding people in the country or exports. Only 10% is fed to animals contributing to the production of secondary biomass. The rest leaves the process of biomass utilization in the form of waste. Stable manure participates in supplying the soil with nutrients, therefore its utilization is settled. In addition to stable manure, 40–50 M m^3 of sewage sludge is produced, with a dry matter content of 1–2 Mt. Practically the whole of this huge amount does nothing else but pollute the environment, also decreasing the capacity for renewal of the biomass resource.

Energy cycle

In many cases the process of biomass production and utilization is analyzed as an energy resource, with efficiency characterized by various indicators. Knowing the energy balance of the biomass system is especially important in regarding biomass as an energy source, as has occurred in a number of countries of the world in recent years.

The total amount of biomass produced in 1980 in Hungary was 53.6 Mt tons. In terms of energy content, this amount is equivalent to:

Main products of plants	412.7 PJ
By-products of plants	369.3 PJ
Forestry	160.0 PJ
Total	941.0 PJ

The order of magnitude is illustrated by a comparison of the source side of the national energy system, amounting to 332 PJ.

Of course, in Hungary the production of biomass cannot be considered as an energy-producing sector at this time. No more than 4.5% of the energy content of primary biomass was used as a source of energy. This figure is even lower than 2% in the case of plant production.

From the point of view of energy balance, agriculture has a determinant role. The energy balance of Hungarian agriculture is shown in *Figure 9.10*. The system, as a consumer, used a total of 182 PJ fossil energy, and mainly imported concentrated proteins equal to 20.7 PJ of energy. The main items of energy consumption were: industrial nitrogen fertilizer, 43.2 PJ; fuel for the machinery and drying, 39.3 PJ; transportation outside the production site, 16.1 PJ; food industry (milling and sugar industry in the first place), 36.9 PJ.

The ratio of the energy equivalent of the potentially utilizable primary biomass as an output, and fossil energy use as an input, is 782 PJ / 182 PJ = 4.3. This figure shows that agriculture, relying on the external energy source provided by solar radiation, has a favorably high energy conversion efficiency.

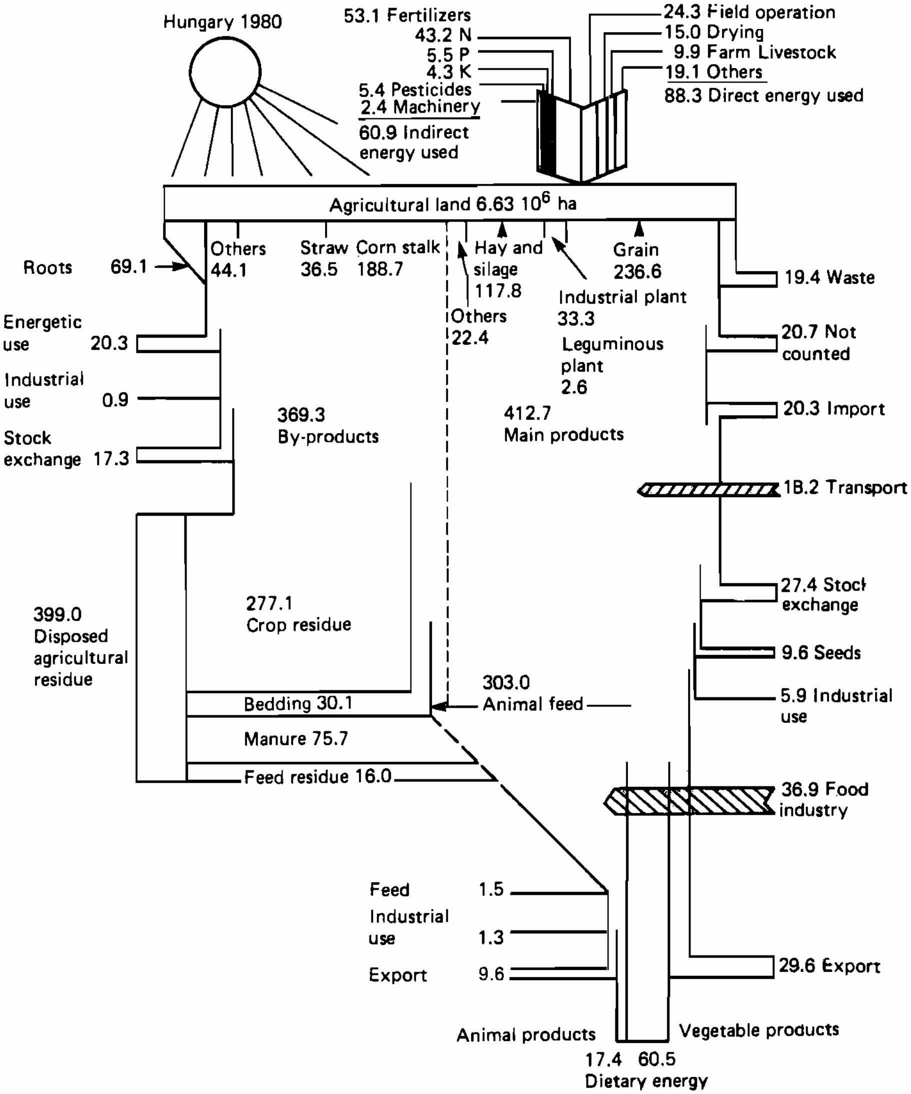

Figure 9.10. **Energy flow in Hungarian agriculture (all values given in 10^{15} joules).**

From the primary biomass of 782 PJ that can potentially be devoted to the production of food, a total of 117 PJ of "food energy" was produced in 1980, after transformation.

The ratio between the production of food energy and of primary biomass requirement is 117 PJ / 782 PJ = 0.15, an unfavorably low figure that can be attributed to the high losses suffered during the transformation process. The main sources of loss are:

(1) From the 369.3 PJ of the by-products, the direct utilization (as fodder, litter, energy, etc.) is some 23% only, so the majority remains on the field. However, the by-product transferred into the soil cannot be expressed directly in terms of energy. The results, in principle, are that the increase of the organic matter content of the soil leads to an increase in its fertility, thus the demand for fertilizers of industrial origin may be decreased.
(2) The animal stock consumed feed equaling 303 PJ of energy in 1980. The energy content of the products suitable for human consumption (meat, milk, eggs) was not more than 30 PJ (i.e., 10%).

According to the project results, some 60% of the energy content of the fodder fed to animals is devoted to the maintenance of life processes. The energy content of stable manure is about 30% of the energy content of the fodder consumed in animal husbandry. The energy balance of the animal husbandry sector is shown in *Figure 9.11*.

9.5. Summary of Conclusions

The calculations show that Hungarian ecological potentials permit a 40–50% higher output in the plant production than was attained in the late 1970s. The actual utilization of these potentials, however, depends on a number of different conditions. According to our investigation, the most important of these are as follows:

(1) The choice of an ecologically based sowing structure.
(2) The conservation of soil productivity by applying ameliorative agricultural technologies and additional ameliorative investments.
(3) The expansion of the share of irrigated areas.
(4) The insurance of a sufficient nutrient supply.
(5) Spreading new agricultural technologies.

According to presently accepted conceptions in long-term plans, a 50% overall increase in plant production is envisaged. The growth potential is, however, different from crop to crop. In some areas, no growth is planned because the aim is only to meet domestic demand, which has already been reached. There are other commodities, such as protein feeds, where output may multiply relative to the present level. The greatest increase in volume

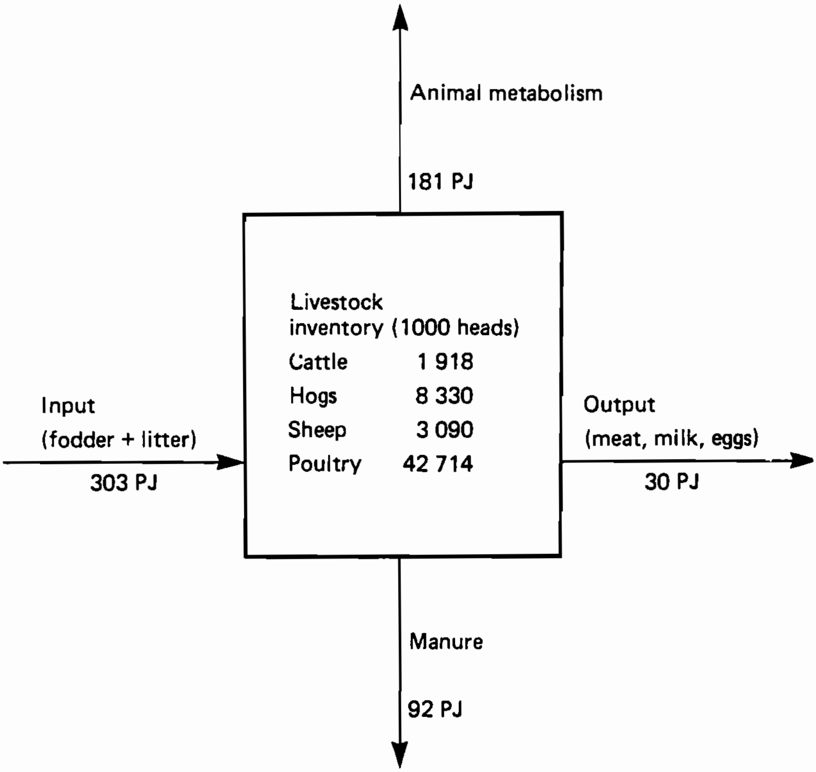

Figure 9.11. Energy flow in Hungarian animal husbandry, 1980 (10^{15}joules=1PJ).

is expected in grain production. An annual 19–20 Mt of total production seems to be a realistic target around the turn of the century.

Relative to the impact of sowing structure optimally suited to ecological conditions on production potentials, the computations show that by a more rational allocation of crops:

(1) The productivity of plant production can be boosted by 10–15% on average.
(2) In addition to a higher output in the case when the proposed optimal crop allocation is used, the risk of production declines due to random weather fluctuations is substantially reduced.

The volume of ameliorative investments has no significant impact on the optimal sowing structure, but it does influence the upper level of production potentials. In the case of maximal ameliorative efforts, a production surplus of 10% can be achieved relative to the analogous variant without amelioration.

The impacts of postponing ameliorative investments upon production potentials have also been projected. Without any further amelioration, the reduction of production potentials will be equivalent to at least 5% of the total grain production in the year 2000. It is worth pointing out that, according to the calculations, it seems to be more expedient to carry out ameliorative interventions in areas of higher base productivity than in those of lower productivity.

In relation to the connections between nutrient supply and sowing structure, the following could be established. An eventual reduction of N-fertilizer inputs involves a decrease in yields and changes in the optimal sowing structure, and also a lower demand for phosphorus and potassium fertilizers. The increase of the share of phaseolus crops can be observed in this case.

At the supply side of the nutrient balance of agriculture, manure and other organic residues and by-products should be given a larger role in the future. This would result not only in decreasing the dependence on expensive energy, but also in improving soil fertility and in moderating certain unwanted environmental processes. Such a shift, however, is feasible only if major technological changes take place.

Acknowledgments

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9A. Appendix

Table 9A.1. Critical soil water depth (m) when the pH of the groundwater is <8.5.

Salt content of groundwater		*Salt content of the soil*	*Soil water management categories (see Table 9A.3)*						
Level	*%*	*(%)*	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*
0–1	20–50	.05	2.0	2.5	2.5	2.5	2.0	–	–
		.05–.075	2.5	3.0	2.5	2.5	2.5	2.5	–
		.075–.10	3.0	3.5	3.0	2.5	2.5	2.5	2.5
		.10–.15	–	–	–	–	3.0	3.0	3.5
		.15	–	–	–	–	3.0	3.0	3.5
1–2	50–75	.15	2.5	2.5	2.5	2.5	2.5	–	–
		.05–.075	3.0	3.0	2.5	2.5	2.5	2.5	–
		.075–.10	3.0	3.5	3.0	3.0	2.5	2.5	2.5
		.10–.15	–	–	–	3.5	3.0	3.0	3.0
		.15	–	–	–	–	3.5	3.5	3.5
2–4	75	.05	3.0	3.0	2.5	2.5	2.5	–	–
		.05–.075	3.5	3.5	3.0	3.0	3.0	3.0	–
		.075–.10	3.5	4.0	3.0	3.0	3.0	3.0	3.0
		.10–.15	–	–	–	3.5	3.5	3.5	3.5
		.15	–	–	–	–	3.5	3.5	3.5
4–8	75	.05	3.5	3.5	3.5	3.5	3.5	–	–
		.05–.075	4.0	4.0	3.5	3.5	3.5	3.5	–
		.075–.10	4.0	4.0	4.0	3.5	3.5	3.5	3.5
		.10–.15	–	–	–	4.0	4.0	4.0	4.0
		.15	–	–	–	–	4.0	4.0	4.0

Table 9A.2. "Critical" soil water depth (m) when the pH ≥ 8.5 in the ground water.

Salt content of groundwater		*Salt content of the soil*	*Soil water management categories (see Table 9A.3)*						
Level	*%*	*(%)*	*I*	*II*	*III*	*IV*	*V*	*VI*	*VII*
0–1	50	.05	2.5	3.0	2.5	2.5	2.5	–	–
		.05–.075	3.0	3.0	2.5	2.5	2.5	2.5	–
		.075–.10	3.5	3.5	2.5	2.5	2.5	2.5	2.5
		.10–.15	–	–	–	3.0	3.0	2.5	2.5
		.15	–	-	-	-	3.0	2.5	3.0
1-2	75	.05	2.5	3.0	2.5	2.5	2.5	-	-
		.05-.075	3.5	3.5	3.0	2.5	2.5	2.5	-
		.075-.10	4.0	4.0	3.0	3.0	3.0	2.5	2.5
		.10-.15	-	-	-	3.5	3.0	3.0	3.0
		.15	-	-	-	-	3.5	3.5	3.5
2-4	75	.05	3.0	3.5	3.0	3.0	3.0	-	-
		.05-.075	4.0	4.0	3.5	3.0	3.0	3.0	-
		.075-.10	4.0	4.5	3.5	3.5	3.5	3.0	3.0
		.10-.15	-	-	-	3.5	3.5	3.5	3.5
		.15	-	-	-	-	4.0	4.0	4.0
4-8	75	.05	3.0	3.5	3.5	3.5	4.0	-	-
		.05-.075	4.0	4.5	4.5	4.0	4.0	4.0	-
		.075-.10	4.0	4.5	4.5	4.5	4.5	4.0	4.0
		.10-.15	-	-	-	4.5	4.5	4.5	4.5
		.15	-	-	-	-	4.5	4.5	4.5

Table 9A.3. Water management categories of the soils.

Soil categories		*Water holding capacity* (volume %)	*Available moisture content in % of water holding capacity*	*Permeability* (mm/h)
I	Soils with very low water holding capacity and very high permeability	Below 16	Above 300	Above 300
II	Soils with low water holding capacity and very high permeability	16–24	50–60	Above 300
III	Soils with medium water holding capacity and high permeability	24–32	50–60	100–300
IV	Soils with high water holding capacity, a high available moisture content and medium permeability	32–40	40–50	70–100
V	Soils with high water holding capacity, a high available moisture content and medium permeability	32–40	20–40	70–100
VI	Soils with very high water holding capacity and low permeability	Above 40	20–40	30–70
VII	Soils with very high water holding capacity and very low permeability	Above 40	Below 20	Below 30

Table 9A.4. Fertilizer dose (kg) needed to produce 0.1 t of corn.

	Soil nutrient state[a]				
Soil categories (see text)	*Very poor* 1	*Poor* 2	*Medium* 3	*Good* 4	*Very good* 5
Nitrogen					
I	3.3	3.0	2.6	2.0	1.2
II	3.4	3.2	2.8	2.2	1.4
III	3.5	3.3	3.0	2.5	1.4
IV	3.7	3.5	3.2	2.6	1.8
V	3.6	3.3	3.0	2.4	1.5
Phosphorus					
I	2.4	2.0	1.6	1.1	0.5
II	2.5	2.2	1.8	1.2	0.7
III	2.8	2.4	2.0	1.4	0.6
IV	2.6	2.3	1.9	1.3	0.5
V	2.8	2.5	2.1	1.5	0.8
Potassium					
I	3.1	2.8	2.4	1.8	1.0
II	3.2	3.0	2.6	2.0	1.1
III	3.2	2.8	2.3	1.8	0.9
IV	3.6	3.4	3.0	2.4	1.3
V	3.3	3.0	2.5	2.1	1.7

[a] Soil nutrient state is defined in *Tables 9A.7*, *9A.8*, *9A.9* for N, P, K, respectively.

Table 9A.5. Fertilizer dose (kg) needed to produce 0.1 t of wheat.

	Soil nutrient state[a]				
Soil categories (see text)	*Very poor 1*	*Poor 2*	*Medium 3*	*Good 4*	*Very good 5*
Nitrogen					
I	3.3	3.0	2.6	2.0	1.2
II	3.3	3.1	2.8	2.3	1.2
III	3.3	3.1	2.85	2.5	1.2
IV	3.6	3.3	3.0	2.7	1.5
V	3.4	3.2	2.0	2.5	1.3
Phosphorus					
I	2.7	2.3	1.9	1.4	0.6
II	3.0	2.5	2.0	1.5	0.7
III	3.0	2.6	2.2	1.7	0.7
IV	3.2	2.8	2.3	1.6	0.5
V	2.9	2.7	2.35	1.8	0.7
Potassium					
I	2.2	2.0	1.7	1.2	0.5
II	2.6	2.2	1.8	1.3	0.6
III	2.3	2.0	1.6	1.1	0.4
IV	2.7	2.5	2.2	1.6	0.5
V	2.4	2.2	1.9	1.4	0.5

[a] Soil nutrient state is defined in *Tables 9A.7, 9A.8, 9A.9* for N, P, K, respectively.

Table 9A.6. Fertilizer dose (kg) needed to produce 0.1 t of barley.

	Soil nutrient state[a]				
Soil categories (see text)	*Very poor 1*	*Poor 2*	*Medium 3*	*Good 4*	*Very good 5*
Nitrogen					
I	3.0	2.8	2.4	1.6	0.8
II	3.2	3.0	2.5	1.8	1.0
III	3.3	3.0	2.6	2.2	1.2
IV	3.4	3.1	2.8	2.4	1.5
V	3.5	3.2	3.0	2.5	1.3
Phosphorus					
I	2.7	2.4	2.0	1.4	0.6
II	3.0	2.6	2.1	1.6	0.8
III	3.0	2.7	2.3	1.8	0.8
IV	2.8	2.5	2.2	1.8	1.0
V	3.2	2.8	2.4	2.0	0.8
Potassium					
I	3.4	3.0	2.5	1.8	1.0
II	3.5	3.1	2.7	2.0	1.2
III	3.3	2.9	2.4	1.5	0.8
IV	3.6	3.3	2.9	2.1	1.3
V	3.5	3.1	2.6	1.8	0.8

[a] Soil nutrient state is defined in *Tables 9A.7, 9A.8 9A.9* for N, P, K, respectively.

Table 9A.7. Limit values of soil organic matter content to define soil nutrient state with respect to nitrogen fertilizers.

Soil category	*Organic matter (%)*				
	Very poor	*Poor*	*Medium*	*Good*	*Very good*
I	2.00	2.01–2.40	2.41–3.00	3.01–4.00	4.01
	1.50	1.51–1.90	1.91–2.50	2.51–3.50	3.51
II	1.50	1.51–1.90	1.91–2.50	2.51–3.50	3.51
	1.20	1.21–1.50	1.51–2.00	2.01–3.00	3.01
III	2.00	2.01–2.50	2.51–3.30	3.31–4.50	4.51
	1.60	1.61–2.00	2.01–2.80	2.81–4.00	4.01
IV	0.70	0.71–1.00	1.01–1.50	1.51–2.50	2.51
	0.40	0.41–0.70	0.71–1.20	1.21–2.00	2.01
V	1.80	1.81–2.30	2.31–3.10	3.11–4.00	4.01
	1.40	1.41–1.80	1.81–2.60	2.61–3.50	3.51
VI	1.30	1.31–1.70	1.71–2.40	2.41–3.30	3.31
	0.80	0.81–1.21	1.21–1.90	1.91–2.80	2.81

Table 9A.8. Limit values of soluble soil phosphorus content to define soil nutrient state with respect to phosphorus fertilizers.

Soil category	*Ammonium lactate soluble* P_2O_5 (ppm)				
	Very poor	*Poor*	*Medium*	*Good*	*Very good*
I	50	51–90	91–150	151–200	251–400
	40	41–80	81–130	131–200	201–400
II	40	41–70	71–120	121–200	201–400
	30	31–60	61–100	101–160	161–360
III	40	41–70	71–110	111–180	181–380
	30	31–60	61–100	101–150	151–350
IV	50	51–80	81–130	131–250	251–450
	30	31–60	61–100	101–200	201–400
V	40	41–70	71–120	121–180	181–380
	30	31–60	61–100	101–140	141–340
VI	50	51–80	81–130	131–200	201–400
	30	31–60	61–100	101–150	151–350

Table 9A.9. Limit values of soluble soil potassium content to define soil nutrient state with respect to potassium fertilizers.

Soil category	*Ammonium lactate-soluble* K_2O (ppm)				
	Very poor	*Poor*	*Medium*	*Good*	*Very good*
I	100	101–160	161–240	241–350	351–550
	80	81–130	131–200	201–300	301–500
II	90	91–140	141–210	211–300	301–500
	60	61–100	101–160	161–250	251–450
III	150	151–250	251–380	381–500	501–700
	120	212–200	201–330	331–450	451–550
IV	90	91–120	121–160	161–220	221–420
	50	51–80	81–120	121–180	181–380
V	200	201–280	281–400	401–550	551–750
	150	151–230	231–330	331–450	451–650
VI	120	121–160	161–220	221–300	301–500
	80	81–120	121–180	181–250	251–450

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CHAPTER 10

Northeast Bulgaria: A Model for Optimizing Agroindustrial Production Structures

T. Georgiev, T. Popov, G. Ivanov, and L. Stefanov

Abstract

The aim of the investigation is to elaborate an economic and mathematical model to improve production management and marketing of food products on a regional level. The present model differs from others, in theory and practice, in the following ways: it considers soil, climate, and economic conditions of the region when choosing alternative production technologies; it investigates the influence of intensive and superintensive technologies; it restricts the negative consequences of production on environment; and it takes into account the interrelations between state and personal farms, production and processing, and food production and consumption.

The area of investigation – the northeast region of Bulgaria – occupies an important place in the national agricultural picture. It encompasses almost a third of the arable land and fields in the country. A major solution of the model suggests an increase (from 5% to 41%) in the relative share of intensive and superintensive technologies in wheat and corn growing and in livestock productivity (28% for milk and 26% for meat).

The LP model proposed here considers the most important ecological elements that influence agricultural production under three types of technologies: traditional (standard), intensive, and superintensive technologies. The model allows quick and effective management decisions, conducive to the preservation and reproduction of natural resources.

10.1. Introduction: Background and Problem Statement

The regional economic and mathematical model for optimizing agroindustrial production is part of a whole series of similar models, elaborated by the International Institute for Applied Systems Analysis (IIASA) and by national scientific organizations in member countries of the institute.

The regional economic and mathematical model for optimizing agricultural production in northeast Bulgaria differs from all other models, including those of socialist countries, due to the specifics of the existing economic management mechanism of agricultural production in Bulgaria. This mechanism combines overall centralized planning of the economic branches with a decentralized way of achieving these aims.

The planning body determines the state plan tasks for agricultural production on the three main levels of production management – national, district, and economic organization – respectively, in the system of the National Agro-Industrial Union (NAIU), District Agro-Industrial Unions (DAIU), and Agro-Industrial Complexes (AIC), through the unified plan of socioeconomic development of the country. It is in conformity with the Bill for the specific regulations of the economic mechanism of agriculture, in force from January 1, 1982.

The fulfillment of these tasks should be in concordance with the requirements of the centralized funds, the long-term intergovernmental agreements, and the self-supply of the districts and regions with food and agricultural commodities. These tasks are considered unfulfilled when the production is realized outside the respective system of NAIU, DAIU, or AIC.

The number of indicators of the state tasks for the different regions and economic organizations has been decreased to promote initiative and independence of the separate units, and the indicators are differentiated in accordance with the district's specific production. The following indicators have been established in a differentiated way:

(1) State plan tasks.
(2) Norms and limits of resource supply.
(3) Premiums on purchasing prices.
(4) Normative payment for regulating the differentiated income.

The state plan tasks before the AIC are, for instance:

(1) Selling of agricultural production, realized outside the AIC.
(2) The region's self-supply.
(3) Hard currency from foreign trade activities.
(4) Implementing scientific and technical achievements.
(5) Limits for supply of machines, raw materials, fuels, energy, etc.
(6) Capital investment limits.

In these conditions the most important task, which the economic organizations should solve themselves at every stage of their development, is the optimization of their production activities by rational utilization of natural, economic, and labor resources. Due to the complexity of horizontal concentration of agricultural production after the establishment of AICs and Industrial Agrarian Complexes (IACs), the most modern methods and technologies should be applied for solving this task. It is all the more necessary when this concentration goes beyond the boundaries of a single economic organization and affects larger administrative units – districts or regions, as is the case with optimization of agricultural production in northeast Bulgaria (*Figure 10.1*).

Figure 10.1 A map of Bulgaria showing the northeast region (shaded area) under discussion.

This region includes the Varna, Razgrad, Ruse, Silistra, Tolbuhin, Targovishte, and Shumen districts. Its population is 1812690 people, or 20.3% of the country's total. The population density is 79.7 people km^2, a little below the average for the country. The most densely populated are the Varna (122.2) and Ruse (116.1) districts, while the least densely populated is the Tolbuhin district (53.8).

The region encompasses the east Danube plain, the north shore of the Black Sea and the Danube, and the foot of the Stara Planina mountain. Despite its proximity to the sea, the climate is moderately continental and is suitable for growing grain, vines, vegetables, etc.

Irrigation in the region is by the rivers Kamchija, Provadijska, Russenski Lom, etc. The importance of the river Danube as a principal water supply is constantly growing. The region's layout consists mainly of hills and plains, and is suitable for development of some agricultural branches.

The region is characterized by black soil and grey wood soil, with greater importance and predominance of the former, which is suitable for growing grain, sunflowers, sugar beets, etc.; the grey wood soil is appropriate for vines and fruits.

The region occupies a key position in the country's agriculture. It encompasses 29.5% of the arable land and 32.2% of the country's fields. Its territory accounts for 34.7% of the sown grain crops. Consequently, it is considered as a bread basket of the country and is extremely important for feeding the population.

The main grain crop of the region is wheat, which occupies 35.1% of the area; its production is 38.7% of the country's total. With the exclusion of the Targovishte district, the average yields in the other districts are higher than the national average. In 1982, the highest yields per area unit were in the Tolbuhin (5860 kg/ha) and Razgrad (5030 kg/ha) districts.

Barley plays an important role for the forage balance of the region, which produces 18.5% of the country's barley, with average yields higher than the national average.

Another crop of importance is corn. The region produces 45.9% of the country's corn and encompasses 38.0% of its total area in the country. In 1982, the highest average corn yields were in the Ruse district (7504 kg/ha), the Silistra district (6551 kg/ha), and in the Razgrad district (6635 kg/ha), which are, respectively, 2020, 1067, and 1151 kg more than the average yields for the country.

Northeast Bulgaria is well known as a producer of beans and accounts for 71.4% of the national bean production. They are grown mainly in the Tolbuhin and Silistra districts.

The region encompasses 45.6% of the sunflower area, 55.7% of the soybean area, and 27.8% of the sugar beet area of the country.

The most widely spread of these crops is sunflowers, grown mainly in the Tolbuhin, Silistra, and Razgrad districts. The region occupies the first place as to area, production, and average yields of sunflowers in the country.

The conditions in the region are suitable for the development of vegetable growing, mainly in the Danube lowlands. The area of vegetable crops in the region is 23.2% of the total vegetable area in the country and accounts for 20.9% of the total production.

Vine growing is a specific branch of the region, accounting for 26.0% of the total wine and dessert vines, with a marked predominance of the former.

In the vicinity of the Danube river, a large industrial vine belt has been created with the purpose of growing vines for export.

Livestock breeding in the northeast economic region is very well developed. The most important branch is cattle breeding. The region breeds 27.9% of the cattle and 28.9% of the cows in the country. In 1982, the region produced 473 238 thousand liters of cow milk (30.8% of the total milk production). Cows in the region are highly productive. In 1982, the average milk yield per forage cow was between 3259 and 3999 liters (with the exception of the Shumen district), which is 326 liters above the national average.

Sheep breeding is the second branch of importance in the region, which breeds 28.6% of the sheep and produces 21.8% of the sheep milk and 34.8% of the wool in the country. The districts of Tolbuhin and Shumen breed the most sheep.

The well-developed grain production provides favorable conditions for the industrial development of pig breeding. The region is one of the principal producers of pig meat for the needs of the country and for export.

Poultry breeding has also been industrialized. The region breeds 29.2% of the poultry and produces 41.2% of the eggs.

Agricultural production in the districts included in the region is organized into 57 agroindustrial complexes with 1153.5 kha arable land and a labor force of 206 948 people. One AIC encompasses 20.2 kha arable land (12.4 for the country), 28 561 thousand leva fixed assets (18 728 for the country), a labor force of 3 631 people (2 658 for the country). In 1982, the region produced 30% of the total agricultural production.

The analysis of the natural resources, specialization, size, and concentration of agricultural production shows that the northeast economic region is characterized by a high degree of agricultural intensification, and it is of great importance for increasing food and agricultural production.

The present version of the model encompasses only data for the Tolbuhin district. Data for the Razgrad district are in the process of elaboration and, after that, practically experimented data for the whole region will be included.

The planning of the national economy, including that of agricultural production in the conditions of a socialist society, is a necessary and purposeful activity, which ensures the direct coordination of economic and social processes. The effectiveness of the system "agroindustrial production planning" depends to a large extent on its ability to reflect the complex influence of many factors of economic, sociological, biological, technological, etc. character. All this presupposes the application of the systematic approach. In the elaborated economic and mathematical model for optimizing the agroindustrial production structure in northeast Bulgaria, which is the subject of this chapter, this approach has been used as the methodology for solving complex socioeconomic, scientific, technical, and production problems related to agricultural production and its effect on the environment.

The object of planning agriculture on different hierarchical levels (branch, region, etc.) is a complex dynamic probability of an open economic system, where interrelations and interdependence between the different elements lead to a chain reaction, i.e., changes in one element of the system bring about changes in the system as a whole.

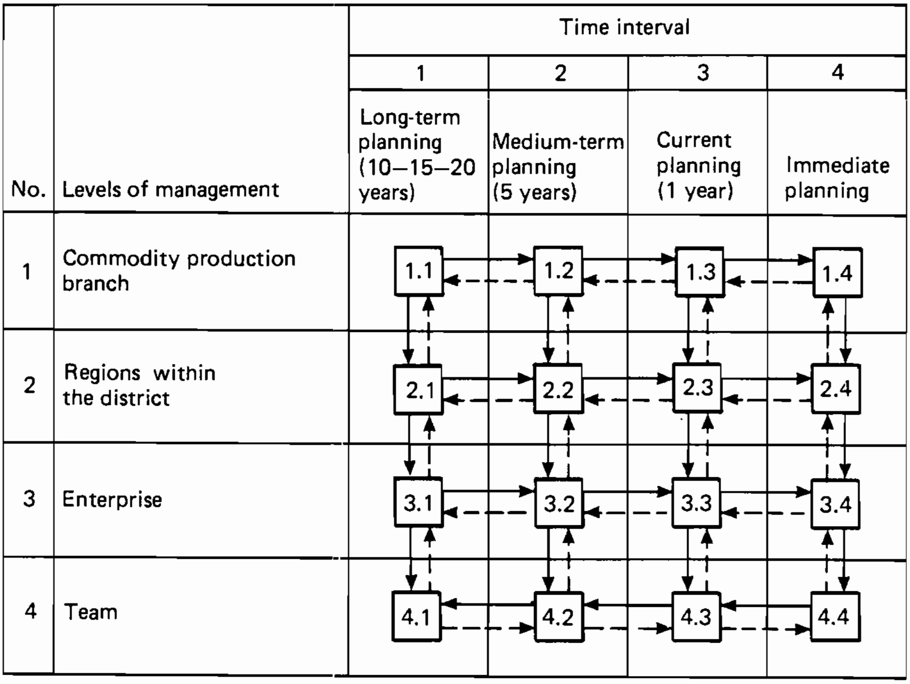
The application of the systematic approach in planning presupposes alternative elaboration of project decisions, previous to the planning activity. In this specific case, the numerous alternatives are determined by the possibility of using the resources (land, fertilizers, machines, etc.) and by the existence of a number of combinations for achieving the set target – the possibility of food product interchangeability, their production by different technological means, etc.

The hierarchical planning and management structure, in conformity with the principle of democratic centralization, means that the relations between the different levels (enterprise, region, center) should be built into the integrated, centralized, planned management to allow for economic independence and initiative of the separate units.

10.2. General Description of the Model

The complex character of agroindustrial production calls for the application of a system consisting of logically, informationally, and algorithmically related economic–mathematical models, reflecting the economic, organizational, and technological aspects of reproduction in their objectively existing unity. The reflection of the hierarchical levels of planning and management of agricultural production determines the necessity for elaborating economic and mathematical models (EMM) for the following levels: branch, region, enterprise, team. Depending on the aims and the temporal aspect, the EMMs will have different structures (*Figure 10.2*). The elaboration offers the experimental EMM for optimization of the agroindustrial production structure on a regional level in the conditions of Bulgaria. The main part of agricultural production in the country is generated in the public sector, where production is organized in the following forms:

(1) Agro-Industrial Complex (AIC) – basic agricultural organization in Bulgaria.
(2) Industrial-Agrarian Complex (IAC) – agricultural organizations vertically integrated with food industry enterprises.
(3) Scientific-Production Complex (SPC) – agricultural organizations integrated with scientific units
(4) Industrial-Livestock Complex (ILC) – pig and poultry plants, calf-fattening complexes.
(5) Auxiliary farms for producing agricultural goods at enterprises, offices, etc.



No.	Levels of management	Time interval 1 Long-term planning (10–15–20 years)	2 Medium-term planning (5 years)	3 Current planning (1 year)	4 Immediate planning
1	Commodity production branch	1.1	1.2	1.3	1.4
2	Regions within the district	2.1	2.2	2.3	2.4
3	Enterprise	3.1	3.2	3.3	3.4
4	Team	4.1	4.2	4.3	4.4

Figure 10.2. System of economic-mathematical models for agricultural production planning, with regard to hierarchical levels and the temporal aspect of planning

Together with the public sector, there are personal farms of workers in socialist agricultural organizations, which add to the production in the public sector. The main bulk of the production in these farms is intended for personal needs and any surplus production is sold. The personal and auxiliary farms are organizational forms of additional agricultural production intended to increase production.

In the conditions of Bulgaria, the agricultural production on a regional level can be defined as follows: production of food commodities with the aim of fulfilling the targets set by the state for increasing food production in the region, and at the same time ensuring the most effective use of all production resources with the least possible negative effect of the technologies applied on the environment.

Bearing the above in mind, the economic–mathematical model (EMM) should be looked upon as a multipurpose system, and its solution will require a number of obligatory constraints in the realization of the set aim, together with the objective function.

In conforming with Bulgaria's existing mechanism of production management in territorial aspects, the EMM should help to elaborate a production program for developing specialization and concentration of agricultural production in the region, which is in accordance with the following conditions:

(1) The national concept for allocation, concentration, and specialization of agricultural production on the country's territory.
(2) The fulfillment of the national indices for food commodities production as to quantity and nomenclature.
(3) The full satisfaction of people's food requirements in the region, according to the accepted norms and the sources of food production (social, auxiliary, and private farms); maximum quantity of food products, which the region could receive from the centralized commodity fund; the quantity of food products that the region could supply (or give to) other regions.
(4) The specific natural and economic conditions.
(5) The availability of production resources (in the region or supplied from elsewhere – fertilizers, machines, fuel, capital investment, etc.).

The solution of the EMM will provide answers to the following questions:

(1) What, how much, and how should crops be produced?
(2) What resources are necessary for the practical realization of the production program?
(3) To what extent will the state indices be fulfilled and the food requirements of the region be satisfied?
(4) What will be the economic effectiveness of agricultural production?
(5) What are the effects of the respective production technologies on the environment?

10.2.1. Economic and mathematical model of the task

The economic–mathematical model of the task has a block structure (*Figure 10.3*). This is determined by the necessity for solving questions related to allocation of production in public, personal, and auxiliary farms. In this case, all AIC, IAC, and SPC are included in one block; ILC in another; personal and auxiliary farms in a third; and processing agricultural production industry in a fourth block. The conditions, related to the balance and structure of food products for internal consumption in the region, as well as the source of their production or supply, are included in a separate block. The connecting block of the EMM encompasses conditions connected to the fulfillment of state tasks set for the region, and to the problem of effective capital investment utilization.

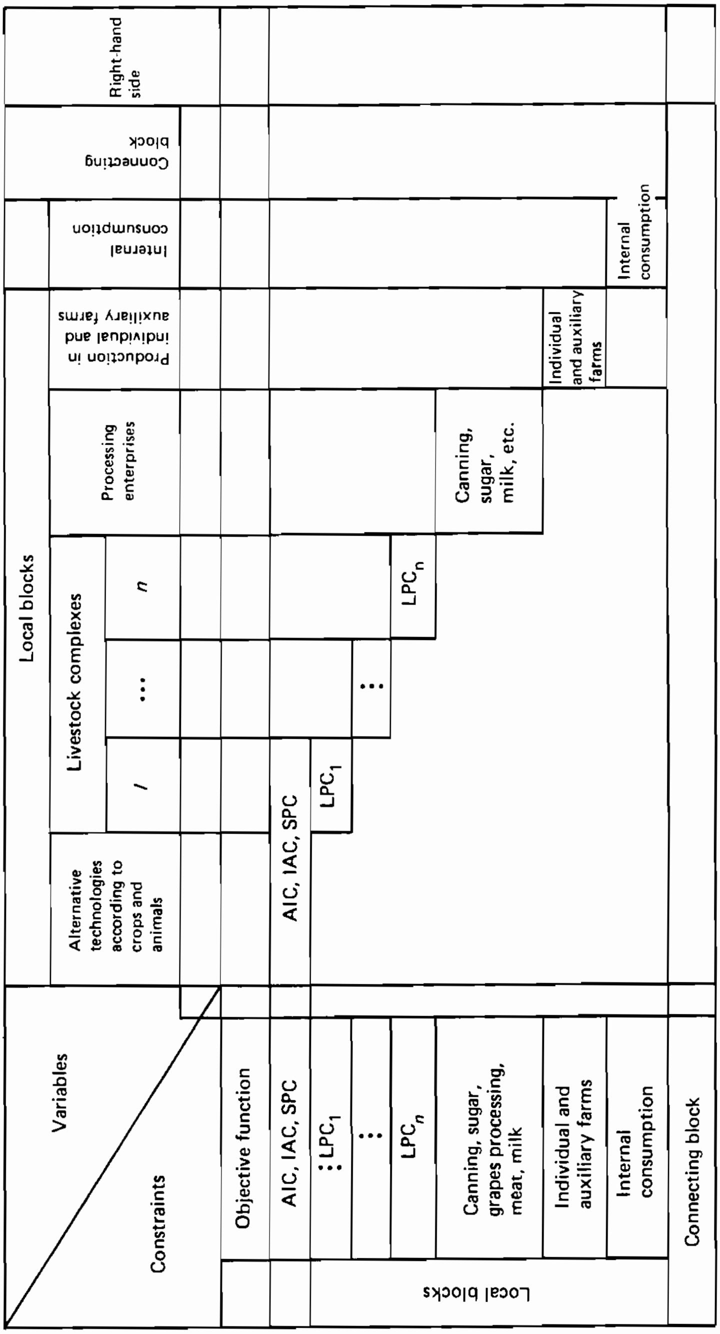


Figure 10.3. Matrix model of the regional economic–mathematical model.

The system of variables and constraints, included in the local blocks as well as the connecting block of the EMM, will be discussed at length.

10.2.2. Local block for optimization of the production structure in AIC, IAC, and SPC

This block includes a system of variables and constraints and provides information in the following directions:

(1) Type and quantity of agricultural production, generated in the region's public sector.
(2) Effective technologies to be used.
(3) Indispensable resources.
(4) Possibilities for productional utilization.

The solution of the task excludes the problems concerning the production and territorial arrangement. As a result, all the agricultural organizations are included in one and the same block.

System of Variables

The variables included in this block of the EMM can be divided into the following groups:

(1) For plant growing, variables denoting:
    (a) The area of the crops (in hectares), by alternative technologies depending on predecessor, degree of intensiveness, machines, etc. The number of variables depends on the number of crops grown in the region and the possibilities of applying alternative technologies in the specific conditions: wheat with intensive technology, wheat with superintensive technology, and corn with intensive technology.
    (b) The quantity of plant production (in tons), by type and varieties, intended for realization outside the region (food grain, feed grain, tomatoes, grapes, etc.).
    (c) The quantity of plant production (in tons) intended for internal consumption in AIC, IAC, and SPC (seeds, forage, fruit, vegetables, etc.).
    (d) The quantity of plant production (in tons) intended for other organizations in the region (fruit and vegetables for canning plants, concentrated and other forage for ILC for regional forage balance, etc.).

(2) For livestock production, variables denoting:

   (a) The number of animals by production groups and breeding technologies (cows with technology, cows with technology – , sheep with technology 1, heifers with technology 1, etc.).
   (b) The quantity of livestock production (in tons) and the direction of its use (internal consumption in AIC, IAC, for the purposes of a processing plant in the region, for processing or realization outside the region).

(3) The size and qualification of the necessary labor resources. When defining the number of variables denoting the size of labor resources and formulating the constraints of the labor balance, the starting point is that the number of permanently engaged workers in plant growing is determined by the necessary qualified labor for realizing agrotechnical activities in a defined optimal term, while the performance of agrotechnical activities not requiring qualified labor may be carried out by temporarily engaged workers. Thus, the constraints in this group will denote: the number of permanently engaged workers by category (crop raisers, vine growers, livestock breeders, etc.), and the number of man-days of temporarily engaged labor in each period.
(4) The size of capital investment according to direction of use (transformation of one type of land into another, animal buildings, melioration, purchase of agricultural machines, etc.).
(5) The quantity of fertilizers, fuel, water, etc.
(6) The degree of pollution of the environment.
(7) The necessary agricultural machines (tractors, harvesters).
(8) Additional variables for automatic calculation of natural and economic indicators (grain, fruit, profit).

System of constraints

Depending on the type of conditions that they denote, the constraints in this local block may be divided into the following groups.

Balance of land constraints. With the help of these constraints, the conditions related to the balance of land by categories, are formulated. They make sure that the areas for crop growing on every type of land in the public sector, the land allotted for private and auxiliary farms of the same type, do not exceed the land available in the region:

$$\sum_k X_{kl} + X_{zl} + X_{pl} \le B_l \qquad (10.1)$$

where X_{kl} is area (in ha) of k-type crop grown on l-category of land, X_{zl} area (in ha) of l-category land for personal farms, X_{pl} is area (in ha) of l-category land for auxiliary farms, and B_l is size of l-category land in the region (in ha).

Crop rotation constraints. These ensure the fulfillment of the agrotechnical requirements for correct crop rotation on every category of land in the region:

$$Q_1\sum_{k} X_{krl} - Q_2\sum_{r} X_{rkl} \le 0 \qquad (10.2)$$

where X_{krl} is area of k-type crops (in ha) alternating with r-type crops on P-category land, X_{rkl} is area (in ha) of r-crops alternating with k-type crops on l-category land, Q_1 is coefficient denoting the relative share of k-type crops in crop rotation on l-category land, and Q_2 is coefficient denoting the relative share of r-type crops in crop rotation on l-category of land.

Labor balance constraints. Constraints are formulated for each of the controlled periods in plant growing, by branches, which ensures that the necessary labor in different periods does not exceed the availability of labor in the region. The balance of labor is worked out together for qualified and unqualified workers:

$$\sum_{j} a_{ij} Y_{ji} - P_{ir} Y_r - X_i \le 0 \qquad (10.3)$$

where a_{ij} is necessary labor in i-period per unit of j-type crop, Y_{ji} is size of j-type crop in i-period (ha), Y_r is number of required permanently engaged workers, X_i is the size of temporary help required in i-period, and P_{ir} is number of working days in i-period in which every permanently engaged worker can participate.

In livestock breeding, labor intensity is steady, so the constraint for the labor balance is worked out not in periods but for the year as a whole.

Constraints linking the production of different agricultural commodities with the ways of their realization (intended to be sold, for seeds, for forage, etc.). This set of constraints ensure that the produced commodity should be equal to the realized commodity:

$$\sum_{j} d_{tj} X_{tj} - \sum_{p} X_{pj} - \sum X_{p'j} = 0 \qquad (10.4)$$

where p is selling index, p' is intermediate index, X_{tj} is the size of j-activity performed by t-technology, (in ha), d_{tj} is production (in tons) received from unit of j-activity performed by t-technology, X_{pj} is production (in tons) received from j-activity realized in p-direction, and $X_{p'j}$ is production (in tons) from j-activity intended for internal consumption.

Constraints for feeding agricultural animals. This group of constraints ensures the production and supply of forage for satisfying the animals' requirements in the region.

For the nonruminant animals, a constraint is formulated to express the balance between production and the need for concentrated forage mix.

The feeding of ruminant animals is ensured by a set of constraints that are divided into two groups:

(1) Constraints that ensure the main nutritive components – feed units, digestive protein, calcium, phosphorus, etc. [equation (10.5)].

(2) Constraints that define the limits of variation for the quantity of different types of forage. They ensure the normal structure and volume of the protein [equation 10.5′)]:

$$\sum_g a_{kg} z_g - \sum_f p_{kf} q_f \le 0 \qquad (10.5)$$

$$Q^k_{\max}\sum_g a_{kg} Z_g \ge \sum_f P^p_{kf} q^p_f \ge Q^k_{\min}\sum_g a_{kg} Z_g \qquad (10.5')$$

where a_{kg} is necessary k-nutritive components in feed units per g-type animals, Z_g is number of g-type animals, P^p_{kf} is content of k-nutritional component per area unit of f-forage of p-group forages, q^p_f is area of f-type forage from p-group of forages (in ha), and $Q^k_{\max}$ and $Q^k_{\min}$ are minimum and maximum share of k-nutritive component in animal diet.

Overall resource constraints. These ensure the necessary resources (water, fertilizers, fuel, pesticides, etc.). As regards the quantities of resources, the EMM may be solved if:

(1) The quantity of r-resources is previously determined by the state plan [equation (10.6)].

(2) R-resource is not limited and is defined with the solution of the task:

$$\sum_j a_{rj} X_j \le L_r \qquad (10.6)$$

where a_{rj} is the required r-resource for development of j-activity, L_r is the limit of r-resource, and X_j is j-activity (branch).

Constraints for controlling pollution of the environment as a result of the agricultural technologies applied. The further raising of people's standard of living calls for industrial and agricultural production increases. In this connection, the question of choosing optimal growth rates of production, in conformity with preservation of the environment, gains in importance. The quick growth rates of industrial production and the application of more chemicals to agricultural production leads to an increase of man's influence on the environment, a decrease of natural resources, and to raising man's negative effect on nature and society as a whole. There are cases of demolishing natural systems, diminishing natural resources, deterioration of people's health, and other not fully investigated phenomena. As practice shows, nitrogen fertilizers bring about increased yields, but their incorrect application may lead to nitrate pollution of soil and underground water, as well as having a negative effect on the qualitative composition of vegetable food products. One of the main tasks at present is to find a criterion for the nitrate quantity in the soil, which on the one hand will be enough for achieving the desired yields, and on the other will be admissible from the point of view of people's health.

The extensive application of pesticides is one of the reasons for the most widespread and dangerous pollution of the agricultural environment. Pesticides have a positive influence on agricultural production, but they also have substantial disadvantages: whatever the poison is, sooner or later pests and insects become used to it. The species that survive give birth to a more resistant generation. Moreover, the poison acts at random, killing wild animals and useful insects. Most poisons have a cumulative effect on man's organisms.

For pollutants, the task could be solved in the following directions:

(1) The first includes all variables, for all possible technological variants of breeding crops and animals, independent of the pollution they cause. The total quantity of each pollutant is calculated by types of soils and technological variants for the different crops, and is submitted for expert assessment.
(2) The second approach excludes the variables denoting activities with a high degree of application of chemicals that pollute the soil, water, or production above the admissible quantities.

In the northeast Bulgarian case study, the second approach is used.

10.2.3. Local blocks for optimizing the size of livestock branches and animal feeding in industrial production complexes

The inclusion of these local blocks as components in the EMM for optimizing the structure of agroindustrial production on a regional level is an objective necessity, related to improvement of management and planning in territorial aspects.

Every IPC is included in a separate block in the EMM. The necessary forage, by type, structure, and quantity, for animal feeding is ensured by AIC, IAC, SPC, and on the region's territory. By inclusion of a suitable system of variables and constraints the following questions are answered: size of the complexes (number of animals by type of production groups); capital investments necessary for building new and enlarging existing ILC;

necessary forage by type, structure, and quantity for animal feeding; quantity of produced livestock production and directions of utilization.

These local blocks include the following groups of variables and constraints.

System of Variables

A system of variables is used to denote the number of animals by production groups, type and quantity of forage for feeding the animals bred at the respective ILC; quantity of livestock production and the direction of its utilization; the necessary capital investments and their use – building of new animal houses, introduction of new technologies, purchase of highly productive animals; the number of permanently engaged workers for each category; additional variables for automated calculation of indicators, characterizing the activities in the livestock complexes.

Livestock constraints

These ensure biologically rational feeding of agricultural animals; labor balance; balance between livestock production and the direction of its use; automatic calculation of indicators, characterizing activities in ILC; the relation between livestock branches and livestock complex capacity, which could analytically be represented in the following way:

$$\sum_j X_j = B_k + X_r - X_n \tag{10.7}$$

where X_j is number of animals in j-group, B_k is number of animal places, X_r is newly built animal places, and X_n is unused animal places.

The way that the other constraints were formulated is discussed in detail in Section 10.2.2.

10.2.4. Local block or optimizing production variety in processing plants

These include the production of canned goods and the processing of grapes, meat, and sugar. Production is optimized according to larger groups of products, and not according to production variety. These blocks include the following variables and constraints.

System of variables

A system of variables is used to denote type and quantity of production, produced in the region and intended for processing (fruit, vegetables, milk, grapes, etc.); type and quantity of production for processing, supplied from other regions; the quantity of final products by groups (canned fruit and vegetables, juices, sugar, milk, cheese, ice cream, sausages, etc.); the size of the new production capacity; additional variables denoting the size of some economic indicators.

System of constraints

For the balance and use of raw materials. This constraint denotes the limited size of the resource raw material (by type and variety), procured through the region's own production and supplied from other regions, and the conditions for balance between the quantity of raw material and the quantity of production in which it participates:

$$\sum_k a_{sk} X_{sk} + \sum_m a_{sm} X_{sm} \le X_s \tag{10.8}$$

where X_{sk} (X_{sm}) are the quantities of s raw material used for production of unit of final product k (one intermediate product m) (in tons), a_{sk} (a_{sm}) are coefficients denoting the need of s raw material per unit of k product (per unit of m-product), and X_s is quantity of s raw material (in tons).

For the balance between the quantity of the final products and production capacity:

$$\sum_j \sum_i X_{ij} \le \sum_j B_{ij} \tag{10.9}$$

where X_{ij} is quantity of final product produced on i-type technological line in j-branch (canning, milk processing, meat, etc.) (in tons), and B_{ij} is capacity of i-type technological line in j-branch.

For the balance of labor resources. Besides the above-mentioned constraints, related to all processing plants, the specifics of production in processing different products calls for formulation of additional variables, which more fully reflect the specific conditions for balance and use of raw materials in different branches of the processing industry. They are the following:

(1) Milk processing plants. The use of a considerable number of semiprocessed products for the production of final products (cream for butter, ice cream, etc.) calls for the formulation of constraints for the balance between the quantity of final and semiprocessed products. The analytical representation of these constraints is analogous to that in equation (10.9).

(2) Meat processing plants. These are intended for distribution of the raw material, by type and category of meat:

$$\sum_{i} X_{ij} \le B_{ij} \tag{10.10}$$

where X_{ij} is quantity of j-type meat (pork, veal, etc.) distributed in i-direction (in tons), and B_j is quantity of j-type meat (in tons);

$$\sum_{k} X_{ijk} \le X_{ij} \tag{10.11}$$

where X_{ijk} is quantity of k-category meat (in tons) of j-type distributed in i-direction.

(3) Wine industry. Linking the quantity of the produced final, intermediary, additional, and waste production with the quantity of processed grapes.

10.2.5. Local block for development of personal and auxiliary farms in the region.

Food production in Bulgaria is mainly carried out in the public sector. However, part of the agricultural production is supplied by private and auxiliary farms. This means that when elaborating the complex plan for agroindustrial production development in the region, agricultural production in private and auxiliary farms, as well as the necessary resources, should be taken into account.

The reflection of these conditions is realized in a local block of the EMM. The inclusion of this block allows for answering the questions how much of what products shall be produced in these farms and what resources are necessary for their production.

System of variables

The variables included in this block can be divided into two groups:

(1) Denoting the type and quantity (in tons) of agricultural production in plant growing (fruit, vegetables, etc.) and livestock breeding (meat, milk, eggs).

With the aim of diminishing the number of variables, it is useful to include aggregated variables in the EMM, denoting structural type vegetables, fruit, meat, and milk. In their elaboration, the quantity of the necessary resources, ensuring the production of a certain type of product, is established. It is preferable that they be included in an aggregated form.

(2) Denoting the quantity of necessary resources that should be supplied from the public sector (land, fertilizers, seeds, etc.).

Resource constraints

(1) For the minimal/maximal size of production (in tons) that must be supplied from private and auxiliary farms in the region.

$$B_{j\max} \geq X_j \geq B_{i\min} \tag{10.12}$$

where X_j is quantity of j-agricultural product (in tons) produced in private or auxiliary farms, and $B_{i\min(\max)}$ is minimum or maximum quantity (in tons) of j-product that should or could be produced in these farms.

(2) For ensuring the required resources. By solving the EMM, the necessary resources supplied from the public sector to private and auxiliary farms will be established:

$$X_i = \sum_j a_{ij} X_{ij} \tag{10.13}$$

where X_i are additional variables denoting the quantity (in tons) of i-resource for these farms, X_{ij} is quantity of j-production (in tons) for whose realization i-resource is necessary, and a_{ij} is coefficient denoting the quantity of i-resource necessary for one unit of j-production.

In cases where the maximum size of some resources is predetermined, the following condition is formulated:

$$X_i \leq B_i$$

where B_i is maximum amount of i-resource that could be ensured for the development of these farms.

10.2.6. Local block for food supply in the region

System of variables

The system includes variables denoting the quantity of basic food products necessary for satisfying people's food requirements in the region, according to the accepted norms (bread, fruit, vegetables, canned foods, meat, milk, etc.) supplied from the centralized commodity fund; public, private, and auxiliary farms in the region; and from other regions on the basis of exchange. The number of products in the EMM of the task is quite large, so aggregated variables have been used, denoting structural ton vegetables, fruit, meat, etc.

Variables for demand of commodities are also included. It has already been mentioned that in optimizing agroindustrial production structure on a regional level, a certain degree of satisfying food requirements should be ensured. This has been determined by the competent authorities for a specific planned period. For this purpose, the EMM of the task has included variables denoting people's food requirements.

Consumption constraints

This block includes constraints ensuring the supply and demand of required production for consumption (of meat, fruit, vegetables etc.) in the region. A separate constraint has been formulated for each group of food products, which ensures the production or supply of this group with the aim of satisfying food requirements in the region.

10.2.7. Common (connecting) block of the EMM

This block of the EMM includes a system of variables and constraints that formulate the general requirements for production and use of food products, as well as for the utilization of resources in the region.

System of variables

Additional variables, to denote the size of natural and value indicators of the region as a whole, are included; also variables denoting the insufficiency of some resources necessary for fulfilling the obligatory indicators, determined by competent authorities.

Constraints

For the balance of capital stock and capital investments. Changes in the nature, level, and efficiency of production are to a large extent determined by expansion, reconstruction, modernization of existing branches and activities, building of new production facilities, increasing the number of animals, introducing new technologies, raising workers' qualification, etc. All this requires a certain amount of capital investment, looked upon as potential capital stocks.

In comparison to other production resources, which are more or less stable, after their distribution, capital investments may be redistributed among the organizations in the region. The size of capital investment is directly related to production efficiency.

As concerns the necessity of capital stocks, the task can be solved in two directions. In the first, capital investment is planned bearing in mind that the capital stocks are ensured on the basis of certain technologies and agroindustrial production organizations. In the second, capital investment is planned taking into consideration the level of ensuring the food industry and agriculture in the region with the capital stocks for the planned period.

In planning the necessary amount of capital investment for a certain period, the starting point is the necessary capital stocks at the end of the same period. A balance of the capital stocks is worked out, taking into account their availability at the beginning of the planned period.

The formulation of conditions related to planning and distribution of capital investments by branches, directions, and activities leads to including two groups of constraints:

(1) Constraints related to defining the size of the necessary capital stocks and capital investments by direction of utilization. This group includes as many constraints as there are variables for the size of capital investments by direction:

$$\sum_j A_{sj} X_{sj} \le F_s + \bar{X}_s \qquad s = 1,2, \ldots, m \tag{10.14}$$

where X_{sj} are variables denoting the size of j-production (in tons) utilizing capital stocks from s-direction, A_{sj} is coefficient for the size of required capital stocks from s-direction for unit of j-production, F_s is residue of fixed capital from s-direction at the end of the planned period (in leva), and $\bar{X}_s$ is variable for the size of capital investment, required for the introduction of fixed capital from s-direction (in leva).

(2) Constraints for connecting the required with the available capital investments in the planned period.

$$\sum_s \bar{X}_s \le B_k \tag{10.15}$$

where B_k is size of capital investments that can be used in the region during the planned period (in leva).

When sometimes the capital investments are limited, the following constraints are introduced, denoting the minimum and maximum size of the capital investments:

$$B_{s\min} \le \bar{X}_s \le B_{s\max} \tag{10.16}$$

where $B_{s\min(\max)}$ is minimum/maximum size of capital investments from s-direction that should or could be used in a defined amount (in leva).

For the minimum size of commodity production. These constraints are determined by type and quantity by the state plan (food grain, feed grain, fruit, vegetables, grapes, canned goods, meat, milk, etc.):

$$\sum_j X_{ij} \ge B_i \tag{10.17}$$

where X_{ij} is quantity of i-commodity production achieved by j-activity, and B_i is obligatory quantity of i-commodity production.

For ensuring automated calculation of the natural and value indicators. These constraints, necessary for the analysis of the optimal solution (total production, gross income, material expenditures, labor costs, profit, grain, milk, etc.), are given by:

$$\sum_j P_{ij}X_{ij} = X_i \tag{10.18}$$

where X_{ij} is size of j-activities forming i-indicator, P_{ij} is the role of j-activity unit in forming i-indicator, and X_i is the quantity of i-indicator.

10.2.8. Objective function

The EMM under discussion may be solved with different optimal criteria: maximum profit, gross production, labor productivity, minimum cost, etc. In our specific case we have chosen the indicator "profit".

$$\begin{gathered} F_{\max} = -C_{kl}X_{kl} + C_{pj}X_{pj} - C'_{p'j}X_{p'j} - C_gL_g + C_tX_{tp} + \\ C_jX_j - C_{jf}X_{jf} + C_{tj}X_{tj} - C_{zs}X_{zs} - \bar{C}_s\bar{X}_s \end{gathered} \tag{10.19}$$

With this optimal criterion, the coefficients of the variables in the objective function have the following meaning:

(1) Coefficients C_{kl} for variables X_{kl}, denoting the cropped area in the public sector (AIC), express the size of production costs invested for growing and collection of crops. These coefficients are written with a negative sign in the objective function.

(2) Coefficients $C'_{p'j}$ for variables $X_{p'j}$, denoting quantity of plant production in the public sector (AIC) and intended for realization (to be sold to the state or people in the region, to other regions, to processing plants in the region, etc.), signify the size of conditional profit. They are written with a positive sign in the objective function. We use the concept "conditional profit" because these coefficients are equal to the price of the production minus the preparation expenditures.

(3) Coefficients $C'_{p'j}$ for variables $X_{p'j}$, denoting the quantity of plant production for the purposes of AIC (seeds, forage, etc.), signify the size of production costs for packaging and storing of production. They are written with a negative sign in the objective function.

(4) Coefficients C_g for variables Z_g, denoting the number of agricultural animals bred in AIC, signify the size of production costs (without

forage produced in the AIC). They are written with a negative sign in the objective function.

(5) Coefficients C_t for variables X_{tp}, denoting the quantity of livestock production by direction of use, signify the conditional profit received from unit of production and equal to production price, without costs for packaging and realization. They are written with a positive sign in the objective function.

(6) Coefficients C_j for variables X_j, denoting the number of animals bred in ILC, signify the size of the conditional profit. They are equal to the total production realized from one animal without production costs. They are written with a positive sign in the objective function.

(7) Coefficients C_{if} for variables X_{if}, denoting type and quantity of forage used in ILC, signify the supply price of forage unit. They are written with a negative sign in the objective function.

(8) Coefficients C_{ij} for variables X_{ij}, denoting the quantity of final products produced in food industry plants, signify the size of the conditional profit from a product unit. They are written with a positive sign in the objective function.

(9) Coefficients C_{js} for variables X_{js}, denoting the quantity of raw materials in processing plants; signify the supply price per unit quantity of product. They are written with a negative sign in the objective function.

(10) Coefficients C_s for variables $\bar{X}_s$, denoting the size of capital investment by directions of use, signify the quantity of normative coefficient for effectiveness of capital investments. They are written with a negative sign in the objective function

10.3. Analysis of the Results from the Experiment with EMM

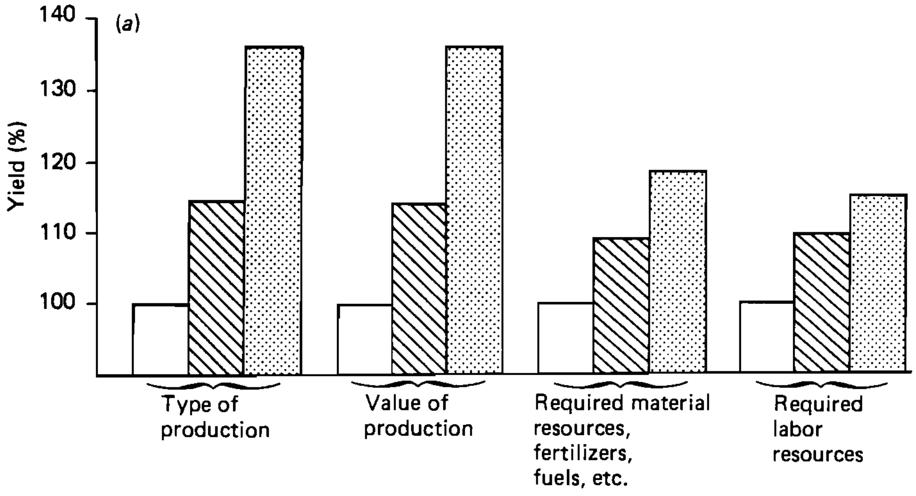
The arable land in the Tolbuhin district is 318 000 ha. The district will have at its disposal 35 000 permanently engaged workers, participating directly in agricultural production by the period of the planned year. The necessary permanently engaged workers, by category for the practical realization of the optimal plan in the EMM, will be defined as a relationship between the required labor in man-days with high labor intensity and the possible number of man-days that permanently engaged workers can put in for this period, taking into account the temporary labor force, and those working in other spheres of production. With the help of coefficients in the objective functions, a mechanism is created that ensures the participation of temporarily engaged labor in the optimal solution after full employment of permanently engaged workers in the production.

In solving the EMM for optimizing the agroindustrial production structure in the Tolbuhin district, the aim is to investigate the effect of alternative technologies on production structure and its efficiency, all other conditions being equal, and on this basis to make reasonable management decisions.

Without undermining the significance of other branches, most important for the intensification of agricultural production, and increase of its effectiveness in the conditions of the district, is the intensification of wheat and corn production by application of intensive and superintensive technologies. That is so because intensive wheat and corn production plays a major role in solving the grain problem. These two crops encompass an average of 60–62% of the arable land in the district and predetermine the agricultural economy. There exists a rich biofund (highly productive varieties with potential possibilities) of 10–12 t/ha. The district is characterized by suitable climatic and soil conditions for growing these crops. The analysis of the natural and value indicators, which characterize different technological variants for growing these two crops, shows that intensive and superintensive technologies have advantages over the traditional ones (*Figure 10.4*).

If the "standard" technologies are taken as a basis of 100% then, when wheat is grown by intensive technology, the yield increases by 14%, material expenses by 9%, and labor expenses by 10%. When superintensive technology is applied in wheat production, the yield increases by 36%, material expenses by 18%, and labor expenses by 15%. For corn, the percentage growth rate with intensive technologies is as follows: yield – 45%, material expenses – 35%, labor – 28%; with superintensive: yield – 205%, material expenses – 75%, labor expenses – 34%. The analysis of these data shows that production growth rates increase considerably more quickly than production costs, a tendency that is felt more strongly with superintensive technologies. With the application of intensive technologies for wheat growing, for instance, each 1% increase in material expenses leads to a yield increase of 1.56%, and to 6.2% with superintensive technologies. With corn, the growth rate is 1.18% and 2.73% with intensive and superintensive technologies, respectively. Depending on the specific conditions, average wheat yields vary from 5 to 7.5 t/ha: using traditional technologies – 5 to 5.5 t/ha, intensive – 6 to 6.2 t/ha, superintensive – 7-7.5 t/ha. Average corn yields vary between 6 and 12 t/ha: using traditional – 6 t/ha, intensive – 8 to 8.5 t/ha, superintensive – 12 to 12.5 t/ha. In the region under investigation traditional, or the so-called standard technologies, are still predominantly applied and in certain microregions the relative share of intensive and superintensive technologies varies from 20–40% of the area of the two crops.

From the point of view of the systematic approach, when investigating the effect of intensive technologies on the economic effect, of great interest is not only the direct economic effect, but also what will be the consequences of their application. The intensive and superintensive technologies for wheat and corn production in this case may be looked upon as a means of getting at another economic effect that may be called ***stimulating***. It will manifest itself when the technologies are applied and will be determined most of all by changes in production structure. Two questions of practical interest are what production structures should be carried out in



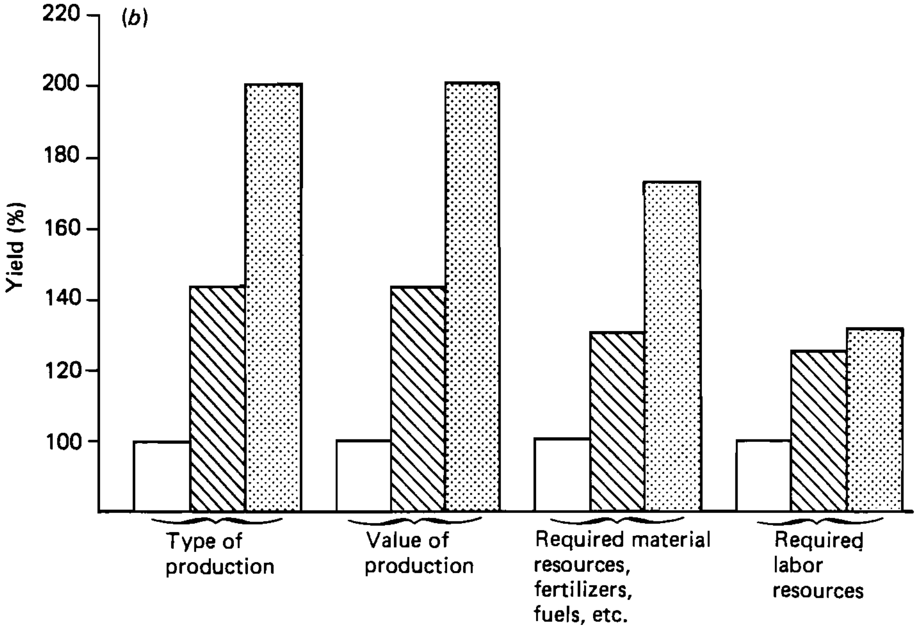


Figure 10.4. Relative characteristics of technologies for (*a*) wheat production per unit land; and (*b*) corn production per unit land. Unshaded columns = traditional technology; oblique shading = intensive technology; dotted shading = superintensive technology.

order to obtain a maximum stimulating effect from the application of intensive and superintensive technologies in wheat and corn production, and what will be the effect on the environment.

In order to answer the above questions, the EMM has been solved in four ways, differing in the constraints on the percentage of application of intensive and superintensive technologies in the growing of the two crops in the public sector. In the first variant, the intensive technologies are maximum 5% of the total wheat and corn area, in the second 12%, in the third 21%, and in the fourth 41%. In the EMM, wheat is included in 9 technologies, and corn in 6, differing in predecessor and intensiveness of technology. By intensive we mean the resource requirements (fertilizers, water, energy, labor, etc.) for the realization of production unit. The technologies have been elaborated by specialists in the district, with the help of scientific workers from specialized institutes, and processed by computers, which ensured the automatic calculation of technological and economic indicators. On the basis of expert assessment, it was accepted that the constraints on the percentage of intensive and superintensive technologies are determined by the predecessor and the natural soil fertility, i.e., intensive technologies will not be applied on unsuitable soil and after an unsuitable predecessor. This is determined by the insufficient availability of all necessary resources on the one hand, and by the desire to preserve the environment and to prevent pollution of the production on the other.

In determining the quantity of chemicals, the experts elaborating intensive and superintensive technologies have taken into account the norms established by the State Committee on Preservation of the Environment. The highest amounts of fertilizers comply to the above norms, as well as to the necessary nutritional components. The nitrates unabsorbed by the crops would hardly reach underground waters, which are at a great depth in this region. The established system of soil cultivation and crop raising ensures a decrease in wind erosion of the soil. The district of Tolbuhin is situated in the northeast plains where water erosion is not very typical.

At present, the elaborated technological variants, on the basis of expert assessment, do not take into account all conditions and factors that affect the yield. Therefore, in our further work, we will employ the approach of Konijn's (1982) model for physical crop rotation. The results from the model for yields forecasting will be used as input parameters in working out and solving the task for optimal utilization of resources and preservation of the environment on a regional scale.

Production structure changes in the four variants have been optimized only for the public sector. Private and auxiliary farms have the same structure because there is no difference in the degree of intensiveness of technologies for crop raising: they provide about 10% of the fruit, vegetables, and animal production.

The solution of the EMM in the four variants demonstrates the changes in the structure of plant growing shown in *Table 10.1*. The increased

Table 10.1. Size and structure of production by variants of intensity in wheat and corn growing.

	Variants							
	I		*II*		*III*		*IV*	
Crops	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Wheat	136700	43	143200	45	143100	45	138500	43.5
Corn	50900	16	41300	13	38200	12	31800	10
Other grains	26700	8	26700	8	26700	8	31200	9.8
Industrial crops	47900	15.2	49200	15.5	50800	16.4	54000	17
Vegetables	1560	0.5	1560	0.5	1560	0.5	1560	0.5
Permanent	5300	1.7	5300	1.7	5300	1.7	5300	1.7
Forage	48900	15.4	50800	16.3	52400	16.6	55600	17.5
Total	318000	100	318000	100	318000	100	318000	100

application of intensive technologies is concurrent with a decrease in wheat and corn area. From 187000 ha (59%) in variant I, the area of the two crops decreases to 170300 ha (53.5%) in variant IV.

A detailed analysis of these data gives sufficient grounds for the following conclusion: the application of intensive and superintensive technologies in wheat and corn production shows greater influence on the area of corn, while wheat area in the different optimal variants changes insignificantly. This points to the fact that the different average yields in the already given limits do not have any impact on the stability of the wheat area in the optimal solutions.

The area of forage and other grain crops is increased. The specialization and concentration of agricultural production in the district, as well as technological changes in production, led to changes in crop rotation: conversion from many field rotations towards fewer but larger fields; application of simpler forms of crop rotation; inclusion of different crops in the process, to their maximum possible amounts. It must be noted that the aim is to introduce appropriate and economically effective crop rotations ensuring stable yields, while preserving soil fertility and the environment.

Crop rotation is ensured by the restrictive conditions given in Section 10.2.2. above.

Production structure in variants allows for introduction of crop rotations that to a large extent comply with the above requirements. The predecessors of wheat, as a principal crop in crop rotation, are: most suitable (beans, lentils) from 13.2% to 16.5%; suitable (corn soya, sunflowers, flax) 57–65%; least suitable (grain, corn, wheat) 29%–20%. The best predecessor structure is in variant IV. This is determined by a decrease in wheat area and an increase in bean and sunflower areas. Taken in isolation and compared with other crops, beans are less effective but, as a predecessor of wheat, assessed for the two-year period, beans and wheat compare to other similar pairs (wheat and sunflowers), i.e., the effect from the beans is its value as a predecessor which determines its increase in variant IV (from

19800 to 22900 ha). In the above predecessor structure, part of the corn area is used as a predecessor of wheat. In reality, this area could be occupied by any other crop, including corn. *Figure 10.5* shows the percentage of intensive technologies in wheat and corn growing by different variants, and their effect on the total size of these crops.

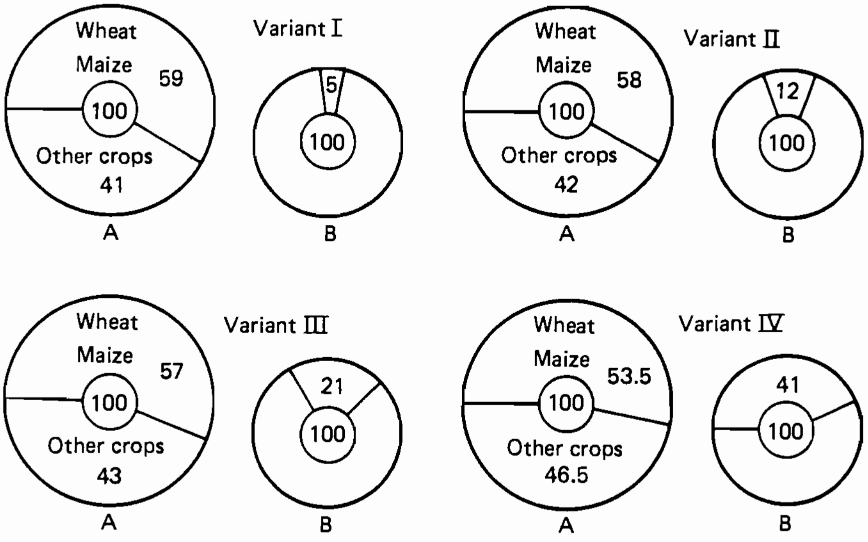


Figure 10.5. The effect of intensive technologies on the size of wheat and maize areas. A = Percentage shares of wheat and maize in arable land; B = percentage shares of intensive technologies for growing wheat and maize.

There are no considerable changes in the number and structure of livestock breeding in the variants, but there are differences in the livestock production and livestock effectiveness (*Figure 10.6*). Compared to variant I, the milk quantity in variant IV increases by 28%, meat by 26%. This livestock production growth is ensured by making fuller use of the genetic potential for animal breeding as a result of their more rational feeding. The figure shows that, even in variant IV, the biological maximum for productivity is not achieved. This is due to application of the optimal criterion "maximum profit", where livestock production reaches the limit of the economic optimum. The data undoubtedly show that the further increase of forage production in the specific conditions is uncompetitive compared to sunflowers and other grain crops.

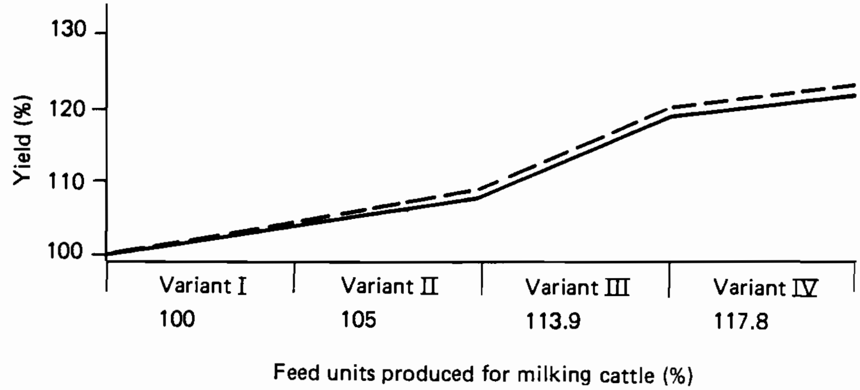


Figure 10.6. The dependency of milk quantity and profit on the forage produced. Solid line = milk; broken line = profit.

The annual ration of ruminant animals in the four variants has a similar structure: silage – 43%, concentrate – 31%, roughage – 19%, hay – 12%, green – 7%. This structure shows the advantages of all-year-round feeding on a standard basis. In the summer period, feeding is combined: concentrate, green, and preserved forages. It is well known that combined feeding in summer is related to some problems such as more complex organization of forage supply, building of new storage places for forage, loss of nutritive elements due to the longer time of forage preservation, etc. Nevertheless, in the specific conditions of the region it has several advantages. The all-year standard feeding ensures:

(1) Intensification of forage production by growing fewer but high-yield crops (corn for forage, alfalfa).
(2) Application of mechanized systems for feeding.
(3) Adaptation of the metabolism of ruminant animals, which leads to raising their productivity.

The necessary forage for calf breeding, pig and poultry breeding complexes, and for the personal sector in all variants, is supplied 100%.

The analysis of the optimal solution results shows that part of the necessary food products (fruit and vegetables) the district should supply from the centralized commodity fund and from other regions.

Grain production in all variants has been balanced with consumption (commodity production, internal consumption in AIC, district forage balance). Quantitatively, it is almost equal in all variants – it varies within 0.5–1.7%. The surplus grain produced in variants III and IV is used for feeding ruminant animals in AIC. This means that by the accepted optimal criterion the production of commodity wheat or corn grain is not effective compared to other agricultural activities.

The number of permanently engaged agricultural workers in the different variants ranges from 33790 to 34896:

(1) Plant growers: 16500–171500.
(2) Mechanizers: 4700–4750.
(3) Livestock breeders: 12000–12500.

The detailed analysis on utilization of labor resources from May to October gives sufficient grounds for the following conclusions:

(1) In the most intensive months (July, August, September), the available labor in plant growing is not sufficient to carry out the optimal structures for solving the EMM. This calls for hiring temporary labor (students, retired people, or people engaged in other spheres). This is mostly felt in the qualified mechanized labor category (15% for July and 17% for August). The above data underline the necessity of qualified labor in agriculture.
(2) The 1700 workers engaged in plant growing are fully used only in three of the six months under examination (July, August, September). During the other months, the degree to which they are engaged is: May – 87%, June – 89%, October – 94%. These people should be engaged in nonagricultural activities in those months as well as during the rest of the year. This would be a factor for keeping the necessary qualified labor in the sphere of agriculture.

The analysis on the relation between manual and mechanized labor in plant growing shows that manual labor still predominates. This determines the need of analyzing different technologies and elaborating programs directed toward mechanization of manual labor processes.

Food industry production plants were included in a more aggregated form in the EMM in order to lessen its size. The main points of optimization were the proportions between raw materials and final production, and between final production and production capacity.

The analysis of the economic indicators characterizing agroindustrial production structure in the region, by variants, is of great interest to the study (*Table 10.2*). The first variant of solution of the task for production structure is taken as 100 because it does not differ significantly in the present degree of production intensity in the region.

As has already been mentioned, the present study aims at defining the links and interdependence between the application of intensive technologies and production structure and efficiency. In this sense, the results from the application of intensive technologies for the production of wheat and corn may be characterized as an increase of the absolute value of

Table 10.2. Economic characteristics of the optimal variants of the solution of the task.

	Variants (%)			
Indicators	*I*[a]	*II*	*III*	*IV*
Gross production	100	106	113	123.5
Material costs	100	102	104.5	109
Labor costs	100	100.5	101.5	103
Profit	100	105	114.5	125
Nitrogen	100	102	103.5	106
Phosphorus	100	101.4	103	105.2
Potassium	100	101.3	103.6	106
Fuel	100	102	103.7	105.9

[a] The first variant of the task's solution is accepted for 100%, simply because it hardly differs in the intensity level from the present practice in the region.

agricultural production, profit, labor productivity, and expenses. The growth rates of production volume and profit rise much more quickly than the growth rate of expenses (*Table 10.2*).

As was mentioned in the introduction, for Bulgarian agriculture in general and, of course, for the northeastern Bulgarian region, different types of agricultural organization – AIC, IAC, SIC, LIC – are typical. In the economic management mechanism, common features and principles dominate. The regional economic and mathematical model for optimizing the agroindustrial production structure recognizes exactly these features and does not make any distinction between the organizations. In the case where the model has to be developed for an individual agricultural enterprise, the specific elements of the economic mechanism need to be taken into consideration.

10.4. Conclusions

Planning and improving socialist agricultural production is one of the most important and complex problems of contemporary economic development. The complexity is determined by the necessity to reflect more comprehensively the influence of many technological, sociological, and economic factors. For instance, if we only consider one side of the problem – quantitative calculation of the interrelations between the size of agricultural production and the degree of preservation of the environment – a number of questions arise, which could scarcely be solved by traditional planning methods. This calls for improvement of the methodology and planning, with the help of which such complex interrelations could be defined.

A question of growing importance for development of methodology and planning is the further elaboration of the planning principles; the more profound study is of existing objective economic laws, characteristic of a socialist economy, including agriculture.

On the basis of the study, the following more important conclusions may be drawn.

Improvement of agricultural production planning by application of the systematic approach should be considered as one of the main tasks before the planning economic departments at different levels. The practical realization of this approach calls for:

(1) Profound study of the complex requirements of the objective economic, biological, and natural laws, typical of agriculture.
(2) The complex consideration of the factors and conditions calls for combining modern mathematical methods and computers with the application of systematic analysis in agricultural production planning.

The solution of the basic problems of optimal planning and management of production on a regional level calls for elaboration of the EMM for complex planning of agricultural production on a regional scale.

From the point of view of adequate reflection of objective economic processes, the EMM for optimizing agricultural production structure on a regional level should allow for:

(1) The agricultural production structure to be optimized simultaneously in the public, private, and auxiliary farms.
(2) Effective forage and raw materials supply of ILC and food industry enterprises.
(3) Construction of an effective regional self-supply system in the region as a whole.

The elaborated regional model for optimizing agricultural production structure has a block structure and includes the following local blocks: block for optimization of production structure in public agricultural organizations (AIC, IAC, SPC); block for optimizing the size of livestock branches and animal feeding in industrial livestock complexes (ILC) on a regional forage balance; block for optimization of production variety in food processing enterprises; and block for developing private and auxiliary farms in the region; and block for food supply in the region.

The analysis of the results from solving the task for optimizing agricultural production structure in the Tolbuhin district shows that:

(1) The production of commodity grain in the region is not as effective as development of livestock production and increase of technical crops area. This is explained by the fact that in all further variants, the grain quantity is that of variant I, and the surplus production is used as forage. The production of surplus grain will lead to a decrease in profit.

(2) At present, the most important factor for intensification of agricultural production is the solution of the forage problem. The results show that when potential production capacity of the animals has not been used to the economic optimum, the most effective production in the region is that of forage. This conclusion bears important consequences in making practical management decisions. The efforts of the district authorities should be directed at improving animal feeding. Otherwise, expensive assets will be utilized insufficiently (buildings, installations, animals), which leads to a decrease in economic efficiency of production.

Forage availability in the district should stress activities such as increase of area and implementation of intensive production technologies. Bearing in mind that the possibilities concerning the former are more restricted, the efforts of the district authorities should be directed at speedy application of intensive technologies in the production of forage corn and alfalfa, the application of modern methods of storing and preserving conserved forage, etc.

(3) In the specific conditions of the district, it is most appropriate to apply all-year-round standard feeding with predominance of conserved forage.

(4) Having satisfied the animals' needs, it is appropriate for the free resources to be utilized for widening production of the following crops: tobacco, beans, soya, sunflowers, hemp.

(5) The application of intensive and superintensive technologies in wheat and corn growing will not lead to pollution of production or of the environment above the limits of accepted concentration. They are intended for application on soils with deep underground water, with high natural fertility, and in combination with the most appropriate predecessors. This leads to increased yields and is in accordance with scientifically plausible normatives for application of fertilizers and for diminishing diseases and pests.

(6) Personal and auxiliary farms in the region investigated provide about 10% of the agricultural production.

The analysis of agricultural production structure in the Tolbuhin district shows that economic and mathematical modeling is an important means for investigating the effect of production factors on its efficiency. The application of the EMM allows for reflecting the consequences of all important factors and interdependencies, and on this basis to draw relevant conclusions.

The results from the solution of the EMM have been discussed at length with the district authorities and a considerable part has been implemented in practice. This gives sufficient grounds to contend that the elaborated EMM may successfully be used for optimizing agroindustrial production structure in all districts in the country.

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CHAPTER 11

Bangladesh: Agriculture, Biomass, and Environment

J.K. Parikh

Abstract

The sustainable development of agriculture in Bangladesh requires careful consideration of the production and utilization of the biomass, which is crucial for a low-income country with high population density. The society depends on the biomass for food, fodder, fuel, fertilizer (organic), and fiber. If the conflicting demands on this biomass resource are not balanced, environmental problems, such as deforestation and loss of soil fertility, are likely to arise.

The LP model developed here deals with production and optimal utilization of this resource in a biomass-constrained Bangladesh. Meeting the energy needs for agriculture, i.e., for mechanization or for working animals (for which fodder is required) and fertilizers and energy ***derived from*** agriculture, is given priority. We examine the choices and implications for different income groups with different assets.

It is shown that, owing to the large demand and high prices of fuels, the biomass allocation for fuels takes priority over feed and fertilizers. In fact, the landless burn all and small farmers burn 80% of animal dung rather than use it for fertilizers. The model also shows that unless substantial amounts of fertilizers are used, the small and middle farmers would incur fodder and fuel shortages on adopting high-yield varieties that minimize straw:grain ratios. Similarly, by 1990, when the population will have increased further, middle farmers will also become vulnerable in meeting their feed, fuel, and fertilizer requirements. To mitigate these effects, improved stoves and other measures are necessary to increase the efficiency of biomass use considerably.

11.1. Introduction: Background and Problem Statement

11.1.1. The agricultural system of developing countries

In rural areas of developing countries, biomass generated by agriculture and forestry is a major resource for food–fodder–fuel–fertilizer (organic) and fiber. Thus, there is pressure from several sectors on biomass and therefore, ultimately, on land. Due to population growth, the pressure on land has increased such that the dependence is detrimental to the environment, leading to deforestation and soil erosion and hence a decrease in soil fertility.

Since biomass and energy are two major resources, it is the purpose of this work to build energy and agricultural biomass interactions as they exist in developing countries of South Asia in a linear programming framework and to test such a model for Bangladesh. In particular, options available to different income groups, and technologies and resources for obtaining and using energy, fertilizers, fodder, and the choices of farming technologies will be examined.

Energy is an important resource for agriculture and, at the same time, agriculture is a resource for energy. This chapter considers this relationship with regard to the developing countries, for which both these linkages are important. Depending on the country, 30%–70% of the intermediate input costs of agricultural crop production are directly or indirectly related to energy; however, agriculture provides 20%–90% of primary energy through the supply of noncommercial energy (wood, waste, dung, etc.). This interactive system of energy and agriculture is shown in *Figure 11.1*. It can be seen that while some dung and residues are used by the agricultural sector itself in the form of fertilizer and feed, the rest is used as an energy resource in unprocessed form in rural households and rural industries. This leads to savings of investment and of imports that would otherwise have been required to obtain commercial energy. The savings may be used to purchase more "processed energy" (fertilizers, diesel oil, pesticides, etc.).

Socio-techno-economic factors intertwined with the energy–agriculture systems are as follows:

(1) In rural agricultural systems, the animal dung and straws from crop residues are used for household cooking, thus linking the household energy sector very strongly to the fertilizer question. It is appropriate to mention here that a number of countries obtain nearly 90% of household energy from non-commercial energy sources, i.e., wood, crop residues, and animal dung. *Table 11.1* shows the contribution of non-commercial energy sources in total primary energy consumption for a few countries.

(2) The working cattle consume straws and waste but provide services such as plowing, irrigation, transport, for which capital-intensive equipment such as tractors, pumps, and trucks would otherwise be

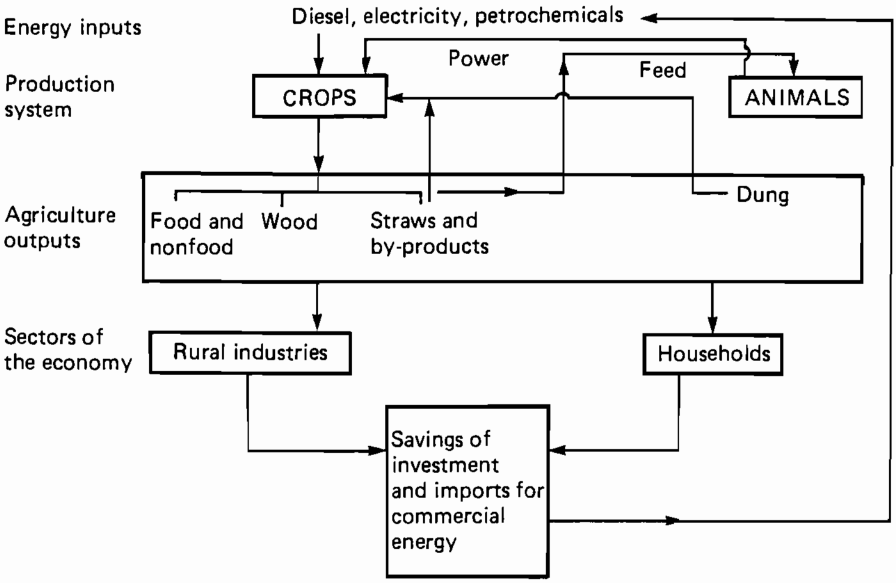

Figure 11.1. Energy for and from agriculture (Parikh, 1981).

Table 11.1. Noncommercial energy as percentage of total energy in selected developing countries, 1978.

10–30%	*31–50%*	*51–70%*	*71–80%*	*81–95%*
Argentina	Brazil	El Salvador	Bangladesh	Ethiopia
Chile	Columbia	Guatemala	Ghana	Nepal
Egypt	India	Sri Lanka	Kenya	Sudan
Malaysia	Pakistan	Thailand	Mozambique	Tanzania
	Philippines			Zaire
	Zimbabwe			

required. However, unlike these machines that consume fuels, bullocks actually produce energy, i.e., dung. Thus, this brings into question the services and energy produced by the working animals versus services provided by machines and their energy and capital requirements. The proportion of working animals in total animals ranges from 30 to 50% in developing countries of Asia.

(3) Between 20–70% of total fertilizers applied come from organic fertilizers. However, the share of organic fertilizers is rapidly declining. The growth of organic fertilizers depends on cattle population, which provides the most significant share of manure. In some developing countries, like India, cattle population has nearly stabilized, while in

Table 11.2. Consumption of fertilizer per capita and per hectare of arable land and land under permanent crops, and the annual average compound growth rate of these indicators, 1970–1978 (kg of nutrients; *FAO Fertilizer Yearbook*, 1974–1979).

	Consumption per capita			*Consumption per hectare*		
	1970	*1978*	*Annual compound growth rate (%)*	*1970*	*1978*	*Annual growth rate (%)*
Afghanistan	1.1	3.5	15.6	2.4	9.0	18.0
Bangladesh	2.1	4.5	10.0	15.7	41.4	12.9
Burma	0.8	2.5	15.3	2.1	8.5	19.1
China	5.4	10.0	8.0	33.5	94.0	13.8
India	4.0	6.8	6.8	13.2	26.7	26.7
Indonesia	2.0	5.1	12.4	13.1	44.9	16.6
Iran	3.3	8.0	11.7	5.9	18.0	15.0
Malaysia	-[a]	28.6	6.3	53.9	57.1	0.7
Nepal	0.5	1.7	16.5	2.7	10.1	17.9
Pakistan	4.7	11.4	11.7	14.6	44.1	14.8
Philippines	5.3	6.5	2.6	28.8	38.5	3.7
Sri Lanka	7.5	9.4	2.9	47.3	62.5	3.5
Thailand	2.3	6.4	13.6	5.9	16.5	13.7
1970–1978:						
Total Asia	5.7	9.6	6.7	25.1	52.3	9.6
Total world	18.8	25.0	3.6	46.6	75.4	6.2

[a] Figures not available.

others there is an annual growth of 1%–3% at most. This is for the simple reason that cattle require large amounts of biomass to sustain themselves and so exert pressure on scarce land for their feed. Moreover, there is an emphasis on improving quality – more meat, milk, services – rather than increasing numbers. Thus, declining cattle growth and high growth rates in chemical fertilizers result in a declining share of organic fertilizers. As can be seen in *Table 11.2*, in most developing countries, even after 1973, the annual growth rates for chemical inorganic fertilizer demand ranged between 6 and 17%. Yet, in absolute terms, the amounts applied per hectare (ha) are small – hardly exceeding 100 kg/ha and sometimes less than 15 kg/ha. Therefore, a clearer understanding on issues related to choices of fertilization is necessary.

(4) Linked with the above is also the fact that nearly 70–90% of rural population survives on agriculture in an environment where the infrastructure of transport and services is weak. This makes it difficult for commercial fuels such as kerosene, diesel, and electricity to reach the rural areas, making self-sufficiency one of the important rules for selecting production technology.

A brief outline of such a model was proposed earlier and is now formulated in detail.

11.1.2. Energy for agriculture

The extent to which each sector is detailed depends on the importance of the sector, i.e., mechanization, irrigation, fertilizers, and pesticide application. As shown in *Table 11.3*, in the developing countries the respective percentages for the first three of these energy uses are 26%, 14%, and 60%. In Southeast Asia specifically, they are 13%, 20%, and 66%, respectively. Thus, fertilizer production makes the largest single use of energy for agriculture. (Pesticides, if separately accounted for, use 1–4% out of a total of 60%.)

Table 11.3. Direct and indirect uses of commercial energy in agriculture (Stout *et al.*, 1981).

Region	*Energy in agriculture* (PJ)[a]	*Percentage distribution* *Fertilizers*	*Mechanization*	*Irrigation*	*Pesticides*
Africa	2	53	42	3	1.6
Southeast Asia	20	66	13	20	0.5
Latin America	11	48	46	4	1.6
China	15	71	9	16	4.3
Developing countries	49	59	26	14	1.0
Developed countries	214	39	57	2	0.9
World	260	45	50	4	1.0

[a] PJ = 10^{15} joules.

11.1.3. Energy from agriculture

As discussed earlier, agriculture provides a large percentage of rural energy, and therefore enters the modeling work in two ways:

(1) Through the selection of crops and livestock, which also produce primary energy resources as by-products.
(2) Through activities that further process agricultural residues in their primary energy forms in order to obtain more processed secondary energy forms through conversions, such as biogas, charcoal, or gasohol.

Thus, the model would consider using primary energy inputs directly as well as processing part of these to obtain more efficient forms of secondary energy. When the above energy sources are insufficient, commercial energy is purchased.

11.2. Bangladesh: Agriculture Sector and Energy Use

11.2.1. General overview

Bangladesh provides one of the most relevant case studies for the application of the model in question. In particular, the model could give insights into food–fodder–fuel–fertilizer relationships because it provides an example where limited biomass resources need to be stretched to fulfill conflicting demands on them.

Bangladesh has one of the highest population densities in the world with 617 persons/km^2, i.e., 88 million people over 144 000km^2 in 1979. Some 90% of the population lives in the rural areas where 93% of the household energy consumption is provided by biomass fuels, such as cow dung, straws, jute sticks, twigs, wood, etc. What is challenging about it is: how does a rural population of 73 million obtain food, fuels, building materials (dung, straw, sticks, mud, etc.) and sustain livestock from the scarce land it has? The present situation of Bangladesh may be of interest to other developing countries whose population growth is high and who may have similar population densities in the next three decades. In addition, the future of Bangladesh, whose population increases at 3% per annum from a high base of 88 million, itself provides a formidable problem where biomass resource utilization may need to be stretched to its maximum limit.

Although the availability of fertile land (88% of the total land), water from rainfall (120–345 cm per year) and rivers, and the possibilities of exploiting domestic natural gas are some of the advantages, they are not enough compared to the magnitude of the problems of a country with a very high population density and average income of US $100 per person per year. The share of agricultural GDP in the total GDP is more than 60%, and 70% of labor is employed in agriculture.

A number of authors have done energy-related studies for Bangladesh. A brief review can be found in Parikh and Krömer (1985).

Household energy consumption patterns for different groups income at the national level are discussed in a paper by Kennes *et al.*, (1984), using the data of the household expenditure survey by the Bangladesh Bureau of Statistics (1980). This study, which is also a part of the present exercise, analyzes primary household energy data and assigns them to nine income classes: seven in rural areas and two in the urban areas.

The present study starts from where that by Kennes *et al.* left off, and re-examines some of the assumptions in a modeling framework where many of the interrelationships are more rigorously tied in. As can be seen later, this chapter deals with many additional aspects that, on cross-checking with other data, have firmed up a considerable number of parameters. A critical analysis of data and relationships also leads to some policy implications, as will be shown later.

11.2.2. Income groups of farmers and household energy consumption

Since household energy is a major component of the rural energy system, some description of that sector is necessary in order to appreciate the purpose of this exercise and the issues involved. More details can be found in the study by Kennes *et al.* (1984).

It is extremely important to distinguish different income groups whose behavior differs in terms of fertilizer use, energy use, and a number of other socioeconomic aspects, such as family size, asset acquisition, etc. The large farmers also have more animals, more trees, and, of course, more agricultural waste.

A household expenditure survey (HES) was carried out by the Bangladesh Bureau of Statistics using 16475 households as samples across nine different income classes. These are converted into land-holding classes so as to make the relationship with agricultural assets and activities explicit (Stolwijk, 1981; Kennes, 1982). The distribution across classes is given in *Table 11.4*. As 90% of the population lives in the rural areas, seven income groups of rural population and only two income groups of urban population are considered. The urban-formal group includes people in government, industry, commercial, and service sectors.

11.2.3. Budget shares for food and fuels

On the average, nearly 70% of the household expenditure is on food items. The actual magnitude varies from 75% for the rural poor to 65% for the rural rich. The urban-formal class also spends 60% of the expenditure on food. A third of the remaining 30% of the budget is allocated to household energy leaving the rest, 18–23% of the total budget, for clothing, housing, and other necessities. The budget shares allocated for household energy expenditure vary from 6.9% for the urban-formal class to 10.7% for the landless. The urban-formal class not only has a high total expenditure but also access to more efficient forms of commercial energy, such as kerosene and natural gas (available to households in Dhaka), which are cheaper if considered in useful energy terms. The average national budget share for energy is 8.7% of the household expenditure. For the lowest to the highest income groups, the energy expenditure ranges from 77 taka (TK) to 181 taka [1] per capita, and amounts to 7.22% of the average per capita income. (The national ratio for expenditure to income is 82%.)

The variations across income classes are small compared to some of the other developing countries. However, the mix of energy forms differs considerably from income class to income class. Even these small differences among income classes shrink when one considers useful energy consumption, as we shall see later.

Table 11.4. Number of people and households per socioeconomic group (Stolwijk, 1981; BBS, 1980; Kennes, 1982).

	People		*Households*			*Income*[a]		
Socioeconomic group	*Number* (000)	*%*	*Average size*	*Number* (000)	*%*	*Income per capita*	*Expenditure per capita*	*Savings per capita*
(a) Small farmers: 0–1.5 acres	9672	11.8	5.40	1790	12.4	979	883	96
(b) Medium farmers I: 1.5–5.0 acres; owner cultivation	10917	13.4	6.65	1642	11.3	1171	1022	149
(c) Medium farmers II: 1.5–5.0 acres; owner cum tenant	10035	12.3	6.65	1509	10.4	1445	1200	245
(d) Large farmers: 5.0–7.5 acres	6020	7.4	8.29	726	5.0	1704	1310	394
(e) Very large farmers: > 7.5 acres	6065	7.4	10.29	590	4.1	2773	1631	942
(f) Landless farm laborers	16912	20.7	4.54	3725	25.7	774	721	53
(g) Nonagricultural rural	14663	17.9	4.54	3230	22.3	1251	1038	213
(h) Urban-informal	4340	5.3	5.84	743	5.1	1099	1007	92
(i) Urban-formal	3143	3.8	5.84	538	3.7	2143	1622	521
Total	81765	100.0	5.64	14497	100.0	–	–	–
Total agriculture (a+b+c+d+e+f)	59619	72.8	5.97	9986	68.9	–	–	–

[a] Income figures given in Bangladesh taka.

11.2.4. Some problems with the energy data

More than 90% of the rural household energy is supplied by noncommercial energy sources. It is difficult to convert a wide variety of these fuels with varying degree of moisture contents, heat values, and volatile matter to the same units using one heat value per fuel, particularly across several income classes. The landless may, for example, gather twigs and branches, the value of which is difficult to quantify in terms of money and energy. Thus, using an average figure of 15 GJ/t of wood may give a high estimate for energy use by income classes that use twigs, and an underestimate for high-income classes that may use good quality wood having 18 GJ/t.

The same type of bias is expected to occur in value terms because of the differences in the quality of the two products. For example, gathered fuels, whose quantities and quality standards are doubtful, are converted into taka presumably using prevalent prices for each of them, which may again differ with region, season, quality, and supply availability. There is also ambiguity about converting time spent on gathering fuels into money terms so as to account this activity in the income of the households. Thus, "budget share" for energy expenditure may have several simplifications and assumptions built into it. Notwithstanding these difficulties, the following conclusions emerge.

Table 11.5. Supply and demand balance at national level for energy resources.

	National use per BBS (million t)[a]	*GJ per quantity*[a]	*Assumed efficiency*	*National consumption (primary)* (PJ)	*Estimate by HES* (PJ)
Fuelwood[b]	9.88	15.0	0.12	148.0	45.4
Straw	3.26	12.6	0.08	40.9	38.0
Dung cake[c]	5.22	13.8	0.10	72.2	52.7
Agricultural waste	8.71	12.6	0.08	109.5	50.6
Jute stick	0.87	18.0	0.15	15.5	12.7
Bagasse	0.40	7.4	0.10	3.3	11.6
Coal[d]	0.088	24.0	0.15	2.1	–
Kerosene[d] (1000 l)	390	35.0	0.35	13.6	NR
Electricity[d] (10^6 kWh)	189	10.5	0.80	2.0	NR
Gas[d] (MCF)	7700	9093	0.65	7.6	NR

[a] Obtained by multiplying weighted per capita average of BBS with the national population (81.76 million in 1976–1977). Quantities are in tons unless mentioned otherwise. HES data are for 1973–1974 and are derived from supply considerations. [b] HES data indicate fuelwood 7.4 PJ twigs and leaves 19.0 PJ, and other fuels 19.0 PJ. [c] Collection coefficient of 50% is assumed. [d] Consumption data from BBS survey for kerosene, electricity, and gas consumption are very different from related data available from the corresponding ministries of supply. Since the per capita use is small (less than a few percent), multiplying with 81.8 million could lead to major inaccuracies in such small consumption. Therefore, the government data on supply are quoted, i.e., 390000 litres of kerosene, 189000 kWh electricity, 7700 MCF natural gas, instead of BBS consumption data. NR = not relevant.

11.2.5. Primary energy terms

Converting the quantity units into energy terms, using *Table 11.5*, one finds that the national average consumption of 5 GJ per capita consists of 36% wood, 18% dung, 10% straw, 27% agricultural waste (essentially from rice), 3.8% from jute sticks, 4% from kerosene, and 1.6% from electricity. However, there is a considerable difference between rural and urban energy consumption in amounts and patterns. The energy consumption pattern is shown in *Figure 11.2*.

Useful energy is derived by multiplying the primary energy with the efficiencies. *Table 11.5* gives the assumed average heat contents and the efficiencies for each type of fuel. For cooking and other uses, using these numbers, one finds that the useful energy consumption indicated for each income class in *Figure 11.2* varies much less for different income classes than the primary energy consumption. They all fall in the narrow range of 0.52–0.62 GJ per person. The anomaly, concerning much lower urban energy consumption than rural energy consumption, is resolved in this way.

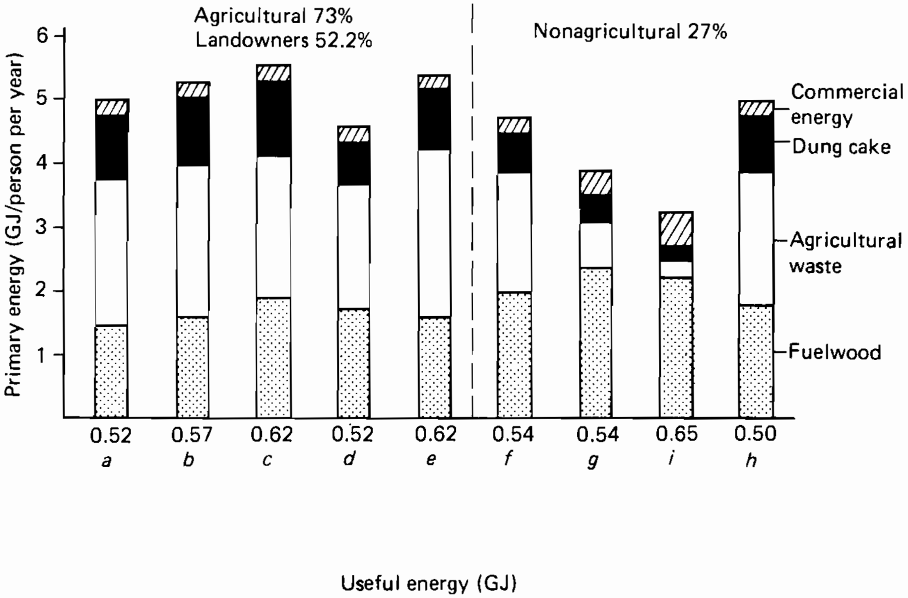

Figure 11.2. **Household use of primary energy by different income classes, 1976–1977 (*a* = landless, *b* = small farmers, *c* = medium farms, *d* = large farms, *e* = very large farms, *f* = rural nonagricultural, *g* = urban-informal, *h* = urban-formal, and *i* = national average).**

11.3. Model Description

A linear programming model is constructed in order to capture interactions between:

(1) Crop and livestock production.
(2) Organic and inorganic fertilizers.
(3) Commercial and noncommercial energy used in rural areas of developing countries in the household, agriculture, and rural industries sectors.

The objective function is to maximize the revenues from crop and energy production. The model takes into consideration:

(1) Three crop commodities important for Bangladesh covering more than 90% of harvested land.
(2) Eight activities of energy production and purchase (these include the production of primary and secondary energy products, e.g., biogas and final energy purchase).
(3) Twelve activities of fertilizer provision (for these types of nutrients, nitrogen-, phosphorus-, and potassium-based, times four distinct activities, i.e., purchase of chemicals, biogas, manure, and crop residues).
(4) Requirements for food and energy for income classes, and availability of land and other resources such as tractors, draft animals.

In addition, the model has the flexibility of introducing several land classes and/or subregions. Energy demand for cooking is considered in competition with energy demand for agriculture.

The model is general and applicable to many of the low-income developing countries but would require different approximations and, of course, input data depending on the data availability and characteristics of the selected country.

Code to the Symbols

(1) Activities are in capital letters.
(2) Running index is indicated by subscript.
(3) Identification index is indicated by superscript.
(4) Coefficients are in small letters.

Activities, Resources, Agents, and Units

Index	Unit	Text
c		*crop index*
1		wheat
2		rice
3		jute

j		*income class index*
1	1000	small farms
2	1000	middle farms I
3	1000	middle farms II
4	1000	large farms
5	1000	very large farms
6	1000	landless
b		*animal type index*
1	1000 head	not working
2	1000 head	working
f		*feed (from crop residues) index*
1	kt	bought feed (grains, etc.)
2	kt	feed from pasture
n		*fertilizer index*
1	ton	nitrogen
2	ton	phosphorus
3	ton	potassium
k		*energy index:* B = purchased, Q = produced
1	1000 kg	crop residues
2	1000 kg	dung
3	1000 kg	fuelwood from homesteads
4	1000 kg	fuelwood from forests
5	1000 kg	fuelwood from plantations
6	1000 m^3	biogas
7	1000 l	kerosene
8	1000 l	diesel

Note: The model could be run monthly or annually. However, only the first constraint is illustrated with symbol m. In the rest of the equations, symbol m is dropped for convenience (except in the case of plowing and irrigation). The motivation behind the objective function and construction of each module is discussed below.

Objective Function

For a given rural area, we maximize the revenues from crops minus the costs of purchasing fertilizers, commercial energy, feed, and hired labor. Each crop is selected according to the agroclimatic conditions, and its initial pattern is given as the one that exists currently. Livestock is assumed to be given as present and its maintenance is imperative.

Maximize for the rural area:

$$\sum_j \left\{ \underset{\substack{c\ \text{yield} \times \text{area} \times \text{price}\\ \text{(revenue from crops)}}}{\sum y_{cj} \cdot L_{cj} \cdot p_c} - \underset{\substack{n\\ \text{cost of bought}\\ \text{nutrients}}}{\sum p_n \cdot B_{n,j}} - \underset{\substack{k\\ \text{cost of bought}\\ \text{energy}}}{\sum p_k \cdot B_{k,j}} - \underset{\substack{f\\ \text{cost of bought}\\ \text{feed}}}{\sum p_f \cdot B_{f,j}} \right\} \tag{11.1}$$

where j is income class index, c is crop index, n is index for types of nutrients, k is index for energy sources, y_{cj} is yield of crop c by income class j (t/ha), L_{cj} is land area under crop c by income class j (kha), p_c is price of crop c per ton, p_n is price of ton of fertilizer of type n, $B_{n,j}$ is bought nutrients (in tons) by class j, p_k is price of bought energy (kerosene, diesel, electricity) per physical units (kl or MWh), $B_{k,j}$ is bought energy in physical units by class j, p_f is price of bought feed per ton, and $B_{f,j}$ is bought feed (in kt) by class j.

Notice that due to weak infrastructure in the rural areas, only the purchased commodities from outside the rural areas are minimized in the stated objective function. However, the objective function could be varied depending on the viewpoints. For example, one may wish to minimize the use of noncommercial energy sources explicitly and consider their prices here. The maximization is subject to the constraints of resource availability, individually as well as collectively. For example, each income class has private assets such as land, livestock, etc., as well as access to the collective resources such as wood resources, or unused biomass resources from other income classes such as dung and crop residues that are exchanged freely. In reality, while most often some of the noncommercial energy resources are gathered, obtained in return of farm labor or goods, or given away, there are some instances when these are actually done with cash. It will be shown later that energy sources such as biogas, charcoal, or ethanol, are also considered in this static model. The discussions on the constraints, assumptions, and technical coefficients are given below and equations for constraints are given.

11.4. Crop Production and Crop Residues

Each income class has fixed amounts of land and also broad allocation of crop production, which is assumed to be given. The yield–fertilizer responses are assumed to be given. In Bangladesh, wheat, jute, and rice are important crops covering nearly 90% of the harvested land; this is indicated in *Table 11.6*.

11.4.1. Crop residue coefficients

The crop residue coefficients for each selected crop are given exogenously. Thus, on the basis of yield, land allocation, and crop residue coefficients, crop residues are generated separately for each income class. They could have the following uses:

(1) Feed for the cattle, working animals, etc.
(2) Fuel for household cooking by different income class.

Table 11.6. Crop-related data for Bangladesh, 1976–1977.

Indicators	*Units*	*Wheat*	*Milled Rice*	*Jute*
Crop residue[a] per ton of crop, including straws, husk, and all by-products	t	2.5	2.5	3.5
Yield by income class j:	t/ha			
Small		1.48	1.92	1.32
Medium (owner)		1.50	1.77	1.32
Medium (tenant)		1.51	1.73	1.32
Large		1.52	1.65	1.32
Very large		1.57	1.60	1.32
Land area by j:	kha			
Small		15.54	736.39	54.35
Medium I		36.79	2170.08	151.23
Medium II		36.45	2093.68	145.85
Large		45.97	2906.39	191.98
Very large		26.22	1975.74	105.46
Total		160.06	9882.33	648.87
Price per ton	taka	2048	1699	2690

[a] Calorific value of crop residue as feed is taken as 1.6 Gcal/t with protein content 35 kg/t.

(3) Fertilizer for farms with or without burning.

(4) Other purposes such as construction, handicrafts, mats, furniture stuffings, etc., to be given exogenously.

The last is given exogenously as a percentage of total. All residues from different crops are added for a given income class j, which allocates them to the above uses depending on requirements and other opportunities.

11.4.2. Set of constraints on the objective function

Crop Residue Balance

r_c	Crop residue from crop c (in tons of dry matter per hectare). Symbol r denotes crop residue.
f^r_{cb}	Feed required (in kt of dry matter) from crop residues per year by 1000 heads of animal type b.
N^r_{cj}	Crop residue (in kt of dry matter) used directly as nutrients in the fields for crop c by class j.
F^r_{cj}	Crop residues (in kt of dry matter) used as feed by class j.
O^r_c	Crop residues (in kt) used for other purposes.
L_{cj}	Land for crop c (in kha) by income class j.

A_{bj}	Animal type b (1000 heads) owned by class j.
Q^r_{cj}	Crop residues for crop c (in kt) used for burning by income class j.
$F^r_{cj}\sum_b f^r_{cb}A_{bj}$	Feed for animals from crop residues.

Crop residues are available only in the months of harvest. (However, the application of the model is only done annually and not monthly).

$$\underset{\substack{\text{crop residue}\\ \text{production}}}{-y_{cj}\cdot L_{cj}\cdot r_c} + \underset{\text{feed}}{F^r_{cj}} + \underset{\text{fields}}{N^r_{cj}} + \underset{\substack{\text{house-}\\ \text{holds}}}{Q^r_{cj}} + \underset{\substack{\text{other}\\ \text{purposes}}}{O^r_{cj}} \le 0 \tag{11.2}$$

This is for each income class j. Residues are labeled r.

Total use of crop residues by all income classes is Q_1:

$$\sum_j \sum_c Q^r_{cj} \le Q_1 \tag{11.3}$$

11.5. Livestock: Maintenance and Services

The livestock module consists of the feed and human labor requirements for the animals, dung production and its use by various income classes, and the services provided by the working animals. Only cattle and buffaloes are considered in the model because they have high feed requirements and also highly volatile dung production, and they provide services. Thus, horses, sheep, goats, etc., are not considered. The number of animals and their distribution between various income classes are considered to be exogenously given. For service purposes, the equivalent animals are calculated by using the equivalence principle:

$$2 \text{ cows} = 1 \text{ bullock} = \frac{1}{2} \text{ buffalo}$$

Meat, milk, and other products given by animals are not considered because of the limited objective of studying energy-related issues.

The ownership of animals according to income groups is given by Asseldonk (1982), and is reorganized here in terms of working and nonworking animals as shown in *Tables 11.7* and *11.8*.

The working and nonworking animals had to be separated because of higher calorie intake of working animals. In the present study, animal calorie and protein requirements were taken to be 2.6×10^6 kcal and 80 kg of protein, respectively, for nonworking including calves, and 3.8×10^6 kcal

Table 11.7. Number of working animals (1000 animals; Asseldonk, 1982).

	Cattle			
Socioeconomic group	*Male*	*Female*	*Total male cattle*[a] *(Buffaloes)*	*Driving power equivalent*
Landless laborers	211	64	8	259
Small farms	771	530	10	1056
Medium farms, tenants	1269	656	23	1643
Medium farms, owners	2234	1153	42	2895
Large farms	2035	464	104	2475
Very large farms	1096	447	190	1699
Total	7,616	3,315	376	10,027

[a] .5 working buffalo ~ 1 working male cattle ~ 2 working female cattle.

Table 11.8. Livestock-related data, 1976–1977, adapted to the model.

Indicators	*Units*	*Nonworking cattle*	*Working cattle (incl. buffaloes)*[a]
Ownership by income class:	10^3 A[b]		
Small		1236	1056
Medium I		1435	1643
Medium II		2528	2895
Large		2333	2475
Very large		976	1699
Landless		1071	259
Total		9579	10027
Calorie intake per animal per year	10^6 Mkcal/A	2.6	3.8
Percent obtained by grazing	%	30	30
Dung output per animal per year	t/A	0.65	0.95
Fraction of dung collected	t/t	0.8	0.5

[a] 1 cow = .5 bullock; 1 bullock = .5 buffalo (for plowing purposes). [b] A = animal.

and 80 kg of protein per working animal. A kg of feed from rice straws contains 1.6×10^3 kcal and 35 g of protein. It is assumed that one quarter of the feed will come from the grassland including fallow land. The livestock-related data adapted for the model are given in *Tables 11.7* and *11.8*.

11.5.1. Maintaining working and nonworking animals

Feed requirements: Feed required in addition to that obtained from pastures (approximately 30% of the requirements) could be obtained from crop residues and, when that is not sufficient, the feed could be bought. The calorie and protein contents of the individual feed have to be greater or equal to the calories and protein required by the animals. In addition to feed, maintaining animals requires human labor.

Animal Feed Balance: f

$(\text{cal})^B, (\text{prot})^B$	Calorie and protein coefficients of bought feed (in 10^9 kcal and kt of feed).
B^f	Bought feed (in kt).
$f_b^{\text{cal}}, f_b^{\text{prot}}$	Calorie and protein requirements per year for one animal (in 10^6 kcal and t, respectively).
A_b	1000 animal heads of type b.
$(cal)^r$, $(prot)^r$	Calorie (in 10^6 kcal/t) and protein (in t/t) of crop residues.

Fixed amounts of $(\text{cal})^{past}$ and $(\text{prot})^{past}$ are obtained from grazing in pastures.

Calorie balance:

$$-(\text{cal})^{past} - (\text{cal})^B B^f - (\text{cal})^r * F^r + \sum_b f_b^{\text{cal}} * A_b \leq 0 \tag{11.4}$$

Protein balance:

$$\underset{\text{pastures}}{-(\text{prot})^{past}} \quad \underset{\text{purchased feed}}{-(\text{prot})^B * B_f} \quad \underset{\text{crop residue}}{-(\text{prot})^r * F^r} \quad \underset{\text{requirements}}{+\sum_b f_b^{prot} * A_b} \leq 0 \tag{11.5}$$

This is for each income class j. Animal feed is labeled by f.

11.5.2. Dung production and its uses

The availability of dung for both types of animal is considered along with the collection coefficient, which is generally smaller for working animals. This could be used by each income class from the livestock it has as follows:

(1) For cooking in the household [2].
(2) As manure in the farms.
(3) As input in the biogas plants.

Animal Dung Balance

d_b	Dung in dry matter (d.m.) per year in kt per 1000 animals of type b.
c_b^d	Fraction of d_b that is collected or gathered.

Q_j^{db}	Biogas produced from dung (in km^3 per year).
N_j^d	Dung (in t of d.m.) that is used directly as manure.
Q_j^d	Dung used in households by jth income class for cooking (in t).
e_b^d	Tons of dung required for 1000 m^3 of biogas.

$$-\underbrace{\sum_b c_b^d d_b A_{bj}}_{\substack{\text{collected}\\ \text{dung from}\\ \text{animals}}} + \underbrace{N_j^d}_{\text{manure}} + \underbrace{e_b^d Q_j^{db}}_{\text{biogas}} + \underbrace{Q_j^d}_{\substack{\text{household}\\ \text{cooking by } j\text{th}\\ \text{income class}}} \leq 0 \qquad (11.6)$$

Total dung used for cooking by all income classes is Q_2:

$$\sum_j Q_j^d = Q_2 \qquad (11.7)$$

This is for each income class j. Animal dung is labeled by $\mathbf{d}$.

11.6. Fertilizer Sector

There are four ways of obtaining fertilizers:

(1) By using crop residues, i.e., burning or plowing back straws on the ground.
(2) By using dung.
(3) By using biogas sludge.
(4) By purchasing chemical fertilizers.

The first three of these are organic fertilizers.

However, recall that the objective function minimizes only purchased commodities. Therefore, the choice of how much biomaterials are used, and for what purpose, depends on the relative prices of bought fuel, fodder, and fertilizers, and on the demand for each. Shortfall is made up by the purchased fertilizers.

In *Tables 11.9* and *11.10*, chemical fertilizer consumption by each income class is given in terms of the three nutrients used per hectare. While the magnitude of fertilizer use was obtained from BBS, it was assumed that all income groups use N, P, and K in the same proportions, i.e., 68.6: 25.4: 6.0. In some of the earlier runs, it was additionally assumed that an equal amount (i.e., 50% of the total) will come from organic fertilizers, i.e., manure from dung and burning crop residues. However, as we shall see later, this is an overestimation, and perhaps less than 30% comes from organic fertilizers.

Table 11.9. Total consumption (in kt; Stolwijk, personal communication).

Nutrient[a]	*Small farms*	*Medium farms (tenants)*	*Medium farms (owners)*	*Large farms*	*Very large farms*	*Total*
Urea	27.5	75.2	78.9	102.2	75.2	359.0
TSP	9.8	26.7	28.0	36.3	26.8	127.6
MP	1.7	4.8	5.0	6.5	4.7	22.7
NP	0.3	0.9	0.9	1.2	0.8	4.1
NPK	0.5	1.3	1.3	1.7	1.3	6.1
SP	0.1	0.3	0.3	0.4	0.3	1.4
Total	39.9	109.2	114.4	148.3	109.1	520.9

[a] Urea = 46% N; TSP = 46% P_2O_5; MP = 60% K_2O; NP = 42% P_2O_5; NPK = 15–15–15; SP = 18% P_2O_2. Average prices per kg nutrient: 1 kg N = T3.49; 1 kg P_2O_5 = T2.80; 1 kg K_2O = T 1.79.

Table 11.10(a). Nutrients from inorganic fertilizers (in kg/ha).

Type of farm	*Nitrogen*	*Phosphorus*	*Potassium*	*Total*
Small	8.243	3.058	0.706	12.007
Medium I	7.612	2.823	0.671	11.106
Medium II	8.277	3.063	0.723	12.063
Large	10.899	4.040	0.957	15.896
Very Large	4.895	1.817	0.423	7.155
Total	7.561	2.804	0.661	11.026
%	68.576	25.429	5.993	100%

Table 11.10(b). Contributions of organic fertilizer are worked out using the following values of N, P, and K.

Organic fertilizer	*Nitrogen*	*Phosphorus*	*Potassium*
Crop residues (kg/ton)	2.5	0.8	0.7
Dung (kg/ton)	10.0	5.0	12.0
Biogas sludge (kg/ton of dung)	16.0	14.3	10.0

Fertilizer Nutrients Balance

$(\text{nut})^{d,n}$	Nutrient of n type (in t per kt of dung).
$(\text{nut})^{r,n}$	Nutrient of type n (in t of d.m. per kt of crop residues).
$(\text{nut})^{b,n}$	Nutrients of type n (in from 1000 m^3 bio-gas).
F_{cj}^{n}	Applied fertilizers on crop c by class j (in t).
B^{n}	Purchased chemical nutrients (in t).

$$N^{b}_{nj} = Q^{db}_{j} * (\text{nut})^{b,n} \tag{11.8}$$

N^{d}_{n}, N^{r}_{n}, N^{b}_{n}, and B^{n} are activities of fertilizing with dung, crop residues, biogas sludge, and bought chemical fertilizers, respectively.

$$\underset{\text{applied fertilizer}}{\sum_{c} F_{ncj}} \quad \underset{\text{bought chemical fertilizer}}{- B^{n}_{j}} \quad \underset{\text{manure}}{- (\text{nut})^{d,n} N^{d}_{nj}} \quad \underset{\text{crop residues}}{- (\text{nut})^{r,n} * N^{r}_{nj}} \quad \underset{\text{biogas sludge}}{- N^{b}_{nj}} \leq 0 \tag{11.9}$$

The equation is repeated for each type of nutrients N, P, and K, i.e., $n = 1, 2, 3 =$ N, P, K, respectively.

11.7. Energy from Agriculture

11.7.1 Energy supply side

The energy module considers different types of energy sources used in households, rural industries, and agriculture. They are classified in three categories:

(1) Noncommercial energy, which is gathered or produced within the agricultural system, such as wood, dung, and crop residues.
(2) Secondary energy forms obtained after the conversion processes using noncommercial energy forms. However, the charcoal and gasohol options are not relevant for Bangladesh. Therefore, although theoretically possible to include, they are dropped here for convenience.
(3) Commercial energy that is purchased, such as kerosene, diesel, electricity, or natural gas.

The manner in which each of these categories is treated is discussed below. The distinction is made by income class if the production is controlled by the user. For example, biomass use is included in the first category, which is directly used by the consumer without processing. The 12 energy sources are treated as follows:

(1) *Crop residues:* As mentioned before, production of each crop is multiplied by the crop residues it produces. Since each income class maintains control over how to use them, this energy source (or fertilizer source) is treated for each income class separately. Having produced the crop already, obtaining residues costs only labor.

(2) *Animal dung:* For two categories of cattle – working and nonworking cattle – two different dung coefficients are taken and two different collection coefficients. A working animal, which is also a strong adult, eats 30–50% more than nonworking animals, more than 50% of which are calves. Thus, the dung output of a working animal is higher but, on the other hand, the collection coefficient is low because they are not stall-bound.

Three categories of wood are considered as fuelwoods:

(3) *Fuelwood 1:* In this category, the supply is gathered from homesteads (clusters of trees within houses), thus requiring only labor. The upper limit of wood is estimated from the area under them and its productivity. The heat values of twigs, branches, and barks are low.

(4) *Fuelwood 2:* The supply is obtained from natural forests by employing human labor. Its upper limit is specified by the area under forests multiplied by productivity. The heat value of forest wood is higher than dry matter collected around homesteads.

(5) *Fuelwood 3:* This is harvested from wood plantations which are grown commercially, thus requiring investment, management, and perhaps transport. The heat value of this wood is the highest.

The above-mentioned biofuels could be processed through conversion facilities to obtain more efficient and high-valued energy forms. These energy forms require initial investment, but in this static model they are considered after deriving their annual costs, assuming a certain rate of return (10%). A selected few secondary energy forms obtained from biofuels are as follows [3] :

(6) *Biogas plants:* Cattle dung could be converted into biogas (methane) by anaerobic digestion processes. The residue biogas sludge could still be used as fertilizer nutrient (values for which are shown in the fertilizer sectors). Thus, it allows manure to be used as a more efficient energy form as well as retaining the possibility of using the sludge as fertilizer. The annualized price is, however, high because its capital cost is nearly US $250 for a 2 m^3/day plant. It requires 6 tons of dung for 1000 m^3 of gas production.

(7) *Commercial energy forms:* Purchased energy, such as kerosene, diesel, and electricity, come into this category. They are usually brought into rural areas from urban areas. In the rural energy model they are purchased only in the absence of other fuels, partly because their availability in the rural areas is a constraint due to the poor distribution system, and partly because the rural population is unable to pay for them in cash.

The 12 categories of fuels are used by 3 sectors, i.e., households, rural industries, and agriculture, with different efficiencies, details of which are discussed below.

11.7.2. Energy demand side

Household sector (excluding alcohol and diesel). This includes all households, split into different income classes, in rural and urban areas. The energy used by rural households is assumed to be mainly for cooking and lighting. All fuels except alcohol and diesel could be used for cooking. They are all measured in terms of useful energy, i.e., primary energy contents multiplied by efficiencies with which they are used. For lighting, only three sources are considered: kerosene, biogas, and electricity. However, since the quality of light by each source is different, rather than using "useful energy concept" in the case of lighting, one merely asks: how many units would be required annually by a household if lighting is by only one particular source? The values taken for the three sources (for Bangladesh), respectively, are: 25 l of kerosene, 220 m^3 of biogas, or 160 kWh of electricity. However, it should be noted that in the present conditions in most rural areas of developing countries, the use of kerosene lamps for lighting is common.

Food processing, in particular, parboiling paddy, boiling milk, etc., is quite significant, but because of inadequate data it is assumed that household energy demand surveys include this component within cooking.

Agriculture sector (including diesel, heavy oil, and electricity). This includes energy use for tractors, irrigation pumps, and trucks, and the competition of each for use in activities such as plowing, transport, and irrigation is considered with other methods such as by animals, humans, or others.

11.8. Validation of the Model

Much was learned from the exercise of the validation of the model by checking consistency of all parameters for 1976–1977.

11.8.1. Food–fodder–fuel–fertilizer relationships

The resource system of Bangladesh is extremely constrained and precariously balanced. These features are captured in the linear programming model developed here, where some choices are made partly on price considerations, i.e., relative prices of fodder, fuel, and fertilizer, and partly on matching assets (livestock, land), energy supply from these, and the energy requirements. The objective function minimizes purchased fuels and fertilizers, and maximizes income.

Due to uncertainties in the data, a number of variations were made to test the model, to examine consistency, and to probe sensitivities. A base run is selected for the purpose of providing a revenue system that describes, in our view, the reality as closely as possible. Nearly 50 runs were made for the sensitivity analysis and to probe the ranges of uncertainties in the parameters.

11.8.2. How does the present system behave?

A number of runs had to be made to reproduce the existing rural energy system, which in the present case is characterized by certain energy and inorganic fertilizer uses that were already reported for the year 1976[1]. The ranges of parameters had to be tried to obtain a reasonable run characterizing the present energy system of Bangladesh. In the base case for 1976, some of the already known features, such as amount of inorganic fertilizers used, commercial energy purchased, wood supplied, etc., were held fixed as they are already known. However, this was not the case for the policy runs where the model was allowed to make optimal choices. These changes are as follows:

(1) Increase of wood supply from 6 to 10 Mt (includes branches and twigs and to some extent leaves).

(2) Increase in cooking efficiencies (which also leads to additional resources as less resources are required for obtaining the given demand of useful energy).

(3) Increase in dung collection coefficients for nonworking animals from 80% to 90%, and for working animals from 50% to 80%.

(4) Reduction in straw consumption from 1.7 to 1.0 per animal. (The latter implies either that large quantities of feed come from pastures and grains or that cattle are starved to a considerable extent.)

Since there are a number of uncertainties in the actual data of each of the parameters described above, these scenarios gave insights into bounds of the system. It is interesting to see that none of these "improvements" led to additional unused organic materials in the system. They only reduced the purchased or deficit amounts of fertilizer, fuel, and fodder. In other words, there was no case when supply of biomass exceeded the needs.

Some selected runs are reported fully in *Table 11.11* and are described below.

Run 1: The base run is selected as the one that represents the 1976–1977 situation as closely as possible. It is characterized by 10 Mt of total wood supply for cooking, 13Mt of collected dung supply, 53 kg/ha of total fertilizer application ratio, and fuel

Table 11.11. Base run (corresponding to 1976–1977) and variations of assumptions.

Fuel	*Base*[a] (Run 1)	*Wood availability 8 Mt* (Run 2)	*Dung availability 18 Mt* (Run 3)	*Fertilizer rate reduced 33 kg/ha* (Run 4)
Per capita energy for cooking:				
Crop residues (kg)	140	165	140	140
Animal dung (kg)	105	129	105	105
Fuelwood 1 (kg)[b]	64	64	64	64
Fuelwood 2 (kg)[b]	97	64	97	97
Commercial energy:[c]				
Kerosene (l)	0	0	0	0
Electricity (kWh)	0	0	0	0
Organic (dung + crop residue + biogas):[d]				
N in kg/ha (%)	6.6(20)	5.2(16)	11.6(35)	6.6(24)
P in kg/ha (%)	3.9(31)	3.0(24)	6.8(55)	3.9(35)
K in kg/ha (%)	7.6(99)	5.9(77)	13.5(100)	7.53(62)
Inorganic:				
N in kg/ha (%)	26.8(80)	28.2(84)	21.8(65)	21.4(76)
P in kg/ha (%)	8.5(69)	9.4(76)	5.6(95)	7.1
K in kg/ha (%)	0(1)	1.7(23)	0(0)	4.7
Use of dung total (kt):	13 197	13 196	18 475	13 197
Fertilizer (%)	50	39	64	50
Fuel (%)	50	61	36	50
Use of crop residues (kt):	45 723	45 723	45 723	45 723
Fertilizer (%)	4	4	4	4
Fuel (%)	19	23	19	19
Fodder (%)	61	57	61	61
Other (%)	16	16	16	16

[a] Base run is characterized by 1976 data + 10 Mt wood, 13 Mt dung, and 53 kg/ha total fertilizers. The rest of the runs are like base run except for the change that is shown.
[b] These two categories are to be viewed together. The distinction between the two is not considered, due to data limitation in all of these and subsequent runs. [c] Since this version of the model excludes energy for lighting, kerosene and electricity uses are negligible in the base run. [d] The first numbers refer to fertilizer in kg/ha. The numbers in brackets show the percentage share of organic fertilizer for a particular organic nutrient. The remainder is from inorganic sources. The reverse applies to the inorganic nutrients.

efficiencies as given in *Table 11.5*. The fuel:fertilizer ratio for the dung works out to be 50:50.

Run 2: Same as base run, except 8 Mt of total wood supply instead of 10 Mt. Due to a reduction of wood supply, dung utilization for fuel increases and the fuel:fertilizer ratio of dung reduces to 61:39.

Run 3: Dung output per animal is taken to be 0.91 t for nonworking and 1.33 t for working animals, giving on the average collected dung of 0.9 t per animal, as assumed by most in the literature; but this is probably unrealistic considering the age distribution of cattle and fodder availability in Bangladesh. Interestingly, the additional dung put into the system is not burnt, but is allocated to fertilizer, giving the 36:64 fuel:fertilizer ratio assumed in the literature.

Run 4: This run is similar to the base run but has somewhat reduced (33 instead of 53 kg/ha) fertilizer application rates, which reproduces actual purchase of chemical fertilizers reported for 1976–1977 more closely than the base run. This should have been characterized as the base run. However, it has little effect on the energy picture and, therefore, the base run was not changed for the sake of convenience. It is interesting to see that no changes in the energy scene can be seen in the above runs, implying that fodder and energy needs are met first, and then adjustments are made in the fertilizer sector. Thus, all the variations given above use about 6 Mt of dung for fuel first, and then use varying amounts of dung for fertilizer depending on the availability.

11.8.3. The fuel efficiency question

Seen from another angle, the model is used to predict the ranges of unknowns in the system. For example, the estimates in the literature for fuelwood use (including twigs, leaves, and branches) in Bangladesh range from 4 to 20 M per year (HES, 1976). A special inquiry carried out by FAO (Douglas, 1982) puts these estimates at around 6 Mt. The results of the model suggest that the wood supply has to be between 8 and 10 Mt at least to meet other constraints in the system. The fuel efficiencies of noncommercial fuels, also, could not be as low as the 5% presumed by some, but range around 10%. [However, this could best be settled by assessments in the laboratory of a few representative cooking stoves and fuels. Islam's (1980) experiments suggest 10% efficiencies.]

Thus, the model helps in fixing the uncertain parameters in that there is no alternative way to meet the quoted demand by HES except with fuelwood ranging from 8 to 10 Mt, fuel efficiencies of the order of 10%, fodder availability of about 1.4–1.7 t per animal, and dung collection of about 0.7 per animal. Tyers (1978) assumes 0.5 per animal, which is too low. Manibog (1982) and many others including BHS, on the other hand, assume only 35% use of dung for fuel but the present study puts it at a much higher level: around 50% on average and up to 90% for small farmers [4]. To provide 0.7 t of dung, the straw consumption has to be at least 1.6 t (40–50% of fodder is converted into dung), and collection efficiency of dung has to be up to 90%. These happen to be the values taken in the model.

Another interesting feature of the results is that the 1200 KJ of useful energy (at 10% efficiency) in 1 kg of dung is 4–5 times more valuable at the prevailing prices of fuel and fertilizers in most developing countries than the 10 g of N, 6 g of P, and 12 g of K that it contains. These are also the conclusions of the recent study by Aggarwal and Singh (1984), who have done a cost–benefit analysis for a state in India. Thus, if the farmers use dung for manure at all, it is due to one or more reasons stated below:

(1) They have other better and preferred fuels (such as commercial energy or wood) available and they do not need to use dung for fuel on economic grounds.
(2) The value of manure in terms of nutrients is a minor aspect compared to the improvements brought about in soil characteristics by providing humus and organic matter to hold the plants.
(3) Some additional possibilities (but unlikely) are that they are simply unaware of economic advantages of burning dung compared to using it as manure.
(4) More likely reasons could be unavailability of chemical fertilizers and commercial fuels in the rural areas at the quoted prices and the relative needs for these in different seasons.
(5) In addition to the economic advantage of burning dung, other reasons could be that both the supply of dung and the need for fuel are continuous (daily) functions of time rather than peaking during a season, and use of dung minimizes the effort of stocking. It is not likely that a woman will go several kilometers to collect wood when she could use the dung from her backyard. Thus, its use for fertilization – which is a seasonal need – could have low priority out of season. During monsoon, when it is difficult to dry dung for fuel, it is better to use it as manure in the fields.

The last reason, especially, applies to Bangladesh and resource-scarce regions of developing countries where fuel scarcities are severe. A pilot sample survey needs to be carried out to ask the questions suggested above, and to test some additional hypotheses and ascertain who uses dung for manure and why.

In particular, the use of high average norm of 0.9–1.0 t of dung per animal leads to overestimation of dung up to 20 Mt. But when one considers that a third of the animals are calves of less than 3 years of age, and uses the norm of 0.7 t, then the total availability decreases to 13 Mt. When the supply was arbitrarily increased to 20 Mt in one run, the dung was used for burning and the rest for other purposes, there still remained 6 Mt as in the case of 13 Mt. Thus, 6 Mt is 35% of 20 Mt but 50% of the 13 Mt. This, then, explains why the present study differs from others.

11.9. Results of the Model: Policy Scenarios

Having validated the model and having fixed the parameters, one could use the model to look into policy issues. These policy issues are relevant for Bangladesh.

11.9.1. Would all the farmers accept HYV? Under what conditions?

It is argued by some that high-yielding varieties (HYV) are not acceptable by farmers because of the small straw output per ton of grain that HYV give compared to the traditional varieties (1:1 rather rather than 2:1 or 3:1) [5]. Therefore, the model runs were made to find out biomass implications of measures of introducing HYV.

The HYV are specifically bred to give more grain than straw. However, HYV require much more fertilizer compared to the traditional varieties. Assuming 1 kg of fertilizer gives 10 additional kg grains, 100% increase in fertilizer levels in Bangladesh (from 33 to 66 kg) could lead to an increase from 1.5 tons of paddy per hectare to nearly 2 tons per hectare, i.e., a 30% increase. A 200% increase in fertilizers, i.e., 100 kg ha, leads to the average yields of 2.5 t/ha for paddy and wheat, and to 1.7 t/ha for jute. Thus, two levels of fertilizer application were considered with two levels of prices: base run prices (actual prices of 1976) and "increased" prices. The crop residue coefficients for traditional and HYV scenarios are given in *Table 11.6*. The results are discussed below and are summarized in *Table 11.12*. There are also other factors that increase yield, such as irrigation, soil improvements, etc., but only yield increases due to fertilizers are considered.

As we are concerned only with policy scenarios, i.e., how farmers of different income groups would respond to the introduction of HYV and under what conditions, it is assumed, for the sake of simplicity, that *all* the farmers switched to HYV, keeping other conditions of 1976 for runs (2), (7), (8), and (9) constant. Population in 1983 is used, keeping all the state variables, except fertilizers and yields, constant. Therefore, the results are dramatic. Of course, in real life the farmers would switch gradually, but this run is made to assess the policy implications of introducing HYV on farmers of different income groups. It is interesting to see that a 30% increase in yield due to HYV reduces availability of crop residues from 45.5 Mt to 35.5 Mt. But when the fertilizer levels are increased threefold, leading to a 60% yield increase, then again the availability of crop residues increases sufficiently such that the original situation is approximately restored. In fact, runs carried out without HYV show that in the short term, the farmers are better off without HYV as far as fuel and fodder are concerned.

The small farmers are hurt the most, as their fodder availability per animal is reduced to half in the second case and does not retrieve itself even in the third case. Fodder availability of medium-level farmers is reduced by 15% in the third case. Large farmers have enough fodder in both cases, but their fuel use of crop residues decreases in the second case.

Table 11.12. Comparison of the base run with HYV scenarios (F = fertilizers, pop = population, Y = yields).[a]

Fuel	*Base* (Run 1)	*F × 2, +30% Y, with HYV* (Run 5)	*F × 3, +60% Y, with HYV* (Run 6)	*F × 2, +20% pop, +30% Y, no HYV* (Run 7)	*F × 3, +20% pop, +60% Y, with HYV* (Run 8)
Per capita energy for cooking:					
Crop residues (kg)	140	68	130	190	164
Animal dung (kg)	105	175	115	94	120
Fuelwood 1 (kg)	64	64	64	53	53
Fuelwood 2 (kg)	97	97	97	81	81
Commercial energy:					
Kerosene (l)	0	0	0	0	0
Electricity (kWh)	0	0	0	0	0
Organic (dung + crop residue + biogas):					
N in kg/ha (%)	6.6(20)	2.0(3)	5.9(6)	7.4(11)	4.0(4)
P in kg/ha (%)	3.8(31)	1.2(5)	3.5(9)	4.0(16)	2.4(6)
K in kg/ha (%)	7.6(99)	2.5(35)	6.9(63)	7.4(76)	4.8(44)
Inorganic:					
N in kg/ha (%)	26.8(80)	64.8(97)	94.4(94)	59.5(89)	96.2(96)
P in kg/ha (%)	8.5(69)	23.5(95)	33.6(91)	20.8(84)	34.7(94)
K in kg/ha (%)	.0(1)	4.6(65)	4.1(37)	2.3(24)	6.2(56)
Total use of dung (kt):	13197	13197	13197	13197	13197
Fertilizer (%)	50	47	46	47	32
Fuel (%)	50	53	54	53	68
Use of crop residues (kt):	45723	35552	43756	59440	43756
Fertilizer (%)	4	0	3	12	1
Fuel (%)	19	12	18	24	28
Fodder (%)	61	67	62	49	51
Other (%)	16	21	17	15	20

[a] See footnotes to *Table 11.11.*

11.9.2. What could happen when population increases?

The population of Bangladesh is assumed to have increased at 3% annually until the year for which the base run of the model is made. Population increases of 20% and 40% over 1976–1977 figures are considered as two cases. How do the allocation patterns change in such a situation? It is assumed that per capita useful energy for cooking, which is the lowest in the world, does not change. The population increases of 20% and 40%, respectively, are assumed to take place evenly in all classes, and questions related to diseconomies of scale for subdivided farms of smaller units are not considered. To feed this population somewhat better than today, 60% increase in yields and three times higher fertilizer application rates are assumed, the rationale for which is discussed in the earlier scenario. No increase in livestock is assumed because they have been approaching a stable level for the last few years (though this is not true of goats, which are not in this energy model because they do not work). The results of the two scenarios are summarized in *Table 11.13*.

Table 11.13. Comparison of the base run with higher population scenarios of the future (Y = yields, pop = population, HCE = higher cooking efficiency).[a]

Fuel	*Base* (Run 1)	*+30% Y, no HYV, +20% pop* (Run 7)	*+60% Y, +20% pop* (Run 8)	*+60% Y, with HYV, +40% pop* (Run 9)	*+60% Y, with HCE, +40% pop* (Run 10)
Corresponding year	1976	1983	1983	1990	1990
***Per capita energy for cooking*:**					
Crop residues (kg)	140	190	164	188	78.6
Animal dung (kg)	105	94	120	113	71.3
Fuelwood 1 (kg)	64	53	53	46	45.6
Fuelwood 2 (kg)	97	81	81	69	69.5
***Commercial energy*:**					
Kerosene (l)	0	0	0	0.58	0
Electricity (kWh)	0	0	0	2.28	2.28
***Organic (dung + crop residue + biogas)*:**					
N in kg/ha (%)	6.6 (20)	7.4 (11)	4.0 (4)	3.1 (3)	6.7 (7)
P in kg/ha (%)	3.9 (31)	4 (16)	2.4 (6)	1.9 (5)	4.0
K in kg/ha (%)	7.6 (99)	7.4 (76)	4.8 (44)	3.7 (35)	7.9 (72)
***Inorganic*:**					
N in kg/ha (%)	26.8 (80)	59.5 (89)	96.2 (96)	97.2 (97)	93.5 (93)
P in kg/ha (%)	8.5 (69)	20.8 (84)	34.7 (94)	35.3	(95)
K in kg/ha (%)	0(1)	2.3	(24)	6.2	(56)
Total use of dung (kt):	13197	13197	13197	13197	13197
Fertilizer (%)	50	47	32	25	53
Fuel (%)	50	53	68	75	47
Use of crop residues (kt):	45723	59440	43756	43756	43756
Fertilizer (%)	4	12	1	0	2
Fuel (%)	19	24	28	38	16
Fodder (%)	61	49	51	39	59
Other (%)	16	15	20	23	23

[a] See footnotes to *Table 11.11*.

It can be seen that the continuation of the 1976-1977 pattern could almost be managed on the average in 1983 with some modifications, of course, and with considerable hardships to the landless and small farmers. The situation in 1990 is especially alarming. Despite large inputs of purchased commercial energy for cooking and significant addition of chemical fertilizers (increase to 60 kg/ha), fodder of the order of 0.8 t per animal would be required so as to replace the agricultural residues that are burned in the households. By this time, not only the landless and small farmers but even the middle farmers are vulnerable, in both fodder and energy requirements. This is because, with the same amount of land and animals, they cannot support 40% higher population. However, large and very large farmers manage to balance all their requirements even in 1990.

11.9.3. What effects would alternative cooking practices have?

Due to the predominant role of cooking energy, which claims a large proportion of noncommercial energy as well as total energy in Bangladesh, it is relevant to look into the role of higher efficiency that can be brought about by improved stoves, better cooking practices, and alternate pans, etc. Many of these are discussed by Parikh (1985). Without going into actual details, one could assume that each of the fuels considered could be used with higher efficiencies, as shown in *Table 11.13*.

Run 10 in *Table 11.13*, showing the implications of higher cooking efficiencies, makes it clear that the policy concerning improved stoves and cooking practices pays off even in the short term. It is the major step that will make it possible for a Bangladesh with 40% more population in 1990 to obtain its cooking energy requirements from the available funds.

It can be seen that the per capita use of each of the noncommercial fuels goes down compared to the base run (1) for 1976. This enables the population to reduce kerosene demand for cooking and to obtain at least some fertilizers from organic sources. The ratio of dung utilization for fertilizer:fuel improves from 25:75 as in run 9 to 53:47 in run 10, which is even better than the base run of 1976 with 40% less population. The utilization ratios of crop residues for fodder:fuel:fertilizer:other also improve and are similar to the base run improving the fodder situation.

Although in Bangladesh cooking with natural gas-based electricity appears to be more desirable than with kerosene, which has to be imported and is highly taxed, this option is not put into the model as we are concerned with rural areas where natural gas cannot be transported for a few consumers.

Biogas, charcoal, and ethanol production programs may have relevance in special farms, but their contributions to the national energy scene would not be significant.

Even to keep 10 Mt of fuelwood supply (for cooking only) going in the future may require afforestation programs and high cooking efficiencies because, as shown by Douglas (1982), the present supply of about 10 Mt already comes from deforestation and is more than the natural regeneration limits.

Thus, the model makes a strong quantitative case consistent with other variables for improved cooking practices, which is perhaps the only major option available to improve biomass availabilities for fuel, fodder, and fertilizers.

11.10. Conclusions and Policy Implications

Food–fodder–fuel–fertilizer relationships are complex in the case of resource-constrained Bangladesh, where high population density reduces the per capita availability of biomass to a great extent. Moreover, due to the low purchasing power long-term solutions, which may be desirable, are limited.

The purpose of this study is threefold:

(1) Verification of existing data and identification of crucial parameters.
(2) Understanding of dynamics of interrelationships for different income groups.
(3) Insights into future developments.

We take each purpose in turn.

11.10.1. Dynamics of the fodder–fuel–fertilizer interrelationships

These are studied under varying conditions such as changes in price, biomass availability, efficiency improvements in utilization, etc. However, prior to that, considerable time had to be spent on data analysis. In doing so, some estimates, which have until now been somewhat ambiguous in the literature, are firmed up. These are, for example, the ranges of 8–10 Mt wood supply, 10% fuel efficiencies for cooking, dung use for fuel:fertilizer 50:50, straw consumption per cattle 1.4–1.7t/animal with dung output of about 0.7 t/animal.

It seems that the nearly 12000 kJ that are contained in 1 kg of dung, which could be burned at 10% efficiency, is more valuable than the fertilizer contents of 0.01 kg nitrogen, 0.006 kg phosphorus, and 0.012 kg potassium. In fact, if nutrients were the only criteria for using manure – and not the humus and improvements of soil quality – then it would take a 4–5 times increase in fertilizer prices before the small farmers would switch from burning it to using it as fertilizer. In other words, the dung will be used as manure only by those who due either to their income or fuel abundance have other preferred fuels, but those who do not have alternative fuels would choose to burn dung for fuel rather than use it as fertilizer.

11.10.2. Insights into income groups

Our results show that subsistence-level households end up burning dung and sometimes straw. The reason for this is twofold. There is not enough biomass production available to the landless and small farmers (with less than 1 ha of land and one or two animals) to take care of their needs for fodder, fuel, and fertilizers. Additionally, straw is used to feed the animals, in preference to using it as a fertilizer.

While changing to HYV for 20% additional yield, or also when fuelwood availability is reduced from 10 to 8 Mt, landless and small farmers run into fodder deficits. They burn almost all their dung for fuel in many of the scenarios. More arguments for this were given above in the base run discussion. When population increases by 40%, even medium farmers become vulnerable to fodder deficits.

Large and very large farmers of the villages also use crop residues for fuel, but in their case, even after meeting cooking requirements, which are small in comparison with the biomass supply, there is enough available to feed the animals and for fertilizers. They use all their dung as manure and are not vulnerable even in 1990 when a 40% increase in population reduces their per capita land and animals.

11.10.3. Insights into future developments and strategies

(1) It is clear that most of the additional fertilizer required for the yield necessary to feed the future population would have to come from inorganic fertilizers, with the possible exception of potassium fertilizers.

(2) If high-yielding varieties (HYV) are to be promoted, it would require a simultaneous support program for fodder for the animals, especially for the small farmers because they give 40% less crop residues. Additional fodder would be necessary until the time when the fertilizer doses become sufficiently high so that the high yields compensate for the losses (due to reduced crop residues per ton of yield).

(3) When, in 1990, the population increases by 40% over its 1976 figure of 82 million, additional fodder provisions of about 50% (for the same number of animals as in 1976), large purchases of commercial energy, and high inputs (100 kg/ha) of fertilizers may be necessary. Almost all the additional fertilizer inputs, except potassium, will have to come from inorganic fertilizers. Improvements in cooking efficiencies and even cooking with natural gas based electricity – which turns out to be cheaper than imported kerosene – need to be promoted.

An even more comprehensive exercise is underway for obtaining better insights into the role of animal power versus mechanization, monthly shortages of fuels, the role of energy conversion technologies such as biogas plants, charcoal kilns, alcohol distilleries, etc. The conditions for applicability to other countries are discussed in Section 11.1. Finally, it should be stressed that the issues discussed here are relevant for most low- and middle-income developing countries, including many provinces of China and India, and concern nearly two billion people.

Acknowledgments

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Notes

[1] 15 taka = 1 US dollar; the help of Jan Morovic in processing household energy data is gratefully acknowledged.

[2] Although only the nitrogen is lost while burning, and phosphorus and potassium remain in the ashes, very often the ashes are not carried back to the fields but are used up for cleaning utensils.

[3] The revised model also incorporates family level (2 m^3), homestead level (10 m^3), and village level (100 m^3) biogas plants; pit kilns, brick kilns, portable metal kilns for charcoal and sugar cane, cassava and corn distilleries.

[4] Interestingly, this often quoted figure of 35% use of dung for fuel purposes, used by many studies of Bangladesh and several other countries, has its origin in a reference for India. The author had serious reservations about this number. These doubts are confirmed by the model runs. It may be appropriate to incorporate this point in future rural energy surveys to obtain a clearer picture.

[5] Manibog (1982) mentions that the fuel value of jute is so great that fiber is considered a by-product. Tyers (1978) finds that on increasing energy prices for rice growing, small farmers switch to jute growing. The present model does not go into crop allocation and assumes it to be fixed.

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PART III

Synthesis

CHAPTER 12

Sustainable Development of Agricultural Systems: Concerns, Approaches, and Policy Insights

J.K. Parikh

It is clear from the preceding chapters that a rich menu of approaches, issues, and policy insights have emerged while dealing with a common theme of interaction of resources, technology, and environment in sustainable development of agricultural systems.

The purposes of this chapter are to summarize the methodological and empirical studies described in this book, to give a comparative evaluation of different methods and case studies, and to highlight new insights that have emerged from this endeavor.

The summaries of individual chapters are already given in each chapter separately. Therefore, priority is given here to an overall summary; and issues that have been dealt with, approaches that have been considered, and insights and results obtained are summarized in a comparative sense. However, a short summary of each chapter is included here so as to cover all of them with a uniform perspective. In addition, summary sheets completed by the authors of the case studies are included.

To carry out systems analysis that deals with resources, technology, and environment for agricultural systems in an economic context is a difficult task not often carried out empirically in the literature. To fill this gap, the present book makes an attempt to deal with these issues in the context of substantive empirical applications in a variety of economies, in countries with a centrally planned economy, market economy, and developing countries. Of course, each of the issues could only be handled in a limited way;

and what is meant by resources, technology, and environment is defined separately by each case study author according to the importance of specific issues in the context of the region and the country concerned.

12.1. Methodological Approaches

Generally in the literature, there are policy studies dealing with agriculture from economic viewpoints and there are agronomic studies dealing with plant growth from biological viewpoints. These viewpoints need to be integrated for a realistic description of the system and for policy analysis. To explore interactions of resources, technology, and environment for policy purposes requires methodological approaches to quantify:

(1) How soil and climate resources determine potential technologies.
(2) How selected production technologies feed back on the soil resources.
(3) How to select appropriate production technologies that meet economic objectives and environmental goals.

The methodological approach described in this book deals with all the three aspects, as well as with the problems of implementing them in practical ways.

Two of the chapters on methodology describe biological approaches that relate soil and climatic resources to crop production while considering the effects of external inputs such as water and fertilizers for different soils. In addition, one of these papers also describes an approach to quantify changes in soil quality as a consequence of crop production. The third chapter then suggests a way to integrate such an approach in an economic framework while taking into account resources and farm technology inputs, such as tractors, harvesters, fuel, energy, etc., for a variety of soils whose characteristics change after each crop. Thus, subsequent cropping would have to be done in an altered soil and hence will have different yields.

12.1.1. Konijn's approach

The physical crop production model described by Konijn is based on the application of agronomic principles in a hierarchic manner. It starts from CO_2 assimilation information for a given location for standard radiative regimes, which gives maximum possible yields of the C_3 and C_4 types of plant. These yields are then modified due to soil conditions (texture, density, porosity), water balance, nutrients availability, etc. Elements such as precipitation, irrigation, evapotranspiration, runoff, and drainage are taken into account to solve for water balance. Potential plant production thus obtained is further modified due to nutrient balance and environmental conditions. The nutrient balance includes soil fertility and organic matter decay while the environment module considers modification of soil due to water erosion through the universal soil loss equation. The resource adjustment module considers the effect of fertilizer inputs for N, P, and K. Thus, one can finally estimate from the potential production that which is actually realizable. Plant growth is followed at 10-day intervals. This approach could be used as a tool and is empirically applied to the Stavropol region of the USSR, which demonstrates its practicability.

It may be noted that Konijn's approach also deals with the feedback on soil quality due to crop production. The environment module and the resources adjustment module update soil properties in his approach.

12.1.2. Approach of G. Maracchi *et al.*

The second similar biological approach to crop production by G. Maracchi *et al.* is specifically developed for the Mugello region in Italy. Although this approach, which also deals with agronomic description of plant growth, is similar to the one discussed above, its difference lies in the new way of synthesizing data. Data are obtained for two crops through remote sensing with time intervals as small as 15-minutes. Such data, although synthesized, are not yet used for economic modeling. The model, which deals with 15-minute time intervals, is actually validated for three crops in the Mugello region, namely, wheat, corn, and grasses. Once again, the validation exercise demonstrates the applicability of this method. The automated data entry and analysis procedures indicate the possibility of applying such local approaches to much larger regional, national, or global levels.

12.1.3. Contribution of Ereshko *et al.*

This chapter provides a methodological approach needed to carry further these agronomic models so as to apply them to problems of economic policy analysis for a region. In principle, the mathematical problem involved in finding strategies for sustainable agriculture is a problem of dynamic programming or optimal control. However, the use of the traditional approaches to solving such problems are computationally impracticable for the investigation of strategies for sustainable agriculture. This is due to the highly nonlinear character of the feedbacks in the system and its large dimensions, which explode exponentially with the number of time periods considered. Also, the number of time periods has to be rather large. This is because the economic impact of the production decisions has to be considered on an annual basis, while soil quality modifications take years as the environmental processes involved are comparatively slow.

Ereshko *et al.* describe alternative ways to simplify the problem and make it computationally practicable. Although full optimality is sacrificed in the suggested procedures for exploring alternative strategies, the simplifications are based on notions of agronomic realism of cropping patterns. Thus, one may expect that the loss of optimality may not be serious. (This, however, is not established by the authors.) Their procedure searches for sustainable cropping patterns for each soil class separately in the first stage, and an optimal cropping pattern for all the soil classes is selected in the second stage to meet economic objectives. Some of these procedures are applied in the Stavropol case study and shown to be practicable.

12.1.4. The uses of methodological approaches in the case studies

While the methodological developments described here required considerable effort, and new ideas have emerged from this endeavor, some of the case studies develop their own methodology dealing specifically with their regions. Therefore, the distinction between methodological studies and case studies mainly derives from the primary motivation behind the respective work. That is, methodological studies are carried out to fulfill the need for dealing with certain conceptual and scientific problems, whereas the case studies are carried out primarily to assist with the policy issues dealing with regional agricultural systems. Since all the case studies have different concerns, a few methodological approaches developed during the course of this work are not suitable for all the case studies. Exception to this is the case study of Stavropol, USSR, which has tried to use two of the methods developed during this work.

Moreover, the methodological and case studies were done somewhat simultaneously. Testing of new methods takes time, and the new data requirements could be difficult to fulfill. Therefore, some of the case studies have used simple crop yield responses (rather than crop production models developed here) in conjunction with a conventional linear programming framework for obtaining more insights into the interplay of resources, technology, and environment in regional agricultural systems. However, the way these have been used and the new insights obtained are by no means conventional. Not all studies involve excessive modeling. In most studies, in addition to modeling, there is a detailed quantitative description of the region concerned, which leads to a better appreciation of reality and hence to some preliminary policy conclusions.

Thus, the methodological approaches described in this book fill a gap in the existing literature of practical methods to deal with problems of sustainable agricultural systems.

12.2. Summary of Individual Case Studies

While conclusions and abstracts appear in each chapter, a synthesizing summary, which is uniform in perspective, can provide an integrated perspective and highlight special features of each. In addition, summary sheets completed by the authors are also provided to furnish readers with comparable information.

12.2.1. Stavropol, USSR

This case study represents many person-years of work, spread over several years, by scientists from a number of disciplines and involving several institutions in the USSR: in Stavropol and in Moscow. It has received the attention of policy makers at the highest level even during the problem formulation and execution stage.

The region is an important one with an area of 8 million hectares representing 2% of grain, 9% of wool, and 4% of sunflower production of the USSR. The Stavropol region is subject to extreme variations in weather, which cause considerable fluctuations in agricultural output. Moreover, the allocation of fallow land is essential to maintain soil moisture and fertility. In order to ensure a particular output, what should the extent of fallow land be under different optimization criteria?

The special feature of this case study is its effort to obtain potential yields from the physical crop production model and then link them in an economic model with planned investments. The climatic fluctuations in this region are such that unfavorable years could have only 30% percent of the yields of the favorable years. This necessitates the use of the crop production model; it is first used to estimate the parameters of the growth potential of several crops by using the actual data from past years. The functions estimated are later used for other climatic patterns.

The main objective of the Stavropol study is to define environmentally sound production strategies and their investment needs. The outcome of the effort gives the following:

(1) Evaluation of potential yields for different land classes and agricultural (climate) zones in different weather conditions.
(2) Estimation of optimal doses and kinds of organic and chemical fertilizers corresponding to maximum yields for different crop rotations and technologies.
(3) Solution of the problem of distribution of resources with constraints on their quantities.
(4) Evaluation of optimal fallow areas under winter wheat using two criteria: maximum average outputs and maximum stability of yields.
(5) Elaboration and realization of two linkage schemes, viz, evaluation of optimal rotations, technologies, and input distribution to minimize the total cost of production for a given grain output.

The model suggests that it may be worthwhile to increase fodder production by 30%–40% at the expense of reduction in grains by 10%. The results suggest that for the stable output of winter wheat, substantial portions of land in zones I and II must be kept under fallow. The extent ranges from 33%–50% depending on the optimality criteria and levels of fertilizer application chosen. If one were to consider cost minimization while doubling (or more) the 1960 output level, then the upper limit on the share of fallow is 42%. Further increase in output can be expected only through other measures, such as different varieties, alternative farming technologies, etc.

12.2.2. Iowa, USA

The importance of Iowa in US agriculture can be understood from the fact that 19% of corn and 14% of soybean production of the USA is grown there. In absolute terms, this amounts to nearly 50 million tons of grain in an area of 12 million hectares.

The concern for soil erosion is great in this state because the soil loss of about 100 t/ha per annum is not uncommon there, with more than 1.8 million hectares losing 20 t/ha or more each year. This concern is reflected in the model, which centers around limiting the soil erosion to specific levels, e.g., 10 or 20 t/ha soil loss. This is a distinct theme quantitatively taken up here, although many countries refer to this problem in general terms.

On the methodological front, the special features of this case study are:

(1) Inclusion of 30 crop rotations and 9 soil management practices in 5 land classes.
(2) Coupling of Iowa to the rest of the USA in macroeconomic terms to determine prices internally through such a model.

The results indicate that the investments made to reduce soil erosion to 10 t/ha could have a very short payback period of less than five years. However, this scenario also leads to a substantial increase in fertilizer consumption and changes in cropping patterns where initially production of sorghum drops, but soybean and corn crops increase. By the year 2000, production of soybeans also declines, but corn continues to increase. However, this conclusion may apply to the situation in Iowa only and, even there, authors qualify their statement carefully. Nonetheless, the cost-effectiveness of soil erosion measures comes as a pleasant surprise, when most people in other situations contend that investments for curbing soil erosion are formidable and benefits are obtained only in the long term.

12.2.3. Northeast Bulgaria

The objectives as well as the approaches selected for this region and the Nitra case study are similar, namely, how to arrive at optimal crop allocation patterns given the demand structure, suitable land, machinery, capital, labor, and other resource requirements of different crops and total resource availability in the region. Is there a contradiction between planned targets and model results? Both the studies use a static linear programming model to address this question.

The Northeast region of Bulgaria accounts for roughly 33% of total national grain production as well as 29%. of cattle, sheep, and poultry breeding. Therefore, the LP model considers grain, forage, vegetable, and industrial crops and includes processing. For wheat and corn, several types of technologies are considered – traditional, intensive, and superintensive – each requiring different capital, labor, fertilizers, and other inputs. The Tolbuhin district is one of the six districts (318 000 ha) of the Northeast region to which the general model developed for the region is first applied. The model shows that when the share of area on which intensive technologies are applied increases from 5 to 41% in the area allocated to wheat and corn, one could increase the share of area for other crops from 41 to 46.5% i.e., releasing an extra 16 700 ha for other crops. The model elaborates on the problem of a shortage of workers if productivity of the land is to increase, and discusses the roles of permanent and part-time workers.

12.2.4. Nitra, Czechoslovakia

The Nitra region includes 1.5% of the agricultural land of Czechoslovakia and produces approximately 1.8% of the national agricultural output. The main crops of the region are wheat, barley, sugar beets, and feeds. The state plan anticipates a substantial increase in the next decade in cattle, milk, meat, and maize from this region, leading to a 75% increase per hectare in value terms. Twenty agricultural enterprises manage nearly 100 000 hectares.

The LP model formulated here considers several classes of 2 types of soil morphology (lowland, hilly), 2 types of precipitation levels, climatic zones, and several types of soils, all of which are reclassified 16 distinct soil–climatic zones. A comparison of model results with other estimates made (based mainly on demand and trends) shows that the model predicts maximum levels of wheat and sugar beet production to be substantially lower, and spring barley to be somewhat higher. In addition, it is shown that the recommended cropping pattern would reduce the amount of soil loss to some extent.

12.2.5. Suwa, Japan

The distinctiveness of this case study lies in its treatment of the problem of water pollution due to rice cultivation and intensive vegetable production, for which a recursive model is used and is also linked to the question of employment. The "tank model" is used to capture the inflows and outflows of water in Lake Suwa. The question here is not of water resources, which are adequate, but of water quality.

The disaggregation is carried out in terms of different activities such as vegetable growing, paddy farms, orchards, livestock, etc. The water use of each activity is determined, as are pollution levels. The material balance of the nutrient flow, i.e., nitrogen and phosphorus, into Lake Suwa is obtained, including the discharges of other activities such as urban sewage, tourism, etc. The limit of pollutants is set, and the level of each activity considered, in a scheme to prevent eutrophication of the lake. Since income and labor associated with every activity are known, it is possible to see what happens to different combinations of activities under different policies. If a policy for curbing eutrophication has to be pursued, the results indicate that vegetable growing should be reduced. This would not mean a significant loss of income but considerable loss of employment. This result leads to a new perception of the environmental problems where, until now, economic costs have often been discussed but employment issues have seldom been considered.

12.2.6. Hungary

The major highlight of this case study is its detailed zone-by-zone study of agroecological conditions and identification of environmental problems for each ranging from soil compaction, soil erosion, salinity, logging, etc. Rather than putting significant efforts toward new model development, several ongoing efforts are integrated to obtain new insights and to examine individual components. In addition to a study of soil quality, energy flows in Hungarian agriculture are also traced.

Using a linear programming model, it is suggested that Hungarian agriculture would do well to concentrate on grain and oilseed production (rather than livestock) where it has comparative advantage in the international markets. Moreover, if the productivity is to be sustained, then ameliorative measures for soil preservation may be necessary to prevent loss of grain production of as much as 1 million tons. The ameliorative measures need to be made first on the most productive land. The costs of such measures are within affordable limits. The grain output could 40–50% higher than that of the late 1970s.

12.2.7. Bangladesh

The problems of developing countries are so different from those of the developed countries that this case study almost seems isolated from the others. However, the problem of allocating biomass resources for food–fodder–fuel–fertilizer is significant for nearly 3 billion people of the world, including India and China. The linear programming model formulated here is different from others on yet another count. It considers six different types of farmers: landless, small, medium (2), large, and those with very large farms, and compares their decision making criteria according to their own boundary conditions. Severe fodder shortages showed up in many policy runs, e.g., while switching to high-yielding varieties or when population increases.

When organic manure is used for fuel, soil fertility could decline, and fuelwood removal could mean loss of vegetative cover (a more severe term might be deforestation). Efficient cooking stoves and a fodder support policy for those switching to high-yielding varieties are some of the recommendations that follow from such a model. It also shows vulnerabilities of the landless and small farmers to even small changes in the system.

12.3. Case Studies: Contrasts and Common Threads

Our efforts have produced a unique output because the case studies cover a wide variety of systems, as follows.

Economic systems

This book encompasses market economies (Italy, the USA), centrally planned countries (Bulgaria, Czechoslovakia, Hungary, and the USSR), a developing market economy (Bangladesh), and a market economy with a protective policy for agriculture (Japan). Bangladesh, which is one of the poorest and most populated in the world, could be considered representative of developing countries where resource scarcity leads to severe problems in meeting even subsistence-level requirements.

Agricultural systems

The range of the case studies covers large farms of hundreds of hectares operated by the state, cooperatives, or commercial farmers, and farms smaller than a few hectares operated by commercial farmers, e.g., subsistence farmers of Bangladesh, and small farmers of Japan and Italy.

Resources and technology

The resources covered are mainly land, soil, capital, and labor. However, in some cases biomass, energy, and water resources are also included. Technology refers mainly to farm practices such as crop rotation, input-intensive farming, tillage, and irrigation practices. In rare cases the concept of technology had to be extended to efficient utilization of resources, such as energy or biomass.

Environmental concerns

In general, the data and research approaches in the literature covering environmental aspects of agriculture do not allow rigorous analysis of environmental issues for either scientific or policy analysis. This is not to undervalue the work done in this area, where an admirable beginning has been made by many taking different viewpoints. Given existing limitations in this discipline, most models presented here try to deal with the nature of the environmental problem as it exists and as it could develop with time, although sometimes only descriptively or indirectly.

These problems, naturally, differ from region to region. It is water pollution, due to discharges of nutrients, in Japan and Czechoslovakia; soil erosion in Iowa, Hungary, and Czechoslovakia; deforestation and loss of soil fertility in Bangladesh. Those dealing directly with environmental problems are Iowa, Japan, and Hungary. The remaining chapters highlight the problems indirectly or *a posteriori*.

Environmental concerns are relatively recent compared to economic concerns. This is also reflected in these studies in that costlier solutions for the sake of prevention of environmental degradation are not yet recommended except by the Iowa case study, and to some extent by the Hungarian study, which discusses additional costs for ameliorative measures to prevent soil erosion or accepting limitations or goals of production. Japan also strongly recommends a shift in production patterns to reduce the problem of water pollution. Due to the subsistence nature of its economy, Bangladesh has limited alternatives; and biomass allocation for food, fodder, fuel, and fertilizer is a major concern for the small and medium farmers. The environmental issues here are reduction in soil fertility due to use of manure for fuel, and loss of vegetative cover due to livestock grazing and fuel gathering.

Similarly, concerns for labor shortages in agriculture are evident in the case studies from socialist countries, whereas the impact on agricultural unemployment of an environmentally preferred strategy is highlighted in the market economy case study of Japan. Concerns for unemployment or for vulnerability of the small farmer, as in the case of Bangladesh study, may also be due to the small size of holdings in these countries.

Environmental concerns versus crop production plans

Treatment of environmental issues could be divided into two categories of case studies: those that put environmental concerns at the center and work out a production plan, or those that put production plans at the center and work out environmental implications.

Thus, the diversity of economic systems, the structure of agriculture, and depth of environmental concerns are reflected in the different case studies in terms of their major focus on environmental concerns or on crop production plans. This point is discussed below.

It is interesting to note that in the countries with a market, i.e., USA and Japan, the environmental concern is the primary one and is put at the center of the problem from which crop production patterns are worked out. For example, Iowa focuses on minimizing soil erosion and then the cropping patterns are worked out, resulting in a recommended reduction in sorghum but increase in corn production. In this regard, the good news is that the soil-conserving practices pay off not only in the long term but also in a short term of less than five years. On the other hand, Japan considers water pollution to be the major theme from which conclusions are drawn to reduce paddy cultivation and to increase vegetable or nonpaddy production. However, the bad news is that in order to contain water pollution through reduction of rice cultivation, there could be a loss of employment – a price to be paid to improve water quality.

The socialist countries, such as Bulgaria, Czechoslovakia, Hungary, and the USSR, deal first with their production plans and only then are the environmental implications considered. However, Hungary considers the soil erosion reduction practices very seriously and emphasizes the need for ameliorative measures. This may be partly due to its small size and partly due to intensive agriculture and partly due to the management of Hungarian agriculture through a system of indirect controls, where the producing units make their own production decisions. However, there are definite signs of increased awareness of environmental problems in all the socialist countries.

12.4. Concluding Comments

During the course of this work, many conceptual advances have been made within the systems analytic framework to deal with both environmental issues, such as soil erosion, water pollution, loss of vegetative cover, etc., and with technological solutions, such as crop rotation, ameliorative practices, improved stoves, high-yielding varieties, etc., for better utilization of resources for agriculture. In addition to developing tools, there have been empirical applications to a wide variety of regions within the centrally planned socialist and developed market economies, and for the subsistence agriculture of Bangladesh. Some of the case studies have been done by eminent scientists and academicians with considerable influence in decision making at a high level and with strong backing from their institutions, suggesting the need felt by policy makers for systems analytic methods.

Differing policy insights have been obtained for different regions, which have been discussed in detail in individual chapters, but overall conclusions are as follows:

(1) The problem of the sustainability of agriculture requires that adequate attention be paid to resource potentials, technology utilization, and environmental consequences.

(2) A clear trend in all the case studies shows that the perception of problems for the sustainability of agriculture has changed, in that there is a shift from preoccupation with resource shortages to concern for environmental impacts.

(3) Appropriate technological alternatives can ameliorate the problem and can even enhance soil productivity. Measures to preserve or enhance soil productivity may be economically justified.

In addition to the specific insights already obtained from the limited effort presented here, as expressed by the international roster of authors of these studies, this exercise has opened up many possibilities of further work using the tools developed during the course of this work.

12A. Appendix: Summary Forms

Country:	**Bangladesh**
Title:	Bangladesh: Agriculture, biomass, and environment
Author(s):	J.K. Parikh
Organization:	International Institute for Applied Systems Analysis in cooperation with the Center for World Food Studies, Amsterdam, The Netherlands
Central objective:	To examine energy and agriculture interactions in developing countries and biomass allocation for food–fodder–fuel–fertilizers. How to provide the biomass for the increasing population of Bangladesh?
Related issues:	Effects of new technologies, such as high-yielding varieties, future prospects of sustainability of biomass.
Area in 1000 ha:	14 000
Crops considered:	Rice, wheat, jute.
Target years:	1976, 1983, and 1990.
Disaggregation:	Seven groups of small, medium, large farms, and nonagricultural groups in rural and urban areas.
Resources considered:	Biomass, land, energy.
Technology:	High-yielding varieties, alternative supply of fertilizers, improved cooking stoves, to use less biomass.
Environmental considerations:	Implicit understanding of deforestation due to excessive biomass use for energy and of loss of soil fertility due to use of manure for fuel.
Validation:	Carried out for 1976. Valuable insights obtained from the validation itself.
Insights obtained:	Small and medium farms use organic fertilizers for fuel rather than as fertilizers, thereby reducing soil fertility. They are also vulnerable to fodder deficits, if biomass continues to be used for fuel. Large farms not vulnerable up to 1990.
Policy suggestions:	While promoting high-yielding varieties, which have less straw content compared to traditional varieties, fodder support may be needed. Improved cooking stoves could reduce the use of biomass for fuel, making more fodder and fertilizers available.

Country:	**Bulgaria**
Title:	Northeast Bulgaria: A model for optimizing agroindustrial production structures
Author(s):	T. Georgiev, T. Popov, G. Ivanov, and L. Stefanov
Organization:	Research Laboratory "Problems of the Food Complex", Sofia
Central objective:	To elaborate and apply EMM for optimal resource utilization for the production of food products on the regional level.
Related issues:	Investigation of the impact of intensive technologies on the structure and effectiveness of food production with the aim of making optimal management decisions for production development in the region.
Area in 1000 ha:	300
Crops considered:	Mainly wheat and corn; also sunflowers, beans. Livestock: cattle. pigs, poultry, and sheep.
Target years:	The approach and the EMM are valid for 1990.
Disaggregation:	Public sector (AICs, IACs, and LPCs processing enterprises) plus private and auxiliary farms.
Resources considered:	Land, labor, fertilizer, fuel, fodder, etc.
Technology:	Standard, intensive, superintensive.
Environmental considerations:	Intensive and superintensive technologies are applied only on lands with a high natural soil fertility and after suitable processing.
Validation:	–
Insights obtained:	Livestock production is more effective than grain production: surplus grain will lead to decrease of profit. Solution to the forage problem is needed; advisable to apply all-year-round feeding with predominance of conserved forage. Private and auxiliary farms in the region provide about 10% of the agricultural production.
Policy suggestions:	–

Country:	**Czechoslovakia**
Title:	Nitra, Czechoslovakia: Regional and technological development of agriculture
Author(s):	J. Hirš, L. Kátrik, P. Kubaš, and D. Lupták
Organization:	Institute for Rationalization of Management of Agriculture, Bratislava
Central objective:	To evaluate the possibilities of further intensification of agricultural production of the given region and its possible impacts on the region's economy, and the effects of the new technologies on the natural resources (soil and water).
Related issues:	Further intensification of agricultural production, increased consumption of agrochemicals and their environmental impacts.
Area in 1000 ha:	101
Crops considered:	
Target years:	1985–1990
Disaggregation:	16 agroeconomical units.
Resources considered:	Soil, land.
Technology:	Large-scale production and crop rotation. Full mechanization of the plant production by means of highly efficient machines.
Environmental considerations:	Leaching of chemical substances into the surface water.
Validation:	Some parts for 1980.
Insights obtained:	The consumption of fertilizers needs to be rationalized. The use of manure and other natural materials needs to be increased. New agromelioration measures are planned. Irrigation to be maximized up to water resources.
Policy suggestions:	To elaborate further activities and apply them in planning the development of the given region.

Country:	**Hungary**
Title:	Hungarian agriculture: Development potential and environment
Author(s):	C. Csáki, Z. Harnos, I. Vályi, and K. Rajkai
Organizations:	Karl Marx University of Economic Sciences, Bureau for Systems Analysis, National Planning Office, Hungarian Academy of Sciences
Central objective:	To estimate (1) production potential of the existing soil resources and (2) long-term environmental impacts of continuing present practice in cultivation. How to increase the productivity and efficiency of Hungarian agricultural production by using more rational combinations of existing technological alternatives?
Related issues:	Rational utilization of by-products of biological origin and waste materials.
Area in 1000 ha:	4600
Crops considered:	Wheat, rye, barley, rice, maize, potatoes, sugar beets, sunflowers, soybeans, peas, alfalfa, red clover.
Target years:	1990, 1995, and 2000.
Disaggregation:	35 agroecological regions, 31 soil types.
Resources considered:	Land, water, energy, biomass.
Technology:	Alternative supply of fertilizers, ameliorative agrotechnology, and irrigation.
Environmental considerations:	Soil characteristics are expressed by four parameters: the extent of erosion, the extent of compaction, the soil pH, the nutrient level of soil. Environmental impacts are calculated on the basis of these indicators.
Validation:	–
Insights obtained:	The output of plant production sector may reach a 40–50% higher level than in the late 1970s, the growth potential being different from crop to crop. Risks due to the variability of weather can be substantially decreased by using optimal sowing structure. With maximal ameliorative investments, a production surplus of 10% can be achieved. The impacts of postponing ameliorative investments can be substantial.
Policy suggestions:	The complex utilization of the country's biological resources is an essential part of the economic development strategy. Depending on the domestic and foreign demands and opportunities, the quality and composition of the biological production and the types of utilization should be constantly reappraised and modified, in a manner aligned with the protection of the natural environment and the improvement of living standards.

Country:	**Japan**
Title:	Japan's Suwa Basin: A regional agricultural model
Author(s):	T. Kitamura, R. Nakamura, S. Ikeda, H. Tsuji, M. Matsuda, S. Hoshino, Y. Matsuo, and N. Nakayama
Organization:	Kyoto University, Kyoto, Japan
Central objective:	To understand the structure of regional agricultural systems. To find application-oriented methods of agricultural planning (including water pollution) in order to correct the structural defects of regional agriculture.
Related issues:	Balanced development with region-specific sustainability related to social, economic, and physical (or ecological) structure in rural areas.
Area in 1000 ha:	50
Crops considered:	Rice, upland crops (not specified), fruits, cattle, pigs, vegetable, flowers.
Target years:	1975.
Disaggregation:	Two subregions. Four activity groups, which are classified by farming patterns based on economic land classification.
Resources considered:	Labor, rice land, upland, orchards, number of farms, water resources, water quality (phosphorus, nitrogen).
Technology:	Modernized technology in rice, intensive vegetable production and some fruits; traditional rice cultivation that uses fertilizers but without land consolidation.
Environmental considerations:	Water pollution due to the excessive use of fertilizer.
Validation:	Carried out for 1970 and 1975. Valuable insights obtained from the validation itself
Insights obtained:	By using the method of economic land classification, four types of farm management are identified. In order to increase agricultural products, the farm management of the highest income level (upland crop farming) will increase, but water pollution will also occur. Concerning the recursive type of calculation in linear programming, more exact estimations of activity coefficients are necessary.
Policy suggestions:	In order to avoid water pollution in Lake Suwa and in the groundwater of related areas, suitable controls for the use of fertilizer or its disposal are recommended, especially for upland crop farming. A pollution monitoring system for groundwater should be introduced.

Country:	**USA**
Title:	Iowa, USA: A policy analysis
Author(s):	B.C. English, D. A. Haney, A. Kapur, and W.H. Meyers
Organization:	Center for Agricultural and Rural Development, Economics Department, Iowa State University
Central objective:	To reevaluate the impact of soil loss on yields and net returns to Iowa farmers, and the effects of alternative policies to reduce soil loss.
Related issues:	Impact of policy alternatives on nitrogen use and production.
Area in 1000 ha:	11 932
Crops considered:	Corn, wheat, soybeans, sorghum, oats, and hay.
Target years:	1980, 1985, 1990, 1995, and 2000.
Disaggregation:	12 agroclimatic areas, 5 land classes, 3 conservation methods, 3 tillage practices, 30 crop rotation options.
Resources considered:	Land, soil.
Technology:	Constant technology assumed but with variable inputs and variable choices of conservation and tillage practices.
Environmental considerations:	Soil loss relationship to yield.
Validation:	Economic model validated up to 1980.
Insights obtained:	Farmers' net returns were improved when restrictions were placed on soil loss, suggesting that foresight of the impacts of soil loss would lead farmers to use more soil-conserving techniques and change their cropping patterns.
Policy suggestions:	If there is market failure implied by farmers' inability to foresee the consequences of current soil losses, there are societal gains to be obtained by government action to restrict use of erosive farming practices. The offsite impacts of this soil erosion would create additional societal costs if no policy action were taken.

Country:	**USSR**
Title:	Stavropol, USSR: An agricultural management model
Author(s):	A.A. Nikonov, V.I. Nazarenko, L.N. Petrova, F.I. Ereshko, E.M. Stolyarova, V. Yu. Lebedev, S.B. Ognivtsev, S.O. Siptits, N.N. Milyutin, V.N. Popov, R.R. Guliyev, and M.P. Yevsiukov
Organizations:	All-Union Academy for Agricultural Sciences, Stavropol Research Institute for Agriculture, Computing Center of the USSR Academy of Sciences, All-Union Research and Technological Institute of Cybernetics
Central objective:	To elaborate the procedure of estimating potential production level of the region considering resources available, appropriate technologies, and environmental consequences based on a system of mathematical models.
Related issues:	Optimal distribution of resources (fertilizers, water, fuel, labor, etc.) and arable land among different crops. Optimal choice of rotations. Estimation of economic consequences of unfavorable weather conditions.
Area in 1000 ha:	8043.3
Crops considered:	Winter wheat, barley, corn, sugar beets, oats, vegetables, grasses, sunflowers, soybeans, potato.
Target years:	1990 and beyond.
Disaggregation:	5 agricultural zones, 8 land classes, 10 (fallow and non-fallow) technologies, 3 crop rotations, 4 climate scenarios
Resources considered:	Land, labor, fuel, fertilizers, water, tractors, grain harvesters, pesticides, electric power.
Technology:	Standard technologies with variable meanings of all types of resources for every agricultural zone, crop, and rotation.
Environmental considerations:	Soil moisture and soil fertility and climatic considerations while choosing technologies. Implicit consideration of soil properties considered in the model while calculating the crop rotation.
Validation:	Validation of PCP model for 20 crops for period 1971–1982.
Insights obtained:	Optimal distribution of fallow areas, technologies, and fertilizers for winter wheat cultivation for 5 agricultural zones, 3 rotations, 20 values of gross output, minimizing total cost of production. Elaboration of optimal resources distribution when maximizing several criteria (grain, forage, livestock, etc.).
Policy suggestions:	–

About the Editor

Jyoti K. Parikh, Professor, Indira Gandhi Institute of Development Research, Bombay, is a systems analyst working in the area of energy and environment. She has been affiliated with the International Institute for Applied Systems Analysis for nearly eight years, working on energy problems of the developing countries in general and, specifically, of India, Bangladesh, and Brazil. She developed an energy demand model for India during her tenure at the Planning Commission, Government of India.

Dr. Parikh pursued her postgraduate studies in theoretical physics at the University of California–Berkeley and the University of Maryland–College Park, USA. Her work in theoretical physics has taken her to the University of Frankfurt, the Tata Institute of Fundamental Research, and the Bhabha Atomic Research Centre at Bombay. She subsequently worked on problems of science and technology policy and on environmental issues at the Department of Science and Technology, New Delhi.

She has served as an energy consultant to the World Bank, the US Department of Energy, the European Economic Community, and UN agencies including UNIDO, FAO, UNU, and UNESCO. Dr. Parikh has published more than 50 papers in the area of theoretical physics, energy, and environment in addition to several books and monographs in the energy field.

This book focuses on the interactions between resources, technologies, and environment in agricultural systems and on their consequences for long-term agricultural development. Specifically, the issues addressed are:

(1) How should we estimate biological potentials of a given region, and what are the necessary factors in realizing them?

(2) How do certain technological options, resource limitations, and environmental consequences of cultivation affect each other? What is their relative importance? How should we allocate priorities and establish a process of adjustment?

(3) How does one design a production plan (what to grow, how to grow) for a region that ensures sustainability of production from a long-term point of view?

(4) What are the additional costs of agricultural production, if soil productivity (and this can be operationally defined) has to be preserved?

The outcome of this research has thus given us some methodological contributions as well as a set of case studies in different countries representing different economics and ecological conditions. It should be mentioned that, in addition to those described in the three chapters on methodological studies (Chapters 2, 3, and 4), some interesting methods have also been developed in the case studies, notably for the USA and Japan.

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