A MATHEMATICAL MODEL FOR REGIONAL CROP ALLOCATION

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

By

Abdelaziz Bouzaher

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Operations Research

Georgia Institute of Technology

June, 1978

A Mathematical Model for Regional Crop Allocation

Approved:

Mokhtar S. Bazaraa, Chairman

R. J. Graves

L. G. Callahan

W. N. Musser

Date Approved by Chairman 5/29/78

ACKNOWLEDGEMENTS

To Dr. M. S. Bazaraa, my thesis advisor, a special recognition for his valuable guidance and tremendous encouragement throughout the course of this work. To Dr. L. G. Callahan, Dr. R. J. Graves, and Dr. W. N. Musser, my reading committee, a sincere appreciation for their helpful suggestions and positive criticism. To my parents to whom I owe so much.

TABLE OF CONTENTS

LIST OF TABLES

Tables | Page

LIST OF FIGURES

Figure page

SUMMARY

In this study a mathematical model for regional agriculture planning is formulated. Crop rotation requirements and different levels of input utilization are explicitly specified. To account for the special conditions of developing economies, differences in production functions are specified within each region. Moreover, several goals are included in the model, such as demand satisfaction, minimizing unemployment, and maintaining satisfactory levels of foreign exchange. The problem is solved as a goal program under the criteria of minimizing the sum of weighted deviations from the specified targets.

Two real world applications are used to test the model, a two-region Algerian model and a nine-region Egyptian model, both having adequate sets of constraints and variables. The results do not call for a complete specialization, even though substantial resource reallocation is indicated. Compared to minimum cost and maximum return linear programming formulations, it is found that substantial unemployment reduction can occur. Thus, it is concluded that a goal programming formulation has great potential in incorporating both economic welfare and income distribution into a regional agricultural analysis.

CHAPTER I

INTRODUCTION

Over the past twenty years, analytical tools have found a growing use in analyzing and planning agricultural systems and answering questions such as what to grow, where, and how. The nature of the agricultural sector makes its planning both a difficult and a crucial task since it carries the responsibility of feeding the world population.

Understanding the agricultural sector requires that knowledge be drawn from a wide variety of disciplines. The growth process of a crop rests on academic subjects such as physics and chemistry, botany, biology, horticulture, and agronomy. The production process of a crop requires labor input and is influenced by management decisions and consumption habits, thus making social sciences such as economics and psychology also important.

There are hosts of factors that influence the crop yield, as shown in Figure 1, and specialized studies, such as by Trenbath [1976], Waggoner [1976], or Tanji and Fried [1977] are important in delineating and understanding the interacting effects, and explaining the biological relationships between input factors such as fertilizer, pesticide and water and yield response. Only then can the various aspects of crop performance be revealed and planning undertaken to help decide between alternative production levels or techniques and spatial location of crops.

1.1 Planning in the Agricultural Sector

As Bishay [1974] notes: "The planning of agricultural development is a process aiming at the maximization of the sector's contribution to

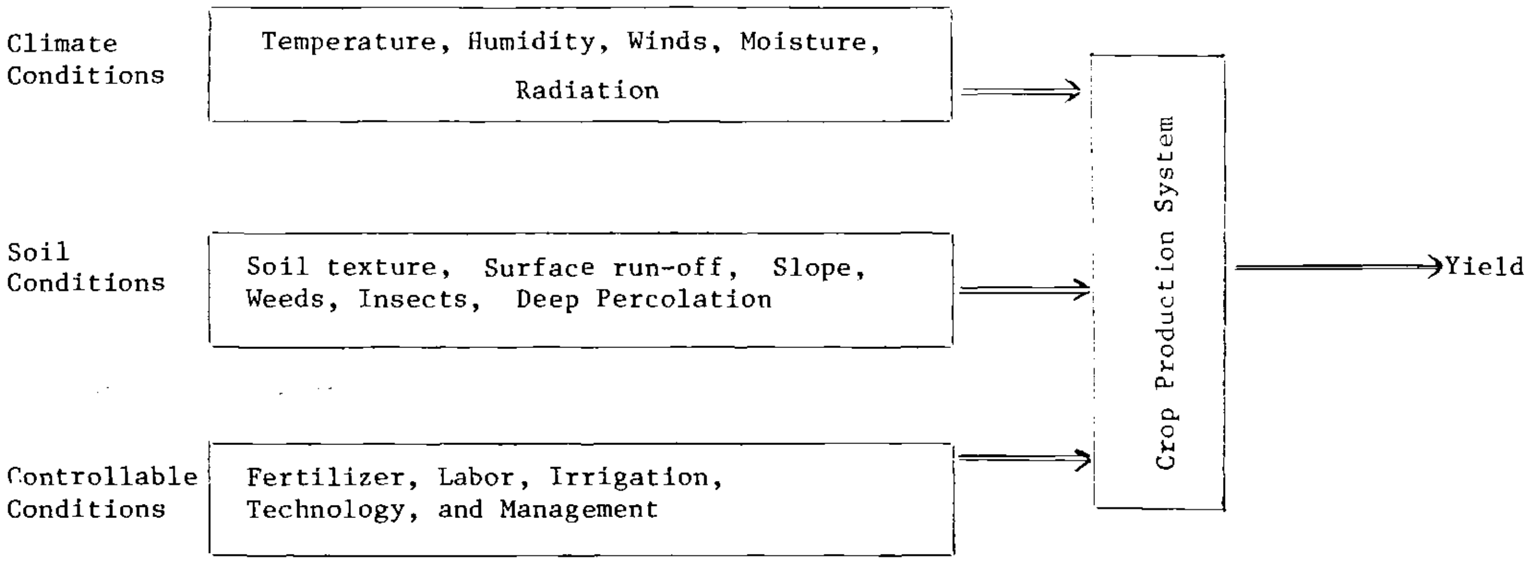


Figure 1. Some of the Many Factors Influencing the Crop Production System

the economic welfare of the society." But its nature makes it less responsive to programs than most of the other non-agricultural sectors. Agricultural production is highly fluctuating and specialized economic theory such as by Doll and West [1968] and Rae [1977] is considered relevant in understanding crop production systems and deriving general principles to be used in the planning process. Investments need longer periods for maturity and are vulnerable to natural conditions. Production follows a seasonal pattern and labor, which needs to be skilled in a range of seasonal tasks, is not needed uniformly. Population patterns and consumption and nutritional needs are also important.

There are different types of planning, and without loss of generality, we can classify them according to three basic dimensions: economic, temporal, and regional.

a) Economic Dimension

In this case, the follwing three levels can be distinguished:

i) Macroeconomic. Models in this class may range from simple aggregate ones to multi-sector detailed ones. A further distinction can be made relating to the type of decision variables in the model.

Optimal growth theory models concentrate on the determination of an economic growth rate. A review of these can be found in Manne [1974] for multi-sector models and in Taylor[1975] for economy-wide models.

Optimization models for which a review can be found in Pariente 1977 , and need to be detailed enough to be operational; they should be solved numerically to provide forecasts. In this case, the decision variables relate to some welfare measure of the economy.

ii) Sectoral. When more details are needed on a particular sector, macro-economic models become impractical, and a detailed analysis dictates the use of a unique sectoral model. Different levels can also be distinguished, a review of which can be found in Duloy and Norton [1973]. Depending on the formulation adopted, these models can be useful in determining the magnitude, location, and timing of investments in a particular sector.

iii) Project Level. In this case, a detailed analysis of a set of projects is necessary to help decide the choice of a particular one according to some specified criteria. Methods of engineering economy, such as benefit cost analysis, could be of use in this context; see for example, Thuesen, Fabrycky, and Thuesen [1971].

If an integrated approach is needed to account for the effects on the other sectors, a sectoral analysis would be desirable. An example is the energy sector model developed by Dela Garza, Manne, and Valentica [1973].

b) Temporal Dimension

Planning can be static or dynamic depending on the targets set and the kind of information needed.

i) Static Models. Basically, whenever a short-term horizon is considered, over which resource supplies can be considered fixed, one-year models are used. These models can be nation-wide or sectoral. This class can also include operational models used in day-to-day management decisions.

ii) Dynamic Models. Whenever a time span longer than a year is considered over which resource supplies can no longer be taken as fixed, the problem of investments to increase the capacities of production becomes relevant and long range models are formulated. The usual horizon period is five years in agriculture, but longer or shorter periods can be included, depending on the length of time over which investments become profitable or mature. For general purposes, see Parienthe [1977] , and for agricultural dynamic models, see Bishay [1974]. We note that longer range models of 15-20 years are also helpful to limit the framework in which the whole economy or a particular sector are to change. They deal with strategic variables such as growth rate, capital formation, and full employment, and their use is more spread in countries with a central planning process.

c) Spatial or Regional Dimension

Basically, when the geographic location is needed, this dimension is introduced and the models can be formulated at the level of the entire economy, a unique sector, or subsector.

In an agricultural system, the regional production possibilities, the natural differences in soil and climate, and the integration with other sectors of the economy are very important.

For instance, the characteristics of each region influence greatly the size of farms, the methods of production, and the types of crops to be planted. The topology of the land can impose a specific technolgy and its type can exclude certain crops from being grown. Relative yields are dependent on not only soil and climate conditions, but also on the availability of resources and technology levels. In some cases, institutional constraints can also play a major role. Moreover, the spatial aspect is basic in agricultural planning, because of the distribution of the land among different regions.

d) Specific Elements Peculiar to Developing Countries

So far, we presented the problem of agricultural planning in broad terms. There are, however, some major issues relating to developing economies. These issues have not received an adequate treatment in the literature. Heady [1975] states: "Since the objectives of agricultural development and constraint types are quite different in these countries, spatial agricultural planning models need to be adapted to the main characteristics of their agriculture." But he also notes: "Developing countries have not widely used interregional models for agricultrual policy making because they have been unable to fulfill the prerequisites for model building." The prerequisites are:

- The existence of a mathematical tool to formulate and solve the problem.

- The availability of computing facilities of the required magnitude.

- The availability of the vast amount of basic data for various homogeneous regions.

More recently, researchers started addressing this problem and efforts have been underway to create the prerequisite for building spatial models in developing countries. Duloy and Norton [1973] and Bishay [1974] included various objectives of agricultural development and incorporated constraints on production, transportation costs, and investment capabilities. Other studies, such as those by Randhawa and Heady [1964] and Alvin and Hyung [1975] included only a few factors of production, for example, land constraints. Generally speaking, these studies consider a few aspects of the problem, use aggregate models, and may be considered only as a first step in developing more complete models.

e) What This Thesis is Attempting to Do:

We have seen different types of planning and the information that can be derived from them. A more realistic and comprehensive planning should consists not only of one model, but of a whole system of interrelated models, as illustrated in Figure 2, so as to capture the totality of the production process and the diversity of factors which can influence directly and indirectly the allocation problem of resources in agriculture, because we cannot dissociate long-term plans from yearly plans or day-to-day management operations, nor can we separate the treatment of individual sectors from that of the total economy.

Development of such a system of interrelated models needs time and resources. So, our aim is to concentrate on a unique area, that of developing a short-term model for regional allocation of crops in the agricultural sector. The idea is depicted in Figure 2, which gives the scope of the study as represented by the hatched surface on a three-dimensional scale: time-wise, the model will be static, space-wise, it will be regional; and economics-wise, it will be sectoral. In addition, it will be adapted to include the specific elements peculiar to developing countries.

1.2 The Use of Mathematical Programming Models in the Agricultural Sector

a) General Considerations

Since the agricultural sector is vital for the entire economy, any changes in the economic system, such as demands or technology, are reflected at different levels. Trade-offs in production occur

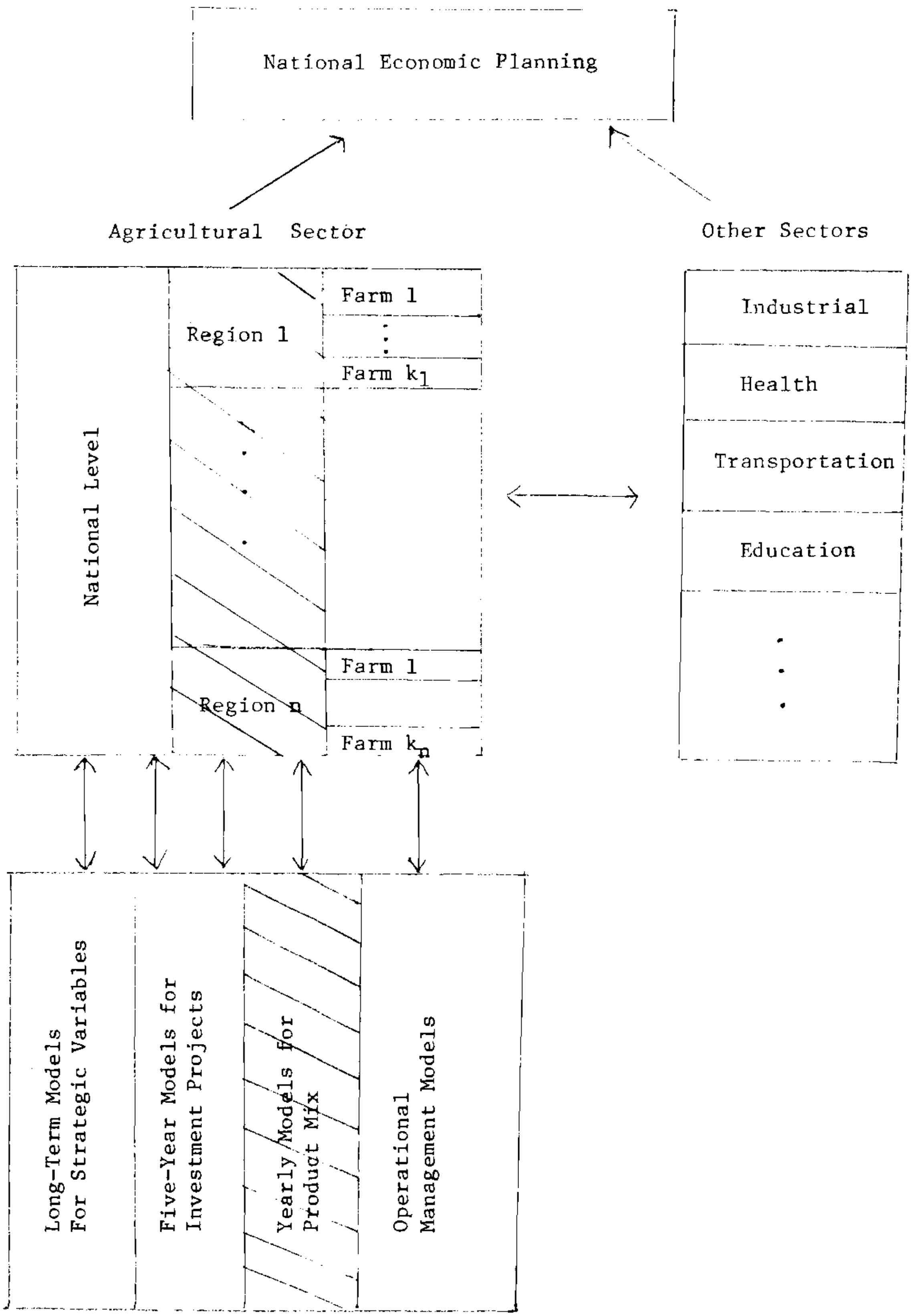


Figure 2. Interrelated System of Models
and Scope of Thesis

on both an interregional and intraregional basis. Patterns for using resources can change not only the production mix and its magnitude, but also the spatial distribution of crops and the ways resources are combined. It is then important to be able to determine the best regional allocation of crops for the most efficient use of the available resources, under certain prevailing conditions, and to estimate the possible changes resulting from new policies before their implementation. For this purpose, mathematical programming tools can provide valuable ways of modeling the different interactions and answering these questions. Selected references for different methodological aspects of modeling in agriculture are: Bruckman [1975], Chen [1976], Garrod and Adams [1977], Grooms [1977], Pugh [1977], and Rose [1977].

Another class of models widely used in agricultrual planning is econometrics. Normally these models are not detailed enough to be operational, and usually include sectors other than the agricultural sector. A review of these models can be found in Just [1972] and King [1975].

In addition to mathematical programming and econometric models, simulation models have also found some use in agriculture. In general, their use is restricted to plant growth processes and management problems at a micro level,as in the work of Jones [1976], Vries [1977], and Waggoner [1977], or simulating economic development at an aggregate level such as in Nellor and Madahar [1974].

Linear Programming and its extensions seem to be the most widely used tool in agricultural planning. Textbooks are now available that cover the basics of linear programming in agriculture. For details, the reader may refer to Heady and Candler [1958], Camdus [1969], Agrawal and Heady [1972], Beneke and Winterboer [1973], and Barnard and Nix [1973].

Mathematical programming can provide details at both national and regional levels. At the national levels, details will help adjust prices and supply to meet the demands and establish interdependence among regions. At the regional level, these models can help measure the flexibility of resources within the regions and the possibilities of substitution of factor of production between regions and determine the impact on the individual farms. The formulation of such a model takes on the general form:

Problem P

$$\text{Maximize } f(x) = Z \quad (1)$$

$$\text{Subject to } g_1(x) \geq D \quad (2)$$

$$g_2(x) \leq R \quad (3)$$

$$h(x) \leq B \quad (4)$$

Where:

x: is a vector of relevant production such as crops and livestock

$f(x)$: is the functional form of the objective desired.

D: is a vector of demands to be met

R: is a vector of available resources

$g_1(x)$: is the functional relationship of interactions between x and D

$g_2(x)$: is the functional relationship of the interaction between x and R

$h(x) \leq B$ is a bound relationship.

This formulation can be adapted to encompass all the aspects mentioned in the above sections. Namely, for a regional analysis, the vector x will include production activities by region and transportation activities between regions. The vector D will include demands at both regional and national levels for the activites to be chosen by the model. The vector R will include the resource availabilities at the regional level, and if any, at the national level. Any other exogenous constraints will be included in the form of bounds in equation (4) above.

The specifications of the coefficients will also reflect any particular policies to be tested, such cases are treated by Salaverry [1969] and Gotsch [1975,i,ii].

b) The Non-Linear Programming Form (NLP)

In this case, the objective function and/or the constraints are nonlinear. The nonlinearities are usually due to returns to scale or to the inclusion of risk consideration. The most frequent formulation is quadratic, as found in Takayama and Judge [1964], Simmons and Pomareda [1975],Wiens [1976], and Adams, King, and Johnston [1977].

c) The Linear Programming Form (LP)

When the vector x is continuous and the functional relationships in problem (P) above are linear, the problem is a pure linear program. For details on the use of linear programming in agriculture the reader may consult Yartengo [1969], Luperti [1970], Balika and Somogyi [1970], Eyvindson [1972] Chew [1972], Acsay [1973], Kondakov [1975], and Walker and Monnypenny [1976]. These references mostly treat the methodological aspects related to the use of linear programming and to the underlying assumptions.

Even though linear programming has been used extensively and can solve large problems efficiently, it has some severe limitations which reduce the modeling possibilities. For instance, the assumption of linearity prohibits the inclusion of economies of scale. For small examples, ways to include these aspects are treated in Irwin 1974 and Rae 1977 .

d) The Goal Programming Form (GP)

This form has not been adapted to regional analysis even though it is similar in structure to linear programming. It offers, however, a major flexiblity by allowing a number of goals which are not necessarily compatible to be taken into account simultaneously.

Each goal is formulated as an equality constraint with the addition of two variables which represent any underachievement or overachievement of the goal target.

Let m = number of activities

A_{tj} = per unit contribution of the jth activity towards the achievement of goal t.

G_t = target for the t^{th} goal. Then the t^{th} goal can be formulated as:

$$\sum_{j=1}^{t} A_{tj} X_j + n_t - P_t = G_t$$

where x_j is the level of activity for j

n_t = underachievement of the t^{th} goal

p_t = overachievement of the t^{th} goal

$x_j, n_t, p_t \geq 0$

The objective function, also called achievement function, can take two general forms:

- If all the goals to be achieved are considered equally important, then the objective is to minimize $\sum_t W_t(n_t, P_t)$, a sum of weighted deviations.

- If there is a priority structure to be observed, then the ob- objective is to minimize:

$$g = \{\underline{P}_1(n_1,p_1),\ \underline{P}_2(n_2,p_2)\ \ldots\ \underline{P}_t(n_t,p_t)\}$$

where $\underline{P}_1$, $\underline{P}_2$,...,$\underline{P}_t$ are the ordered priorities on the goals projected. The procedure will start by finding the solutions that optimize the first goal. Among these solutions one finds the set of solutions that optimize the subsequent goal, and so forth.

It is to be noted that by adequate choice of the formulation and the weights, the problem can be set to handle the cases where the goals are to be met exactly, at least to a certain level, or at most at a certain level. For a formal exposition of the method and its extensions, the reader may refer to Benayon 1971 and Ignizio 1976 . Some applications can be found in Neely [1976] for forestry, Hasenauer [1976], Price [1976] Charnes and Cooper [1961], for industrial problems.

1.3 The Proposed Research, Its Significance, and Objectives

The problems under consideration can be stated precisely as that of formulating a mathematical programming model to determine the best allocation of crops and livestock in a set of regions which share certain numbers of objectives. Methodologically, a different approach is to be used to include the important factors of regional differences, crop interdependencies, and the different goals under consideration. The model will be designed to include the main features of less developed economies, but would be flexible enough to be adapted in any area where the geographic distribution of crops is important. The significance of the problem can be viewed in two ways. First, through the literature survey, it appears that regional studies are mostly equilibrium models that assume a free market and complete information. The objective is almost always the maximizaiton of profit under different forms. But in the case of developing economies, the above assumptions are impossible to justify and more realistic ones need to be formulated. For instance, the agricultural sector suffers from a number of insufficiencies, and at the same time, is the source of income for the majority of the population; technologically, it is far behind the levels achieved in advanced countries. Its growth is not homogeneous, that is, it is divided into two main parts, one part is usually privately owned and uses traditional methods of production and has a labor intenstive production function; the other part, under government control, uses more subsidies and a relatively modern technology, and is more capital intensive. Because of the lack or limited industry, the agricultural sector carries the charge of feeding the entire population; this emphasizes the crucial role of agricultural employment and government subsidies in the policy making process of these countries. It is also to be noted that self-sufficiency very seldom occurs and importation is the rule in most cases. Thus, the following questions arise: Are traditional mathematical programming tools capable of modeling the above described situation? What forms would the resulting models take? And could they be solved efficiently? Secondly, an important objective of this study is to include more realistic aspects of the production process, such as limiting resources other than land, like water, fertilizer, and labor, and to explicitly model the rotation relationships. A transportation model will be built into the regional problem to account for the effect of transportation costs and capacities on the optimum solution. In other studies, this latter aspect is either omitted, or else different market regions, which are independent of the producing ones, are defined. Based on the problem stated above and its significance, our objective is to develop a model to determine the geographic allocation of crop and livestock production, and interregional commodity flows, in a manner consistent not only with the characteristics of each crop in each region, but also with the economic characteristics of the sector in developing economies. The emphasis will not be on profit maximization, but rather on achieving certain strategic goals such as demand satisfaction, employment, and minimum foreign-trade deficit. Thus, our objective is substantially different from what has been done, because in addition to economic welfare, an income distribution dimension will be introduced into the model to account for the importance of employment in developing economies.

The model is aimed to help readjust the spatial distribution of production on the basis of comparative advantage and regional needs. In other words, a question to be answered is: are the developing countries using their agricultural resources efficiently and getting the most of it? If not, what needs to be adjusted?

Finally, our method of approach will be to use a goal programming formulation and adapt it to take advantage of simplex routines for solution purposes. Note that activities such as selling, storing and hiring labor will not be considered, for their impact on the allocation problem is marginal. Management problems are implicit in the delineation between the modern and the traditional part of the agricultural sector. The actions and attitudes of individual producers are not important in our analysis because we assume a centrally planned economy in which prices and demands are known in advance.

Specific Objectives

Livestock and crop fields are analyzed simultaneously in this study to:

1) Formulate a model for analyzing interregional adjustment and efficient resource allocation,

2) Determine the optimal land use and the spatial allocation of of agricultural productions

3) Determine what change would occur relative to the existing patterns resulting from:

- demand and output requirements
- transportation costs
- technology requirements

5) Test and evaluate the goal programming formulation for two real world examples. This technique is also compared with the linear programming results using the more conventional cost minimization and return maximization objectives.

6) Test the model for two real world problems of different sizes, the first from Algeria and the second from Egypt.

1.4 Outline of the Thesis

We will present a literature survey in chapter two, that will enable us to look at the different formulations, their purposes, their contexts and the different techniques used to solve them. We will emphasize the insufficiencies with regard to our problem and compare some of the approaches used.

In chapter three we will develop the theoretical model. This includes the definition of the unit region, the decision variables, the constraint set, and the objective function. We will also state the underlying assumptions and present some details on the solution procedure. Chapter four will be an application of the model to an Algerian two-region case. We will state the assumptions, the data source, and present the results along with their interpretations. Chapter five will be an application to a nine-region model from Egypt. The data sources and derivation of coefficients will be discussed together with the assumption and adaptation of the model to the Egyptian agriculture. The solution will then be discussed and empirical results evaluated.

Finally, in chapter six, recommendations will be made for directions in which both the model and the solution procedure can be refined to help the interregional allocation in the agricultural sector.

CHAPTER II

LITERATURE SURVEY

As noted in chapter one, the problem of efficient allocation of resources in agriculture is critical. Many countries have experimented with quantitative methods as aiding tools in the process of designing agricultural plans that are consistent with the overall economic objectives and that could be used to evaluate the impact of certain policies.

The purpose of this chapter is to review different models encountered in the literature and to review the methods of solution. This will enable us to derive some of the difficulties inherent to the different approaches and to point out the relationship of this thesis to the current literature.

Models are specialized in different ways according to economic functions, sectors, regions, or time periods. We will be focusing our attention on regional and sectoral agriculture models, both static and dynamic. Depending on the formulation adopted, these models can be used in deciding, for example, the timing, location, and scale of the agricultural production, or in evaluating the impacts of some policy instruments such as subsidies, quotas, and government programs. They range from aggregate sector models to detailed farm models.

2.1 Static Linear Programming Models

These are the most widely used models because of the possibility offered by linear programming to formulate and solve very large problems. They are basically static in that they usually incorporate policies which

which have to be effective within a period of one year. The annual decision concerning the spatial agricultural product mix represent an example of a static model.

a) Maximum-Return Models

The type of formulation is based on the maximization of some measure of welfare:

Problem MRLP Maximize $f(R) = XR$

Subject to

$$AX \leq L$$
$$BX \geq D$$
$$X \geq 0$$

where X is a vector of regional activities, R a vector of return, A a matrix of regional land input coefficients, L a regional vector of land resources, B a matrix of demand coefficients and D a vector of demands.

There are, however, some basic differences between the different models in this case. Heady and Srivastava [1975] specify R to be a vector of net regional returns and the demand vector to be a vector of national demand for grain crops only. In another study by Heady and Randhawa for the Indian agriculture [1964], R is a vector of values of output per acre, the demands are also specified for certain selected crops only, and welfare economic constraints are included to assure a minimum regional income. Related to the same formulation are studies by Hopper [1965], Sahota [1968], and Folkesson [1968].

More detailed studies also exist, such as that by Bishay [1974], in which net revenues, with output and input prices evaluated at the world market prices, are maximized subject to regional and national resources market prices, are maximized subject to regional and national resources which are extended to include labor and water resources. Foreign aid and transportation costs are then introduced to provide extensions to the basic model and an economic interpretation of the dual variables is provided.

We note that these models do not incorporate explicitly either crop rotations, or different production functions for the same crop. These latter characteristics are usually found in studies carried out at the level of the farm, that is, when the problem is no longer of the regional allocation type. A particularly interesting study was performed by Kerry and Edwards [1968] . It incorporates explicit land relationships and investigates factors that may limit linear programming as a predictive tool in agricultrual supply response studies. The conclusions drawn from the study center around the difficulty of measuring and predicting indiviudal farmer's preferences.

More studies in this class include soil fertility differences by Heady and Loftsgard [1973], detailed agricultural tasks and practical use by Candler [1977], and computer oriented studies by Larson and Hogg [1977].

b) <u>Minimum-Cost Models</u>

The general formulation of a minimum cost regional model of production and allocation is as follows:

<u>Problem MCLP</u> Minimize $\sum_{r=1}^{R} C_r X_r + \sum_{r}^{R} \sum_{s}^{R} T_{rs} Y_{rs}$

Subject to $A_r X_r - \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{rs} + \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{sr} \geq d_r \quad r = 1,\ldots,R$

$B_r X_r \leq S_r \quad r = 1,\ldots,R$

$X, Y \geq 0$

The objective function is that of minimization of production and transportation costs over the regional production activities X_r and transported commodities Y. Here, A_r is the output matrix of region r, d_r is the demand vector in region r, B_r is the input matrix in region r, S_r is the vector of resources supply in region r, C_r is the unit production cost vector in region r, and T_{rs} is the unit transportation cost vector from region r to region s.

Additional constraints may be added to include transportation of inputs, in which case the input matrix B_r will be partitioned into B_r^m, B_r^i , where B_r^m is the matrix of mobile factors such as water, capital, and in some instances, labor, and B_r^i is the matrix of immobile factors such as land. Also, bounds on transportation activities can be added to reflect limitations in the capacity of the transportation network. Bounds on regional production activities can be added to reflect insitutional constraints.

Probably the most complete studies in this class of problems are those covered in the book of Heady and Srivastava 1975 . They bring together the results of more than 20 years of research in applying programming models, essentially linear, to the problems of production and regional allocations in the U. S. agriculture. The work is a progression from a simple prototype model of regional production and distribution to models that allow for considerable detail through the inclusion of such factors as different technologies, transportation costs, domestic and export relationships, different pricing and income, different farm sizes and land classes, and environmental impacts. More specialized studies are done by Nichol, Heady, and Wade [1973], and Nichol, Heady,and Howard [1974].

A large scale linear program to estimate the demand for land and water used in U. S. agriculture is developed by Nichol and Heady 1975 . This study incorporates all major agricultural activities, land resources for 223 agricultural producing regions, water resources for 51 water supply regions, and 27 consumer markets. Although the stydy is very comprehensive and gives the detail of estimating the data, it does not provide for aspects such as crop interdependencies, varying levels of inputs and different objectives. Also, the model turns out to be very large in size, including 5,426 actitivites and 3,220 equations without foreign trade activities.

About the usefulness of these models in developing economies, Singh 1976 notes in a book review:

> They are in general normative models and such as may have limited operational value in analyzing development problems. . . .They raise questions, especially about the use of such models in less developed countries. . . .They do not provide an analysis of the richness of institutional structure and its constraints.

Finally, we can also include in this class models for individual farm planning, to which not much literature is devoted. Some methodological and practical aspects are reviewed by Reish [1971] and a practical example is solved by Huffman and Stanton [1970]. This example focuses on the determination of the accuracy of relatively low cost linear programming solutions for farm management. It is found that the best estimates of input-output coefficients are more accurate than standard matrices from a data bank.

c) Some Extensions

Although most of the literature using linear programming has been concerned with primal solutions, some work has been devoted to duality and other extensions.

and other extensions

i) Duality and Shadow Prices. Using the general formulation (MCLP) in (b) above, if for each region r, we let U_r and w_r be the vectors of dual variables, the optimality conditions are written as follows (see for example, Bazaraa and Jarvis 1977 chapter 5 :

$$A_r X_r - \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{rs} + \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{rs} \geq d_r \rightarrow (A_r X_r - \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{rs} + \sum_{\substack{s=1 \\ r \neq s}}^{R} Y_{sr} - d_r) u_r = 0 \quad (5)$$

$$B_r X_r \leq S_r \rightarrow (B_r X_r - S_r) w_r = 0 \quad (6)$$

$$u_r A_r - w_r B_r \leq C \rightarrow (u_r A_r - w_r B_r - C_r) X_r = 0 \quad (7)$$

$$-u_r + u_s \leq T_{rs} \rightarrow (-u_r + u_s - T^f_{rs}) Y_{rs} = 0 \quad (8)$$

Relation (5) measn that for each region the demand must be satisfied and the price of a product is positive only if there is no excess of that product in region r. Relation (6) means that, resources being limited, the price to use them is positive only if there is no excess supply. Relation (7) means that the regional activities X_r with associated negative net returns are not produced. Relation (8) menas that the demand price of commodity Y in region s is less than or equal to the price of the same commodity in region r plus the transportation cost between r and s, and only commodities for which the equality holds are transported from r to s. The optimality conditions then give us some insight into the structure and interpretation of the results of the model.

The dual solution provides equilibrium prices of products and prices for the use of limited resources, that is, when the supply and demand are equal for producers and consumers. The dual solutions thus can be used to determine the subsidy price which should be paid in a given region in addition to the existing price to induce regions to produce certain food products at certain minimum levels, or price reduction to limit production of certain goods.

Heady and Randhawa [1964] give an interpretation of the dual solution for the Indian case. In another study by Whittlesey and Skold [1965] attention is focused on the use of shadow prices associated with land as a guide for estimating government costs of changing crop production in any region. A note by McCall [1971] gives some insight into the relationship between duality and primal degeneracy together with practical ways to handle it for farm problems only.

Dual variables and prices in a pure competition market framework are exactly equivalent. Thus, linear programming applied to a pure competitive sector like the American agriculture can be quite logical and useful. Their rise in developing economies where prices are very seldom optimum in a linear programming sense, is still to be investigated.

ii) Other Modeling Aspects. Parametric linear programming is used in some cases to evaluate the input coefficients and is referred to in textbooks by Heady [1958], Agrawal [1972], Beneke [1973], and Rae [1977]. One real world work by Badewitz [1970] uses parametric programming to determine the economic value of the coefficients of a linear program, using shadow price interpretation of the dual variables. But the problems solved are not big enough to give a real insight into the usefulness of the technique.

Two other works use special structure linear programming and are worth mentioning.

The first by Bär [1975] is the formulation of a problem of cooperative production managment including several farms based on the Dantzig-Wolfe decomposition principle [1961]. The interest here is in the use of shadow prices, from the solution of the master problem, as benchmarks for the individual farms so that no discrepency occurs between the objective of the cooperative as a whole and the objectives of the individual farms. Similar works can be found in Hardie [1969] and Tsuboi [1977]. The second work, by David and Mosci [1974], uses a network formulation to solve irrigation problems in which crop allocations are indirectly determined by the optimal flow of water thourgh the system. The optimal solution is obtained using an out-of-kilter algorithm. Other similar applications are available in Kurlypo and Uapina [1970].

2.2 Dynamic Linear Models

The main difference between static and dynamic models is that investment activities are included in dynamic models and resources are allowed to vary from one period to another,thus allowing the variation of production capacities. These models may also include provisions for future land reclamations. Hence, the objective of dynamic linear models is to determine the optimum regional agricultural production and investment.

The problem can be formulated to minimize the overall production and transportation costs or to maximize the total revenue over a fixed period of time. A simplified formulation for illustration purposes is as follows:

$$\text{Minimize} \sum_{t=1}^{T} e^{t-1}(C_t X_t - V_t a_t)$$

Page missing from thesis

investment decisions for permanent crops only.

It is to be noted that none of the studies mentioned above includes crop relationships over time and that no adequate treatment is given to the choice of the planning horizon and the terminal conditions in the plan; the latter is important since the investments made in the last year of the plan do not affect the production levels within the planning horizon. That also points out the necessity of linkage of the agricultural programs to long-range economic plans.

2.3 Recursive Programming Models

Recursive programming was introduced in the late fifties by Henderson [1959]. It is basically a synthesis of linear programming and time series analysis of data. It is aimed at predicting the short-term allocation of land among specified crops. Central to the analysis are the decisions of the individual producers. The basic model is formulated so as to maximize total return over all regions subject to land availability and crop acreages expressed as recursive relationships.

$$\text{Maximize} \sum_{j=1}^{m} \sum_{i=1}^{n} \pi_i X_{ij} \tag{9}$$

$$\text{Subject to} \sum_{j=1}^{m} \sum_{i=1}^{n} X_{ij} \leq \sum_{j=1}^{n} b_j \tag{10}$$

$$\begin{aligned} (1 - \underline{\beta}_i) \sum_{j=1}^{m} X_{ij,t-1} &\leq \sum_{j=1}^{m} X_{ij,t} \\ (1 - \bar{\beta}_i) \sum_{j=1}^{m} X_{ij,t-1} &\geq \sum_{j=1}^{m} X_{ij,t} \end{aligned} \tag{11}$$

where:

Π is the expected return per acre of the i^{th} crop

x_{ij} is the acreage of crop i in region j

b_j is the total availability of land in region j

Henderson's most important modification to the basic linear programming is the attempt to convert the solutions from the normative stage to the predictive stage. The set of constraints (11) expresses upper and lower bounds on acreage which are derived from historical data on actual year to year change using time series methods. Hence:

$X_{ij,t}$ is the solution acreage of the i^{th} crop in region j in year t

$X_{ij,t-1}$ is the actual acreage of the i^{th} crop in region j in year (t - 1)

$\underline{\beta}_i$ the maximum precent by which the producers are willing to decrease last year's acreage of crop i

$\overline{\beta}_i$ the maximum percent by which producers are willing to increase last year's acreage of crop i

Henderson's first model did not incorporate some important factors. Subsequent studies added some refinements. For instance, Day [1960] confined his study to one region, the Mississippi Delta and specified more constraints for each crop for both acreage and yield. He also allowed for alternative ways to produce each crop, which added a new dimension to the basic model: prediction of changes not only in acreage but also in production. More refinements are introduced by Schaller [1962] regarding differences in soil type between regions. Some more recent studies based on the same models but with different applications are those by Lee [1972], Anderson and Stryg[1976], and Ericksen and Buller [1976].

2.4 Non-Linear Models

a) Deterministic Models

This class of models has the same set of constraints as in the linear programming case, but their objective function is nonlinear. In general, the demand and supply vary according to prices. The objective is the maximization of some measure of income which is a function of the demand and supply vectors.

Usually, the demand and supply functions are linear and integrable. This makes the objective function a quadratic maximization of the sum of producers' and consumers' surpluses.

If we let D be vector of demands, S a vector of supplies, and P a vectors of prices, then, since prices depend on both bupply and demand, we have:

$$P = f(D) \text{ and } P = g(S)$$

The return function would then:

$$R(D,S) = \int_0^D f(S)dS - \int_0^D g(S)ds = F(D) - G(S)$$

For more details on the deribation of the return function and on the integrability conditions, the reader may refer to Pariente [1977,appendix II].

The allocation models then becomes:

$$\text{Maximize} \quad F(D) - G(S) - CX$$

$$\text{Subject to} \quad AX - D \geq 0$$

$$BX - S \leq 0$$

$$X, D \leq \geq 0$$

where A is an ouput regional matrix, B an input regional matrix, and X a vector or regional cropping acitivities.

where A is an output regional matrix, B an input regional matrix, and X a vector or regional cropping activities.

In agricultural studies, it is usual to consider the resource vector, such as water and land, as known, but the demands as functions of prices. That simplifies the problem and permits the simulation of a market equilibrium. Takayama and Judge [1964,i] formulated such a model with demand functions specified for each region, and gave some theoretical insight into the interpretation of the solution in [1964,ii]. Duloy and Norton [1973], in developing CHAC, a model for the agricultural sector in Mexico, included the demand function into the constraint set and used linear approximations to end up with a complete linear program. Also, a quadratic regional model for the U. S. agricutlrue can be found in Heady [1975], based on the same principles

b) Risk Consideration

When it is recognized that the producer preferences and attitudes toward uncertainty are important, the notion of risk becomes a relevant factor to include in programming agricultural models. The basic source of risk is confined to yields nad is reflected in prices through supply and demand functions.

By using demand functions and risk factor for cropping activities: the objective function becomes:

$$\text{MAX Revenue} = X'W[A - \alpha BWX] - C'X - \phi[X'TX]^{\frac{1}{2}}$$

where:

X is a vector of aggregate activites in acres

W is a diagonal matrix of average yields

C is a vector of cost coefficients

A and B are coefficient matrices of thelinear demand function

$P = A - \alpha BXW$.

ϕ is a risk aversion coefficient

T is a variance covariance matrix of gross returns from cropping activities.

Basic to this method is the assumption that producers behave according to MAX $\mu = E(R) - \phi V(R)$, that is, to choose among the maximum expected return with the one with minimum variance. Details of the method can be found in Hazzel and Scandizzo [1974], extensions and applications in Simmons and Podhareda [1975] and Wiens [1976]. A critical review of the method and empirical results is found in Adams, King, and Johnston 1977 .

Although the importance of nonlinear models is being more and more recognized, they have been less used than linear models because of the difficulty to satisfy the necessary theoretical requirements to obtain a global optimum. Difficulties also arise in estimating the parameters of the demand and supply functions accurately to reflect the actual market conditions. Another limitation is that an accurate model will have to introduce risk coefficients for different crops and by regions, a difficult and complex task.

c) Other Methods and Models

Dynamic programming techniques have great potential for problems like crop rotations or sequences over time, and multiple cropping programs within a year. But their use has been confined mostly to farm problems such as growth paths, sequencing of agricultural tasks, and water. Examples can be found in Agrawal and Heady [1972].

The application of dynamic programming to regional allocation of crop production has never been attempted explicitly because it is not computationally feasible or economical. One study in Andrews [1977] uses a dynamic programming formulation of a two-region model to describe the changes in regional production and distribution at a high level of aggregation. Also, the model can be solved for one crop at a time, thus presupposing an optimal spatial distribution at the outset.

We have mentioned, while discussing the non-linear program formulation, that interregional analysis usually uses explicit linear demand functions but no supply functions. In a study by Larson and Hogg [1968] extended by Huang and Hogg [1976], both supply and demand functions are explicitly formulated to determine equilibrium regional prices; they use a separable programming technique to solve the problem, but no computational experience is reported for real world problems to evaluate the efficiency of the approach. For further details on dynamic and separable programming, the reader may refer to Hadley [1964].

Thus, we have seen that in the class of non-linear models, only quadratic formulations have tackled problems of regional crop production. In general, linear approximations are used to enable the use of simplex based routines. The rest of the methods have found only marginal use.

2.5 Integer Programming Models

There are many important special conditions which characterize the resource allocation problem in agriculture and which cannot be dealt with in any practical way without the use of discrete variables. In this regard, the (0-1) formulation proves very useful as found by Edwards and Clark [1963] and Seagraves [1964]. The most common of these special conditions are summarized below:

a) Either/Or Choices

If it is desired or imposed that either corn or soybeans are to be planted, then a non-linear restriction appears:

$$X_c \cdot X_s = 0$$

This expression could be replaced by two linear inequalities in an integer program:

$$X_c \leq M_c Y$$

$$X_s \leq M_c (1-Y)$$

$$Y = (0,1)$$

where M_c and M_s are upper bounds on the levels of X_c and X_s. Other typical problems are different livestock feed alternatives or different technologies expressed in different sets of constraints, only one of which needs to be satisfied. Then, given m constraints of the form:

$$h_i(X_i) \leq 0 \qquad\qquad i = 1,\ldots,m$$

to guarantee that at least n of them are satisfied, the following modification will do:

$$h_i(X_i) - M_i Y_i \leq 0$$

$$\sum_{i=1}^{m} Y_i \leq m - n$$

$$Y = (0,1) \text{ for all } i$$

where M_i is an upper bound on $H_i(X_i)$ for each i.

An optimizing algorithm applied to this problem would seek to relax (m-n) constraints depending on which, by being relaxed, gives the best objective function value.

b) Fixed Charges

If a certain crop or group of crops necessitates a fixed complement of machinery to be grown, we would modify the objective $MAX = \sum_j \Pi_j X_i$ to become: $\sum_j \psi_j(X)$

$$\text{where } \psi_j(X) = \begin{cases} 0 \text{ if } X_j = o \\ \Pi_j X_j - C_f Y_f \text{ if } X_j \geq 0 \end{cases}$$

$Y_f = (0,1)$ and X_j = acreage of crop j.

and add a constraint: $X_j \leq M_f Y_f$

where $M_f \leq C_f$ is an UB on X_j.

c) Types of Problems Solved and Procedures

The usual well solved problems are in the class of small farm organizations such as by University of Georgia [1974], land use planning, where the attention centers around the competing uses of land in agricultural and non-agricultural uses, as done by Nautiyar [1975]. Other important applications are in food management problems as done by Duffry [1974]. The procedures used are based on cutting planes and are reviewed in Candler [1972].

In conclusion, we can say that integer programming has not found any use in regional analysis, but only in small farm problems. That seems to be due to the lack of efficient algorithms for solving large scale integer programming problems.

2.6 Simulation Models

Simulation models have not been used for regional allocation of crop production. But their limited use for individual farm planning is spreading and their usefulness is becoming well recognized, especially when the problems contain some intractable features such as decreasing average cost, integer constraints on the levels of input and output, and weather uncertainty. Some examples are Zusman and Amiad [1965], Carlsson and Lindgren [1969], and Jones [1976]. Also, simulation has found more applications by agronomists in the study of physiological growth processes of crops and irrigation systems.

In addition, simulation could also be used in the context of another model. For instance, in a linear program simulation can be used to determine the possible variations of prices without affecting the optimal production mix; an illustration is found in Engler and Meyer [1973]. Some problems have been raised, however, with regard to the merits using simulation as compared to other analytical tools. See for example, Chandler and Penn [1973].

2.7 Statistical and Probabilistic Models

a) Regression Models

The most important formulation is the single equation model fitted by least squares. Multiple equation models have been found more realistic and useful as done by Borkon and Boles [1970] and Sirotenko [1976].

In spite of the fact that regression models require relatively less detailed data, they have severe limitations for regional analysis, because of the limits on the number of independent variables that can be included and the difficulties associated with isolating the many effects of variables. Some models are found to give as good results as linear programming; for that, see Shumay and Chang [1977].

b) Markov Chain Models

Markov Chain models have been used to predict land use patterns, that is, the different usages of land among which agricultural land is subdivided into larger groups, such as crop land, pasture, and grazing. This severely limits the scope of the method for allocating individual crops. The main advantages of using Markov-chains is that dynamic models can be formulated to predict long term land use changes. The methodology assumes that the variable of interest is land use. A finite Markov chain process then requires that n different land use categories be defined and that movements between these categories over time be summarized in a land use flow matrix. Then the probability of moving from category L_i to L_j in one period of time is computed as:

$$P_{ij} = \frac{L_{ij}}{\sum_{i=1}^{n} L_{ij}} \qquad i = 1,\ldots,n$$

where L_{ij} is the land that was in category L_i in period $t - 1$ and shifted to category L_j in period t. The prbabilities are in fact proportions of land. The transition matrix derived from observed land use changes, together with a vector of initial land use Π_0, is used to project land uses for each future period t based on the property of Markov chains by solving the following system:

$$\Pi_n = \Pi_0[P]^n$$

A dynamic formulation of this model can also be derived. For more details and specific applications, the reader may refer to Burnham [1973] and Drummon [1977].

Finally, Markov chains can be used within mathematical programming models to control resource transfers, providing a more systematic way to generate bounds over time. For an application within a linear program, see Scott and Chen [1972].

c) Stochastic Programming

This technique has not found any use in the area of regional agricultural production. Illustrative examples are found in earlier works such as by Heady [1958] but the technique found limited use only. A review and formal exposition of the method can be found in Blau [1974].

2.8 SUMMARY

The literature search has revealed that several aspects of the problem defined in the introductory chapter have not been adequately incorporated in past research. In addition to the limitations of certain techniques to handle such a probelm, adequate formulation of the most important characteristics of cropping patterns and economic situation of the agricultural sector in developing countries, needs to be further investigated to develop a model with enough flexibility to incorporate several objectives and the basics of the production process. The next chapter will be devoted to developing such a model and indicating the solution procedure to be adopted.

CHAPTER III

DEVELOPMENT OF THE MODEL

In this chapter we develop a linear goal programming model for agricultural regional planning. The model minimizes a weighted sum of deviations from a set of prescribed goals. We start by reviewing certain economic concepts that will be useful in the development of the model.

3.1 Economic Concepts

The study of economics is considered necessary in understanding crop production systems, since it can provide principles that help in deciding among alternative production levels or techniques. Our aim is not to provide an introduction to the subject but only to some concepts that are important in making some assumptions for the model.

Basic to the production process is the concept of a *production function*. It is agreed upon that the production function, also called the *response function*, is the unique relationship between factors of production and output. More formal definitions can be found in Rodes and West [1968] or Rae [1977].

Mathematically, it can be written as:

$$Y = f(X_1, \ldots, X_n)$$

where Y refers to the crop yield and X_i $(i = 1, \ldots, n)$ refers to specific factors of production. It is assumed that only factors that can be brought under control and which influence the crop yield, are included in the inputs.

Figure 3 depicts a one-variable input production function which shows the relationship between a factor X_1 and the yield, Y. It is assumed that all other factors are held at a constant level, that is:

$$Y = f(X_1 \mid X_2, \ldots, X_n)$$

From the same figure, we also note that the production function exhibits diminishing returns to the factor X_1, which is a characteristic of agricultural production. This principle is stated in Rhodes and West [1968] and follows: "If increasing amounts of one input are added to the production process while all other inputs are held constant, the amount of output added per unit of variable input will eventually decrease."

To help determine the optimum combination of factors, we need to refer to another technical concept, the rate of factor substitution (RFS) between two factors, also called marginal rate of substitution. It measures the rate at which the planned level of one input, say X_1, could be changed if we planned to increase the level of another input, say X_2, by a very small amount while maintaining the same level of output. It is calculated as follows: $RFS(X_1, X_2) = \Delta X_1 / \Delta X_2$.

In particular, the rate of substitution is constant when the amount of one factor replaced by the other factor does not change as the added factor increases in magnitude, which is illustrated in Figure 4 by the straight line, also called isoquant. That is, one unit of X_1

substitutes for one unit of X_2 and the RFS will be equal to the slope of the isoquant. Thus if the isoquant is not linear, different points on the isoquant correspond to different RFS. In this case, adequate piecewise linear approximation could be used to approximate the production surface and lessen the bias introduced by simply assuming that the production function is linear; this point is illustrated in Figure 5.

Another concept which is basic to the choice of farm size is the concept of returns to scale. In the production function $Y = f(X_1,\ldots,X_n)$ if all factor resources are considered variable, the interest focuses on the increase in output ΔY as the factors are increased by the same proportion ΔX. In particular, if the proportions of increase of X_i $(i = 1,\ldots,n)$ and Y are the same, constant return to scale prevail. Such a production function is called homogeneous, that is if $Y = f(X_1, X_2)$, then $kf(X_1, X_2) = f(kX_1, kX_2) = kY$. A two-factor production function illustrating this property is shown in Figure 6.

In real world problems, the underlying concepts defined above are still valid but the number of factors is high enough to make a graphical or a tabular analysis impossible. Instead, more powerful mathematical methods are required.

3.3 The Main Features of the Model

a) Definition of the Producing Unit

Because of the wide variation in climate, soil, and production possibilities between regions, the basis of a spatial model is the definition of a set of homogeneous regions consistent with the characteristics of the resources and the possible production techniques

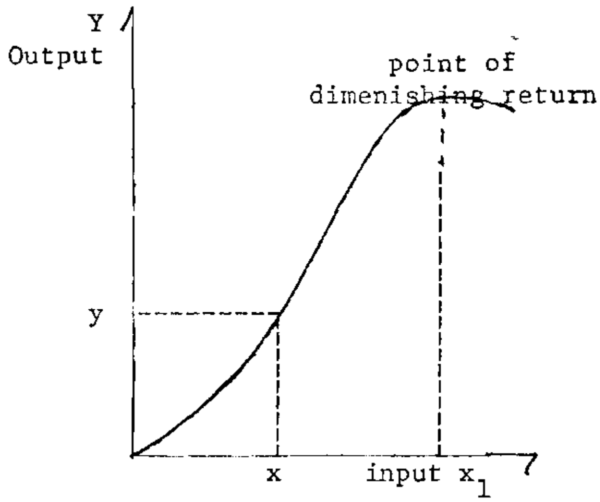


Figure 3. One-Variable Production Function

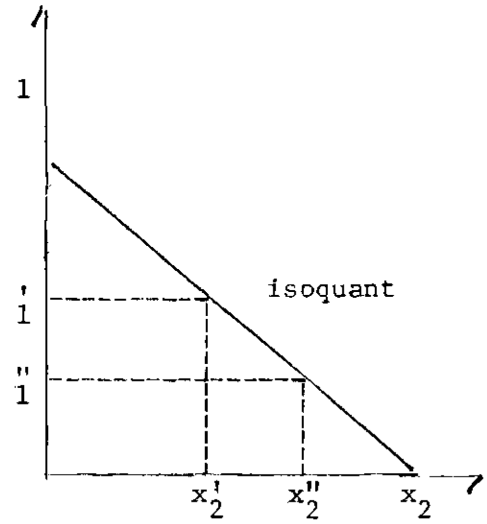


Figure 4. Constant RFS

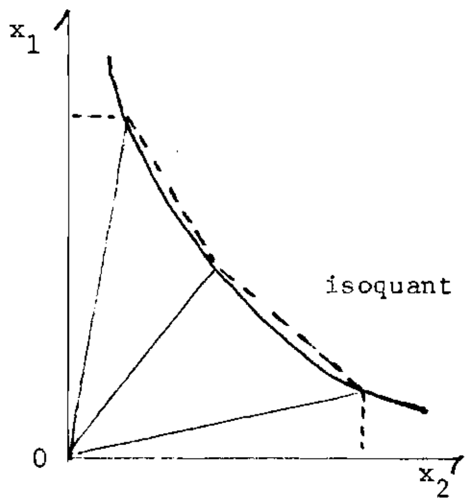


Figure 5. Linear Approximations of a Nonlinear Production Surface

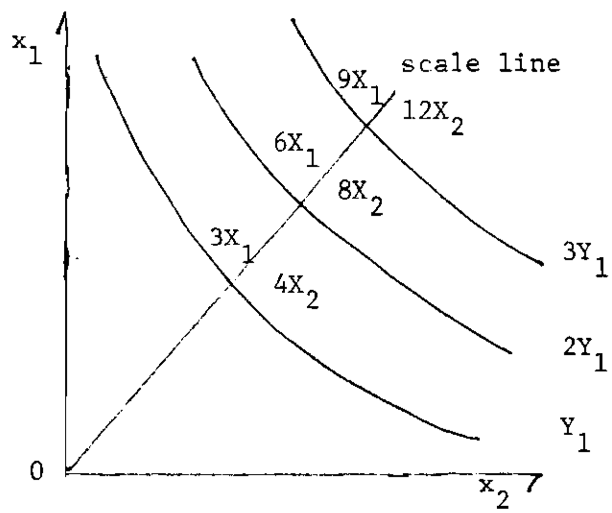


Figure 6. Constant Return to Scale

in each region. But that reveals the important problem of aggregation. The ideal situation would be to have the spatial unit correspond to the farm, but that would create problems of intractable size. Thus another alternative is to be found.

Past applications of budgeting and linear programming handle this question in two ways:

1. Define a typical farm representative of a set of farms with similar production techniques and size. Thus the most likely allocation for a farm must be multiplied by the number of farms in the group it represents to yield an aggregate response. This aggregation scheme is not commonly used due to the lack of data.
2. Define the region, rather than the farm, as the unit element in the model. This method, however, does not take into account the possible variations between farms, especially those related to mobility and shiftability of production factors. Moreover, it tends to average the variations among individual farms such as quality of resources and climatic conditions.

For a review of using micro data to derive macro results, the interested reader may refer to Stovall [1966], Day [1969], and Paris and Rausser [1973]. For an empirical analysis, see Egbert and Kim [1975] and Williams and Rae [1976].

In case of a developing economy, another element is to be considered. This element is the difference between the cooperative part and the private part of the agricultural sector. We have given a description of the differences between these two parts in Chapter I, and will refer to them as Sector I and Sector II respectively.

To be able to use each sector as the producing unit representing all farms in it, the following assumptions are made:

In a given region, for each sector, we suppose we have n^s farms $(i = 1,2,\ldots,n)$, m^s activities $(j = 1,2,\ldots,m)$ and P^s factors of production $(k = 1,2,\ldots,P)$ where $s = 1$ for Sector I and $s = 2$ for Sector II. Thus for each farm in a given sector, let:

Y^s_{ij} = level of the j^{th} activity in the i^{th} farm

X^s_{ijk} = amount of the k^{th} factor used by the i^{th} farm to produce the j^{th} activity

Θ^s_{ijk} = amount of the k^{th} factor to be used in the i^{th} farm to produce one unit of the j^{th} activity

$Y^s_{ij} = f^s_{ij}(X^s_{ij1}, X^s_{ij2},\ldots,X^s_{ijp})$ is the production function for the j^{th} activity in the i^{th} farm.

The production function of the i^{th} farm in each sector is assumed homogeneous, that is, $a\,Y^s_{ij} = f^s_{ij}(a\,X^s_{ij2},\ldots a\,X^s_{ijp})$, denoting that if the amount of each factor is increased by the proportion a, the level of the activity will increase by the same proportion.

We also assume:

$$F^s_j = \sum_{i=1}^{n} f^s_{ij} \quad \text{and} \quad Y^s_j = \sum_{i=1}^{n} Y^s_{ij}$$

where F^s_j, the production function of the j^{th} activity in sector s, is the sum of the production functions for the different farms in that sector, Y^s_j, the total level of activity j for sector s, is the sum of the activity levels of the n farms in that sector.

Similarly, we must have :

$$\sum_{j=1}^{m} A_{jk}^{s} Y_j^{s} = \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ijk}^{s} Y_{ij}^{s} \leq R_k^{s} = \sum_{i=1}^{n} \theta_{ik}^{s}$$

where the amount of the k^{th} resource used to produce all activities j in sector s is equal to the sum to be used by the individual farms. The second half of the expression indicates the amount, R_i^s, of the k^{th} resource available in the sector is the sum of the amounts θ_{ik}^{s} available in the individual farms.

And finally, for each region, we must have:

$$G_j = \sum_{s=1}^{2} F_j^s \quad \text{and} \quad Z_j = \sum_{s=1}^{2} Y_j^s$$

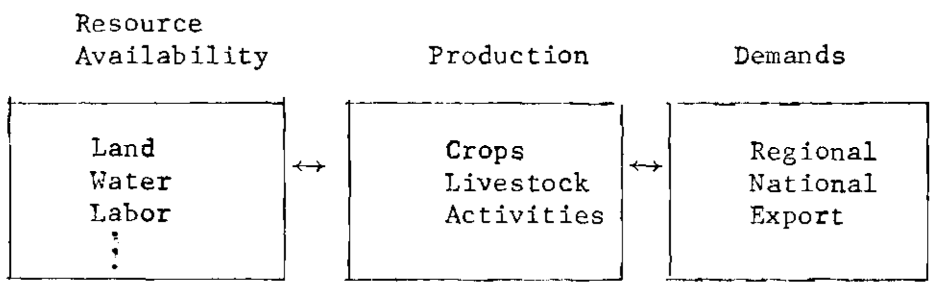
where G_j, the production function of the j^{th} activity for the region, is the sum of production functions for the two sectors in region j, and Z_j, the total activity level for the region, is the sum of the activity levels in the two sectors.

To minimize the aggregation bias between the results of the macro model and the results of a micro model that would include all the farms individually as the producing units, a classification of the regions needs to be based on technical homogeneity. The latter is a combination of certain technical criteria such as soil type, weather conditions, availability of resources and type of sector. On this basis, the area under study may be divided into a number of regions with a minimum variance in the degree of homogeneity within each region and a high variance between different regions. The advantage of this classification is that the production functions estimated in each sector of each region will represent the real technical conditions in the given sector within the given region. That would be very helpful in defining the production activities to be included in the model.

Note, however, that this classification may result in defining too many regions for which data collection and implementation of the program results would be very difficult or impossible. This leads us to using another criterion which is based on management or administrative practice. Since technical homogeneity and uniform administrative practice will very seldom coincide, a compromise is to be found. Note that in our case, the distinction between the two sectors within each region determines most of the technical homogeneity; the administrative basis will serve to have regions of comparative importance.

b) The Components of the Model

The model will define and quantify the major interactions between the three following components of the agricultural environment:



i) The Resource Component. The resource component indicates the supply of scarce factors of production and the differences of production functions from one sector to another and from one region to another. The supply of resources will be assumed to be of two kinds:

Fixed

These resouces include the acreage of dry and irrigated land for crop production including land for pasture and permanent crops. The supply of water comprising not only reservoirs, dams and wells, but also expected rainfall. The supply of agricultural labor is assumed to be abundant, but will have a limiting aspect to account for the scarcity of skilled labor in developing countries.

Flexible

These resources include fertilizer, pasture, and equipment and are assumed flexible since their availability would be increased at an additional cost, say through importation.

ii) The Production Component. It includes the endogenous variables of the model, which will ultimately constitute the élements of the regional allocation problem. These variables can be divided into three sets related to the agricultural activities, interregional flows of agricultural products, and deviations from goal achievements.

In the first set, the values of the production variables in the solution indicate the most appropriate agricultural product mix in different regions. They include livestock production and correspond to the best production techniques in terms of optimal amounts of labor, machinery and fertilizer. Details on the treatment of these elements will be given with the mathematical formulation. The second set of varialbes will provide information on the most appropriate inter-regional flow of products to satisfy supply and demand equilibrium in each region. The explicit consideration of the transportation relationships is important, because it will permit a realistic and more detailed analysis of the effects of transportation costs on the optimum agricultural product mix in the different regions. The last set of variables will provide information on the most appropriate trade-offs to be made relative to achieving such goals as food demands, employment, international trade expenditures and overall costs. The magnitude of the deviations from the set goals, and whether they represent an overachievement or an underachievement, can serve the process of policy making, especially in the area of importation and exportation.

iii) The Demand Component. In a developing economy demand of basic nutritional goods is not a function of prices but rather a function of the population size and minimum nutritional needs. This is largely due to the fact that government in developing economies tends to contribute to such basic goods through subsidies in such a way as to make them available to the population at reasonable prices for the income level of the country. For this reason, we assume that demands are exogenous to the model and hence fixed.

Since transportation costs are taken into account, the classification of the demand requirements by regions becomes necessary for determining the optimum flow of agricultural products among different regions. After having described the basic components of the model, we will now summarize the relevant assumptions and give the mathematical formulation.

3.3 Assumptions

1). No perfect market conditions prevail, which implies that the prices and demands are fixed. That is, a central authority is assumed to fix the prices and declare the country's needs before the production process starts.

2). Spatially separated but interdependent regions exist according to the criteria described above.

3). Each region contains two separate sectors called Sector I and Sector II. Some regions may contain only one of two sectors if it is imposed by the specific case.

4). The input-output relationships are identical for all farms belonging to a given sector in a particular region.

5). Constant rates of factor substitution are assumed.

6). The production function is assumed linear in all regions.

7). The planning horizon is one agricultural year.

8). Labor supply is assumed completely flexible and can be aggregated for the whole year. It will be indexed as man-days.

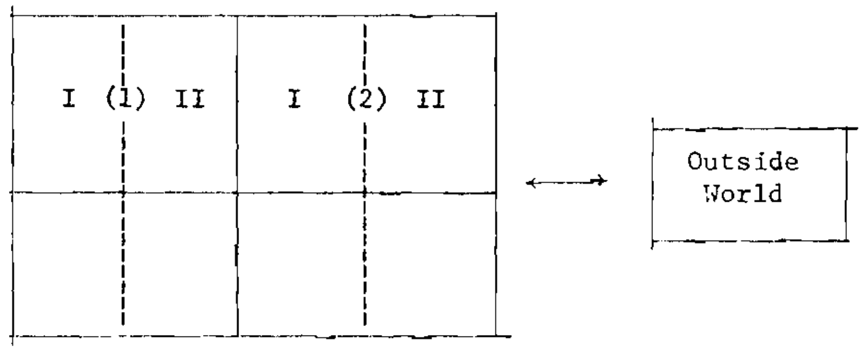
9). Transportation between any two regions is done by the cheapest possible means.

10). International transportation costs are not explicitly considered but included in the cost of the imported products themselves.

11). Variables are supposed continuous and divisible.

3.4 Mathematical Formulation and Notation

The following diagram depicts the area under study with its different regions:



where solid lines indicate boundaries separating different regions, and dashed lines indicate the two sectors within any given region. Note that the production function is specific to the sector but the resources and data availabilities are specific to the region.

We will now define the set of variables, the constraints, and the objective function, giving details of the different interactions and land relationships, together with adopted notation.

a) Definition of Variables

The variables of the model are specified as the different alternative agricultural production activities in every region. That is, in every region a suitable set of activities is formulated in accordance with the technical and natural characteristics of that region. In fact, most of the activities will appear in all regions, but, for example, in a region which has a cold dry climate, crops like cotton and rice need not be considered.

i) The Continous Crops. Continous crops take a full agricultural year to give an output, and are rotated every four or five years with other crops or fallow. They are basically food grains, and feed grains, which cannot be planted more than one time on the same piece of land during the same year. Most of them are winter crops but in some cases they may be spring or summer crops.

A continuous crop will be denoted by X_c, where c = 1,...,C. For example, c = 1 may denote wheat, c = 2 may denote barley, and c = 3 may denote corn. One unit of these activities represent one acre of crop; other units such as hectar may also be used.

Excluding rainfall, a distinction is made between irrigated land and dry land. The symbols I and D are used to denote irrigated and dry land respectively. Furthermore, a distinction is made according to the level of fertilization used: F1 denotes light fertilization and F2 denotes heavy fertilization.

To summarize, we have the following variables:

$XDF1_{s,c,j}$ = Acreage of dry land using light fertilization

$XDF2_{s,c,j}$ = Acreage of dry land using heavy fertilization

$XIF1_{s,c,j}$ = Acreage of irrigated land using light fertilization

$XIF2_{s,c,j}$ = Acreage of irrigated land using heavy fertilization

Here s = 1 indicates Sector I, s = 2 indicates Sector II, c is the crop identifier, and j is the region identifier. For example, $XDF1_{1,3,5}$ is acreage of dry land allocated to Sector I of region 5 for growing crop 3 using low fertilization. Note that the difference between the two sectors, in terms of production functions, will be reflected in the efficiency of irrigation and amounts of fertilizer applied to the crops. Sometimes, the traditional sector, may not have fertilizer applications at all.

Note also that cropping activities are aggregated activities, that is, tasks like plowing, harvesting, tilling, are combined to make up one unique activity of growing a certain crop on a given piece of land, by some prespecified technique.

ii) The Rotation Activities. Rotation activities will include the vegetables and other crops which may be grown more than one time a year. They will be included in adequate rotations according to their cropping systems and agronomic characteristics. There are several ways to enter these rotations into the model depending on whether we leave it to the model to determine the best sequence of crops or not. Some work in this area is done for the farm level by Heady and Candler [1958], Gee and Edwards [1968], and Barnard and Nix [1973].

The representation of crop rotation requirements into programming models, and the interpretations of the solutions in terms of the practical rotations to be followed is a difficult task. One major problem is the lack of data on crop response to changes in rotations. When there is an interaction among crops such that the yield of one crop is a function of the rotation within which it is grown, it is desirable to define rotation. For example, maize in a maize-oats-meadow-maize rotation is likely to yield more and respond differently to fertilizers than does continuous maize. Here the whole rotation will be entered as a single activity.

Other considerations for including rotations are, soil fertility conservation, and control of weeds and diseases. For instance it is preferable to rotate shallow-rooted crops with deep-rooted crops since each type obtains nutrients from different levels in the soil. Also, rotating crops that use soil fertility with ones that add to it as in the case of cotton and clover in Egypt, is a desirable thing to do. In practice, little data exist to describe such phenomena, and we will base our work on current rotation practices and their demonstrated results in terms of yields and inputs used. We will formulate crop inter-dependencies in two ways:

(1). Compounding a Rotation into a Single Activity. In this case, the input-output data for the individual crops are added into single activities which are then entered in the matrix constraints as such. To illustrate, consider the rotation:

First year: Wheat

Second year: Beans

Third year: Barley

The input-output data for the individual crops is given below:

	Wheat (1 acre)	Beans (1 acre)	Barley (1 acre)	Total
Cost ($)	400	200	300	900
Land (acres)	1	1	1	3
Labor (hours)	200	80	50	330

Then we call this rotation R1 and enter is as a single activity with cost coefficient 900 and with unit land consumption of 3 acres and unit labor consumption of 330 hours.

Suppose that the solution indicated a production of 20 units of the above rotation activity. This means that 20 acres of wheat, 20 acres of beans and 20 acres of barley are grown each year in the following manner, during a sequence of three years:

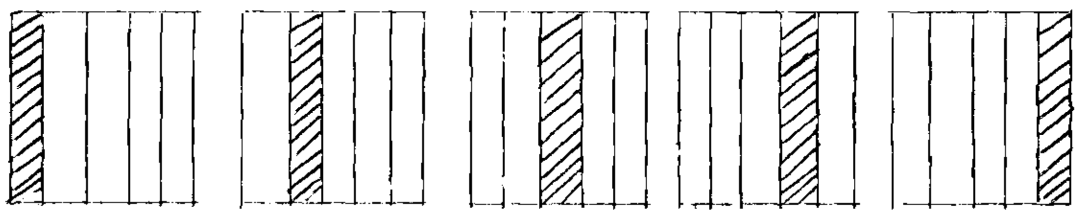
1st Year	2nd Year	3rd Year
Wheat	Beans	Barley
Beans	Barley	Wheat
Barley	Wheat	Beans

The above rectangles represent 60 acres of land divided into three parts of 20 acres each, which gives the desired rotational effect. The advantage of this treatment is that it allows for interdependency between crops in the rotation, and the results of the program solved can be interpreted very easily in terms of practical rotations.

Now suppose that the above rotation R1 appears in the solution at a level of 100, and that another rotation R2, consisting of potatoes-pasture-barley appears at a level of 30. In such a case a farm land would have to be divided into two blocks, each with its separate rotation. If the practical implementation of the solution makes it desirable not to grow the same crop on two different areas within the farm, and since barley belongs to both rotations, one may add the restriction $R1.R2 = 0$ in the model. This would cause nonlinearity of the model. For the regional allocation problems, however, based on the sizes of the farms in the region, the rotations retained in the solution would be distributed among the different farms in such a way to avoid this problem.

(2). Bounds on the Individual Crops. Another way in which we will handle rotations is to place bounds on individual crops or groups of crops that form the rotation. For example, if we know that for the purpose of disease control, we need tomato crops to be separated by five years on the same piece of land, and if 50 acres of land are available, then only one fifth of this land, that is 10 acres, may be planted with tomatoes any given year, which gives the rotational effect shown below:

Years: 1 2 3 4 5



There are two cases to consider depending on whether the area of land available to the rotation crops is fixed and known in advance or depends on the levels of non-rotation crops which compete for the same resources in the program.

Fixed Bounds

Suppose that for reasons related to soil fertility and disease control, it is required that four years are to separate successive plantings of tomatoes and potatoes on the same land, three years between successive carrot crops, two years between successive crops of beans, and year between successive crops of peas. If only 100 acres are available, then the maximum area of tomatoes and potatoes combined must not exceed one fifth of the 100 acres. Similarly, the maximum fraction of land that can be allocated is one quarter for carrots, one third for beans, and one half for peas. We then represent the rotational requirements by the following matrix of land constraints:

Constraints (acres)	Tomatoes	Potatoes	Carrots	Beans	Peas	RHS
Total Land	1	1	1	1	1	$\leq$ 100
Maximum Tomatoes and Potatoes	1	1				$\leq$ 20
Maximum Carrots			1			$\leq$ 25
Maximum Beans				1		$\leq$ 33
Maximum Peas					1	$\leq$ 50

Note that the sum of the individual crop bounds is 128 acres, which exceeds the total land resources of 100 acres, therefore giving some flexibility of choosing the best sequence.

<u>Other Bounds</u>

This is the case where land is available to activities other than rotations. In the above example, if we include wheat and permanent pasture into the program, they will also be competing for the land. Here we will include the rotational effect in the following manner. Even though we do not know in advance the total land available to the vegetable crops, we know that it will be equal to the sum of the areas allocated to each one of them. If we let T, P, C, B and PE stand for the area of tomatoes, potatoes, carrots, beans, and peas respectively, requiring that the combined area of tomatoes and potatoes, for example, be less than or equal to one-fifth of the total are, could be written:

$$T + P \leq 1/5(T + P + C + B + PE), \text{ or}$$

$$0.8\ T + 0.8\ P - 0.2C - o.2\ B - 0.2\ PE \leq 0$$

Normalizing, the following constraint is obtained:

$$4T + 4P - C - B - PE \leq 0$$

This land constraint is entered in the constraints matrix in that form. We can do the same transformation for all other crops that require rotation relationships and end up with a matrix of contingency relations between crops in which only the diagonal elements are positive.

So far, this method is feasible for determining the amounts of different areas of crops to be grown, taking into account the rotational effect. But it still needs to be adjusted to tell us the sequence in which crops will be grown and in what amount. The same contingency relationship will be used here to accomplish the desired adjustment.

Using the same previous example, if we wish peas to follow either beans or carrots, but not tomatoes or potatoes, because of possible disease, and carrots to follow only potatoes, we would add the following constraints to the contingency matrix defined before:

Constraints (acres	T	P	C	B	PE	RHS
Peas Sequence			-1	-1	1	≤ 0
Carrots Sequence		-1	1			≤ 0

Thus, the peas area will not exceed the combined area of carrot and beans, and since it must also obey the maximum peas constraints already formulated, the rotational affect is complete. The same thing is valid for carrots.

Note that if it is desired that one acre of a given crop is to be followed by less than one acre of another crop, then we only need to replace the -1 coefficient by the desired proportion in the corresponding constraint. Along the same line, if we have a rotation in which beans will have to follow carrots twice, we would add the constraint:

Constraint (acres)	T	P	C	B	PE	RHS
Bean Sequence			-2	1		≤ 0

Any other proportion can be handled similarly. We then see that the adequate transfer rows can create the necessary links between crops resulting in the desired rotational effect.

Also, while the first method of combining rotations into single activities automatically allowed for the correct sequencing of crops, that method was relatively less flexible than the last one, since each crop in the sequence had to occupy a fixed proportion of land relative to the other crops in the rotation, and these fixed proportions would have to be chosen before the problem is solved.

In our work, we will allow for the use of both methods. The first method will be used to handle continuous crops that need to be rotated every four or five years with some other crops; the second one will be essentially used for sequencing vegetable crops.

Notation

A rotation activity, exogenously defined, will be denoted by Y_i, where i = 1,2,...,R. For example, i = 1 may denote tomato-lentil-carrot, and i = 2 may denote wheat-wheat-pasture-meadow. One unit of these activities represent as many acres as there are crops included in the rotation.

Excluding rainfall, a distinction is made according to the level of irrigation used: L denotes low irrigation and H denotes high irrigation. Furthermore, a distinction is also made according to the level of fertilization applied: F1 denotes light fertilization and F2 denotes heavy fertilization. To summarize, we have the following variables:

$YLF1_{s,i,j}$ = acreage of land using low irrigation and light fertilization

$YLF2_{s,i,j}$ = acreage of land using low irrigation and heavy fertilization

$YHF1_{s,i,j}$ = acreage of land using high irrigation and light fertilization

$YHF2_{s,i,j}$ = acreage of land using high irrigation and heavy fertilization

where s = 1 indicates Sector I, s = 2 indicates Sector II, i is the rotation identifier and j is the region identifier. For example $YLF2_{2,2,1}$ is the acreage of land allocated to Sector II of region 2 which need to be free with no rotational requirements are entered the same way, but no relationship to other crops will be formulated for them. Note also that when sequences of crops are to be grown during the same year, we will adjust the land resources by a cropping ratio of land utilization or intensification.

iii) The Permanent Crops. We will define permanent activities by S_0 where $0 = 1,\ldots,N$ is the number of fruit categories. Each category will be a compound of fruits of the same type. We are considering only the existing acreage devoted to fruits already in production and include it in the supply of land. Additional orchard plans will not be considered because the programming framework we are using is not suited for dynamic analysis. These permanent activities are of interest to us because they do compete for other resources such as water, labor, fertilizer, and machinery, and that has inevitably an effect on the optimal allocation of other crops. They will have a distinct land equation to make sure that they do not violate these conditions. These activities will be included at two levels of irrigation and fertilization.

We will then have the following set of variables:

$SLF1_{s,0,j}$ = acreage of land using low irrigation and light fertilization

$SLF2_{s,0,j}$ = acreage of land using low irrigation and heavy fertilization

$SHF1_{s,0,j}$ = acreage of land using low irrigation and heavy fertilization

$SHF2_{s,0,j}$ = acreage of land using high irrigation and light fertilization for growing rotation 2 using low irrigation and heavy fertilization.

Other crops which are generally grown several times during the year and have to be rotated adequately will be left to the model to determine the amount of the acreage and the sequences in which they are to be grown. They will be linked together through a set of land constraints specifying their rotation requirements. These crops will be denoted by Z_k, where k = 1,2,...,k. For example, k = 1 may denote beans and k = 5 may denote tomatoes. One unit of these activities represent one acre of land. Excluding rainfall, a distinction is made according to the level of irrigation used: L denotes low irrigation and H denotes high irrigation. In addition, two rates of fertilization are distinguished: F1 denotes light fertilization and F2 denotes heavy fertilization.

To summarize, we have the following:

$ZLF1_{s,k,j}$ = acreage of land using low irrigation and light fertilization

$ZLF2_{s,k,j}$ = acreage of land using low irrigation and heavy fertilization

$ZHF1_{s,k,j}$ = acreage of land using high irrigation and heavy fertilization

$ZHF2_{s,k,j}$ = acreage of land using high irrigation and heavy fertilization

where s = 1 indicates Sector I, s = 2 indicates Sector II, k is the crop identifier, and j is the region identifier. For example, $ZLF1_{1,5,8}$ is the acreage of land allocated to Sector I of region 8 for growing crop 5 using low irrigation and light fertilization. Note that crops

Where s is the sector identifier, 0 is the permanent crop identifier, and j is the region identified.

iv) Livestock Activities. Here we consider only major livestock activities such as dairy cows, beef cows, and sheep. Some other types will be added according to the specific application. These livestock activities utilize water, pasture, and feed commodities that are appropriate for their defined rations and location. In addition to their producing meat and dairy products, they contribute to the fertilizer balance through their wastes to be evaluated in nitrogen equivalents. Note that this latter aspect is important in developing countries where, especially in Sector II, farms very seldom use chemical fertilizers but rather livestock waste.

The feed requirements will be entered directly in the demand matrix which is a different way from using transfer activities, the usual formulation. We will denote livestock by L_a, $a = 1,\ldots,4$.

$a = 1$ for dairy cows

$a = 2$ for beef cows

$a = 3$ for sheep

$a = 4$ for other types to be specified.

Thus $L_{s,a,j}$ is used to denote the head of type a in sector s of region j.

v) Pasture Variables Pasture activities can be included in appropriate rotations as defined earlier or on their own. In the latter case, there will be a distinction between dry and irrigated pasture. As in the case of continuous crops, there is only one level of irrigation but two rates of fertilizer application. In some cases, pasture may not be fertilized, and that will be specified in the input coefficient matrix.

$PD_{s,b,j}$ = acres allocated to pasture of type b using dry land in sector s of region j, b = 1,...,B

$PT_{s,b,j}$ = acres allocated to pasture of type b using irrigation in sector s of region j, b = 1,...B

vi) Fertilizer Variables. These variables include the different types of fertilizers used in each specific case. Their level in the solution program will indicate the best fertilizer balance associated with the optimal regional crop allocation. The set of variables will be:

$F_{v,j}$ = metric tons of fertilizer of type v used in region j.

vii) Machinery Variables. To avoid handling integrality conditions on each kind of equipment, we will define G groups of machinery that are used for some agricultural tasks together with an average number of days per year each group can be used. We thus have the following variables:

$E_{e,j}$ = Days of equivalent machine type e used in region j

viii) Transportation Variables. A transportation model for the crop and livestock production will be included to help determine the regional euilibrium of supply and demand and the distribution network denoting flow among the regions. Here we let $U_{\Phi,j,j'}$ be commodity of type Φ transported from region j to region $j', j \neq j'$.

ix) Deviation Variables. These variables are introduced in the model to measure the overachievement and underachievement of the demand goals unemployment and foreign trade deficit. The following variables are defined:

N_{ij} = Underachievement of the employment target in region j, expressed in man-days

P_{ij} = Overachievement of the employment target in region j, expressed in man-days

$I_{\Phi j}$ = Underachievement of the demand target for product Φ in region j, expressed in metric tons

$E_{\Phi j}$ = Overachievement of the demand target for product Φ in region j, expressed in metric tons

N_2 = Underachievement of the meat demand goal expressed in metric tons

P_2 = Overachievement of the meat demand goal expressed in metric-tons

N_3 = Underachievement of the dairy product demand goal

P_3 = Overachievement of the dairy product demand goal

N_4 = Underachievement of the maximum foreign exchange target

P_4 = Overachievement of the maximum foreign exchange target

b) The Constraint Set

In this model, we will decompose the constraints into two sets. The first set of constraints deals with restrictions that are inherent in each region, such as availability of land, fertilizer, water and so forth. The other set of constraints represents restrictions that are shared by all regions such as total land available, demands of meat and dairy products and foreign exchange. This latter set of restrictions may also include any specific institutional constraints or particular bounds to be defined.

i) Regional Constraints.

(1). The Land Matrix

In each region j, the dry acreage of land LD_j, the irrigated acreage LI_j, and the acreage allocated to permanent crops LP_j are given. Thus, we must incorporate restrictions that limit the acreage used by all activities to their resource availabilities.

We start by the dry land restriction:

$$\sum_{c=1}^{c} \sum_{s=1}^{2} XDF1_{s,c,j} + \sum_{c=1}^{c} \sum_{s=1}^{2} XDF2_{s,c,j} + \sum_{b=1}^{B} \sum_{s=1}^{2} PDF1_{s,b,j} + \sum_{b=1}^{B} \sum_{s=1}^{2} PDF2_{s,h,j}$$

$$\leq LD_j$$

This constraint limits the use of dry land used by all continuous crops and pasture to the available resources of dry land in both sectors for each region. To keep the length of the equations down for clarity purposes, we adopt the following notation: $\sum_{f,c,s}$ will indicate that the summation is performed over all crops c at the two levels of fertilizer, F1 and F2, in the two sectors of each region. Then writing the above dry land constraint according to this notation gives:

$$\sum_{f,c,s} XDF_{s,c,j} + \sum_{f,b,s} PDF_{s,b,j} \leq LD_j$$

A detailed representation of the complete model will be found in Appendix A.

For irrigated land, an equation is specified in the same way, which includes continuous crops and pasture, crop rotations and all other crops whether in sequence or free. It limits the use of available irrigated land, LI_j, in both sectors of each region. The constraint is as follows:

$$\sum_{f,c,s} XIF_{s,c,j} + \sum_{f,b,s} PIF_{s,b,j} + \sum_{f,i,s} (YLF_{s,i,j} + YHF_{s,i,j}) + \sum_{f,k,s} (ZLF_{s.k,j}$$

$$+ ZHF_{s,k,j}) + \sum_{f,0,s} (SLF_{s,0,j} + SHF_{s,0,j}) \leq LI_j$$

Following this constraint is the set of land relationship to be specified in each sector for each region to explicitly account for the rotational requirement of non-continuous crops. It will have the general form:

$$A_j Z_{k*j} \leq 0$$

where K* = 1,...,K* with K* being a subject of k is the set of crops to be entered in appropriate sequences by the model. A_j is a matrix of contingency relationships and Z_{ij} is a vector of non continuous crops.

The next land restriction specifies a bound on the acreage of permanent crops:

$$\sum_{f,0,s} SLF_{s,0,j} + \sum_{f,0,s} SHF_{s,0,j} \leq LP_j$$

Note that the summation of the land resource LD_j, LI_j, and LP_j will not necessarily be equal to the total land available in each region because we allow for multiple cropping within a given year, which takes into account the cropped area instead of the land area.

(2) Fertilizer Balance

For each type of fertilizer $v = 1,\ldots,V$, there is a fertilizer balance relationshiop equating the fertilizer requirements for all crops to the amounts to be purchased together with any livestock contribution. This latter aspect is being more and more recognized in specialized literature but has not been included in regional models; the interested reader may refer to Brzoza [1975] and Tanji [1977].

The balance equation for fertilizer type v is written as follows:

$$\sum_{f,c,s} (\alpha_{s,c,j}\ XDF_{s,c,j} + \alpha_{s,c,j}\ XIF_{s,c,j}) + \sum_{f,b,s} (\alpha_{s,b,j}\ PDF_{s,b,j} + \alpha_{s,b,j}\ PIF_{s,b,j}) + \sum_{f,i,s} (\alpha_{s,i,j}\ YLF_{s,i,j} + \alpha_{s,i,j}\ YHF_{s,i,j}) + \sum_{f,k,s} (\alpha_{s,k,j}\ ZLF_{s,k,j} + \alpha_{s,k,j}\ ZHF_{s,k,j}) + \sum_{f,0,s} (\alpha_{s,0,j}\ SLF_{s,0,j} + \alpha_{s,0,j}\ SHF_{s,0,j}) - \sum_{s=1}^{2} \alpha_{s,a,j}\ L_{s,a,j} - F_{v,j} = 0$$

where:

$\alpha_{s,\Phi,j}$ is the per acre requirement of fertilizer for cropping activity Φ, where $\Phi = c,b,i,k$, or 0.

$\alpha_{s,a,j}$ is the contribution of livestock type a in sector s in region j to the fertilizer balance.

$F_{v,j}$ is the total amount of fertilizer v in region j to be determined by the model.

Note that a different coefficient is specified for each crop at each level of fertilization, at each level of irrigation, and in each sector of a given region. In addition, the different requirements will be measured in metric tons of fertilizer.

(3) Pasture Balance

Here also, a pasture balance for each pasture type b = 1,...,B in each region is specified. Since, especially in the traditionally sector aftermath pasture and straw quantities derived for havested crops are used to feed livestock, we will account for that in the pasture balance. They are usually derived from empirical use. The equation will give the equilibrium between the quantities of pasture required by livestock and the quantities produced plus any contributions derived from all cropping activities. The constraint is written as follows:

$$\sum_{s=1}^{2} \sum_{a=1}^{4} \beta_{s,a,j} L_{s,a,j} \leq \sum_{f,b,s} (\mu_{s,b,j} PDF_{s,b,j} + \mu_{s,b,j} PIF_{s,b,j}) +$$

$$\sum_{f,c,s} (\beta_{s,c,j} XDF_{s,c,j} + \beta_{s,c,j} XIF_{s,c,j}) + \sum_{f,i,s} (\beta_{s,i,j}, YLF_{s,i,j} +$$

$$\beta_{s,i,j} YHF_{s,i,j}) + \sum_{f,k,s} (\beta_{s,k,j} ZLF_{s,k,j} + \beta_{s,k,j} ZHF_{s,k,j}) +$$

$$\sum_{f,0,s} (\beta_{s,0,j} SLF_{s,0,j} + \beta_{s,0,j} SHF_{s,0,j})$$

Where:

$\beta_{s,a,j}$ is the requirement in metric tons of pasture per head of livestock a in sector s of region j.

$\mu_{s,b,j}$ is the yield per acre in metric tons of pasture type b in sector s of region j

$\beta_{s,\Phi,j}$ is the per acre contribution of crop $\Phi =$ e,i,k,or 0 to the pasture balance in sector s of region j.

(4) Water Constraints

To account for the differences in seasonal requirements of the different crops and the randomness of precipitation, we will have an irrigation equation for each sector in which the requirements of all crops grown in that season are compared to the resources of water available in the specific location. If we let the agricultural year be divided into T periods, $T \geq 1$, where T is to be specified for each case, we will have T equations. Note that the irrigation and precipitation have to complement each other so that we will account for this aspect by subtracting the amount of rainfall from the irrigation requirement. However, any soil moisture stored is not part of the irrigation requirement; the irrigation is defined to be the requirement without which the crop is limited from lack of water.

Then for each period $t = 1,\ldots,T$ in each region $j = 1,\ldots,A$ the following constraint is formulated:

$$\sum_{f,c,s} (\omega_{s,c,j}\, XIF_{s,c,j}) + \sum_{f,b,s} (\omega_{s,b,j}\, PIF_{s,b,j}) + \sum_{f,i,s} (\omega_{s,i,j}\, YLF_{s,i\,j} + \omega_{s,i,j}\, YHF_{s,i,j}) + \sum_{f,k,s} (\omega_{s,k,j}\, ZLF_{s,k,j} + \omega_{s,k,j}\, ZHF_{s,k,j}) + \sum_{f,0,s} (\omega_{s,0,j}\, SLF_{s,0,j} + \omega_{s,0,j}\, SHF_{s,0,j}) + \sum_{s=1}^{2} \bar{\omega}_{s,a,j} L_{s,a,j} \leq \theta_j^t\, \omega_j^t$$

Where:

$\bar{\omega}_{s,a,j}$ is the requirement in cubic meters of water per unit of livestock activity a, in sector s of region j

$\gamma^{t}_{s,\Phi,j}$ is the requirement of water in cubic meters per acre of activity Φ = c,b,i,k,0 during period t. The requirements are specified for each level of irrigation, for each level of fertilizer, and in each sector of a given region.

ϱ^{t}_{j} is the effective rainfall during period t in region j. No specification is made for Sectors I or II for obvious reasons. This amount is considered stochastic and treated as such whenever data is available.

$\omega_{s,\Phi,j} = \gamma^{t}_{s,\Phi,j} - \varrho^{t}_{j}$ gives the net amount of irrigation.

One way to formally treat the stochastic nature of precipitation is to derive a distribution function of effective precipitation from empirical data on precipitation during each period t, say $F_{tj}(\varrho^{t}_{j})$. Then if we give ourselves a risk level $(1 - \alpha)$ such that: Probability [rainfall $\geq$ $^{t}_{j}$] $\geq \alpha$ we will have: $\varrho^{t}_{j} = F^{-1}_{tj}(\alpha)$. Note also that the above formulation of water constraints incorporates a diminishing return response relationship between crop yield and water application, through differentiation between two levels of irrigation for certain activities, which will be reflected in the yields per acre of crop. For water modeling see Andrews [1972].

(5) Machinery Balance

For each type of machinery group e = 1,...,G an equation is to be specified. Based on theoretical capacities of equipments, an average number of days a year per group of equipment will be determined and made available, during the whole agricultural year, for crop work.

Using the notation specified above the equations will be as follows:

$$\sum_{f,c,s} (\varepsilon_{s,c,j}\ XDF_{s,c,j} + \varepsilon_{s,c,j}\ XIF_{s,c,j}) + \sum_{f,b,s} (\varepsilon_{s,b,j}\ PDF_{s,b,j} + \varepsilon_{s,b,j}\ PIF_{s,b,j}) + \sum_{f,i,s} (\varepsilon_{s,i,j}\ YLF_{s,i,j} + \varepsilon_{s,i,j}\ YHF_{s,i,j}) + \sum_{f,k,s} (\varepsilon_{s,k,j}\ ZLF_{s,k,j} + \varepsilon_{s,k,j}\ ZHF_{s,k,j}) + \sum_{f,0,s} (\varepsilon_{s,0,j}\ SLF_{s,0,j} + \varepsilon_{s,0,j}\ SHF_{s,0,j}) \leq \varepsilon_{e,j}\ M_{e,j}$$

Where $\varepsilon_{s,\Phi,j}$ is the number of days of machine time required each year per acre of crop Φ = c,b,i,k,or 0. $\varepsilon_{e,j}$ is the capacity of each type of equipment in days per year in region j. Again specification is to be made for different levels of irrigation, fertilizer, and different sectors in each region j. Note that we specify different capacities to account for differences in climatic conditions and soil types between regions. For instance, in a sandy and hot region a tractor will break down more often than in a mild region and that will diminish its capacity in machine time. Also, bad weather may preclude machine operations for certain regions.

An illustrative example will clarify the above statement. If wheat, $XDF1_{1,1,1}$, and corn, $XIF2_{1,2,1}$, both in Sector I of region 1, need 100 and 50 hours of tractor time per acre respectively, and if we know that a tractor capacity is 800 hours a year, then the partial equation will be:

$$100\ XDF1_{1,1,1} + 50\ XIF2_{1,2,1} \leq (800 - 60)\ M_{e,j}$$

where 60 hours will not be available from equipment e because of bad weather.

Finally, M_{ej} is the number of equipment of type e needed to accomplish the machine operation on all types of crops during the entire agricultural year in region j.

(6) Labor Constraints

Labor supply is assumed unlimited because of real conditions in developing countries and in fact, one of the goals of the model, is to reduce unemployment through agricultural labor. We will divide the supply of labor in two parts, both measured in man-days per year, in each region j.

- Ordinary labor supply: HO_j, not limiting
- Skilled labor supply: HS_j, limiting factor

We do not distinguish between peak and normal periods because the supply of ordinary labor is assumed unlimited. For skilled labor, after the solution is obtained it is possible to plan the labor accordingly. For ordinary labor, HO_j is considered the employment target to achieve in each region. Thus, the labor equation is as follows:

$$\sum_{f,c,s} (\lambda_{s,c,j}\ XDF_{s,c,j} + \lambda_{s,c,j}\ XIF_{s,c,j}) + \sum_{f,b,s} (\lambda_{s,b,j}\ PDF_{s,b,j}$$

$$+ \lambda_{s,b,j}\ PIF_{s,b,j}) + \sum_{f,i,s} (\lambda_{s,i,j}\ YLF_{s,i,j} + \lambda_{s,i,j}) + \sum_{f,k,s} (\lambda_{s,k,j}$$

$$ZHF_{s,k,j}) + \sum_{f,0,s} (\lambda_{s,0,j}\ SLF_{s,0,j} + \lambda_{s,0,j}\ SHF_{s,0,j}) + \sum_{s=1}^{2} \sum_{\lambda=1}^{4} \lambda_{s,a,j}$$

$$L_{s,a,j} + N_{1,j} - P_{1,j} = HO_j$$

Where:

$\lambda_{s,\Phi,j}$ is the requirement in man-days of work per year per acre of cropping activity $\Phi = c,b,i,k,0$ in region j.

$\lambda_{s,a,j}$ is the per unit requirement of labor for each type of livestock a, in sector s of region j, measured in man-days per year.

N_{1j} and P_{1j} are the under and over achievement variables in each region j of the employment goal.

The coefficients will be specified for each level of irrigation and fertilizer and for each sector. Note that these coefficients, together with the machinery coefficient implicitly determine the levels of technology in each sector of each region. For skilled labor, the same type of equation as for ordinary labor is specified, but does not include goal achievement variables. The per unit crop requirements for skilled labor are specified accordingly. Note that skilled labor is intended to cover all operations that require technical capabilities including management operations.

(7) Demand Matrix

It will model the relationships between supply, coming from production levels to be determined by the model, and demand requirements in each region. The transportation activities will permit the achievement of a regional equilibrium together with any foreign trade. We will include the major crops which, from past experience, have shown a deficit relative to the demand and which are likely to be the most limiting. We will specify the general form of the equation here. In the practical applications, for each crop a different equation is formulated.

Let $J_{\Phi,j}$ represent cropping activity Φ = c,b i.k,0 in region j and $\mu_{\Phi,j}$ be the yield of that activity. Of course the yield will be different depending on whether the crop is grown in Sector I or II and its production function specifying levels of irrigation, fertilizer, labor and machinery. Then for each such activity the demand balance is of the following form:

$$\mu_{\Phi,j} \; J_{\Phi,j} + \sum_{\substack{j=1 \\ j \neq j'}}^{A} (U_{\Phi j'j} \quad U_{\Phi jj'}) - \xi^{\Phi}_{s,a,j} \; L_{s,a,j}$$

$$- E_{\Phi j} + I_{\Phi j} = D_{\Phi,j}$$

Where:

$U_{\Phi j'j}$ is the quantity in metric tons of crop Φ transported from region j' to region j.

$\xi^{\Phi}_{s,a,j}$ is the requirement per unit of livestock a in sector s of of region j, of crop Φ to feed the livestock activities $L_{s,a,j}$. Note that livestock feed requirements are only included in the appropriate demand equation such as feed grains.

$E_{\Phi j}$: is the overachievement amount relative to the goal target for the demand of crop Φ in region j.

$I_{\Phi j}$: is the underachievement amount relative to the same goal.

$D_{\Phi j}$: is the goal target in terms of demand for crop Φ in region j.

It is to be noted that the deviation variables can be used for foreign trade policy making and may be treated as exportation and importation levels respectively and be useful in analysis of foreign trade.

Whenever possible it will be preferable to obtain the levels of exogenous demands, $D_{\Phi,j}$ from data on population and nutritional needs per individual for each product. Regional projections, if based on the same preoccupations can also be used.

ii) Constraints on the Global Level. These constraints will include any institutional constraints, quotas imposed on certain crops and bounds. The demands of meat and dairy products are also considered at this level because of their special importance in feeding the population. In addition, capital expenditures are included to reflect limitations on capital used by the private sector and foreign exchange expressed in dollars.

(1) Meat and Dairy Constraints

Since we do not expect all the livestock production to be slaughtered, we have to used an indication on the percentage that would be kept alive for reproduction and income purposes, and adjust the per unit overall production of meat as follows. If L_a, livestock a, produces 200 kilograms of meat and if 50% of these units are to be preserved, then the per unit production is considered 200 x 0.5 = 100 for all units of livestock a. Thus, we will include the production of meat per unit, call it η, after adjustment. That will give the following meat demand equation:

$$\sum_{a=1}^{4} \sum_{j=1}^{A} \sum_{s=1}^{2} \eta_{s,a,j} L_{s,a,j} + N_2 - P_2 = D_m$$

Where:

$\eta_{s,a,j}$ is the per unit adjusted production of meat by livestock type a in region j, sector s.

N_2, P_2 are the under and over achievements from the goal meat demand D_m exogenously specified. For dairy products, milk is the most relevant and has the following equation:

$$\sum_{a=1}^{4} \sum_{j=1}^{A} \sum_{s=1}^{2} \sigma_{s,a,j} L_{s,a,j} + N_3 - P_3 = D_d$$

Where:

$\sigma_{s,a,j}$ is the estimted production of milk, in liters, per unit of livestock a in sector s of region j.

The capital equation for the private sector is basically included for short term institutional capital and has the form:

$$\sum_{\Phi} \sum_{j=1}^{A} (\delta_{1,\Phi,j} J_{1,\Phi,j}) \leq \bar{K}_1$$

Where:

$J_{1.\Phi,j}$ is any cropping activity in the private sector in region j that requires capital.

$\delta_{1,\Phi,j}$ is the capital requirement per acre of crop production $\Phi = c,b,i,k,0$ in the private sector in each region j.

$\bar{K}_1$ is the resource of short term capital available to sector s during the agricultural year.

Finally, the foreign exchange constraint is mainly dependent on machinery because most of it is usually imported. It will also include the required importations of fertilizers and agricultural products.

The constraint will have the following form:

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \left(\sum_{v=1}^{V} \tau_{s,v,j} F_{s,v,j} + \sum_{e=1}^{G} \tau_{s,e,j} M_{s,e,j} + \sum_{\Phi} \tau_{s,\Phi,j} I_{s,\Phi,j} \right)$$

$$+ N_4 - P_4 = D_0$$

Where:

$\tau_{s,v,j}$ is the amount of foreign exchange required for each unit of fertilizer v

$\tau_{s,e,j}$ is the requirement for each unit of equipment e.

$\tau_{s,\Phi,j}$ is the requirement for each ton of crop product imported.

D_0 is the maximum foreign exchange expenditures allowed for the particular agricultural year.

Any other institutional bounds on acreages of crops can likewise be formulated at the global level.

c) The Objective Function

Given the above sets of variables and constraints, one expects to find several feasible agricultural spatial programs of production and thus a criterion of choice is required. Our perspective is to find a plan which would be satisfactory in terms of the goals desired. To do that we consider the set of constraints in the model This set includes two types of restrictions:

- The resource restrictions having the form $AX \leq b$ and $BX \leq d$, where b is a vector of exogeneously fixed levels of resources such as land, water, and skilled labor, and d is a vector of variable resources whose levels are to be determined within the solution of the model.

- The goal restrictions, from which the objective function is generated, include employment, demand satisfaction, and foreign exchange targets. The form of these constraints is $AX + Y_j - Z_j = G_j$. For instance, the employment equation specifies the number of man-days employed per year plus an deviation from the required target. In the equation above, if $y_j > 0$, then $Z_j = 0$ and we have an underachievement relative to the target set. If $y_j = 0$ then $Z_j > 0$ and we have an overachievement relative to the same target. If y_j and Z_j are both zero, then the goal target is met exactly. It is to be noted however that in the case of developing economies, the target set are high enough to make the interest focus on minimizing the undesired deviations from goals. We will then have the objective function as a weighted sum of the under-achievements of employment and demand levels and overachievement of foreign exchange. Thus the objective function will be as follows:

$$\text{Min} \sum_{j}^{\text{Regions}} [(w_{\Phi,j}\ I_{\Phi,j}) \ , \ (w_{ij}\ N_{ij}) \ , \ (w_2\ N_s) \ (w_3\ N_3) \ , \ (w_4\ P_4)]$$

where the w's are appropriate weighting factors to be discussed with each specific case.

3.5 The Solution Procedure

Because of the difficulties associated with being able to define a realistic priority structure over the different goals and because of unavailability of adequate software resources, we will adapt the problem to be able to use convential simplex routines. Thus, the objective function will be equal to the sum of the weighted deviation specified in the last section. This means that we are giving the same priority to all goals which, in fact, is a reasonable thing to do.

The weighting factors can be derived in two ways:

i) The first way is to compute the cost of deviating from each goal by one unit and use it as a weighting factor. For instance, if we deviate from a wheat demand by -10, and if each of these ten units will be purchased outside at a cost of $2, then we retain 2 as the desired factor.

ii) The second way is to identify the conflicting goals such as demand satisfaction and minimum foreign exchange and use range analysis procedures in the following way to derive the weights:

Given the goals of our problem specified in the following table:

	N_i	P_i	N_4	P_4	RHS
Objective Function	1	0	0	α	0
Achievement of Demand Goal i	1	-1			D_i
Achievement of Hard Currency Goal, No. 4			1	-1	D_4

Where i represents the demand target of the i^{th} product and goal four is the foreign exchange maximum. By setting $\alpha = 0$ and minimizing the objective function as in linear programming, we will minimize the underachievement of demand i, i.e., N_i. This would give us a first program solution. Then increasing α gradually on the basis of range analysis results, we will derive a set of programs from which a "good" one is to be chosen according to the importance attached to each goal.

Finally, whenever data is available, we will formulate a minimum cost objective, solve the problem, and introduce the cost equation in the constraint set so as to achieve the goal of minimum overall cost. In that case, the magnitude of the total cost derived from the linear program, or its modification if it is too high, will constitute the total cost target goal. Deviation variables will then be introduced accordingly. Finally, a maximum return objective function will be formulated and its results compared with the goal formulation. This objective will be:

$$\text{Max} \sum_{j} \sum_{s} \sum_{\Phi} \pi_{j,s,\Phi} \, J_{j,s,\Phi} - \sum_{\substack{j=1 \\ j \neq j'}} \sum_{\substack{j'=1 \\ j' \neq j}} \sum_{\Phi} t_{\Phi jj'} \, U_{\Phi jj'}$$

Where:

Φ is the index of all activities in the model.

$J_{j,s,\Phi}$ represents the vector of activities.

$\pi_{j,s,\Phi}$ is the vector of revenues.

jj' is the cost of transporting product from region j to region j'.

The last term gives the overall costs of transportation for all activities Φ in the model.

CHAPTER IV

A TWO-REGION ALGERIAN MODEL

With a population of nearly 18 million and an agricultural sector of over 42 million hectars, Algeria is divided in two major natural zones:

- The North zone extending from the Mediterranean Sea to the limits of the desert.
- The South zone which is the Sahara, occupies two-thirds of the country and produces only dates.

It is then the North that carries the charge of producing the agricultural goods and feeding the population. But the impact of the natural conditions on the region and its production possibilities is very important because of the particular Mediterranean climate where heat and rain follow each other instead of being complementary.

Under these conditions and the lack of adequate pricing and government policies, the agricultural production has been virtually stagnant for about ten years. In 1962, eighty percent of the population depended on agriculture for a living. In 1975, more than fifty percent of the Algerian work force was employed in the agricultural sector and unemployment still remains a major issue.

Because data concerning the supply of resources and cropping requirements were not available for all areas forming the agricultural Algerian sector, only two regions were studied for which basic data was available. In the first section, we will present a brief description of the two regions, their characteristics and relative importance. In section two, we will discuss the derivation of the coefficients for the model, together with the assumptions used. In the last section, a presentation of the results and their interpretation will be given.

4.1 Description of the Two Regions

As stated in chapter three, the basis for a regional model is the definition of homogeneous units. In our case, soil type and climate conditions are the criteria used. Figure 7 shows the two regions under study:

- The first region, Oran, is located in the west part of the country and produces mostly vegetables and permanent crops. Cereals are also produced but in minor proportions.

- The second region, Constantine, is located in the northeast part of the country and is basically a grain producing region. In addition to differences in natural conditions which are summarized in Table 4.1, region two suffers from the lack of a good transportation system and the shortage of chemical products and technical assistance.

Within each region, two sectors are differentiated. Sector I, the cooperative sector, is relatively more modernized in that it uses more technology and scientific growing methods. It is government controlled and thus receives all the financial and technical assistance needed. In most cases, it has better quality lands and irrigation systems than the other sector. Sector II, the private sector, benefits

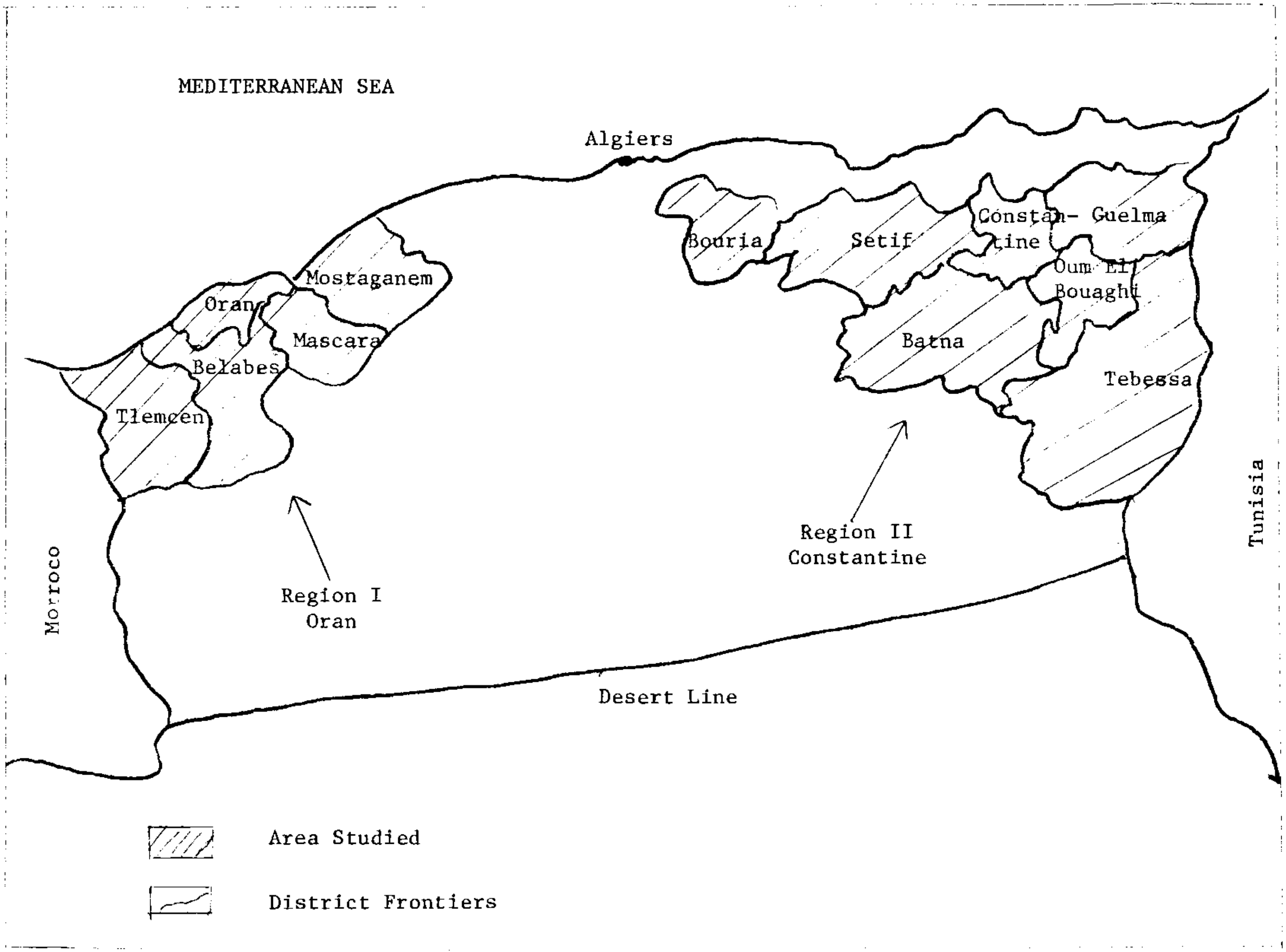


Figure 7. The Two Regions of the Algerian Model

Table 4.1 Natural Differences Between the Two Regions

Characteristics	Region I - Oran	Region II - Constantine
Climate	Hot but humid	very cold winters very dry summers
Rainfall (Average mm/year)	630 mm	350 mm
Altitude (Above Sea level)	900 m	1200 m
Temperature (Average)	Average Janu. August 14 12 26	Average January August 20 4 24
Soil Type	light and permeable sandy: good for permanent crops	compact and impermeable clay: good for cereal crops

only from empirical experience and has more lands of less quality. The difference between both sectors can be seen from the production characteristics, the relative importance and the distribution of farm sizes, which we summarize in Table 4.2. Note also that, even though sectors are homogeneous throughout both regions, differences from region to region do exist, and will be reflected in the technical coefficients.

4.2 Derivation of the Model's Coefficients

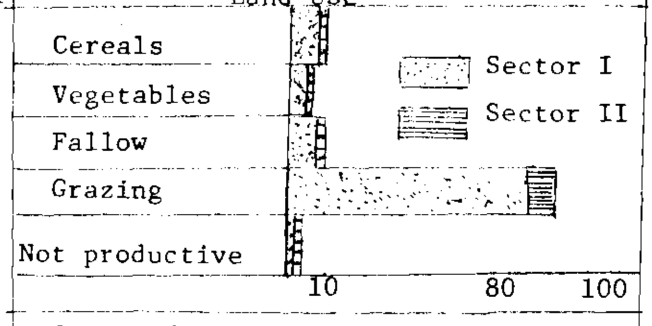
Data was a very limiting factor in the formulation of this model. Basic data on acreages and supplies were available from publications of the Algerian Department of Agriculture by districts, for the 1972-74 period[1]. The lack of data over a period of reasonable length did not permit the use of time series analysis and we preferred to use averages

[1]Ministry of Agriculture and Land Reform, "Superficies et Production" Statistique Agricole, Serie A et B, 1972-1974, Algeria.

Table 4.2 Sector's Differences

%	S I	S II
Agricultural land	16	84
Productive land	33	67
Labor	20	80
% in Gross Product	60	40

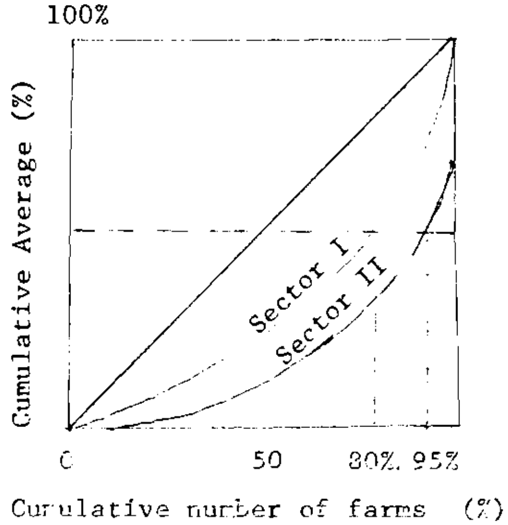
Land Use



Sector I
- -Exportation (vegetables,wine)
- -Best lands with high yields
- -Mechanication - mostly tractors
- -Fertilizers
- -Irrigation

Sector II
- -Livestock and cereals
- -Poor soils with higher fertility loss and low yields
- -Lack of fertilizers
- -Lack of capital

Curve of concentration showing the differences of land distribution



over the three years. Aggregation was performed over the five districts in region I, and the seven districts in regions II to obtain data on the regional basis. The derivation of differences in levels of fertilizer and water are based on general indications, from the same publication cited, on improved crop management systems.

a) The Cropping Activities

We have chosen nine cropping activities which exist in both regions and for which there are high demands relative to other crops. These are wheat, oats, pasture, tomatoes, potatoes, beans, melon, processing tomatoes, and oranges. Wheat and oats are the continuous crops which cannot be grown more than one time a year; they are entered in compounded rotations with pasture and fallow to give a rotational effect over five years as based on farmers' practices.

- For Region I:

  Rotation I is: wheat-wheat-wheat-wheat-oats

  Rotation II is: wheat-wheat-wheat-wheat-pasture

- For Region II:

  Rotation I is: wheat-wheat-wheat-wheat-fallow-oats

  Rotation II is: wheat-wheat-wheat-wheat-pasture

These rotations are differentiated by level of fertilizer and sector. For each region there will be eight such activities on dry land and eight on irrigated land.

Oranges, the permanent cropping activity, are grown only on irrigated land and enter the model in each region as eight different activities depending on the fertilizer rage, the level of irrigation, and the sector. The rest of the crops have to conform to the following rotational requirements:

In Region I:

- Successive plantings of tomatoes must be separated by three years.
- Successive plantings of potatoes, by two years.
- Successive plantings of beans, by one year.

In Sector I

- Beans will follow tomatoes or potatoes.
- Processing tomatoes will follow beans or melon.

In Sector II

- Tomatoes will follow melons or beans. They can also follow processing tomatoes but only in a proportion of 0.75, the rest being kept for experimentation purposes.
- Potatoes will follow beans or melons only.

In Region II

- Successive planting of tomatoes must be separated by four years.
- Successive plantings of potatoes by three years.
- Successive plantings of melons and processing tomatoes by two years.
- Successive plantings of beans, by one year.

In Sector I

- Beans will follow tomatoes, potatoes, or processing tomatoes.
- Processing tomatoes will follow beans or melons.

These rotational requirements are formulated as sequences to be determined by the model based on the methodology described in chapter three, and again differentiation is made for different fertilizer rates and levels of irrigation.

b) Other Activities

- Two livestock types, dairy cows and beef cows, are entered by sector in each region. The choice is based on the shortages of meat and milk in both regions.

-Three types of fertilizer activities, namely nitrogen, potassium and phosphate are specified at the regional level and are used at two different rates each, for all cropping activities.

- The machinery variable representing tractors will specify the level of technology by sector in each region.

- Based on the demand matrix which includes wheat, tomatoes, potatoes, beans, melons, processing tomatoes, and oranges, fourteen transportation variables are specified between the two regions.

- Finally, the rest of the variables are the deviations from the demands, employment, and hard foreign exchange.

c) Coefficients Specifications

i) Fertilizer Balances. The fertilizer coefficients are derived from the following national figures, given in 10^{-3} metric-tons per hectar[1].

Type of Crop	Nitrogen	Phosphate	Potassium
Cereal	12	26	13
Vegetables	36	37	39
Processing	45	67	90
Fruits	103	41	74

The following assumptions are made:

- The private sector, that is, Sector II, uses half of the rates used by the cooperative sector, that is, Sector I, in both regions.

- The second rate of fertilizers would correspond to an improvement

[1]Ministry of Agriculture and Land Reform, "L'Agriculture Algerienne à travers les chiffres", Special Publication, page 62, 1970, Algeria.

of 50% in the actual use.

- Over the period of 1970-1975, region II has consistently used about 16% less fertilizers, than region I; thus we will retain that figure as the difference between the two regions.

The data for different types of fertilizers is summarized in Table 4.3, where F1 and F2 correspond to the two rates of possible fertilization. Note that the rotations coefficients are merely the compound of coefficients of each crop in the rotation. Note also that the kind of beans under consideration is supposed to use very little fertilizer. Included in the fertilizer balance is the contribution of livestock to the nitrogen equation. Estimations in this case are based on recorded data by Nichol and Heady [1975]. In both regions we used the following figures:

- For dairy cows: 0.064 metric-tons of nitrogen equivalent per year.
- For beef cows: 0.026 metric-tons of nitrogen equivalent per year.

ii) Pasture Balance. We specified two kinds of equations:

- The first is a pure pasture balance which gives the equilibrium between the production of pasture coming from rotations and the livestock requirements.

- The second is an oats equation, which, because of lack of data to convert it into a pasture-equivalent basis, is directly expressed in metric-tons of oats for livestock feed. It also includes the contribution of other crops to the balance on an oat-basis equivalent.

The different yields are computed as ratios of average production and acreage over a three year period; the figures coming from publications of the Algerian Department of Agriculture. These figures correspond to

Table 4.3 Fertilizer Coefficients (10^{-3} Metric-tons)

Cropping Activities	Rate	Nitrogen				Phosphate				Potassium			
		Region I		Region II		Region I		Region II		Region I		Region II	
		S I	S II	S I	S II	S I	S II	S I	S II	S I	S II	S I	S II
Rotation 1	F1	60	30	50	25	130	65	110	55	65	32.5	55	28
	F2	90	45	75	37.5	195	100	165	83	97.5	50	82	42
Rotation 2	F1	48	24	40	20	104	52	88	44	52	26	44	22
	F2	72	36	60	30	156	80	132	66	78	40	66	33
Vegetables	F1	36	18	30	15	37	18.5	31	15.5	39	19.5	32	16
	F2	54	27	45	22.5	55.5	28	46.5	23.5	58.5	29	48	24
Beans	F1	3	2	3	2	7	5	7	5	4	3	4	3
	F2	4	3	4	3	8	6	8	6	5	4	5	4
Processed Tomatoes	F1	45	23	38	19	67	33.3	56	28	90	45	76	38
	F2	67	34	57	29	100	50	84	42	135	67.5	104	52
Oranges	F1	104	52	87	43.5	41	20.5	34	17	74	37	62	31
	F2	156	78	130	65	61.5	31	51	26	111	55.5	93	47

the first rate of fertilizer application. Based on the assumption of constant returns to scale, we derived the yields for the activities at the second rate of fertilizer, namely, we assumed an increase of 50% in the yields. Table 4.4 gives a summary of results. The average livestock consumption rates are given in Table 4.5 below:

Table 4.4 Oats and Pasture Yields (10^{-1} Metric-Tons/ha), (Average 1972-1974)

	Fertilizer	Pasture				Oats			
		Region I		Region II		Region I		Region II	
		S I	S II	S I	S II	S I	S II	S I	S II
Dry	F1	18.4	15.4	14.4	14	10.3	8.8	9	8.6
	F2	27.6	23.1	21.6	21	15.3	13.2	13.5	12.5
Irrigated	F1	23	19.3	18	17.5	12.8	11	11.3	10.7
	F2	34.5	28.8	27	26.3	19.1	16.5	16.8	15.6

Table 4. 5 Livestock Requirements

Type	DAIRY				BEEF			
	Region I		Region II		Region I		Region II	
	S I	S II	S I	S II	S I	S II	S I	S II
Oats	15	20	10	15	10	12	6	8
Pasture	50	55	55	60	40	45	45	50

iii) Water Constraints. We have noted before that rotations, since comprising only continuous crops, are irrigated at one level only and that corresponds to their growing seasons, that is, winter-spring. This implies that rotations on dry land will not use water. All other crops are specified at a low and a high level of irrigation which are two and three acre-feet of water per hectar respectively.

No differences are made between Sectors I and II because information was not available for the private sector, but it is assumed that differences occur only in the delivery system and not in the amounts of water. The water coefficients are given for Table 4.6. They have been adjusted to take rainfall amounts into account. An average amount of rainfall is computed from available data for two seasons; season one extending from winter to spring, and season two, from summer to autumn. The results is subtracted from the two levels of irrigation to give the net water requirements for the two seasons. The livestock requirements are based on the averages from Nichol and Head [1975] because national figures were not available.

iv) Machinery Constraints. The machine time requirements are computed from available data as ratios of the number of days of tractors used per year and the average acreage of crops which utilized machine time. Distinction was only made for groups of crops, and livestock was assumed not using machinery. Table 4.7 gives the results.

v) Labor Constraints. The labor requirements reflect the difference in mechanization between the sectors. Their derivation is similar to the machinery coefficients. We assumed that skilled labor is about 25% in Sector I and 15% in Sector II of the ordinary labor in

Table 4. 6 Water Requirements

Activities	Region I Winter Spring	Region I Summer	Region II Winter Spring	Region II Summer
Rotations (low - acre-feet/hectar)	.56	-	1.35	-
Other Crops (low - acre-feet/hectar)	.56	1.37	1.35	1.5
Other Crops (high - acre-feet/hectar)	1.56	2.37	2.34	2.5
Livestock (Dairy)	0.034		0.041	
Livestock (Beef)	0.021		0.026	

Table 4. 7 Machinery Requirements
days/ha/year

	Activities	Region I				Region II			
		Sector I		Sector II		Sector I		Sector II	
		F1	F2	F1	F2	F1	F2	F1	F2
Irrigated	Rotations	4	4.5	2.5	3	5	6	3	4
Irrigated	Other Crops	3	3.5	2	2.5	3	4	2	2.5
Dry	Rotations	3.5	4	2	2.5	4	5	2	1
Dry	Other Crops	-	-	-	-	-	-	-	-

region two. In the first region, the proportions are 30% and 20% respectively. These proportions are based on general indications from publication of the Algerian Department of Agriculture[1]. The figures are given in Table 4.8

Table 4.8 Ordinary Labor Requirements (man days/ha/year) (man days/unit/yr)

Activities	Region I		Region II	
	Sector I	Sector II	Sector I	Sector II
Rotations	10	15	10	16
Other Crops	20	30	20	36
Livestock	30	50	25	45

vi) Demand Matrix. The specification of the yields of all cropping activities is based on data on production and acreage over the period of 1972-1974. An average is determined for each crop in each sector for the low levels of fertilizer and irrigation.

General conclusions from a survey made by the Department of Agriculture on improving the yields of all crops are used to determine the yields at the high levels of fertilizers and irrigations. The indications given at the national level are as follows:

- An increase of 50% in fertilizer rates would result in an increase

[1]Ministry of Agriculture and Land Reform, "Enquete sur le secteur socialiste agricole", Serie Etudes et Enquetes, No. 19, 1975, Algeria.

of about 50% for cereal crops and 25% for vegetables and permanent crops.

- An increase of 50% in irrigation, including better delivery systems and higher applications, would results in about 25% of an increase in cereal yields and only 10% in other crop yields.

The figures are summarized in Table 4.9 for wheat and in Table 4.10 for the other crops.

Table 4.9 Wheat Yields (10^{-1} Metric-tons/hectar)

Activities		Region I				Region II			
		Dry		Irrigated		Dry		Irrigated	
		S I	S II	S I	S II	S I	S II	S I	S II
Wheat in Rotation 1	F1	9.2	8	11.5	10	8	7.5	10	9.4
	F2	13.5	12	16.8	15	12	11.2	15	14
Wheat in Rotation 2	F1	10	9	12.5	11.2	9	8.2	11.3	10.2
	F2	14	13	17.5	16.2	13	12	16.3	15

vii) Global Constraints. The short term capital constraints for the private sector were not considered in this formulation because no reasonable approximations were available on capital requirements by unit of cropping activity. The milk and meat constraints were based on regional production per livestock unit from recorded data. The results are summarized in Table 4.11.

Table 4.10 Crop Yields (10^{-1} Metric-tons per hectar)

Activity		Region I				Region II			
		Low		High		Low		High	
		S I	S II	S I	S II	S I	S II	S I	S II
Potatoes	F1	72.8	83.6	80	90	61.5	66.7	67.7	73.4
	F2	91	101	99	109	76.8	83.3	84.5	91.6
Tomatoes	F1	91	105	100	115	96	68.2	105.6	75
	F2	113	131	124	144	120	85.3	132	94
Beans	F1	6.6	6.8	7.2	7.5	6.8	7.3	7.5	8
	F2	8.2	8,5	9	9.3	8.5	9.2	9.4	10.1
Melon	F1	77.5	90	84	100	44	56	48.4	61.6
	F2	196	113	106	123.7	55	70	60.5	77
Processed Tomatoes	F1	90	82	100	90	120	108	132	128
	F2	112.5	102.5	123.7	112.7	141	128	154	140
Oranges	F1	104.4	95.5	115	105	115	96.4	126.5	106
	F2	130	119	143	128	142	120	156	132

Table 4.11 Milk and Meat Production

Product	Region I		Region II	
	Sector I	Sector II	Sector I	Sector II
Meat (Metric-tons/unit/year)	0.13	0.10	0.11	0.09
Milk (litre/unit/year)	2500	1500	2600	1800

The foreign exchange constraint is expressed in constant dollars for the period 1973-74. It includes agricultural productions, machinery, and fertilizer importations. The details are given in Table 4.12.

d) The Resource Availabilities

The land resources are based on the acreages in both regions of dry and irrigated land over the period 1970-74. Only the acreage of the crops included in the model are aggregated.

- Labor availabilities are based on the population of working age in each region times an average of 270 days a year, considered to be the full employment rate.

- Water resources represent the total amount in each region that is available from wells, dams, and river basins. Underground water was not included because its exploitation requires additional investments.

- Demands are based on national figure projections to feed the population of both regions by 1985 without importations.

Table 4.12 Costs of Importation in $

Product	Constant Prices	Unit
Machinery	30,000	tractor
Wheat	180.00	metric-ton
Tomatoes	400.00	"
Potatoes	450.00	"
Melon	600.00	"
Beans	300.00	"
Processed Tomatoes	200.00	"
Oragnes	200.00	"
Meat	1000.00	"
MIlk	0.1	litres

It is to be noted that irrigated land in both regions is adjusted to account for multiple cropping during the year by a factor of 1.4 in region I and 1.56 in region II, based on past land utilization. See Table 4.13

4.3 Results of the Model and Their Interpretations

The model was formulated with eighty constraints and two hundred variables. It was solved on a CDC CYBER 74 using an optimization procedure package, MPOS.

a) Minimum Weighted Costs Solution

The first run of the model was based on the minimization of the

Table 4.13 Resource Availabilities

Resource	Region I	Region II	unit
Dryland	290,000	810,000	hectar
Irrigated land	141,000	89,900	"
Permanent Crops	16,000	2,800	"
Water (Season 1)	130,000	92,600	acre-feet
Water (Season 2)	100,000	70,000	"
Labor (Ordinary)	60,000,000	85,000,000	man-days
Labor (skilled)	10,000,000	20,000,000	"
Demands			
Wheat	447,630	644,154	metric-tons
Tomatoes	23,035	33,150	"
Potatoes	154,685	222,596	"
Melon	82,800	119,150	"
Beans	5,941	8,550	"
Processed Tomatoes	5,789	8,330	"
Oranges	80,996	116,555	"
Global			
Meat	18,000		metric-tons
Milk	98,000,000		litres
foreign exchange	60,000,000		$

total deviations from the target goals, expressed in dollars. Because any underachievement of the demand goals will cause the difference to be imported, unit prices for importation are used as the weighting factors for the demand deviations.

In the case of employment goals, any underachivement will mean an additional cost for each region to feed the unemployed population in the form of aid or welfare support. Thus, we adopted the minimum wage per day as the weighting factor.

For foreign exchange, the objective is to minimize the overachievement of the goal, that is, the maximum expenditures allowed for each region to buy from outside the country. And since the foreign exchange equation is expressed in dollars, each unit of overachievement will merely cost one dollar. Under these conditions, the solution program is presented in Table 4.14. The equilibrium between the two regions is completed through transportation activities given in Table 4.15. Table 4.16 gives the goal achievement levels and the proportions of deviation from the targets set.

The first thing we notice is the specialization of the two sectors. Sector I produces only livestock and Sector II all other crops. This is explained by the relatively higher yields and more efficient use of factors of production in the private sector. The cooperative sector, even though more modern and government supported, has always suffered from major insufficiencies in management and use of resources. And in reality, most of the cooperatives registered financial deficits over the past ten years.

Table 4.14 Solution Results

Activities	Region I		Region II	
	Sector I	Sector II	Sector I	Sector II
Wheat (ha)	-	231,999		265
Oats (ha)	-	18,273		66
Pasture (ha)	-	39,726		-
Tomatoes (ha)	-	6,693		307
Potatoes	-	17,039		1,308
Melons (ha)	-	11,000		-
Beans (ha)	-	16,385		2,615
Processed Tomatoes	-	-	-	1,000
Oranges	-	13,495	-	2,800
Dairy (unit)	24,120	-	-	-
Beef (unit)	-	-	116	-
Machinery (1)	3,190		80	
Fertilizer (metric-tons)				
- Nitrogen	3,576		251.5	
- Phosphate	6,402		169.3	
- Potassium	4,232		232	

Table 4.15 Transportation Solution

Region I		Direction	Region II
Wheat (metric-tons):	643,000	→	
Tomatoes (metric tons):	13,000	→	
Potatoes (metric-tons):	210,000	→	
Melons (metric-tons):	119,150	→	
Beans (metric-tons):	5,908	→	
Processed Tomatoes (metric tons):	5,670	←	
Oranges (metric-tons):	79,595	→	

Table 4.16 Achievement of Goals

Goals	Region I			Region II		
	Target	Deviation	Proportion	Target	Deviation	Proportion
Wheat	447,630	166,391	-37%	644,154	643,000	-98%
Tomatoes	23,035	16,392	+71%	33,150	13,000	-39%
Potatoes	154,685	16,788	-10.8%	222,596	117,956	-52%
Melons	82,800	55,800	+67.4%	119,150	119,150	-100%
Beans	5,941	5,908	+99.4%	8,550	5,908	-69%
Processed Tomatoes	5,789	5,789	-100%	8,330	5,670	+68%
Oranges	80,996	79,595	+98%	116,556	79,595	-68%
Employment	60,000,000	5,340,000	-9%	85,000000	8,500,000	-10%

Global	TARGET	DEVIATION	PROPORTION
Milk	98,000,000	9,800,000	-10%
Meat	18,000,	14,800	-82%
foreign exchange	60,000,000	370,000,000	+600%

Between regions, specialization is not very clear. Region II, which always has been a wheat producer, seems to give up its specialization to region I. This is explained by the fact that, in reality, land is more scarce in region I but is of better quality and gives higher yields, which made producers specialize in more profitable crops.

In addition, we can see from the solution that the dry land constraint in region I is binding. In region II, even though there is a positive slack for the land equation, the water constraint for the summer season is binding, which limits production.

Using the shadow prices associated with the binding constraints, we can conclude that it is far more important to relax the water constraint in region II than to relax the dry land constraint in region I and that conforms with the real facts. It implies that irrigation investments in region II might be considered in production is to increase.

From the goal achievements table we can note that wheat and potatoes are the crops that suffer an absolute deficit. This conforms with the actual situationin Algeria. Wheat has always been on the top of the list of Algerian importations and the price of potatoes has risen from .5 dinar per kilogram to 3.0 dinars per kilogram in the past five years with very frequent shortages on the market.

The employment achievement is to be considered a very good one since no more than 10% of unemployment is indicated by the solution, compared to the real figures, which are about 25% in region I and 30% in region II.

The "not satisfactory" achievements of meat demand and foreign exchange seem to be the price of reducing unemployment drastically. We give in Table 4.17 the range over which the costs associated with the basic deviation variables are allowed to change before changing the optimal basis.

Table 4.17 can give useful information in trying to estimate the sensitivity of the program to changes in the weighting factors expressed as contributions to the overall underachievement cost. For instance, the potatoes demand will still be unsatisfactory even if each unit of underachivement contributes to reducing the overall cost by up to \$5 or increasing it by up to \$17; outside this range, changes in the allocation program and the demand achievement may occur. The same remarks are valid for melon and processing tomatoes.

We tried to evaluate the sensitivity of the solution by changing the weight of hard currency overachievement from 1 to 0.5. The results are given in Tables 4.18, 19, 20, with $\alpha = 0.5$. The results are quite staggering. No more absolute specialization is indicated between sectors. Region II picks up its specialization of wheat production by the private sector and wheat demands are completed satisfied through the transportation mechanism. A slight decrease of unemployment and a sharp decrease in the underachievement of meat demand also resulted. The new plan, however, is achieved at the expense of spending nine times the maximum of foreign exchange allowed.

Even though the second solution indicates more internal production by the regions, wiht more self-sufficiency for certain crops, the foreign exchange expenses are higher than in the first solution. This is due

Table 4.17 Range of Variation of Weighting Factors

Deviations	Weight	Range
Underachievement of wheat demand	12	9.8 to 14
Underachievement of potato demand	14	-5 to 17
Underachievement of melon demand	20	-10.6 to 22
Underachievement of processed tomatoes demand	10	-2.8 to 13
Overachievement of tomato demand	0	-3.4 to 0
Underachievement of employment goal in region I	5	0 to 46.4
Underachievement of employment goal in region II	5	0 tp 41.6
Underachievement of meat goal	3000	2641 to 9490
Underachievement of milk goal	0.2	0.1 to 2.0
Overachievement of foreign exchange goal	1	0.7 to 1.1

Table 4.18 Solution Results with Weight of Overachievement of Hard Currency Expenditures Equal to 0.5 (α = 0.5)

Activities	Region I		Region II	
	Sector I	Sector II	Sector I	Sector II
Wheat (ha)	50,761	188,074	-	677,872
Oats (ha)	12,690	4,324	-	29,939
Pasture (ha)	-	42,694	-	139,528
Tomatoes (ha)	-	5,255	22	1,724
Potatoes (ha)	-	16,320	-	1,787
Melons (ha)	-	11,000	-	-
Beans (ha)	-	16,382	85	2,532
Processed Tomatoes (ha)	-	-	85	915
Oranges (ha)	12,138	-	2,800	-
Dairy (unit)	25,138	-	72,353	-
Beef (unit)	-	-	-	-
Machinery (unit)	3,646		10,030	
Fertilizers (unit)				
-Nitrogen	4,950		3,896	
-Posphate	8,000		11,965	
-Potassium	5,440		6,259	

Table 4.1 9 Goals Achievement ($\alpha = 0.5$)

Goals	Proportions	
	Region I	Region II
Wheat	-	-
Tomatoes	+47%	-
Potatoes	+6.5%	-92%
Melons	+67%	-100%
Beans	-	-
Processed Tomatoes	-	-
Oranges	-	-
Employment	-8%	-9%
Milk	-10%	
Meat	-37%	
foreign exchange	+900%	

to the fact that the most costly items in the hard currency equation are equipment and chemicals. The implication is that less developed regions can use their resources more efficiently by adjusting their crop distribution among regions, but if they seek more economical independence, they have to produce their own equipment for agricultural use.

b) Choosing from a Set of Programs

We have concluded above that the solution results are very sensitive to the changes in the weighting factors. Thus, a procedure using only one set of weights may lead to a good solution but may be restrictive especially when some of the goals are conflicting. It presupposes an implicit ranking of the goals which may not conform to the real importance attributed to the different goals.

If we consider the wheat demand and the foreign exchange goals, we note that they are conflicting, since we would seek more demand satisfaction and less foreign exchange expenditure; in other words, we want to minimize the underachievement of the wheat demand goal, and at the same time, maximize the underachivement of the foreign exchange goal. We start by setting the weighting factor, called α, associated with the overachivement variable for foreign exchange to zero. The resulting program, P1, is summarized in Table 4.21. Using range analysis from a simplex routine, we increase α gradually to generate programs P2, P3, and P4, also summarized in Table 4.21. In this form, the results can be used to make compromises between different levels of goal targets. For example, if it is found more important to completely satisfy the wheat demand, then a higher amount for foreign exchange will be needed, and if it is vital to limit the expenditures to a certain level, then the decision maker will have to accept having some unsatisfied demand.

Note that similar results can be derived by varying other weighting factors for conflicting goals.

c) Comparison with Linear Programming Solutions

A minimum cost linear program with penalty costs associated with the deviations from goal targets was formulated based on average costs per hectar of cropping activity and average transportation costs between the two sectors. The results are summarized in Table 4.20.

Table 4.20 Transportation Solution ($\alpha = 0.5$)

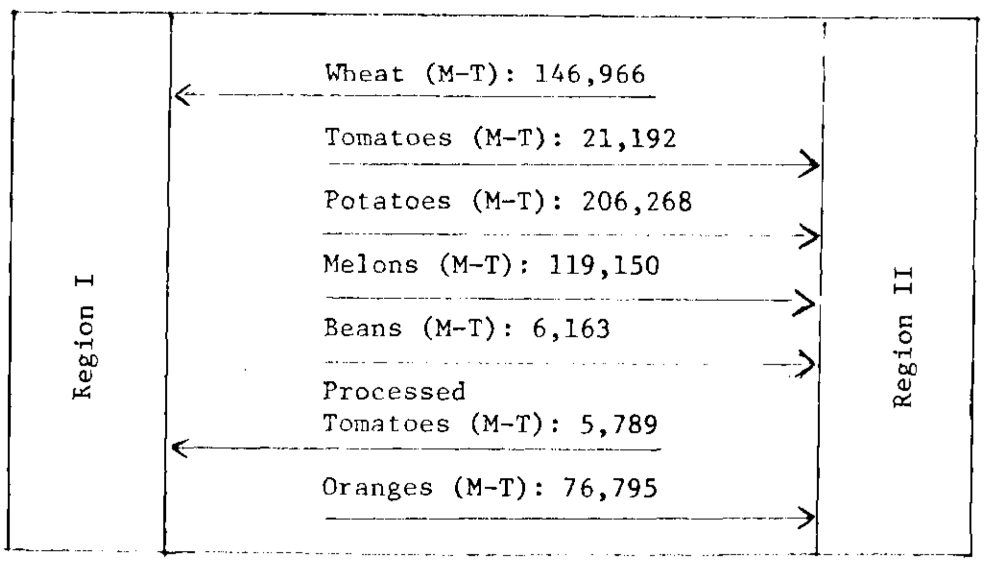


Table 4.21 Tabular Results of a Set of Alternative Programs

Program	α	Range of Variation of α	Underachievements						Overachievement of foreign exchange goal (Million $)
			Wheat Demand (M-T)		Employment (Man-Day)		Global Goals		
			Region I	Region II	Region I	Region II	Meat (Metric-ton)	Milk (Litres)	
P1	0.0	0-0.674	0	0	5,374,000	0	6,690	9,800,000	540
P2	1.0	0.69-1.1	809,390	0	5,330,000	0	14,850	9,800,000	370
P3	1.5	1.3-4.7	1,081,784	0	5,815,000	0	16,000	9,800,000	190
P4	5.0	4.8- ∞	1,091,784	0	5,815,000	0	18,000	9,800,000	60

Table 4.22 Minimum Cost LP Solution

Activity (hectars)	Region I		Transportation Activities (m-tons)	Region II	
	Sector I	Sector II		Sector I	Sector II
Tomatoes		5,770	24,760 →		1,230
Potatoes		17,156	211,300 →		1,229
Melons		11,000	119,150 →		-
Beans		17,542	7,485 →		1,459
Processed Tomatoes		-	← 5,670		1,000
Oranges		13,495	79,595 →		2,800

Figure 4.23 Maximum Return LP Solution

Activities (hectars)	Region I		Transportation Activities (m-tons)	Region II	
	Sector I	Sector II		Sector I	Sector II
Tomatoes		3,533	556 →		3,467
Potatoes		13,800	190,834 →		3,467
Melons		11,000	119,150 →		-
Beans		13,065	2,943 →		5,935
Processed Tomatoes		-	← 5,670		1,000
Oranges		13,495	79,595 →		2,800
Wheat					698
Oats					175
Pasture	-	-	-	-	-
Livestock	-	-	-	308	-

We notice that this solution calls for an importation of all the wheat, milk, and meat to meet the demands. Even though it indicates a foreign exchange amount not larger than the one obtained from the goal program solution, it has several consequences on economic independence and employment targets.

The same problem solved as a minimum cost program with no penalties indicated an infeasible solution. Here all the demand equations were violated. That also shows the limitations of a pure linear programming formulation in solving real problems which cannot be met optimally.

A maximum average return objective function was also solved and the implications are the same as for the minimum cost case. Even though some proportions are changed, the structure of the solution is identical with a minor exception; a small acreage of wheat enters the solution, the rest being imported. The results are summarized in Table 4.23 .

4.4 Conclusion

In spite of some obvious insufficiencies in the data, the solution obtained seems to be a good one. A flexibility is offered by the goal programming formulation to take into account a number of objectives not necessarily compatible. However, the approach requires a careful choice of the weighting factors in the achievement of the overall objective function.

When changes in the goal weights were performed to produce a set of programs, the results were very close in goal achievements, even though the activity levels in the different programs were significantly different.

It is also to be noted that the linear programming formulations indicated global unemployment levels of about twenty five percent. Compared to the results of the goal programming formulation, less than ten percent, it is concluded that a goal formulation seems more appropriate in handling the special conditions of developing economies among which the employment issue is central.

CHAPTER V

A NINE-REGION EGYPTIAN MODEL

With a population of 37 million rapidly expanding at a rate of 2.5% per year, Egypt has an economy that is basically agricultrual. But the country is arid; the maximum rainfall around Alexandria is about eight inches per year and 90% of the land is essentially desert with temperatures in the summer reaching 43° celcius or more.

With the supply of arable land limited, about six million feddans[1], and the scarcity of rainfall,the application of other inputs is very important in meeting high crop yields. The permanency of irrigation has made possible growing about three crops a year instead of one or two in the past, and gave priority to cotton and maize productions in place of barley and wheat. Thus, multiple cropping and rotational requirements, essential to take care of the detrimental effect that cotton production has on soil fertility, are two very important aspects of the Egyptian agriculture.

In 1975, fifty percent of the country's work force was employed in agriculture, but rural unemployment remains a problem. In the past several years, under the pressure of population increase, Egypt has had to import an increasing proportion of key foodstuffs, especially wheat, beef, and feed grains for domestic livestock. But the sharp increase of international prices in 1973-1975 placed an additional weight on foreign exchange requirements. in 1974-1975, agricultural imports

---

[1] One feddan = 1.4 acres.

represented well over half of the total imports, thus a serious effort is needed to reduce expenditures of imported food, especially since Egypt has a significant deficit in its balance of payments: about $3 billion in 1976.

Under these conditions, as noted in a report by the U. S. Agency for International Development [1976]:

> Egypt thus faces a major challenge -- how to increase the rate of growth in agricultural production to generate foreign exchange and also meet its future food requirements. Given a nearly fixed land area, this can be accomplished only by significant increases in yields and changes in cropping patterns to achieve more intensive use of land and labor. If these steps are feasible, then more emphasis can be given to producing those crops for which the country has a comparative advantage.

In adapting the model developed in chapter III to the Egyptian agriculture, we will evaluate the changes in regional cropping patterns that would help the country meet its goals and determine the directions of change to be adapted by the sector as a whole.

Another model for the Egyptian agriculture which appeared in the literature by Sherbiny and Zaki [1974] is worth mentioning at this point because it takes the same perspective of emphasizing global development rather than profit maximization for individual farmers. The model is a maximum net revenue linear program with a set of land constraints and bounds only. The authors claim that a 22% increase in net revenue would result from re-allocation of crops among regions. There are, however, some insufficiencies related to the model:

-The model is based on administrative provinces without regional homogeneity considerations.

-The seasonal aspect of Egyptian agriculture is identified by constraining the cropped areas during the winter and summer seasons. But no land relationships are specified to account for the importance of multiple cropping and rotation requirements as will be seen in section 1.1

- The importance of bersem clover effect on the fertility balance of the soil, closely tied to cotton, is recognized, but it is not incorporated into the model.
- Comparative advantage is restricted to regions only but not among crops, thus restricting the global cropping patterns to be maintained as they were.
- Finally, regions are restricted to have a minimum revenue, but no employment goals and consumption goals are considered.

The following sections will discuss the data base for the model, the results, and their findings.

4.1 The Data Base for the Model

Our main source of data on the Egyptian agriculture is a study by the U. S. Department of Agriculture and the Egyptian Ministry of Agriculture, together with a series of technical reports by the same team.

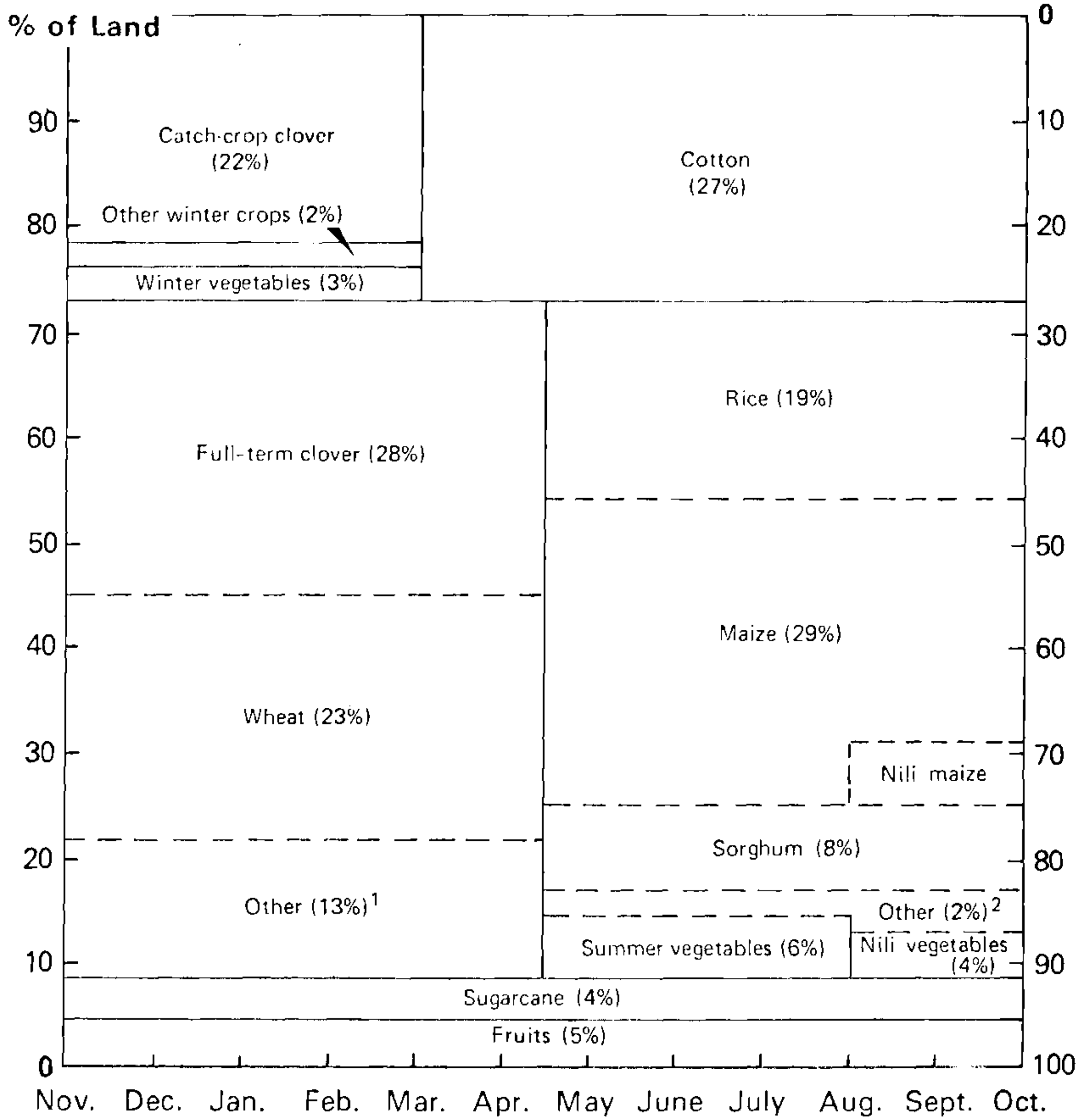
The distinction between Sector I and Sector II as defined in the previous chapters will not be made here because detailed data were not available and most importantly,because the subsistence sector has virtually disappeared from the Egyptian agriculture, which makes it very hard to validate differences in production functions between the private and the cooperative parts of the agricultural sector.

a) The Cropping Patterns

To understand the Egyptian agriculture, knowledge of the basic crop rotation is essential. An illustration of the system is given in Figure 12. Fruits occupy the land permanently and surgarcane is kept for three to five years. Cotton, preceded by a catch crop of bersem clover or by winter vegetables uses the land for about the whole year. Winter field crops frequently occupy a larger percentage of the land than do summer field crops, but each crop requires four to six months of land use. Nili, or fall, field crops are nomally harvested a few months after planting. Summer vegetables in most regions occupy more area than do either winter or nili vegetables, but each crop, on the average, occupies the land for three to four months, thus allowing three or more vegetable crops per year.

From Figure 12 we can also see that if the cotton area expands, more catch-crop bersem clover is produced, but both winter and summer crops are reduced. Note that bersem clover precedes cotton and provides one or two cuttings, hence the area devoted to clover and cotton are about the same. If full-term clover, called permanent bersem,is expanded, adjustments may take place only in cotton and other winter field crops. As an alternative, total land in both winter and summer crops may be expanded with a corresponding cut mainly in land used for cotton. The rotation system required to maintain soil fertility is either triennal with one cotton crop each third year, or biennal, with one cotton crop each second year.

It is interesting to note that the rotational requirements are practically the same through the whole country, thus allowing the formu-



[1] Chiefly horsebeans, lentils and onions
[2] Chiefly sesame, groundnuts

Figure 8. Proportionate Area Devoted to Specified Crops
1972-74 Average

Source: U. S. Department of Agriculture cooperating with U. S. Agency for International Developmetn and the Egyptian Ministry of of Agriculture
Foreign Agricultural Economic Report No. 120

lation of the land matrix relationships to be the same in the different regions.

In addition to the major crops, Egypt also produces a wide variety of minor crops. The areas devoted to each of these crops are not large and no detailed data was available on them, but collectively they occupy a significant proportion of the total cropped area and compete for other resources, thus excluding them from the model may create serious biases. We adopt to account for their effect by grouping them into a single category called "others".

d) The Regions of the Model

The study of the agricultural sector in Egypt referred to above[1], divided the country into 14 agronomic zones based mainly on soil characteristics and cropping patterns, thus allowing for homogeneous regions to be used for our purposes. Figure 13 shows the details on the location of each zone. In our model, we will only include the first nine regions because they involve old land which produces the most important part of the crops. The other regions consist of newly reclained lands and have major problems associated with them such as salinity and waterlogging, poor soils, and relatively high production costs. Further studies are expected to determine the potential use of these lands and ways to improve them before they can become fully contributing to the agricultural sector output. Table 5.1 gives a summary of the different regions, locations, and characteristics.

e) The Activities of the Model

Given the characteristics of the Egyptian agriculture, except

[1] "Egypt: Major Constraints to Increasing Agricultural Productivity," Foreign Agricultural Economic Report No. 120, pg.56.

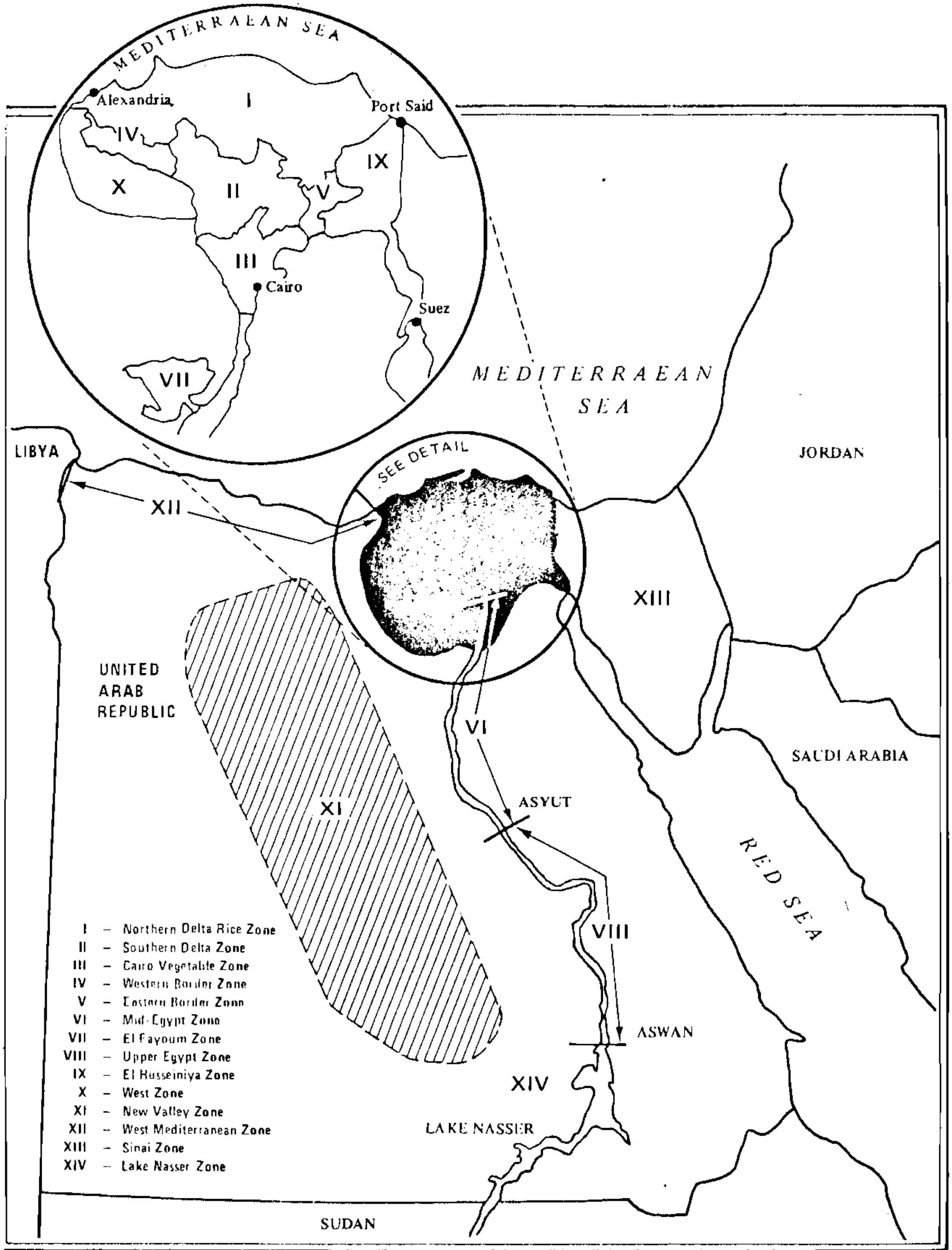


Figure 9. Major Agronomic Zones
Source: The Same as Figure 8

Table 5.1 The Regions' Description

Region Name	Location	Districts	Major Crops	Million Feddans	Crop Ratio	Soil Characteristics
I Northern Delta	Northern Nile Delta from Alexandria almost to Port-Said	All of: -Alexandria -Kafr El Cheikh -Damietta and parts of: -El Beheira -El Gharbiya -El Dakahliya -El Sarkia	-Rice -Cotton -Wheat -Vegetables -Fruits	1.7	2.0	- The coastal part: Marine Soils - The central part: Dark brown soil with 60% clay - Salinity and alkalinity in the north require drainage.
II Southern Delta	Continuation of Northern Delta	Parts of: -El Beheira -El Garbiya -El Dakahliya -El Menoufia -El Sharkia	-Rice -Cotton -Clover -Maize -Citrus -Vegetables	1.0	2.0	- Fine texture of clay with good constructivity and solubility of salts
III Cairo Vegetable Region	Southernmost portion of the Delta	All of: -El Qualionbieh Parts of: -El-Mennifia -El Sharkia -El Giza	-Vegetables - Clover - Cotton - Fruits	0.44	-	- Same as Region II. - The eastern part consists of sandy soils with a high percentage of calcium carbonate.

Table 5.1 Continued

Region Name	Location	Districts	Major Crops	Million Feddans	Cropping Ratio	Soil Characteristics
IV Western Border	South of Alexandria	Parts of: -El Beheira	-Horsebeans -Barley -Cotton -Rice -Fruits	0.15	1.9	- Coarse Calcareous soils with very fine texture - The northwest is clay mixed with coarse sands
V Eastern Border	Southwest of Port Said and Northwest of Cairo	Parts of: -El Sharkia	-Clover -Cotton -Wheat -Horsebeans -Tomatoes	0.17	-	- Same as Region IV - In the south, soils are a deep alluvial dark brown, light to heavy clays
VI Mid-Egypt	Narrow Nile Valley Between Cairo and Asyut	All of: -Beni Sueif -El Minya -Asyut Parts of: -El Giza	-Cotton -Wheat -Horsebeans -Maize -Sorghum -Tomatoes -Citrus	1.0	-	- Deep alluvial white clay soils
VII El-Fayoum Region	Depression lying to the west of Nile Valley about 180 Miles south-east of Cairo	All of: -El-Fayoum	-Cotton -Clover- -Rice -Maize- -Tomatoes	0.3	2.0	- Deep alluvial loans to clays. Moderately saline.

Table 5.1 Continued

Region Name	Location	Districts	Major Crops	Million Feddans	Crop Ratio	Soil Characteristics
VIII Upper Egypt	Southern part of the Nile Valley	-Solaq -Qena -Asman	-Sugar Cane	0.7	1.2	- Sandy Loams
IX El Thusseiniya	West of Suez Canal		-Permanent Crops -Cotton -Wheat -Maize -Rice	.14	1.96	- Recent alluvial dark light clay - Highly saline in the south - High water table

for sugar cane and fruits which are permanent crops, all other crops can be formulated in alternative sequences to be determined optimally by the model. The land relationships in each region will include the necessary fertility requirements through rotating cotton every three years, onions every four years, and all other crops every two years. The sequencing will allow summer crops to follow winter crops and nili crops to follow the summer ones.

The following crops are considered in each region:

Winter Crops	Summer crops
Full-term clover	Rice
Catch-crop clover	Maize
Wheat	Sorghum
Horsebeans	Others
Lentils	Tomatoes
Barley	Other vegetables
Onions	Cotton
Others	
Tomatoes	
Other vegetables	

Nili Crops	Permanent Crops
Maize	Sugar cane
Tomatoes	Fruits
Other vegetables	

The pasture balances include clover, maize, and sorghum. Two variables in each region represent each of the above crops based on two different management cropping systems:

-The first one includes all the present levels of utilization of resources and corresponds to the actual yields for the period 1972-74.

-The second one is an improved system based on more efficient application of fertilizer (+25%), irrigation efficiency, from 51% presently to 70%, labor input (+17%), and machinery (+30%).

Improved yields corresponding to this second system were available from conclusions of the study on the Egyptian agriculture referred to above[1], The system calls basically for improvements in drainage and better water management, seeds and diseases control, adequate machinery, and a more favorable pricing policy, which represent important constraints in improving production.

The livestock activities considerd in the model relate to satisfaction of meat and milk demands, through the management of cattle, buffalo, sheep and goats. Since feed supply is considered a major constraint to an efficient livestock sector in Egypt, the model will make provisions to include only the levels of livestock activities for which an efficient feed supply will be made available. In addition, three fertilizer types are included. These are nitrogen, phospahte, and potassium.

Machinery variables are limited to tractors. Transportation activities include 12 commodities that flow among the nine different regions. These commodities are wheat, barley, horsebeans, lentils, onions, vegetables, rice, maize, surgarcane, fruits, and pasture expressed in terms of starch equivalent.

d) Derivation of Coefficients of the Model

---

[1] "Egypt: Major Constraints to Increasing Agricultural Productivity," Foreign Agricultural Economic Report No. 120, p. 53.

i) The Land Matrix. In each region, a land matrix is specified to include the different cropping alternatives together with their rotational requirement by using proportional bounds on each crop and contingency relationships to conform to the requirements shown in Figure 12. A bound is also specified independently for permanent crops.

On the national level, an institutional constraint on cotton production specifies that it cannot occupy more than a third of the land available. And finally, an equation on the total land available for the Egyptian agriculture is specified linking the nine regions together.

ii) The Fertilizer Equation. Present allocations of fertilizer by crops are nearly the same throughout the country. Detailed experimentation is needed to test the effect of soil variability before data on the proper amount of fertilization needed for different regions could be made available. Thus, we will assume the same rates of fertilizer throughout the regions. Table 5.2 gives the average requirements for each crop based on average utilization for the 1972-74 period.

Livestock waste's contribution to the nitrogen balance is based on the same averages used for the Algerian model and taken from estimations by Nicol and Heady [1975]. The livestock constributions are resepctively 1×10^{-3} metric-tons for sheep and goats, 64×10^{-3} metric-tons for cattle, and 26×10^{-3} metric-tons for buffalo in terms of nitrogen equivalent.

iii) Pasture Equations. The basic and most important livestock feed in the Egyptian agriculture being clover, full-term and catch-crop, maize, and sorghum, an equation is formulated for each region that relates the production levels to the livestock requirements.

Table 5.2 Fertilizer Rates for Existing(E) and Improved (I) Cropping Management Systems (10^{-3} Metric-tons/Feddan)

ACTIVITIES	NITROGEN		PHOSPHATE		POTASSIUM	
	E	I	E	I	E	I
Clover	-	-	-	-	-	-
Wheat	12	15	26	32	13	16
Horsebeans	10	12	20	25	11	13
Lentils	10	12	20	25	11	13
Barley	12	15	26	32	13	16
Onions	12	15	26	32	13	16
Vegetables	36	45	37	45.5	39	46
Rice	12	15	26	32	13	16
Maize	12	15	26	32	13	16
Sorghum	12	15	26	32	13	16
Others	12	15	26	32	13	16
Cotton	45	56	67	82	90	112
Sugar Cane	45	56	67	82	90	112
Fruits	100	125	40	50	74	92

an equation is formulated for each region that relates the produciton levels to the livestock requirements.

The yields can be found in Table 5.7 which gives the regional yield for all crops together.

There are only slight differences in regional feed requirements: the details are shown in Table 5.3, where conversion has been made on the basis of animal units with:

one cattle = 0.8 animal unit

one buffalo = 1 animal unit

one sheep = 0.1 animal unit

one goat = 0.1 animal unit

iv) Water Requirement. In the Egyptian agriculture, the problem of water is important because virtually no dry land crops are grown. The limiting factor is not water unavailability, but rather the lack of proper management and efficient irrigation systems. Table 5.4 gives the water requirements for winter crops and summer crops, and it is assumed that all crops in the same group consume the same amounts,which obviously introduces biases. We will asJo assume that permanent crops are irrigated in the same manner receiving the winter amount with the winter crops and the summer amount with the summer crops. The two seasons extend from November to April and from May to December respectively.

The figures are computed for each region as the ratios of season land available and total water consumption. Improvement in irrigation efficiency is shown under the heading I in Table 5.4 relative to the present system, E.

Table 5.3 Livestock Feed Requirements in Tons/Animal Unit/Year (With C Referring to Clover and MS Referring to Maize and Sorghum)

Region / Type of Livestock	I		II		III		IV		V		VI		VII		VIII		IX	
	C	MS	C	MS	C	MS	C	MS	C	MS	C	MS	C	MS	C	MS	C	MS
Cattle	13.6	8	14.4	8	12.8	8	14.4	8	11.2	8	13.6	8	14.4	8	11.2	8	14.4	8
Buffalo	17	10	18	10	16	10	18	10	14	10	17	10	18	10	14	10	18	10
Sheep	1.7	1	1.8	1	1.6	1	1.8	1	1.4	1	1.7	1	1.8	1	1.4	1	1.8	1
Goats	1.7	1	1.8	1	1.6	1	1.8	1	1.4	1	1.7	1	1.8	1	1.4	1	1.8	1

Table 5.4 Regional Water Requirements (in Cubic Meters/Feddan) Where E and I Stanf for Existing and Improved Cropping Management Systems Respectively

Regions / Season	I		II		III		IV		V		VI		VII		VIII		IX	
	E	I	E	I	E	I	E	I	E	I	E	I	E	I	E	I	E	I
Winter	2.01	2.61	2.02	2.68	2.38	3.1	2.22	2.9	2.19	2.85	2.8	3.64	2.23	2.97	3.11	4.04	2.34	3.04
Summer and Nili	6.03	7.83	4.36	5.8	4.17	5.42	4.63	6.02	5.82	7.56	3.94	5.12	3.86	5.13	6.1	7.8	5.47	7.1

The livestock water requirements are based on empirical evidence showing that livestock compete with land in the following way:

one cattle for one feddan

one buffalo for 0.25 feddan

one sheep or goat for 0.1 feddan

The summer rates are higher because of the important effect of particularly high temperatures.

v) Labor Requirement. Egypt is one of the few developing countries with a surplus of skilled labor, but the problem of efficient utilization of this labor force still remians. It is concluded in the report mentioned earlier in this chapter that skilled labor is not a limiting factor, thus we will include it in the formulation at about 20% of the ordinary labor for purposes of evaluation of that conclusion.

Ordinary labor is a major burden over the Egyptian agricultural sector and its full employment is crucial to the whole economy. Labor requirements are given in Table 5.5. They have been computed as ratios between regional averages of man-days used and acreages of crops. The table shows the figures for the existing system only. The improved system figures are derived by an increase of about 17% over the first level.

vi) Machinery Requirements. This is the part for which absolutely no data was available with the exception of national costs averages of machinery per feddan for selected crops. Since we classified the machinery resources as flexible in the model allowing for their levels to be dependent on the cropping activity levels, the use of data from other

Table 5.5 Regional Labor Requirements (in Man-days/Feddan)

Crops / Regions	WINTER			SUMMER			NILI		PERMANENT	
	Clover	Other Field Crops	Vege-tables	Field Crops	Vege-tables	Cotton	Field Crops	Vege-tables	Sugar Cane	Fruits
I	17	26.7	60	48.7	65.9	84.8	30	63.5	120	147
II	15.7	26.9	66.7	40.93	61.42	92.35	29.16	75	100	134.6
III	17.54	26.47	63.04	37.04	63.33	85.50	31.25	59.52	100	142.6
IV	16.9	22.2	42.9	40.91	77.5	84.6	29.4	57.14	-	166.6
V	16.85	23.3	70	48.27	70	84.84	33.3	80	-	164.3
VI	16.5	22.3	64	50	67.24	84.83	30.63	57.6	111.54	166.7
VII	16.11	24.1	70	63.88	72.7	85.13	31.78	62.5	110.24	180
VIII	14.93	26.58	58.3	63.14	68.75	84.82	28.58	71.43	-	170
IX	17.8	23	62.5	46.15	91.6	82.6	28.57	42.86	203	150

developing countries would only permit to test a given level of technology applied to the Egyptian case. In other words, it will not affect the basics of the allocation problem. We adopted the use of averages of machinery requirements form the Algerian model in chapter IV and a Mexican model from Manne and Goreux [1973] despite obvious differences. The figures are summarized in Table 5.6.

Table 5.6 Estimates of Machinery Requirements
(in days per unit per year)

ACTIVITIES	EXISTING SYSTEM	IMPROVED
Clover	1.5	2
Wheat	2.8	3.3
Horsebeans	2	2.5
Barley	1.5	2
Lentils	1.5	2
Onions	1.6	2.1
Vegetables	1.5	2
Rice	3.0	3.6
Maize	1.8	2.3
Sorghum	2.2	1.7
Cotton	2.4	2.9
Sugar Cane	2.6	3.1
Fruits	1.5	2.0

Table 5.7 Regional Crop Yields (Metric-tons/Feddan)

Regions	I		II		III		IV		V		VI		VII		VIII		IX	
	E	I	E	I	E	I	E	I	E	I	E	I	E	I	E	I	E	I
<u>Winter</u>																		
Clover	24	30	24	30	24	30	24	30	24	30	24	30	24	30	24	30	24	30
Wheat	1.3	1.63	1.6	1.63	1.6	1.63	1.0	1.25	1.4	1.75	1.5	1.88	1.2	1.5	1.2	1.5	1.0	1.25
Horsebeans	.98	1.98	.98	1.18	.98	1.18	.7	.84	.9	1.08	1.1	1.3	.9	1.08	1.0	1.2	.8	.96
Lentils	-	-	-	-	-	-	-	-	-	-	.8	.96	-	-	.8	.96	-	-
Barley	-	-	-	-	-	-	1.0	1.2	1.2	1.44	-	-	-	-	-	-	.9	1.08
Onions	-	-	-	-	-	-	-	-	-	-	5.9	7.08	-	-	10.8	12.5	-	-
Others	2.3	2.76	3.0	3.6	3.9	4.68	3.0	3.6	1.2	1.44	5.6	6.7	2.2	2.64	1.3	1.56	1.9	2.28
Tomatoes	4.5	6.75	4.7	7.05	3.9	5.85	3.8	5.7	3.8	5.7	4.5	6.75	6.0	9	5.6	8.4	3.8	5.7
Other Veg.	6.8	10.2	7.6	11.4	6.8	10.2	1.5	2.25	6.8	10.2	5.4	8.1	6.4	9.5	4.0	6	5.4	8.1
<u>Summer</u>																		
Rice	2.2	2.64	2.2	2.64	2.1	2.52	2.2	2.64	2.2	2.64	-	-	1.7	2.04	-	-	1.8	2.16
Maize	1.6	2.13	1.8	2.4	1.65	2.2	1.6	2.13	1.7	2.26	1.6	2.13	1.4	1.86	1.5	2.0	1.4	1.86
Sorghum	-	-	-	-	-	-	-	-	-	-	2.0	2.4	1.5	1.8	1.7	2.04	-	-
Other	1.9	2.28	4.8	5.76	2.4	2.88	3.9	4.68	1.0	1.2	1.2	1.44	5.5	6.6	0.8	0.96	1.0	1.2
Tomatoes	6.8	10.2	6.6	9.9	7.0	10.5	-	-	6.7	10.05	6.2	9.1	-	-	-	-	6.1	9.15
Other Veg.	9.6	14.4	8.0	12	9.3	13.95	8.0	12	7.9	11.85	8.3	12.45	8.5	12.75	7.2	10.8	12.2	18.3
<u>Nili</u>																		
Maize	1.2	1.6	1.3	1.73	1.3	1.73	0.8	1.06	1.1	1.46	1.2	2.73	0.9	1.2	1.2	1.46	0.8	1.06
Tomatoes	7.4	11.1	7.6	11.4	7.1	10.65	9.0	13.5	6.8	10.2	6.7	10.05	7.7	11.55	6.7	10.05	5.5	8.25
Other Veg.	6.77	10.06	6.2	9.1	7.0	10.5	3.1	4.65	8.4	12.6	5.8	8.7	6.8	10.2	6.4	9.2	6.7	10.05

Table 5.7 Continued

Fruit	5.2	7.28	6.1	8.54	6.2	8.68	6.0	8.56	5.1	7.14	5.1	7.14	4.0	5.6	5.0	7	4.2	5.88
Sugar Cane	27	33.75	29	36.25	33	41.25	-	-	-	-	37	46.25	-	-	37	46.25	-	-
Cotton	.27	.32	.30	.36	.63	.76	.23	.29	.31	.37	.32	.38	.23	.76	.36	.43	.42	.5
Catch Crop Clover	12	15	12	15	12	15	12	15	12	15	12	15	12	15	12	15	12	15

vii) The Demand Matrix. The demand matrix incorporates the relationships between production levels and fixed demands. It also includes a transportation model to determine the required commodity flows between regions, and deviation variabels to evaluate the possiblities of attaining the regional demand goals. The diagonal part of the matrix is formulated using the yield figures from Table 5.7 where distribution is made between the present system of crop management and the projected one with improved yields. The increases range from 20% for almost all fiedls crops to 50% for vegetables.

Included in the demand matrix is a starch equivalent equation which relates the production of clover in terms of nutrition equivalent to the livestock sector.

The data on livestock requirements is based on Table 5.3 where one ton of roughage is equivalent to 0.1 tons of starch.

viii) Constraints at the National Level. Bounds on a minimum land use per season are specified to make sure that no region ends with only a program for the winter crops. Also, a global constraint on the total land available is included to insure that the maximum total acreage available is not violated.

As in the case of the Algerian model, no data was available to formulate the short-term capital constraint. Furthermore, no regional data was available on milk and meat production. We thus used the national averages for all the regions as shown in Table 5.8

Table 5.8 Livestock Production Permit

	Cattle	Buffalo	Sheep	Goats
Meat (Metric tons)	0.12	0.15	0.025	0.025
Milk (Litres)	2000	-	200	150

The foreign exchange expenditures equation was formulated including importaitons of food products, fertilizers, and equipment.

e) Availability of Resources

The summary of resources is given in Table 5.9. The land resources are the cropped areas, that is, the physical land available times the cropping ratio of 2.0 in all regions. That accounts for the special characteristics of the Egyptian agriculture where land is used at least twice a year.

The water resources are evaluated from data based on the Nile capacity of irrigation and no other sources are included in the supply. But provisions are made to account for the inefficiency of the irrigation system and augment the water supply by the corresponding projected improvement. The demand targets are based on projections by the Ministry of Agriculture in Egypt to satsify the regional demand for basic food stuffs by 1985. At the national level, the demands of meat and milk are specified to be 390,000 tons and 2,472 million liters respectively.

A cotton constraint is specified for institutional reasons to limit cotton production and orient producton towards other basic crops. It has an upper bound of 1,738,000 feddans. The total cropped area is constrained to 12,000,000 feddans representing 6 million feddans of land available.[1]

And finally, a foreign exchange constraint includes provisions for both importation and exportation possibilities to minimize the agricultural deficit in foreign trade.

---

[1]"Egypt: Major Constraints to Increasing Agricultural Productivity," Foreign Agricultural Economic Report No. 120, statistical appnedix.

Table 5.9 Resource Supply

Resources \ Regions	I	II	III	IV	V
Total Cropped Area (feddans)	3,316,000	1,975,000	870,000	301,000	343,000
Land for Permanent Crops	56,000	52,000	64,000	21,000	14,000
Winter Water (Cubic Meters)	3,844,000	2,700,000	1,130,000	341,000	380,000
Summer Water	15,300,000	6,000,000	2,700,000	1,115,000	1,200,000
Unskilled Labor (Man-days)	175,000,000	950,000,000	560,000,000	175,000,000	950,000,000
Skilled Labor	35,000,000	100,000,000	56,000,000	17,000,000	95,000,000
Demands					
(Metric-tons)					
Starch	2,568,000	1,345,500	202,500	78,000	129,000
Wheat	676,000	499,000	206,000	31,000	62,000
Barley	38,250	15,750	24,250	16,000	11,500
Horsebeans	38,250	15,750	24,250	16,000	11,500
Lentils	38,250	15,750	24,250	16,000	11,500
Onions	38,250	15,750	24,250	16,000	11,500
Vegetables	2,844,000	2,132,000	2,780,000	697,000	393,000
Rice	2,310,000	391,000	48,000	74,000	171,000
Maize	1,017,000	2,355,000	996,000	43,000	477,000
Cotton	481,000	493,000	104,000	23,000	38,000
Sugar Cane	236,000	145,000	165,000	50,000	50,000
Fruits	450,000	486,000	628,000	203,000	123,000

Table 5.9 Continued

Resources \ Regions	VI	VII	VIII	IX
Total Cropped Area (Feddans)	3,290,000	498,000	1,300,000	268,000
Land for Permanent Crops	56,000	15,000	176,000	8,000
Winter Water (Cubic meters)	7,500,000	630,000	2,140,000	300,000
Summer Water	6,400,000	1,500,000	6,220,000	1,200,000
Unskilled Labor	852,000,000	224,000,000	896,000,000	56,000,000
Skilled Labor	80,000,000	22,000,000	89,000,000	5,600,000
Demands (Metric-tons)				
Starch	799,500	213,000	228,000	76,000
Wheat	472,000	140,000	218,000	8,000
Barley	107,000	35,750	100,000	18,500
Horsebeans	107,000	35,750	100,000	18,500
Lentils	107,000	35,750	100,000	18,500
Onions	107,000	35,750	100,000	18,500
Vegetables	1,599,000	707,000	566,000	477,000
Rice	10,000	33,000	60,000	54,000
Maize	2,435,000	357,000	1,382,000	185,000
Cotton	424,000	69,000	150,000	21,000
Sugar Cane	1,665,000	10,000	10,591,000	10,000
Fruits	279,000	107,000	102,000	54,000

5.2 Results of the Model

A linear goal programming model was developed. The model consists of 450 constraints and 1500 variables, and was solved on an MPSX-IBM 360 at the University of Georgia.

We chose the objective function to be the minimization of weighted deviations from stated goals, such as regional demands, employment targets, national demand fro meat and milk, and expenditures for foreign exchange.

The weighting factors were drived from national average prices of agricultural productions, augmented by 20%, since it is recognized that the internal farm prices in Egypt are below the international market prices by that proportion.

The employment deviations were weighted with the average minimum daily wage, which the country would expect to pay for each man-day of unemployment.

The cropping levels solutions are summarized in Table 5.10. We note from the table that substantial specialization exists between regions, which is more important thatn it is in reality. But the specialization is not absolute except for one crop, onions, which is now concentrated in regions VI and VIII.

Some winter crops like wheat, horsebeans, and varley disappear completely from production whereas the proportion of other crops, such as clover are extended. This is not the case for summer crops. Another interesting observation is the presence of both types of clover in all the regions; that is explained by the fact that clover is basic to the rotational requirement, does not use much inputs, and has relatively high yields.

We also note that except for nili tomatoes and cotton in region III, and maize in region VIII, all crops are produced at the improved level of management cropping systems. From Table 5.11 we note the virtual specialization of the regions in cattle production. That can be interpreted by the fact that cattle are required to meet the goals of both meat and milk demands. Table 5.12 shows the amounts of fertilizer and equipment necessary to implement the program determined by the solution. It is to be noted that the solution calls for a substantial increase in potassium relative to the amount currently available to the agricultural sector. The number of machinery units, tractors in our case, will have to double to meet the required levels of output. Table 5.13 shows the transportation levels of the different crops. Since there are no explicit costs or bound capacities specified on the transportation model, adjustments seem to be regulated by the magnitude of the demand in each region. We also note that some regions have a central role in the distribution problem, which is interesting if studies are to be conducted to locate the best transhipment regions.

When a crop is not retained in the model at a positive level, like wheat, for example, the goal deviation variables become importation variables and only one region specializes in importing the desired products. Then a distribution to other regions is accomplished based on their demands.

Table 5.14 gives the goal achievements for demands, from which we note that self sufficiency occurs for starchy products, vegetables and frutis. An overachievement is indicated for onions and the rest of the products suffer a relatively high underachievement. Compared to the present situation in the Egyptian agriculture, we note that a major re-allocation occurs for cotton, which,in the programming solution, appears with a deficit, while we know that it is an important item in the Egyptian exportations. But that confirms the conclusions of the study by the U. S. Agency for International Development and the Ministry of Egyptian Agriculture, that any increases in other crops has to come through a decrease in cotton production.

On the employment side, we can see from Table 5.14 that except for regions I and IX, unemployment will still be high. Note that the figures in that table include all the rural population in each region. Because no detailed data were available on the work force, the targets were set to full employment. That means that the real proportions of unemployment will be at most 50% of the results in the table.

In order to satisfy all the demands, 4.2 billions dollars of foreign exchange needed for importation in addition to the limit of 500 million set as a target, was found necessary by the model. Compared with the 1.6 billion dollars Egypt had to pay in 1976 for importing agricultural products, the results seems to be satisfactory since at least $3 billion in the foreign exchange equation are incurred by the purchase of machinery and fertilizer.

Table 5.10 Land Activity Needs (1,000 Feddans)

Region \ Crop	WINTER CROPPED AREA									
	Full Clover	Catch-Clover	Wheat	Horsebean	Lentils	Barley	Onions	Others	Tomatoes	Other Vegetable
I	1,086	286			0					
II	476	161			1.3					320
III	12.3	24.6			78					177
IV	5.3	10.6			86					
V	30	1.3			36.5					
VI	39.6	19.1					174.7		879.7	903.2
VII	154.5	36.6								
VIII	17	31.6			1.5		112.6			
IX	4.4	8.9			82.2					

Table 5.10 Continued

SUMMER CROPPED AREA							NILI CROPPED AREA			PERMANENT CROPS	
RICE	MAIZE	SORGHUM	COTTON	OTHERS	TOMATOES	OTHER VEGETABLE	MAIZE	TOMATOES	OTHER VEGETABLE	SUGAR CANE	FRUITS
586	1,086		215								56
	476		481		1.3	1.3		2.5	2.5		52
			202		78	78		156		59.4	4.6
	5.3				86	86					21
	29.9				36.5	36.5		73.1	73.1		14
	39.6		808.5		174.7	174.7					56
145.5	145										15
17	17	114	31.6		114	114		282	282		176
					82.2	82.2				8	

Table 5.11 Livestock Levels (Heads)

	Cattle	Buffalo	Sheep	Goats
I	315,280	-	-	-
II	167,234	-	-	-
III	-	-	230,725	-
IV	11,060	-	-	-
V	17,820	-	-	-
VI	87,280	-	-	-
VII	38,180	-	-	-
VIII	42,303	-	-	-
IX	9,250	-	-	-

Table 5.12 Other Input Levels

Inputs / Regions	FERTILIZER (METRIC-TONS)			EQUIPMENT (LIMIT)
	NITROGEN	PHOSPHATE	POTASSIUM	
I	1,857	36,960	25,391	32,122
II	16,947	36,000	40,600	17,677
III	17,030	20,665	23,230	6,600
IV	5,030	5,550	5,520	2,130
V	5,113	6,220	6,165	2,780
VI	68,400	84,300	97,000	27,880
VII	676	5,030	3,017	4,950
VIII	26,520	25,239	27,680	10,185
IX	3,825	5,056	4,685	2,180

Table 5. 13

Transportation Activities (Metric-tons)

(Where U_{ij} Indicates the Direction of Flow of the Commodity)

STARCH	WHEAT	BARLEY
$U_{1,5}$ = 38,934	$U_{1,8}$ = 218,000	$U_{1,9}$ = 18,500
$U_{1,9}$ = 671,980	$U_{1,9}$ = 39,000	$U_{2,5}$ = 11,500
$U_{2,6}$ = 89,600	$U_{2,1}$ = 933,000	$U_{3,7}$ = 25,403,251
$U_{3,8}$ = 236,215	$U_{6,2}$ = 1,432,000	$U_{6,2}$ = 27,250
$U_{6,3}$ = 186,456	$U_{6,5}$ = 62,000	$U_{6,8}$ = 100,000
$U_{7,9}$ = 224,874	$U_{7,6}$ = 1,966,000	$U_{7,1}$ = 56,750
$U_{9,4}$ = 61,632	$U_{9,4}$ = 31,000	$U_{7,4}$ = 16,000
$U_{9,6}$ = 772,415		$U_{7,6}$ = 25,294,751

HORSEBEANS	LENTILS	ONIONS
$U_{3,9}$ = 50,250	$U_{1,2}$ = 80,475	$U_{1,2}$ = 983,583
$U_{6,3}$ = 74,500	$U_{2,7}$ = 65,846	$U_{1,4}$ = 16,000
$U_{6,5}$ = 11,500	$U_{3,1}$ = 118,725	$U_{3,9}$ = 54,250
$U_{6,8}$ = 174,000	$U_{3,8}$ = 37,280	$U_{6,1}$ = 1,037,833
$U_{8,1}$ = 38,250	$U_{4.8}$ = 61,330	$U_{6,3}$ = 78,500
$U_{8,7}$ = 35,750	$U_{5,9}$ = 21,400	$U_{8,2}$ = 1,284,324
$U_{9,2}$ = 15,750	$U_{7,6}$ = 30,096	$U_{8,5}$ = 11,500
$U_{9,4}$ = 16,000	$U_{9,6}$ = 76,903	$U_{9,7}$ = 35,750

VEGETABLES	RICE	MAIZE
$U_{1,3}$ = 25,427,500	$U_{2,4}$ = 859,363	$U_{1,3}$ = 1,265,000
$U_{2,9}$ = 1,592,137	$U_{4,1}$ = 785,363	$U_{3,5}$ = 411,213
$U_{3,6}$ = 930,861	$U_{6,2}$ = 1,250,363	$U_{3,6}$ = 3,611,792

Table 5.13 Continued

$U_{4,9}$ = 1,236,240	$U_{6,3}$ = 48,000	$U_{1,3}$ = 1,265,000
$U_{5,6}$ = 2,026,978	$U_{6,9}$ = 54,000	$U_{3,5}$ = 411,213
$U_{6,9}$ = 2,437,119	$U_{7,8}$ = 286,988	$U_{3,6}$ = 3,611,792
$U_{8,6}$ = 6,280,667	$U_{8,6}$ = 1,362,363	$U_{4,7}$ = 124,282
$U_{9,1}$ = 28,271,501		$U_{8,3}$ = 2,644,443
$U_{9,7}$ = 707,000		$U_{8,4}$ = 156,133
		$U_{9,8}$ = 4,157,000
COTTON	SUGAR CANE	FRUITS
$U_{1,4}$ = 23,000	$U_{1,6}$ = 1,655,000	$U_{2,3}$ = 685,000
$U_{1,8}$ = 467,215	$U_{1,7}$ = 8,212,953	$U_{3,4}$ = 96,400
$U_{3,2}$ = 348,850	$U_{3,9}$ = 2,283,046	$U_{4,1}$ = 46,800
$U_{6,3}$ = 331,950	$U_{7,9}$ = 8,202,953	$U_{4,7}$ = 23,000
$U_{6,5}$ = 38,000	$U_{9,2}$ = 145,000	$U_{6,2}$ = 1,171,000
$U_{8,6}$ = 308,850	$U_{9,4}$ = 50,000	$U_{6,9}$ = 54,000
$U_{8,9}$ = 21,000	$U_{9,5}$ = 50,000	$U_{8,5}$ = 23,600
	$U_{9,8}$ = 10,591,000	$U_{8,6}$ = 1,106,400

Table 5.14 Employment Goal Achievement

Region	10^6 man-day		Proportion
	Target	Deviation	
I	175	16	-9%
II	950	825	-86%
III	560	490	-87%
IV	175	152	-86%
V	950	920	-96%
VI	852	692	-81%
VII	224	190	-84%
VIII	896	800	-89%
IX	56	34	-60%

5.3 Conclusion

Our formulation of the Egyptian model permitted us to measure the effects that reallocation of crops among regions would have on the entire sector through its demand on employment targets.

It is found that substantial differences occur for the allocation of resources if the Egyptian agriculture fixes its target to meet all its population needs and minimize its foreign deficit.

Further solutions through the sensitivity of the weights associated with the deviations from goals will help identify several alternative plans.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, general conclusions regarding the methodological and empirical results of this study will be presented together with directions for further research in the area of regional allocation planning in the agricultural sector.

6.1 Conclusion

In this study we have formulated a mathematical model for regional crop allocation that takes into account the important aspects of both technical and economical aspects of crop production. In the first case, different levels of input and output have been specified for each activity. In addition, explicit crop interdependencies have been formulated to account for rotational requirements. Even though data limitations affect one's ability to include as many resource constraints as can be found in reality, this model has included the ones which are most likely to have a greater impact on the optimal regional mix, thus relaxing the usual assumption of fixed proportions in the production of each crop. In the second case, economic aspects were introduced through differences in the production function within each region and the inclusion of several objectives.

In this model, goal programming has been adapted for the first time, to regional analysis. This approach was necessitated by the fact that it is impossible to isolate a unique and clearly defined objective function.

The formulation has revealed that important differences in the model results can occur relative to conventional linear programming. For instance, the total specialization between the regions indicated by linear programming solution has not been confirmed by our approach, and that is explained by the fact that the specification of the demand and foreign deficit goals force the regions into using their internal resources efficiently before accepting the usual international specialization. For example, a maximum return linear program would allocate more land to cotton in the Egyptian model because it is highly profitable, about three times more than wheat, but population nutrition and employment targets would be sacrificed. This point is important because profit maximization models lead to maximization of "economic welfare" which refers only to efficiency through maximum social product, and does not consider income distribution. Since the majority of the population in developing economies depends on agriculture for its income, some consideration of income distribution is importatn, which makes the problem of employment essential.

Mathematical programming techniques are usually considered normative, but the results of both the Algerian and Egyptian models have confirmed many of the actual practices even though calling for some major resource reallocation. The trade-off, however, is the design of appropriate and accurate weighting factors. We found the choice of the weights as penalties to be incurred if a deviation from a set goal is indicated to be a realistic and conclusive procedure. Also, much more flexibility can be given to the method by generating several alternative solutions and leave it to the decision maker to make a choice based on the importance attributed to each goal.

The implementation of the results of the model have to come through economic incentives and pricing policies because individual farmers behave according to their expected immediate returns while the model has the scope of decision making in the entire agricultural sector. Information not only on sequences of crops and their location, but also on transportation capacities, amounts of technology, and technical assistance can be of valuable use to the planner.

It is our feeling that this approach can be very useful. Thus an investigation of ways to improve the model seems appropriate.

6.2 Recommendations for Further Research

The model developed in this thesis was of a short-term duration. The inclusion of rotations over longer periods of time introduces a dynamic character into the model which needs to be investigated further through multi-period goal programs for the agricultural sector. Moreover, even though we introduced the weather effect indirectly through partitioning the area under consideration into different homogeneous regions, and through different irrigation systems, bias is introduced by using single-valued yield coefficients, which represent average yield response. An investigation of the possibility of using response coefficients that reflect the impact of weather and technology on crop yield would be an interesting feature to add to the model, especially since this concept has not received any adequate treatment in the literature.

Other possibilities would be offered by introducing a demand function for the private part of the agricultural sector, testing the flexibility of the rotational constraints, and introducing land classes with different rotations associated with each.

In addition, a formulation of the goal program with different priority structures reflecting aggregate utility functions would be an interesting and very useful aspect.

Finally, the differences in interpretation of the results of sensitivity analysis between linear and goal programming makes the necessity of formulating and interpreting the dual goal program another interesting feature.

APPENDIX A

Summary of the Model

1) Notations

i) Variables

Symbols	Description	Unit	Subscripts
$XDF1_{s,c,j}$	Continuous crop on dry land at fertilizer level 1.	acre	j: region
$XDF2_{s,c,j}$	Continuous crop on dry land at fertilizer level 2.	"	s: sector
$XIF1_{s,c,j}$	Continuous crop on irrigated land at fertilizer level 1.	"	c: continuous crop
$XIF2_{s,c,j}$	Continous crop on irrigated land at fertilizer level 2.	"	
$YLFI_{s,i,j}$	Rotation crop at low irrigation and fertilizer 1.	"	i: exogenous rotation
$YLF2_{s,i,j}$	Rotation crop at low irrigation and fertilizer 2.	"	
$YHF1_{s,i,j}$	Rotaiton crop at high irrigation and fertilizer 1.	"	k: endogenous rotations and "free" crops
$YHF2_{s,i,j}$	Rotaiton crop at high irrigation and fertilizer 2.		
$ZLF1_{s,k,j}$	Other crops-sequenced or free at low irrigation and fertilizer 1.	"	o: permanent crop
$ZLF2_{s,k,j}$	Other crops-sequenced or free at low irrigation and fertilizer 2.	"	b: pasture types
$ZHF1_{s,k,j}$	Other crops-sequenced or free at high irrigation and fertilizer 1.	"	a: livestock type
$ZHF2_{s,k,j}$	Other crops-sequenced or free at high irrigation and fertilizer 2.	"	v: fertilizer type
$SLF1_{s,o,j}$	Permanent crop at low irrigation and fertilizer 1.	"	e: equipment type
$SLF2_{s,o,j}$	Permanent crop at low irrigation and fertilizer 2.	"	Φ: commodity type
$SHF1_{s,o,j}$	Permanent crop at high irrigation and fertilizer 1.	"	t: period (season)
$SHF2_{s,o,j}$	Permanent crop at high irrigation and fertilizer 2.	"	( )={c,b,i,k,o}
$PDF1_{s,b,j}$	Dry pasture at fertilizer 1	"	(·)={v,e,Φ}
$PDF2_{s,b,j}$	Dry pasture at fertilizer 2.		

Symbols	Description	Unit	Subscripts
$PIF1_{s,b,j}$	Irrigated pasutre at fertilizer 1.	acre	
$PIF2_{s,b,j}$	Irrigated pasture at fertilizer 2.	"	
$L_{s,a,j}$	Livestock activity	beast	
$F_{v,j}$	Fertilizer activity	metric ton	
$M_{e,j}$	Equipment activity	unit	
$U_{\Phi,j}$	Commodity transportation activity	metric tons	
$J_{\Phi,j}$	Production activity included in demand matrix.	"	
$N_{1,j}$	Underachievement of goal labor	man-days	
$P_{1,j}$	Overachievement of goal labor	"	
N_2	Underachievement of meat goal	m-tons	
P_2	Overachievement of meat goal	"	
N_3	Underachievement of milk goal	litre	
P_3	Overachievement of milk goal	"	
N_4	Underachievement of hard currency expenditures goal	$	
P_4	Overachievement of hard currency expenditures goal	$	
$I_{\Phi j}$	Underachievement of demand goal for product Φ	M-tons	
$E_{\Phi j}$	Overachievement of demand goal for product Φ	m-tons	

ii) Resources

Symbols	Description	Unit	Subscripts
LD_j	Dry land	acre	
LI_j	Irrigated land	"	
LP_j	Permanent crop land	"	
W_j^t	Water available in period t.	cubic meters	
HO_j	Ordinary labor	man-days	
HS_j	Skilled labor	"	

Symbol	Description	Unit	Subscript
$D_{\Phi j}$	Demand of product Φ	m-tons	
D_m	Meat demand	"	
D_d	Milk demand	litres	
$\overline{K}_1$	Short term capital available	$	
D_o	Hard currency available for foreign expenditures	$	

iii) Parameters

Symbol	Description	Unit	Subscript
$\alpha_{(\ )j}$	Per unit fertilizer input	m-tons	
$\alpha_{s,a,j}$	Per unit of livestock contribution to fertiler balance	"	
$\beta_{(\ )j}$	Per unit of crop contribution to pasture balance	"	
$\beta_{s,a,j}$	Per unit of livestock pasture requirement	"	
$\omega_{(\ )j}$	Net per unit of crop water requirement	Cubic meters	
$\omega_{s,a,j}$	Per unit of livestock water requirement	"	
θ_j^t	Coefficient of system irrigation efficiency in period t	%	
$\varepsilon_{(\ )j}$	Per unit of crop machinery requirement	days/yr.	
$\varepsilon_{s,a,j}$	Capacity of machinery type e	"	
$\lambda_{(\ )j}$	Per unit of crop ordinary labor requirement	man-days	
$\lambda_{s,a,j}$	Per unit of livestock ordinary labor requirement	"	
$\mu_{\Phi j}$	Yield of crop Φ per acre requirement	M-tons	
$\xi_{s,a,j}^{\Phi}$	Per unit of livestock requirement of crop Φ	"	
$\eta_{s,a,j}$	Per unit of livestock meat production adjusted	"	
$\delta_{1,\Phi,j}$	Capital requirement per crop Φ for the private sector	$	
$\tau_{(\cdot)j}$	Hard currency expenses incurred by activity (·)	$	

Symbol	Description	Unit	Subscript
$w_{(\ )}$	Weighting factors of different goals		
$\psi_{(\ )j}$	Skilled labor requirement per unit of crop	man-days	
$\psi_{s,a,j}$	Skilled labor requirement per unit of livestock	"	
$\sigma_{s,a,j}$	Per unit livestock a milk production	litres	
$t^{\Phi}_{ij'}$	Transportation cost per unit of commodity Φ from region j to region j'	metric-tons	
$q_{(\ )}$	Per unit production cost	$	
$q^*_{(\ )}$	Per unit importation cost.	$	

2) THE MODEL

MINIMIZE $U_1\ \{W_{\Phi,j}\ I_{\Phi,j}\} + U_2\ \{W_{1,j}\ N_{1j}\} + U_3\ \{W_2 N_2\} +$

$U_4\ \{W_3 N_3\} + U_5\ \{W_4 P_4\}$

Subject to:

a) Regional Constraints

i) Land (Dry)

$$\sum_{c=1}^{C}\sum_{s=1}^{2} XDF1_{s,c,j} + \sum_{c=1}^{C}\sum_{s=1}^{2} XDF2_{s,c,j} + \sum_{b=1}^{B}\sum_{s=1}^{2} PDF1_{s,b,j} + \sum_{b=1}^{B}\sum_{s=1}^{2} PDF2_{s,b,j}$$

$$\leq LDj$$

ii) Land (Irrigated)

$$\sum_{c=1}^{C}\sum_{s=1}^{2}(XIF1_{s,c,j} + XIF2_{s,c,j}) + \sum_{b=1}^{B}\sum_{s=1}^{2}(PIF1_{s,b,j} + PIF2_{s,b,j}) +$$

$$\sum_{i=1}^{R}\sum_{s=1}^{2}(YLF1_{s,i,j} + YHF1_{s,i,j} + YLF2_{s,i,j} + YHF2_{s,i,j}) +$$

$$\sum_{k=1}^{K}\sum_{s=1}^{2}(ZLF1_{s,k,j} + ZHF1_{s,k,j} + ZLF2_{s,k,j} + ZHF2_{s,k,j}) +$$

$$\sum_{o=1}^{N}\sum_{s=1}^{2}(SLF1_{s,o,j} + SHF1_{s,o,j} + SLF2_{s,o,j} + SHF2_{s,o,j}) +$$

$$A_j Z_{k^*j} \le 0 \qquad\qquad k^* = 1,\ldots,K^*;\ K^* \subseteq K$$

$$\sum_{o=1}^{N} \sum_{s=1}^{2} (SLF1_{s,o,j} + SHF1_{s,o,j} + SLF2_{s,o,j} + SHF2_{s,o,j}) \le LPj$$

iii) Fertilizer Balance (For Each $v = 1,\ldots,V$)

$$\sum_{c=1}^{C} \sum_{s=1}^{2} (\alpha_{s,c,j}\ XDF1_{s,c,j} + \alpha_{s,c,j}\ XDF2_{s,c,j} + \alpha_{s,c,j}\ XIF1_{s,c,j} +$$

$$\alpha_{s,c,j}\ XIF2_{s,c,j}) + \sum_{b=1}^{B} \sum_{s=1}^{2} (\alpha_{s,b,j}\ PDF1_{s,b,j} + \alpha_{s,b,j}\ PDF2_{s^*,b,j} +$$

$$\alpha_{s,b,j}\ PIF1_{s,b,j} + \alpha_{s,b,j}\ PIF2_{s,b,j}) + \sum_{i=1}^{R} \sum_{s=1}^{2} (\alpha_{s,i,j}\ YLF1_{s,i,j} +$$

$$\alpha_{s,i,j}\ YHF1_{s,i,j} + \alpha_{s,i,j}\ YLF2_{s,i,j} + \alpha_{s,i,j}\ YHF2_{s,i,j}) +$$

$$\sum_{k=1}^{K} \sum_{s=1}^{2} (\alpha_{s,k,j}\ ZLF1_{s,k,j} + \alpha_{s,i,j}\ ZHF1_{s,k,j} + \alpha_{s,k,j}\ ZLF2_{s,k,j}) +$$

$$\alpha_{s,k,j}\ ZHF2_{s,k,j}) + \sum_{o=1}^{N} \sum_{s=1}^{2} (\alpha_{s,o,j} + SLF1_{s,o,j} + \alpha_{s,o,j}\ SHF1_{s,o,j} +$$

$$\alpha_{s,o,j}\ SLF2_{s,o,j} + \alpha_{s,o,j}\ SHF2_{s,o,j}) - \sum_{s=1}^{2} \alpha_{s,a,j}\ L_{s,a,j} - F_{v,j} = 0$$

iv) Pasture Balance (For Each $b = 1,\ldots,B$)

$$\sum_{s=1}^{2} (\mu_{s,b,j}\ PDF1_{s,b,j} + \mu_{s,b,j}\ PDF2_{s,b,j} + \mu_{s,b,j}\ PIF1_{s,b,j} + \mu_{s,b,j}\ PIF2_{s,b,j})$$

$$+ \sum_{c=1}^{C} \sum_{s=1}^{2} (\beta_{s,c,j}\ XDF1_{s,c,j} + \beta_{s,c,j}\ XDF2_{s,c,j} + \beta_{s,c,j}\ XIF1_{s,c,j} +$$

$$\beta_{s,c,j}\ XIF2_{s,c,j}) + \sum_{i=1}^{R} \sum_{s=1}^{2} (\beta_{s,i,j}\ YLF1_{s,i,j} + \beta_{s,i,j}\ YHF1_{s,i,j} +$$

$$\beta_{s,i,j}\ YLF2_{s,i,j} + \beta_{s,i,j}\ YHF2_{s,i,j}) + \sum_{k=1}^{K} \sum_{s=1}^{2} (\beta_{s,k,j}\ ZLF1_{s,k,j} +$$

$$\beta_{s,k,j}\ ZHF1_{s,k,j} + \beta_{s,k,j}\ ZLF2_{s,k,j} + \beta_{s,k,j}\ ZHF2_{s,k,j}) +$$

$$\sum_{o=1}^{N} \sum_{s=1}^{2} (\beta_{s,o,j}\ SLF1_{s,o,j} + \beta_{s,o,j}\ SHF1_{s,o,j} + \beta_{s,o,j}\ SLF2_{s,o,j} +$$

$$\beta_{s,o,j}\ SHF2_{s,o,j}) - \sum_{s=1}^{2} \sum_{a=1}^{4} \beta_{s,a,j}\ L_{s,a,j} \geq 0$$

v) Water Constraints (For Each $t = 1,\ldots,T$)

$$\sum_{c=1}^{C} \sum_{s=1}^{2} (w_{s,c,j}\ XDF1_{s,c,j} + w_{s,c,j}\ XDF2_{s,c,j} + w_{s,c,j}\ XIF1_{s,i,j} +$$

$$w_{s,c,j}\ XIF2_{s,c,j}) + \sum_{b=1}^{B} \sum_{s=1}^{2} (w_{s,b,j}\ PDF1_{s,b,j} + w_{s,b,j}\ PDF2_{s,b,j} +$$

$$w_{s,b,j}\ PIF1_{s,b,j} + w_{s,b,j}\ PIF2_{s,b,j}) + \sum_{i=1}^{R} \sum_{s=1}^{2} (w_{s,i,j}\ YLF1_{s,i,j} +$$

$$w_{s,i,j}\ YHF1_{s,i,j} + w_{s,i,j}\ YLF2_{s,i,j} + w_{s,i,j}\ YHF2_{s,i,j}) +$$

$$\sum_{k=1}^{K} \sum_{s=1}^{2} (w_{s,k,j}\ ZLF1_{s,k,j} + ZHF1_{s,k,j} + w_{s,k,j}\ ZLF2_{s,k,j} + w_{s,k,j}\ ZHF2_{s,k,j}) +$$

$$\sum_{o=1}^{N} \sum_{s=1}^{2} (w_{s,o,j}\ SLF1_{s,o,j} + w_{s,o,j}\ SHF1_{s,o,j} + w_{s,o,j}\ SLF2_{s,o,j} +$$

$$w_{s,o,j}\ ZHF2_{s,o,j}) + \sum_{s=1}^{2} \bar{w}_{s,a,j} L_{s,a,j} \leq \Theta_j^t\ W_j^t$$

vi) Machinery Constraints (For Each $e = 1,\ldots,G$)

$$\sum_{c=1}^{C} \sum_{s=1}^{2} (\varepsilon_{s,c,j}\ XDF1_{s,c,j} + \varepsilon_{s,c,j}\ XDF2_{s,c,j} + \varepsilon_{s,c,j}\ XIF1_{s,c,j} +$$

$$\varepsilon_{s,c,j} + XIF2_{s,c,j}) + \sum_{b=1}^{B} \sum_{s=1}^{2} (\varepsilon_{s,b,j}\ PDF1_{s,b,j} + \varepsilon_{s,b,j}\ PDF2_{s,b,j} +$$

$$\varepsilon_{s,c,j} + PIF1_{s,b,j} + \varepsilon_{s,b,j}\ PIF2_{s,b,j}) + \sum_{i=1}^{R}\sum_{s=1}^{2}(\varepsilon_{s,i,j}\ YLF1_{s,i,j} +$$

$$\varepsilon_{s,i,j}\ YHF1_{s,i,j} + \varepsilon_{s,i,j}\ YLF2_{s,i,j} + \varepsilon_{s,i,j}\ YHF2_{s,i,j}) +$$

$$\sum_{k=1}^{K}\sum_{s=1}^{2}(\varepsilon_{s,k,j}\ ZLF1_{s,k,j} + \varepsilon_{s,k,j}\ ZHF1_{s,k,j} + \varepsilon_{s,k,j}\ ZLF2_{s,k,j} +$$

$$\varepsilon_{s,k,j}\ ZHF2_{s,k,j}) + \sum_{o=1}^{N}\sum_{s=1}^{2}(\varepsilon_{s,o,j}\ SLF1_{s,o,j} + \varepsilon_{s,o,j}\ SHF1_{s,o,j} +$$

$$\varepsilon_{s,o,j}\ SLF2_{s,o,j} + \varepsilon_{s,o,j}\ SHF2_{s,o,j}) \leq \varepsilon_{e,j}\ M_{e,j}$$

vii) Labor Constraints - Ordinary Labor

$$\sum_{c-1}^{C}\sum_{s=1}^{2}(\lambda_{s,c,j}\ XDF1 + \ _{s,c,j}\ XDF2_{s,c,j} + \lambda_{s,c,j}\ XIF1_{s,c,j} +$$

$$\lambda_{s,c,j}\ XIF2_{s,c,j}) \sum_{b=1}^{B}\sum_{s=1}^{2}(\lambda_{s,b,j}\ PDF1_{s,b,j} + \lambda_{s,b,j}\ PDF2_{s,b,j} +$$

$$\lambda_{s,c,j}\ PIF1_{s,c,j} + \lambda_{s,c,j}\ PIF2_{s,c,j}) + \sum_{i=1}^{R}\sum_{s=1}^{2}(\lambda_{s,i,j}\ YLF1_{s,i,j} +$$

$$\lambda_{s,i,j}\ YHF1_{s,i,j} + \lambda_{s,i,j}\ YLF2_{s,i,j} + \lambda_{s,i,j}\ YHF2_{s,i,j}) +$$

$$\sum_{k=1}^{K}\sum_{s=1}^{2}(\lambda_{s,k,j}\ ZLF1_{s,k,j} + \lambda_{s,k,j}\ ZHF1_{s,k,j} + \lambda_{s,k,j}\ ZLF2_{s,k,j} +$$

$$\lambda_{s,k,j}\ ZHF2_{s,k,j}) + \sum_{o=1}^{N}\sum_{s=1}^{2}(\lambda_{s,o,j}\ SLF1_{s,o,j} + \lambda_{s,o,j}\ SHF1_{s,o,j} +$$

$$\lambda_{s,o,j}\ SLF2_{s,o,j} + \lambda_{s,o,j}\ SHF2_{s,o,j}) + \sum_{a=1}^{4}\sum_{s=1}^{2}\lambda_{s,a,j}\ L_{s,a,j} + N_{1j} -$$

$$P_{1j} = HO_{j}$$

Skilled Labor

$$\sum_{c=1}^{C} \sum_{s=1}^{2} (\psi_{s,c,j}\ XDF1_{s,c,j} + \psi_{s,c,j}\ XDF2_{s,c,j} + \psi_{s,c,j}\ XIF1_{s,c,j} +$$

$$\psi_{s,c,j}\ XIF2_{s,c,j}) \sum_{b=1}^{B} \sum_{s=1}^{2} (\psi_{s,b,j}\ PDF1_{s,b,j} + \psi_{s,b,j} PDF2_{s,b,j} +$$

$$\psi_{s,b,j}\ PIF1_{s,b,j} + \psi_{s,b,j}\ PIF2_{s,b,j}) + \sum_{i=1}^{R} \sum_{s=1}^{2} (\psi_{s,i,j}\ YLF1_{s,i,j} +$$

$$\psi_{s,i,j}\ YHF1_{s,i,j} + \psi_{s,i,j}\ YHF2_{s,i,j}) + \sum_{k=1}^{K} \sum_{s=1}^{2} (\psi_{s,k,j}\ ZLF1_{s,k,j}$$

$$\psi_{s,k,j}\ ZHF1_{s,k,j} + \psi_{s,k,j}\ ZLF2_{s,k,j} + \psi_{s,k,j}\ ZHF2_{s,k,j}) +$$

$$\sum_{o=1}^{N} \sum_{s=1}^{2} (\psi_{s,o,j}\ SLF1_{s,o,j} + \psi_{s,o,j}\ SHF1_{s,o,j} + \psi_{s,o,j}\ SLF2_{s,o,j} +$$

$$\psi_{s,o,j}\ SHF2_{s,o,j}) + \sum_{a=1}^{4} \sum_{s=1}^{2} \psi_{s,a,j}\ L_{s,a,j} \leq HS_j$$

b) Global Constraints

i) Meat Demand

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{a=1}^{4} \eta_{s,a,j}\ L_{s,a,j} + N_2 - P_2 = D_m$$

ii) Dairy Products Demand

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{a=1}^{4} \sigma_{s,a,j}\ L_{s,a,j} + N_3 - P_3 = D_d$$

iii) Short-Term Capital

$$\sum_{j=1}^{A} \sum_{\Phi} (\delta_{s,\Phi,j}\ J_{s,\Phi,j}) \leq \bar{K}_1$$

iv) Foreign Trade Constraint

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \Big[\sum_{v=1}^{V} \tau_{s,v,j} F_{s,v,j} + \sum_{e=1}^{G} \tau_{s,e,j} E_{s,e,j} + \sum_{\Phi} \tau_{s,\Phi,j} I_{s,\Phi,j}) \Big] +$$

$$N_4 - P_4 = D_o.$$

v) Overall Cost

$$\sum_{j=1}^{A} \sum_{s=1}^{2} (\sum_{\Phi} q_{s,\Phi,j} J_{s,\Phi,j} + \sum_{v=1}^{V} q_{s,v,j} + \sum_{e=1}^{G} q_{s,e,j} + \sum_{\Phi} q^{*}_{s,\Phi} I_{s,\Phi,j})$$

$$\sum_{\substack{j=1 \\ j\neq 1}} \sum_{\substack{j=1 \\ j\neq 1}} \sum_{\Phi} (t^{\Phi}_{jj}, U^{\Phi}_{jj}) + N_5 - P_5 = Q$$

vi) Total Land Available (LT)

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{c=1}^{C} (XDF1_{s,c,j} + XDF2_{s,c,j} + XIF1_{s,c,j} + XIF2_{s,c,j}) +$$

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{b=1}^{B} (PDF1_{s,b,j} + PDF2_{s,b,j} + PIF1_{s,b,j} + PIF2_{s,b,j}) +$$

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{i=1}^{R} (YLF1_{s,i,j} + YHF1_{s,i,j} + YLF2_{s,i,j} + YHF2_{s,i,j}) +$$

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{k=1}^{K} (ZLF1_{s,k,j} + ZHF1_{s,k,j} + ZLF2_{s,k,j} + ZHF2_{s,k,j}) +$$

$$\sum_{j=1}^{A} \sum_{s=1}^{2} \sum_{o=1}^{N} (SLF1_{s,o,j} + SHF1_{s,o,j} + SLF2_{s,o,j} + SHF2_{s,o,j}) \leq LT$$

vii) Nonnegativity Constraints

$XDF1, XDF2, XIF1, XIF2, PDFi, PDF2, PIF1, PIF2, YLF1, YLF2, YHF1, YHF2,$

$ZLF1, ZLF2, ZHF1, ZHF2, SLF1, SLF2, SHF1, SHF2, L_a, F_v, M_e U_{\Phi ij}',$

$J_{\Phi}, N_{s,j}, P_{s,j}, N_2, P_2, N_3, P_3, N_4, P_4, I_{\Phi}, E_{\Phi} \geq 0$

BIBLIOGRAPHY

Heady, O. Earl, W. Candler, "Linear Programming Models," The Iowa State University Press, Ames, Iowa, 1958.

Henderson, James M., "The Utilization of Agricultural Land: A Theoretical and Empirical Inquiry," Review of Economics and Statistics, Vol. 41, No. 3, 242-259, 1959.

Day, Richard H., "Recursive Programming and Production Response," Ph.D. Thesis, Harvard University, 1960.

Charnes, A., W.W. Cooper, "Management Models and Industrial Applications of Linear Programming," Vol. I, II, Wiley, New York: 1961.

Edwards, Clark, "Using Discrete Programming," Agricultural Economic Resource, Vol. XV, No. 2, 1962.

Shaller, William Neill, "A Recursive Programming Analysis of Regional Production Response," University of California, Berkeley, Ph.D. Thesis, 1962.

Hadley, G., "Nonlinear and Dynamic Programming," Addison Wesley Publishing Company, 1964.

Randhawa, N.S., E.O. Heady, "An Interregional Programming Model for Agricultural Planning in India," Journal of Farm Economics, Vol. 46, 584-605, 1964.

Seagraves, J.A., "Forcing Integer Solutions in Programming Applications," Proceedings of SFMRC Meeting: Farm Foundation in New Orleans, 1964.

Takayama, T., G.C. Judge, "An Interregional Activity Analysis Model for the Agricultural Sector," Journal of Farm Economics, Vol. 46, 349-365, 1964.

Takayama, T., G.C. Judge, "Spatial Equilibrium and Quadratic Programming," Journal of Farm Economics, Vol. 46, 67-93, 1964.

Hopper, W.D., "Allocation Efficiency in a Traditional Indian Agriculture," Journal of Farm Economics, Vol. 47, 611-624, 1965.

Wittlesley, N.K.M.D. Skold, "Production Quotas and Land Value: Importance of the Dual in Spatial Linear Programming Problems," Journal of Farm Economics, Vol. 47, 993-998, 1965.

Zusman, Rinhas, Amiad Amotz, "Simulation: A Tool for Farm Planning Under Conditions of Weather Uncertainty," Journal of Farm Economics, Vol, 47(3), 574-595, 1965.

Stovall, J.G., "Sources of Error in Aggregate Supply Estimates," Journal of Farm Economics, Vol. 48, 477-480, 1966.

Folkesson, L., "A Linear Programming Analysis of the Agricultural Sector in Sweden," Uppsala Ann, Vol. 34(4), 391-435, 1968.

Gee, C. Kerry, John A. Edwards, "Predicting Farm Organizations with Maximum Profit Linear Programming Models," Special Report No. 260, Agriculture Experiment Station, Oregon State University, Corvallis, 1968.

Larson, A.B., H.C. Hogg, "An Iterative Procedure for Estimating Patterns of Agricultural Land Use," Agricultural Economic Resources, Vol. 20., No.1, 1968.

Rhodes, Doll West, "Economics of Agricultural Production, Markets, and Policies," Irwin: ed., 1968.

Samota, G.S., "Efficiency of Resources Allocation in Indian Agriculture," American Journal of Agricultural Economics, Vol. 50, 584-604, 1968.

Campus, Francesco, "Linear Programming in Agriculture, Theoretical and Practical Problems," Roma, Institute Nazionale di Economia Agraria, 1968.

Carlsson, M., B. Hovmark, L. Linderen, "A Monte Carlo Method Study of Farm Planning Problems," Review Market of Agricultural Economics, Vol. 37(2), 8-103, 1969.

Day, R.H., "More on the Aggregation Problem" Some Suggestions," American Journal of Agricultural Economics, Vol. 51, 673-675, 1969.

Hardies, I.W., "Sahow Prices as Member Returns for a Marketing Cooperative," American Journal of Agricultural Economics, Vol. 51, 818-833, 1969.

Salavery, Jose, A., "An International Linear Programming Model for The Analysis of Agricultural Development in Policies in Peru," Thesis, The Iowa State University, 1969.

Yaztenco, R.C., "More Effective Allocation of Resources by Linear Programming," Philippine Lumberman, Vol. 15(1), 94-103, 1969.

Badewitz, S., "Parametric Linear Programming in Agriculture," Biometrische Zeitschrift, Vol. 11, No. 5, 339-335, 1970.

Balika, S.S. Somogyi, "Applicability of Linear Programming in Large Scale Agriculture," Allattenyesztes, Vol. 19(3), 131-184, 1970.

Borkon, Elaine, James N. Boles, "The 1130 Multiple Linear Regression Systems," California Agriculture Experiment Station, Berkeley, 1970.

Hogg, H.C., A.B. Larson, "An Iterative Linear Programming Procedure for Estimating Patterns of Agricultural Land Use," Agricultural Economic Resource, 1970.

Huffman, D.C., L.A. Staton, "Application of Linear Programming to Individual Farm Planning," American Journal of Agricultural Economics, Vol. 52, 1168-1171, 1970.

Kurlypo, M.F., V.A. Liapina, E.N. Pekmota, "Application of Network Planning and Linear Programming for Operative Management of Agricultural Production," Institute Ekon Organ sel Propzvod Nanch Tr, Vol. 3, 212-220, 1970.

Lupertiz, A.R., "Linear Programming in Agricultural Restructures," Italian Gezz Vet, Vol. 11 (7/8), 4-5, 7-8, 1970.

Beyyoun, R., et. al., "Linear Programming with Multiple Objective Functions," Mathematical Programming, Vol. 1, no. 3, 366-375, 1971.

Olsson, R., "A Multiperiod Linear Programming Model for Studies of the Agricultural Firm," Swedish Journal of Agricultural Economics, Vol. 1(3), 139-177, 1971.

Reish, E.M., "Recent Advances in Farm Planning in Europe and North America," In Papers and Reports, 14th International Conference of Agricultrual Economists, 199-217, 1971.

Thuesen, H.G., W.J. Fabrycky, G.J. Thuesen, Engineering Economy, 4th Edition, Prentice-Hall, 1971.

Agrawal, R.C., E.O. Heady, "Operations Research Methods in Agricultural Decisions," The Iowa State University Press, 1972.

Andrews, D.H., R.R. Weyrick, "An Application of Linear Programming to Water Resources Planning." Agricultural Experiment Station Bulletin 500, 1972.

Chew, T.A., "The Use of Linear Programming in Formulating Policy Decisions, Agriculture," Malaya Agricultural Resource, Vol. 1(1) 63-67, 1972.

Eyvindson, Roger K., "The Use of Linear Programming in National Models of Agriculture," Canadian Dept. Agricultural Publication, Vol. 72/9, 66-85, 1972.

Just, Richard E., "Econometric Analysis of Production Decisions with Government Intervention: The Case of California Field Crops," University of California at Berkeley, Ph.D. Thesis, 1972.

Lee, George, E., "The Use of Linear Programming in National Models of Agriculture and a Recursive Programming Model of Canadian Agricultural Decisions," Canadian Department of Agricultural Publications, Vol. 72/9, 101-109, 1972.

Olsson, R., "A Multi-period Linear Programming Model for Studies of the Growth Problems of the Agricultural Firm," Swedish Journal of Agricultural Economics, Vol. 2(3), 137-173, 1972.

Scott, Jr., J.T., C.T. Chen, "Inclusion of Markov Processes Within Linear Programming Models to Control Resource Transfer," Illinois University, College of Agriculture, Department of Agricultural Economics, 1972.

Acsay, F., "Utilization of Linear Programming for Complex Planning of Field Crop Production, Machine Use, and Equipment Requirement," Budapest, Mezogazdasagi Gepkisezleti Intezet, No. 5, 1973.

Barnard, C.S., J.S. Nix, "Farm Planning and Control," University of Cambridge Press, 1973.

Beneke, R.R., R. Winterboer,"Linear Programming Applications to Agriculture," The Iowa State University Press, 1973.

Binter, J., "Application of Multiperiodical Linear Programming Method for Medium-Term Planning of the Agricultural Enterprise," Gaz Dalkopas, Vol. 18(2), 17-26, 1973.

Burnham, B.O., "Markov Intertemporal Land Use Simulation Model," South Journal of Agricultural Economics, Vol.5, 253-258, 1973.

Cander, W.W., J. B. Penn, "The Substitution of Analytic for Simulation Algorithm: A Comment," American Journal of Agricultural Economics, Vol. 54(2), 235-239, 1973.

De La Garza, G.F., A.S. Manne, J.A. Valentica, "Multi-Level Planning for Electric Power Projects," Multi-Level Planning: Case Studies in Mexico, Editor: Goreaux, L.M. and A.S. Manne, Amsterdam, 1973

Duloy, J.H., R.D. Norton, "CHAC, A Programming Model of Mexican Agriculture," in Multi-Level Planning: Case Studies in Mexico, Editor: Goreaux, L.M., A.S. Manne, Amsterdam, 1973.

Engler, J.C., R.L. Meyer, "Wheat: Production Prices and Productivity," Pes. Plan. Economics, Vol. 3(2), 341368, 1973.

Heady, E.O., L.D. Loftsgard, "Farm Planning for Maximum Profits on the Cresco-Clyde Soils in Northeast Iowa, and Comparison of Farm and Non-Farm Economics for Beginning Farmers: An Application of Linear Programming," Project 1085, Iowa Agricultural Experiment Station, 1972.

Nicol, L.J., E.O. Heady, J.C. Wade, "Mathematical Programming as a Tool in Determining the Economic Implications of Environmental Policy in Agriculture," Proceedings of the Computer Science and Statistics Seventh Annual Symposium of the Interface, Iowa State University, 1973.

Bishay, F.K., "Models for Spatial Agricultural Development Planning," Rotterdam University Press, 1974.

Blau, R.A., "Stochastic Programming and Decisions Analysis: An Apparent Dilemma," Management Science, Vol. 21(3), 271-276, 1974.

Chrysomilides, G.S., "Re-allocation of Resources in Cyprus Agriculture Based on Linear Programming Models with Different Input-Output Coefficients," Oxford Agrarian Studies, Vol. 3(1), 29-49, 1974.

Filho, A.R.T., B.W. Cone, L.M. Eisgruber, "Comparison of Two Alternatives for Increasing Agricultural Production, Use of Fertilizer, and Land Clearing," Brazilian Review of Economics, 28(1), 129 - 149, 1974.

Hazell, P.B.R., P.L. Scandizzo, "Competitive Demand Structures Under Risk in Agricultural Linear Programming Models," American Journal of Agricultural Economics, Vol. 56, 235-244, 1974.

Irwin, George, "A Simplex Linear Programming Method For Handling Some Types of Decreasing Average Cost Problems," Canadian Journal of Agricultural Economics, Vol. 22(2), 40-47, 1974.

Manne, A.S., "Multi-Sector Models for Development Planning: A Survey," Journal of Development Economics, Vol. 1, 1974.

Mellor, J.W., M.S. Medahar, "Simulating a Developing Economy With Modernized Agricultural Sector, Implication for Employment and Economic Growth," Experiment Station Occasional Papers 76, New York State College of Agriculture and Life-Sciences, 1974.

Nicol, L.J., E.O. Heady, J.C.Wade, "Mathematical Programming as a Tool in Determining the Economic Implication s of Environmental Policy in Agriculture," Proceedings of the Computer Science and Statistics Seventh Annual Symposium of the Interface, Iowa State University, 1973.

Sherbiny, N.A., M.Y. Zaki, "Programming for Agricultural Development: The Case of Egypt," American Journal of Agricultural Economics, Vol. 56(1), 114-121, 1974.

Abalu, G.I., "Optimal Investment Decision in Perennial Crop Production, A Dynamic Linear Approach," Journal of Agricultural Economics, Vol. 26(3), 383-393, September, 1975.

Alvin, C.E., M.K. Hyung, "Analysis of Aggregation Errors in Linear Programming Planning Models," American Journal of Agricultural Economics, May, 1975.

Bar, Josef, "A Mathematical Model of a Village Cooperative Based on the Decomposition Principle of Linear Programming," American Journal of Agricultural Economics, 1975.

Bruckman, G. (ed.), "Food and Agricultural Model," Proceedings of the Third IIASA Symposium on Global Modeling," 1975.

Brzoza, A., "Application of Marginal and Linear Programming to Optimization of Fertilizer Allocation," Zagad Ekon Roln, Vol. 3, 21-51, 1975.

Egbert, A.C., H.M. Kim, "Aggregation Errors in Linear Programming Models: Agricultural Sector of Portugal," American Journal of Agricultural Economics, Vol. 57(2), 292-301, May 1975.

Gotsch, C.H., "Linear Programming and Agricultural Policy: Summary and Suggestions for Further Work, Puntjab," Food. Res. Institute Stud. Agricultural Economic Trade Development, Vol. 14(1), 99-105, 1975.

Gotsch, C.H., "Traditional Agriculture in the Pakistan Puntjab: The Basic Model, Linear Programming," Food, Res. Institute Stud. Agricultural Economic Trade Development, Vol. 14(1), 7-25, 1975.

Heady, E.O., U.K. Srivastava, "Spatial Sector Programming Models in Agriculture," Iowa State University Press, 1975.

House, Robert M., "A Methodology for Agricultural Sector Analysis," U.S. Department of Agricultural Economy Res. Serv. Foreign Development Division, 1975.

King, G.A., "Econometric Models for the Agricultural Sector," American Journal of Agricultural Economics, 164-171, May, 1975.

Kondakov, E.P., "Expansion of Tasks of Linear Programming at Several Levels in Agriculture," Doki Tskha, Vol. 207, 127-121, 1975.

Nautiyal, J.C., "Land Use Planning: A Practical Application of Mixed Integer Programming," INFOR, Vol. 13, No. 1, Feb., 1975

Nicol, K.J., E.O. Heady, "A Model for Regional Agricultural Analysis of Land and Water Use," Iowa State University, 1975.

Simmons, R.L., C. Pomareda, "Equilibrium Quantity and Timing of Mexican Vegetable Exports," American Journal of Agricultural Economics, Vol. 57, 472-479, August, 1975.

Taylor, L., P.S. Clark, C.R. Blitzer, "Economy-Wide Models and Development Planning," Oxford University Press, 1975.

University of New England, Department of Agricultural Economics, "Aggregate Programming Model of Australian Agriculture," APMAA, Report No. 7, 1975.

Andersen, F., P.E. Stryg, "Interregional Recursive Linear Programming Model Used in Forecasting Danish Agricultural Development up to 1985," European Review of Agricultural Economics, Vol. 3(1), 7-21, 1976.

Chen, J.H., "Theoretical Background and Analysis of Agricultural Resources Allocations: Production, Distribution, Consumption," Journal of Agricultural Economics, (Taiwan), Vol. 19, 30-38, 1976.

Hasenhaur, R., "Theoretical Analysis and Empirical Application of Goal Programming with Preemptive Priority Structure," Multiple Criteria Decision Making, Proceedings of a Conference, Jouyen-Josas-France, 1975.

Ericksen, M.H., O. Buller, "Empirical Evaluation of Predictive Linear Programming," U.S. Economic Research Service, Microfilm NTIS, PB 253976/A.S., 1976.

Huang, W-Yi, H.C. Hogg, "Estimating Land Use Patterns: A Separable Programming Approach," Agricultural Economic Research, Vol. 28, No. 1, January, 1976.

Ignizio, J.E., "Goal Programming and Extensions," Lexington Books, 1976.

Jones, R.I., "Simulation Modeling in Agriculture: General Considerations," Proceedings Grassl Soc, South Africa, Vol. 11, 87-90, 1976,

Price, W.L., "An Interactive Objective Function Generator of Goal Programs," Multiple Criteria Decision Making, 147-158, Proceedings of a Conference, Jouyen-Josas-France, 1976.

Singh, I, J., "Book Review," American Journal of Agricultural Economics, 768, November, 1976.

Sirotenko, V.G., "Parametric Modeling of Time Series of Inter-Crop Yields," U.S. Library of Agriculture, Nal. 20.5, N86, 1976.

Trenbach, B.R., "Interactions Among Diverse Hosts and Diverse Parasites," Annals of the New York Academy of Sciences," Vol. 287, April, 1976.

Waggoner, P.E., "Contributions of Mathematical Models to Epidemiology," Annals of the New York Academy of Sciences, Vol. 287, April, 1976.

Walker, N., R. Monypenny, "Linear Programming as a Tool for Agricultural Sector Analysis," Rev. Mark. Agricultural Economics, Vol. 44(4), 165-178, December, 1976.

Wiens, T.B., "Peasant, Risk Aversion and Allocative Behavior: A Quadratic Programming Experiment," American Journal of Agricultural Economics, Vol. 58, 629-635, November, 1976.

Williams, R.J., D.E. Ray, "An Improved Land Classification System for Spatial Linear Programming Models," Southern Journal of Agricultural Economics, Vol. 8(2), 51-55, Dec., 1976.

Adams, R.M., G.A. King, W.E. Johnston, "Effects of Energy Cost Increases and Regional Allocation Policies on Agricultural Production," American Journal of Agricultural Economics, Vol. 59, 444-455, 1977.

Andrews, John, "Economic Benefits of Improved Information on World Wide Crop Production," NASA Office of Applications, 1977.

Bazaraa, M.S., J.J. Jarvis, Linear Programming and Network Flows, Wiley, New York, 1977.

Candler, W.V. et al, "Experiences with Farm Oriented Linear Programming for Crop Planning," Canadian Journal of Agricultural Economics, Vol. 25(1), 1977.

Drummond, H.E., "Predicting Changes in Land-Use Patterns Resulting From Water Resource Investments Using a Non-Stationary Markov Process," Office of Water Research and Technology, Microfilm PB 269-409, 1977.

Fuller, S.W., "A Review of Spatial Equilibrium Models of the Crop Sector," Texas Agricultural Experiment Station, 77-1, 1977.

Garrod, P.V., M.M. Aslam, "Models for Agricultural Production: Methods and Considerations," Research Bulletin, Hawaii Experiment Station, 159, 1977.

Grooms, D.W., "Economic Models," Volume 3, United States Government Report A (5GRA), Microfilm 77(15), NTIS/PS-77/0407/5SL, 1977.

McCarl, Bruce A., "Degeneracy, Duality, and Shadow Prices in Linear Programming," Canadian Journal of Agricultural Economics, Vol. 25(1), 1977.

McGregor, A., "Rent Extraction and the Survival of the Agricultural Production Cooperative," American Journal of Agricultural Economics, Vol. 59(3), 478-488, 1977.

Olson, K.D., A. D. Meister, E.O. Heady, C.C. Chen, "Estimating Impacts of Two Environmental Alternatives in Agriculture: A Quadratic Programming Analysis," Iowa State University, CARD Report 72, 1977.

Pariente, Silvia, "Optimization Models For Planning Economic Development," Massachusetts Institute of Technology, Report No. 130, April, 1977.

Pugh, C.L., "A Note on a Model Building Technique for Agricultural and Business Systems," Journal of Agricultural Economics, Vol. 28 (28), 173-175, 1977.

Rae, Allan A., "Crop Management Economics," St. Martin's Press, New York, 1977.

Roop, J.M., R.H. Zeitner, "Agricultural Activity and the General Economy: Some Macro Model Experiments," American Journal of Agricultural Economics, Vol. 59(1), 117-125, 1977.

Rose, C.W., "An Overview of Agricultural Modeling," Applications in Agricultural Modeling, Refresher Training Workshop, 14-22, 1977.

Shumay, C.R., A.A. Change, "Linear Programming Versus Positively Estimated Supply Functions: An Empirical and Methodological Critique," American Journal of Agricultural Economics, Vol. 59(2), 344-357, 1977.

Tanji, K.K., M. Fried, R.M. Van de Pol, "A Steady Sate Conceptual Nitrogen Model for Estimating Nitrogen Emissions from Cropped Lands," Journal of Environmental Quality, Vol. 6(2), 1955-1959, 1977.

Taylor, C.A., "Two National Equilibrium Models of Crop Products," Agricultural Experiment Station, University of Illinois, 1977.

Tsuboi, N., "Israeli Moshave Cooperative Farming: One of the Models for Agricultural Development," IAEA Occasional Papers Series (AJIA KEIZAI), Vol. 18(4), 2-23, 1977.

Vries, F., "Evaluation of Simulation Models in Agriculture and Biology: Conclusion of a Workshop," Agricultural Systems, Vol. 2(2), 99-107, 1977.

Waggoner, P.E., "Simulation Modeling of Plant Physiological Processes to Predict Crop Yields," Environmental Effects of Crop Physiology, Proceedings of Long Ashton Symposium, 5th, 351-363, 1977.