This is to certify that the

thesis entitled

A LAND BASE GOAL PROGRAMMING APPLICATION TO
NATIONAL AGRICULTURAL SECTOR OBJECTIVES
IN A DEVELOPING COUNTRY

presented by

James Glenn Robb

has been accepted towards fulfillment
of the requirements for

M.S. degree in Agricultural Economics

Carl K. Eicher

Major professor

Date 1/7/83

A LAND BASE GOAL PROGRAMMING APPLICATION TO NATIONAL AGRICULTURAL SECTOR OBJECTIVES IN A DEVELOPING COUNTRY

By

James Glenn Robb

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Economics

1983

ABSTRACT

A LAND BASE GOAL PROGRAMMING APPLICATION
TO NATIONAL AGRICULTURAL SECTOR
OBJECTIVES IN A DEVELOPING COUNTRY

By

James Glenn Robb

Quantifying trade-offs and complementarities between objectives is seen as an important input into decision making. The purpose of this study was to investigate the multiple agricultural sector objectives of Costa Rica and demonstrate a land base programming model. The sector objective functions under study were maximizing export earnings, maximizing labor employment, minimizing costs of production and self-sufficiency in the basic grains.

Secondary data sources were used to develop the set of coefficients used in the model. Six agricultural regions and fifteen cropping activities were included in the analysis.

The goal programming model optimizes by using soft constraints with targets, then minimizes weighted deviations between them. This approach is analogous to minimizing disutility (weighted underachievement). For objective functions stated in terms of maximize or minimize targets were generated by using standard linear programming on each function independently. For self-sufficiency in the basic grains 1985 demand projections were used as targets. Trade-offs between objective functions were

developed by analysis of various weightings and sensitivity analysis resulting in representative solutions depicting points on the efficient set. End points of the trade-off set are original goal programming targets.

Major trade-offs were apparent between regional cropping activities compared to the base year, between relative weightings of objective functions, and between short and medium-run planning horizons.

ACKNOWLEDGMENTS

For their assistance, I wish to thank the members of my guidance committee: Carl Eicher, Stephen Harsh and Peter Schmidt. I also gratefully acknowledge the guidance provided by my assistantship supervisor James Johnson. Special thanks are due to Weldon Lodwick who provided countless hours of computer assistance and Mark Cochran who provided data gathering and insight. Thanks to Sue Perkins for her typing and patience.

This thesis is dedicated to Dad, Mom, Tom and Charles.

TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF FIGURES	vii
Chapter	
1. Introduction	1
Problem Setting	1
Objectives of Study	4
Organization of Thesis	5
2. Conceptual Base and Approaches to Multiple Objective Analysis	6
Terminology	6
Conceptual Base	7
Traditional Approaches	10
Multiple Objective Optimization	14
Linear Multiobjective Programming Approaches	21
3. An Overview of Costa Rican Agricultural Sector Objectives	31
The Agricultural Sector	31
Sector Objectives	33
National Sector Planning	40
4. A Land Base Regional Model	42
Introduction	42
Comparative Advantage	42
Regional Specification of the Model	47
Data Base	50
Implications of Regions and Data	57
5. Model Structure, Coefficients, Assumptions and Limitations	59
Introduction	59
Model Structure	59
Model Assumptions, Limitations and Usefulness	74
6. Results of Analysis	79
Introduction	79
Short-Run Results	80
Medium-Run Model Results	94
Conflicts Between Time Horizons	104

Page

Partial Opportunity Costs of Sector Objectives 108
Some Implications: Magnitude of Change for Basic Grains, Self-Sufficiency and Labor Employment 108

7. Summary and Conclusions 112
Review of Problem and Objectives 112
Review of Analytical Model 113
Summary of Results 114
Additional Useful Research 117

APPENDIX A:
Example of GP Model Output: Medium Run Weights 100, 100, 10, 1000 (Model V) 119

BIBLIOGRAPHY 133

LIST OF TABLES

TABLE		Page
3.1	Number of Poor Farms, Non-Poor Farms and Percent of Farms Which are Poor by Farm Size	32
3.2	Projection of Possible Labor Force	36
3.3	1975/76 Imports of Basic Grains and Imports as a Percent of Total Consumption	37
3.4	Demand for Basic Grains: Actual 1975, Projected 1985 and Percent Increase Required	38
4.4	1973 National Crop Production From Central Bank, Census of Aggregate (Crop Specific Association) Data	51
5.1	Codes Used by Crops	62
5.2	Codes Used by Region	62
5.3	Objective Function and Goal Constraint Right-Hand-Sides for Short-Run and Long-Run Models	62
5.4	Current Cultivable Area by Region in Hectares	65
5.5	National Requirements in Metric Tons	66
5.6	Labor Employment ($LABOR_{ij}$) Per Hectare For Regions by Crop	69
5.7	Information on Exports and Internal Consumption for Coffee	70
5.8	Information on Exports and Internal Consumption for Bananas	70
5.9	Information on Exports and Internal Consumption for Sugar-Cane	71
5.10	Information on Exports and Internal Consumption for Cocoa	71
5.11	Information on Exports and Internal Consumption for Cocoa	72

TABLE		Page
5.12	Adjusted Annual Yields Per Hectare Reflecting Double Cropped Production	72
5.13	Crop Yields Per Hectare by Region in Metric Tons	73
5.14	Crop Costs of Production by Region in Colones	74
6.1	National and Regional Values of Objective Functions for Short-Run Models	90
6.2	Medium-Run Natural Results as Percent of Short-Run	101
6.3	Medium-Run	102
6.4	Short-Run Opportunity Cost of Non-Perfect Competition Formulation	109
6.5	Medium-Run Opportunity Cost of Non-Perfect Competition Formulation	109

LIST OF FIGURES

FIGURE		Page
2.1	Two Objective Function Depiction of Efficient Frontier and Specified Preference Function	15
2.2	NISE Estimation Technique	20
4.1	Absolute Advantage in Each Region	45
4.2	Comparative Advantage	45
4.3	Linear Production Possibility	46
4.4	Agricultural Regions of Costa Rica	48
5.1	Depiction of Model	61
6.1	Agricultural Regions of Costa Rica	81
6.2	Short-Run: Maximize Labor (Model I) Production Patterns	83
6.3	Short-Run: Maximize Export Earnings (Model II) Production Patterns	84
6.4	Short-Run: Minimize Cost (Model III) Production Patterns	85
6.5	Short-Run: Equal Weights (Model IV) Production Patterns	86
6.6	Short-Run: Weights 100, 100, 10, 1000 (Model V) Production Patterns	87
6.7	National Short-Run Results: Value Path Display	89
6.8	Medium Run: Maximize Labor (Model I) Production Patterns	95
6.9	Medium Run: Maximize Export Earnings (Model II) Production Patterns	96
6.10	Medium Run: Minimize Cost (Model III) Production Patterns	97

FIGURE | Page

6.11 Medium Run: Equal Weights (Model IV) Production Patterns 98

6.12 Medium Run: Weights 100, 100, 10, 1000 (Model V) Production Patterns 99

Chapter 1

INTRODUCTION

Problem Setting

Decision making takes place in an environment of limited resources given a specified planning horizon. From an economic perspective decision making is an activity that is directed towards maximizing utility (minimizing disutility). Utility has many components. At the national level utility may include income, security, equity and other specific components. These components of utility may often be conflicting. Resolving these conflicts of trade-offs is a major element of decision making. One of the criticisms of traditional decision theory and analytical tools is that a single economic criterion objective function like maximization of profits does not reflect the multiple components of utility maximization and associated trade-offs. In multiobjective analysis the specific objectives of utility maximization are quantified in their own units of measure; it is not necessary to collapse units like <u>hours</u> of labor, <u>cost</u> of production, <u>yields</u>, etc. into a single objective function.

Sfeir and Bromley (1977, p.179) state: "One of the first steps in improving decision making in developing countries is to introduce explicitly the objective function of the policy makers into our conceptual framework. This is not so difficult as might seem at first blush. Countries have targets, and countries have priorities; this represents a multidimensional objective function." Public specification of weights on objectives is seldom done because it implies who will benefit most. The focus here is not on determining the decision or policy makers (government's) weighting (value) structure but to quantify the decision space representing the trade-offs between objectives. This can be done by using stated agricultural sector economic objectives and optimizing different value structures to estimate the trade-off surface between weighted objectives, thus, *a priori* utility is not determined but implicit utility is one point on the trade-off surface. Another method, would be to interactively let the decision makers change objective weightings looking for a solution. As Zeleney states (1974, p.170) "Priority weights should be a result of the analysis rather than its input."

At the national planning level analyzing trade-offs is seen as an input into the decision making process. Jan De Veer (1971) says that planning is always aimed at the future and involves three elements: formulation of objectives, analysis of possibilities, and determination of a program of action. Trade-offs between objectives is part of analyzing possibilities which may feed back into the formulation of objectives stage.

This study will focus on the usefulness of multiobjective planning in an agricultural resource utilization context with the particular focus on Costa Rica. For Costa Rica implications of objective functions like export earnings, labor employment, cost of production, and self-sufficiency need to be analyzed. The spatial location and regional implications of crop production on sector objectives is one component in analyzing conflicts and "bottle necks". Exports provide money for purchasing products of foreign countries and by taxing them the government generates revenues. Agriculture is a sector increasingly relied on to provide employment. Costs of production are important as they reflect efficiency of production, the country's ability to compete in export markets, and the country's ability to meet food demands at the lowest cost to consumers. Being self-sufficient is a major concern (objective) in Costa Rica. Currently this self-sufficiency objective is a function of the basic grain food crops; corn, beans, and rice.

Time horizon is an important component of analysis. Long run steady states are an important type of analysis but often do not fit into a national decision makers planning horizon while short and medium run analysis apply better to their political environment. Constraints are greater in the short than in medium time frame and this has implications for the cropping pattern and the achievement of the national objectives. Planning trade-offs may occur if short-run planning precludes longer term possibilities. Quantifying these trade-offs in a static sense allows decision makers to compare potential contribution to multiple objective functions between planning horizons. In the short-run tree crop (coffee, banana, etc.) production cannot be increased due to establishment or production lag. Conflicts thus can result between time periods in the spatial production pattern that maximized utility.

Objectives of Study

Maximizing export earnings, maximizing labor employment, minimizing cost of production, and being self-sufficient in the basic grains are agricultural sector economic objectives in Costa Rica. The purpose of this study is to investigate these objectives and their associated trade-offs. More specifically, the objectives of these research were:

1. Study mathematical programming optimization techniques that could be used to quantify conflicts and trade-offs between agricultural planning objectives through the use of a demonstration land base model for the stated agricultural sector objectives in Costa Rica.
2. Analyze the implications and direction of change in crop production patterns between the regions for Costa Rica in both a short and medium term planning horizon.
3. Compare model results of the above-specified model to the traditionally used land base linear programming model with a single objective function specified to minimize production costs.

Organization of Thesis

This thesis is organized in the following manner. Chapter 2 presents the conceptual base and optimization approaches to multiple objective function analysis. Chapter 3 is an overview of the Costa Rican agricultural sector and stated objectives for the sector. The land base approach is modelling and an analysis of secondary data sources available for Costa Rica is presented in Chapter 4. Chapter 5 specifies the multiobjective programming model used including its structure, coefficients, assumptions, and limitations. The results of the multiobjective model are given in Chapter 6. In Chapter 7 the study is summarized and conclusions on the apparent advantages of the multiobjective approach compared to traditional linear programming are presented.

Chapter 2

CONCEPTUAL BASE AND APPROACHES TO MULTIPLE OBJECTIVE ANALYSIS

In this chapter a conceptual base for the multiple objective approach to analysis is presented and a methodology developed. The first section presents terminology followed by sections on: a conceptual view and reason for using a multiple objective format; overview of economic approaches; and, the multiple objective model used in this study.

Terminology

Based on Keeney and Raiffa (1976), an "objective" indicates a direction of preference and an attribute is the units in which the objective is quantified. A "goal" is a specific target that differs from an objective in that it is either achieved or not. "Values" give rise to the ranking or relative importance of objectives and goals. They define preference functions and also the approved or disapproved means of attaining goals. For example, an objective may be to maximize employment with more employment as the direction of preference. This objective could be quantified by the attribute of hours. A goal for this objective might be the employment of 1000 people or 2 million hours.[1]

---

[1](40 hours per week) (50 weeks) (1000 people).

Objective functions which are objectives or goals can be conflicting or complementary with respect to a given set of resources. For example, trying to achieve objectives like "maximize employment" and "minimize cost of production" simultaneously in the agricultural sector would at some point become conflicting, it is required labor to be employed beyond the amount necessary to meet demands for production, but would be complementary within a range as labor is required for production. It is often possible to simultaneously move toward two objectives but at some point furthering one objective can often only be accomplished through diminishing the other objective. Such an occurrence implies "trade-offs". If all objective functions could be maximized simultaneously utility would be maximized.

Conceptual Base

Conceptually, objectives and goals are viewed as having a hierarchical structure because they are specified at various authoritative levels. Many of the direct goals and objectives of policy are not themselves ends, but are only means in a complex means-ends chain. Specification of attributes is often difficult because high level goals like "to become developed" must be further defined at lower levels in terms of attributes like employment, costs, etc. At the national level often both objectives, like maximize employment, and goals, like metric tons of grain production, are specified. When analyzing any decision problem objectives must be clearly identified and attributes must be defined that measure attainment and movement toward goals. Irrelevance of results to the planning situation is a reason often given for the scant use of mathematical model results (see Jan De Veer (1971), Quade (1975), Johnson (1977)). This may be due to the assumptions built into the model and/or lack of appropriate data in both quantity and quality. Not having incorporated the multiple nature of objective functions also can lead to a lack of acceptance by decision makers.

In designing agricultural sector plans no one objective is appropriate. At the national level agriculture not only produces food for consumption but also provides employment, supplies foreign exchange, and interacts with many economic and political objectives. The trade-offs between objectives and the concept of objectives being multiple in nature is often acknowledged but seldom emphasized. The purpose of analyzing objectives and their trade-offs is to clarify the decision space or opportunity set for policy makers. Hitch states, "first it is impossible to define appropriate objectives without knowing a great deal about the feasibility and cost of achieving them. And this knowledge must be derived from the analysis."[2]

Nature of Objectives

Objective functions are part of a dynamic process and constantly are being revised whether explictly stated or not.

---

[2]Cited by Quade (1975, p.87).

Objective functions change as decision makers perceptions of the problems change and as the structure of society changes. Also, the relative weightings of objectives change over time. Presumable the overall weighting of agricultural sector objectives changes as a society becomes more industrialized and urban. How objectives are weighted at any particular level of aggregation depends on the values held by those making decisions which can be influenced by information availability and politics. As the distribution of power to make and influence policy changes the relative weightings of multiple objective functions will change.

Stated Objectives

Political decision makers often state policy in very broad terms. Policy is often stated in terms of very broad objectives rather than in specific targets. The more specifically stated objectives are defined the more apparent it becomes what groups in society will benefit. Specific goals, if not achieved, provide fuel for opposition and delineation of priorities can, especially with economic issues, be politically very naive. From an economic perspective fairly broad objectives, like maximize employment and minimize cost, can be approached by optimization and specific targets can be approached in terms of level of attainment or achievement.

Multiple Decision Makers

National level planning is characterized by multiple decision makers which differs from micro optimization based on a single decision maker's objective function. In any political system that is not perfectly totalitarian, conflict resolution is an important component of policy formulation. Combining multiple objectives with multiple decision makers seems to imply quantification of trade-offs.

A Role of Information

The role of information focused on here is as an input in the decision-making process. By supplying decision-makers with some insight into the economic trade-offs between delineated objective functions they may better be able to evaluate their explicit and undisclosed preference orderings. Assuming this is better information than they possessed before analysis, they should be able to better understand the interactions of multiple objectives. In a policy context this type of analytical approach may lead to more informed conflict.

Traditional Approaches

Traditional approaches to economic analysis either assume away multiple objective behavior or use a utility function approach. Assuming away multiple objective behavior is done by specifying a single criterion for analysis, like maximization of profit or minimization of cost, as opposed to utility analysis which is a single function which may contain numerous criterion reflecting multiple objectives.

Single Criterion Analysis

Economic analysis is often based on a single, easily quantifiable, objective function which implicitly approximates the real world. The classical approach to spacial programming models in agriculture (Heady, 1976) is to form the problem with an objective function that minimized the cost of agricultural production subject to exogenous demands. When modeling comparative advantage in agriculture, analysts using a minimization of cost objective function assume that marginality conditions of the perfectly competitive market structure apply. Such an assumption fails to take into account the multiple objective nature of farm level management (Wheeler and Russel, 1977; Chandler and Boehlje, 1971; Dobbins and Mapp, 1979). When analyzing national agricultural sector objectives the undimensionality of this objective function results in incomplete analysis, although cost minimization may be an important component. Using a single objective function model fails to approach the very important issues of multiple and conflicting objective functions.

Utility Function Analysis

Utility function approaches are based on applying the theoretical economic concept of utility maximization. Theoretically economics handles multiple objectives in the premaximization process that defines the utility function. Johnson (1977, p.34) defines the normative nature of these preconditions for maximization and notes that a high proportion of the decision making problem is embodied in establishing an interpersonally valid common denominator (CD). The CD is used to collapse goals and objectives into a single function by attaching values. The CD must be interpersonally valid if, as in most public sector problems, decisions will hurt some in order to benefit others. To get an analytical solution once a utility function is defined requires second order conditions and a decision rule. This requires quantification of the decision makers preferences and some measure of preference attainment (Lee, 1972). Campbell and Nichols (1977) argue for specifying objectives as well as <u>priorities</u> before analyzing alternatives by scaling utility. A common practice is to "price out", that is scale down to a standard level all the non-monitary attributes into a single monitary attribute function. A comparison of alternatives is then made only in terms of "adjusted" levels of the monitary attribute function. The requisite assumptions necessary for such an approach to be valid are strong (Keeney and Raiffa, 1976). As Roy (1971) points out, many difficulties develop in extracting real preferences of the decision makers which often results in an arbitrary representation of preference in a very crude form. This problem is compounded when working at the national level with multiple decision makers and interest groups.

The preference or utility function derived then becomes the objective function which is maximized resulting in a determinate solution like single criterion analysis. Although theoretically very satisfying in an efficiency context, two problems with this type of utility approach are:

1) <u>a priori</u> quantification of preferences

2) economic rationality of quantified preferences.

First, national decision makers often may not be able to define a single set of national preferences to which all decision makers can agree; furthermore, they may not want to be very explicit in revealing preferences. Second, if preferences are extracted, can they be economically rational if information on trade-offs is not available? To make a rational weighting of the objectives that make up utility requires knowledge about the opportunity costs or set involved.

In a mathematical programming context authors questioning the utility approach include Roy (1971), Lee (1972), Zeleney (1974), Bartlett et. al. (1976). Many others have questioned the utility approach on both theoretical and application grounds.

Summary

Cohon (1978, p.315) states traditional single-objective methods "proceed to a so-called "optimal" solution that is best in terms of a single measure of value. Decision makers are given the choice of accepting or rejecting this single solution without learning anything about how the solution compares with other feasible solutions. Since in a public decision-making context, a single objective can be defined only by making important and perhaps controversial value judgements, the analyst is forced by single-objective approaches to usurp a large part of the decision makers responsibilities."

Combining the problems of extracting utility functions in the public sector with the assumed role of public decision makers as those responsible to make value judgements in a world of multiple and conflicting objective functions leads one to multi-objective analysis and ranges of efficient solutions (opportunity sets).

Multiple Objective Optimization

Optimization of multiple objective functions can be viewed as a vector maximization problem. Efficient solutions result when all objectives are maximized or minimized, as appropriate. For example, labor use is maximized and cost of production is minimized. The problem is conceptualized as maximizing a vector of objective functions, F(x):

$$F(x) = \begin{bmatrix} f_1 & (x) \\ f_2 & (x) \\ f_3 & (x) \\ . & \\ . & \\ . & \\ f_t & (x) \end{bmatrix}$$

Subject to:

Functional relationships (matrix of m rows and n columns)

$A_i(x) \quad 0, \; i = 1, 2, 3 \ldots m$, and

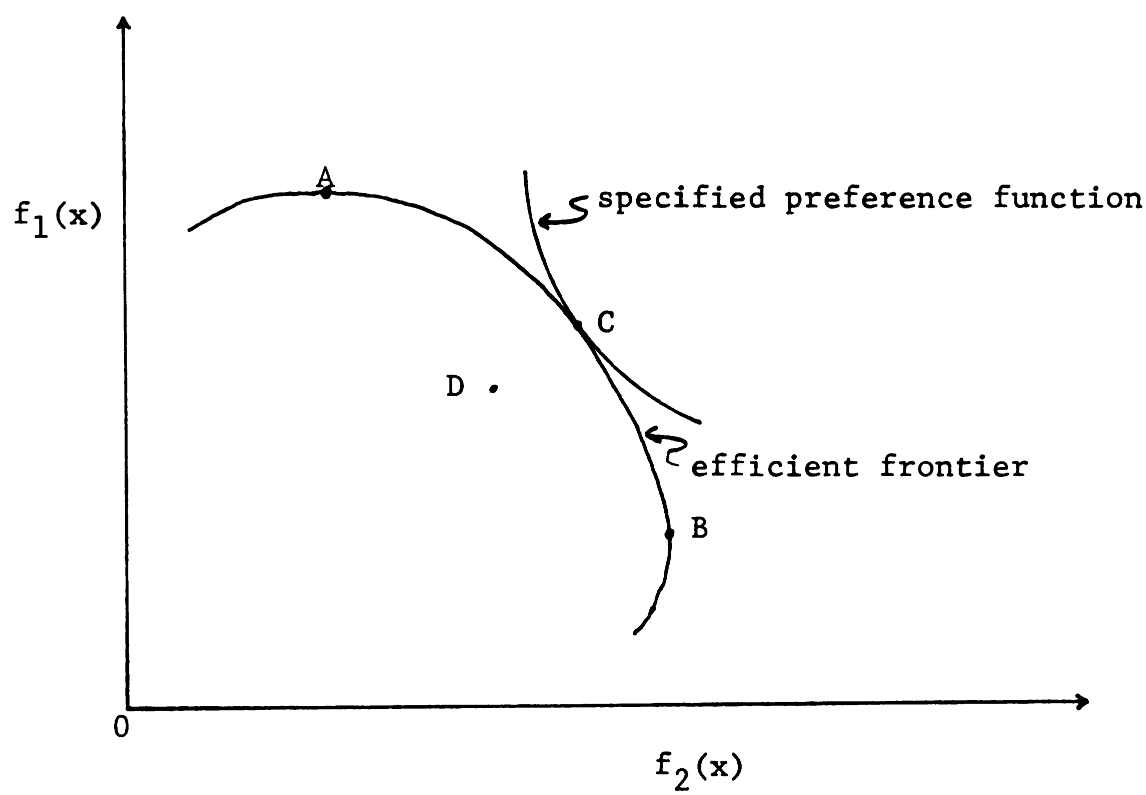
$X_j \quad 0, \; j = 1, 2, 3 \ldots n$,

assuming convexity.

This solution defines the "efficient frontier" or optimal set of possible solutions in objective function space. FIGURE 2.1 is a representation of the two objective function case. The objectives are $f_1(x)$ and $f_2(x)$. Point A represents the result of solving for only $f_1(x)$, point B the results of solving for only $f_2(x)$, and point C the optimal solution given a specified preference

FIGURE 2.1

TWO OBJECTIVE FUNCTION DEPICTION OF EFFICIENT FRONTIER AND SPECIFIED PREFERENCE FUNCTION.



Note: This figure depicts two maximization-type functions.

function. In this example, the curve defining the efficient function does not intersect either the $f_1(x)$ or $f_2(x)$ axes. This demonstrates the case where interaction between objectives ($f_1(x)$ and $f_2(x)$) permits at least some of each objective to come into solution. The efficient frontier is the portion of the figure between A and B which is the competitive range between the two objectives. Complementarity occurs, as depicted, where one or both objective functions can be improved without a negative impact with respect to the other objective.

As depicted (FIGURE 2.1), it is easy to visualize trade-offs between two objectives. But, further consideration brings out some limitations of this depiction. The two objective functions ($f_1(x)$ and $f_2(x)$) generally are not independent. To more completely see the implications of trade-offs we need to look behind the curve to the activities in solution at given points that generate the set. Activities in solution vary continuously (since the objective space varies continuously) resulting in an infinite number of resource allocations occurring -- one for each point on the efficient set.

Conceptually each objective function is defined by an axis in the first quadrant. Multiple objective analysis is then a partial analysis if <u>one</u> related objective function of an interest group, present or future, is not included. Brill (1979) states, "the best planning solution may lie in the inferior region." The inferior region is that area below (toward the origin) the efficient frontier for two maximization-type functions. In the more realistic three objective function problem point D (FIGURE 2.1) may be a selected optimal solution, not point C.

Optimization models assume the objective function is completely specified and that decision makers are optimizers. Hence, decision makers choices could logically be off the efficient frontier because any analytical model is based on simplification of the "real world". One way to partly look at the robustners of a model with respect, solutions off the efficient frontier, is with sensitivity analysis of efficient sets which has been done in a farm management decision setting by Schurle and Erven (1979).

Efficient Frontiers

The efficient vector making up the efficient frontier has been given different names in the literature including the pareto set (Ecker, 1975), non-inferior set (Cohon, 1978), efficient set (Saygideger, Vocke and Heady, 1977) and non-dominated set (Lee, 1974). The vector maximization problem is the problem of finding all solutions which are efficient. The main property of the frontier is that for all solutions outside the set (which by definition can only be interior of the efficiency surface given the optimization structure where all objectives are to be maximized) we can find an efficient solution where individual objective functions are unchanged or improved and at least one strictly improved (Zeleney, 1974).

Efficient frontiers in operations research have been conceptualized by many especially in connection with activity analysis of production and allocation, (Koopmans, 1951) and non-dominated set in portfolio selection (Markowitz, 1959). Charnes and Cooper

(1961) presented the first multiobjective algorithm and have continued analytical development (Charnes and Cooper, 1977).

The utility approach attempts to a priori define the shape of the decision-makers preference function. By optimizing the preference function, the traditional approach gives a one point determination solution. Meisel (1977) says, "The classical (here utility) approach results in a lighter computational burden and a greater burden on the decision-maker, requiring him to use his intuition to estimate the impacts of the trade-offs he is making." Raiffa[3] also makes the point: "Personally, I feel that this quest for a "scientific" and "mathematically objective" rule is all wrong!...; we should limit formal analysis to the characterization and determination of the efficient set and let unaided, intuitive judgement take over from there."

Parametric Estimation

The standard approach to defining efficient frontiers or sets for linear multiobjective programming problems is to use parametric techniques once an initial extreme point (optimum) is found (Ecker, 1975; Lee, 1972). With large matrices it becomes difficult to enumerate all efficient extreme points due to the number of adjacent vertexes that must be analyzed. Parametric techniques are used on the objective function when analyzing multiple objective problems defining the ranges over which coefficients hold constant, by analysis of vectors in the basis. Then

---

[3] Raiffa, Howard: "Decision Analysis", Addison-Wesley, 1970, pp. 155-156. Cited by Zeleney, (1974).

changing the coefficients to their limit within the range they hold constant and iteratively analyzing the new basis that comes into solution. Following the "100 percent rule" (Bradley, S.P., A.C. Hax, and T.L. Magnanti, 1977)[4] more than one coefficient in the objective function can be changed without changing the basis if the sum of relative changes is less than or equal to one $\sum_{i=1}^{n} \leq 1$; i = 1, 2, ..., n coefficients). When more than three objective functions are involved, a set of solutions that estimate the full efficient set must be developed as graphic depiction is not possible. The larger the number of objectives being analyzed the more difficult it is to define the whole efficient frontier exactly.

Non-Inferior Set Estimation (NISE)

This technique, developed by Cohon (1978), estimates the efficient set by iteratively defining points on the efficient set for the two objective function problem. The technique first optimizes each objective function without consideration of the other (points A & B FIGURE 2.2-a).

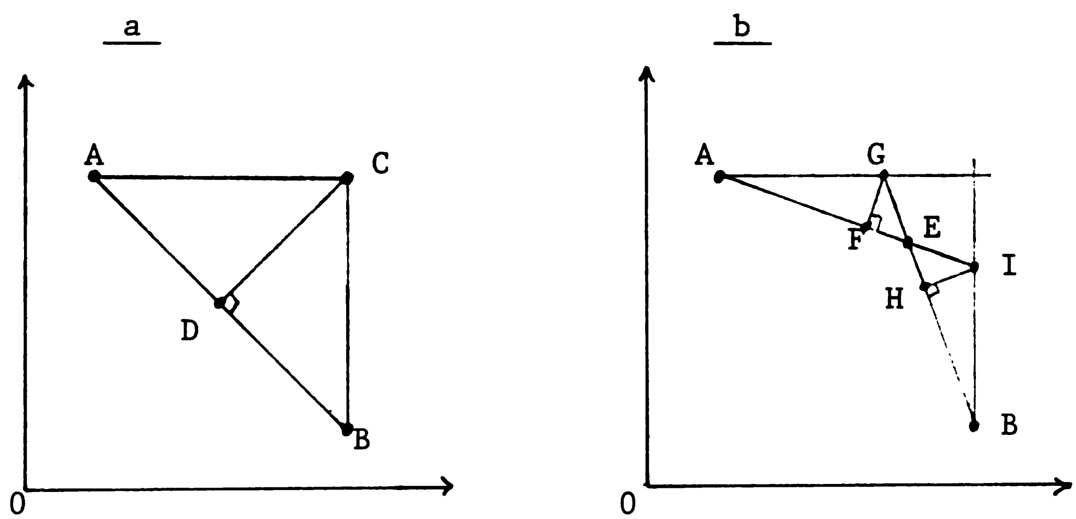
The lines $\overline{AC}$ and $\overline{BC}$ define upper bounds to the graphic solution set. The maximum possible error for the two points A and B is the perpendicular to $\overline{AB}$, $\overline{DC}$. When another point is estimated (E), as in FIGURE 2.2-b, the maximum possible error is $\overline{FG}$ plus $\overline{HI}$. The amount of possible error given by the sum of perpendiculars is iteratively compared to a predetermined acceptable error. Estimation stops when the possible error is less than the acceptable

---

[4]P.112.

FIGURE 2.2

NISE ESTIMATION TECHNIQUE



error. This estimation technique follows the convexity assumptions of mathematical programming. Cohon's algorithm becomes greatly more complicated for more than two dimensional problems and has not yet been applied to the higher dimensions.

Trade-Offs: Two Step Process

The efficient set, as described above, defines the functional space of trade-offs between objective functions. When the whole space is generated the decision makers utility is implicitly defined by the choice (C in FIGURE 2.1) that is made after evaluating the set. The efficient frontier explicitly defines the trade-offs given the assumptions of the analytical model developed. But, except for very simple models, the whole surface is not feasible to generate; therefore, various point solutions are selected from the surface.

The class of decision problem considered here is continuous which means decision makers are working with an efficient set with infinite possible priority structures, although some priority structures may give the same optimum solutions. Two aspects of this problem (Meisel, 1973) are: (1) obtaining a set of efficient solutions which are meaningfully distinct which describe the efficiency surface; and (2) representation of the trade-offs implicit in that set. These two aspects of the problem lead to a two step process. First, is an algorithm to find solutions on the efficient set which is developed in the following section on linear multiobjective programming. Second, is the depiction of implicit trade-offs which results from changing resource allocations under various preference functions.

Linear Multiobjective Programming Approaches

Three approaches to linear multiple objective programming are discussed in this section. These are the weighted linear multiple objective approach, the goal programming approach, and the goal programming approach formulated for Costa Rica. The latter approach is basically a synthesis of the first two.

All approaches rely on the Simplex algorithm. All approaches are developed from the standard linear programming (LP) model. The LP optimizes a single objective function subject to a number of constraints. A standard formulation of basic LP is as follows:

$$\text{Maximize:} \quad F(x) = \sum_{j=1}^{n} c_j \, x_j$$

$$\text{Subject to:} \quad \sum_{j=1}^{n} a_{ij} \, x_j = b_i \qquad i = 1, 2, 3, \ldots, m$$

$$x_j \geq 0 \qquad j = 1, 2, 3, \ldots, n$$

Weighted Linear Multiple Objectives Approach

In the linear case multiple objectives have been analyzed by simply weighting objectives formulated as constraints and maximizing the sum of weights as the objective function (Chandler and Boehlje, 1971). This approach is often proposed as interactive with decision-makers but, easily extends to estimating the efficiency frontier by reformulating the objective function with a number of weights (Saygridegen, Vocke and Heady - for two objectives). Zeleney (1974) has rigorously specified conditions for optimizing Z objective functions from the classic Kuhn-Tucker conditions using scaler (weights) on objectives. The weights (w_i) must satisfy $w_i = 1$ and $\Sigma w_j \geq 0$. The Z dimensional feasible area must be a non-empty polyhedron which prescribes the standard convexity condition on constraints and the objective function assuring that a single point solution (x*) is on the efficient frontier.

The problem assumes all objectives are specified in terms of optimization so the solution for x* on the efficient surface is:

$$\text{Maximize:} \quad f(x^*) = \sum_{j=1}^{n} c_j x_j w_j$$

$$\text{Subject to: } \sum_{j=1}^{n} a_{ij}x_j \; b_i \qquad i = 1, 2, 3, \ldots, m$$

$$x_j \geq 0 \qquad j = 1, 2, 3, \ldots, n$$

$$\Sigma w_j = 1$$

$$w_j \geq 0$$

An alternate formulation of this same basic approach have been presented (Cohon and Marks, 1975) which optimizes one of the constraints (making it the objective function) and formulating other objectives as constraints weighed relative to the objective function numerary.

Goal Programming Approach

Two goal programming models have appeared over time in the literature. The first method was originally proposed by Charnes and Cooper (1961). They proposed a model and approach for dealing with certain linear programming problems in which conflicting "goals of management" were included as constraints. Since it might well be impossible to satisfy exactly all such goals, the attempt is to minimize the sum of absolute values of the deviation from such goals (Ignizio, 1978). Orne et. al. (1975) refers to this as minimizing unattainability. Wheeler and Russel (1977) use this approach in a farm management study and describe the goal constraints as equality constraints with the addition of two special variables. Dobbins and Mapp (1979) refer to this approach as a "Substitution Goal Structure" formulation. The special variables (u_r, v_r) are "reverse slack" (Haverly, 1977) or "soft constraint" (Dekluyver,

1979) variables allowing the equality constraint to be violated at a cost which is specified in the objective function.

Let: r = number of activities

a_{ij} = per unit contribution of the j^{th} activity toward goal r

G_r = goal target for the r^{th} goal

The r^{th} goal is then:

$$\sum_{j=1}^{n} = a_{rj} \cdot x_j + u_r - v_r = G_r$$

where:

u_r = under achievement of r^{th} goal

v_r = over achievement of r^{th} goal

$u_r \cdot v_r = 0$ ie. both u and v cannot be non-zero for the same constraint.

The objective function is to minimize weighed deviations between goals:

Minimize: $\Sigma\ (w_i u_i + w_i v_i)$ where: $i = 1, 2, 3, \ldots, r.$

The second approach is what is most often referred to as goal programming in the recent literature (Bartlett et. al., 1976) and is based on preemptive (Ijiri, 1965) or priority dependent (Dauer & Kruegen, 1977) goal constraints. Goals are treated according to their perceived importance which can be done by attaching preemptive priority weights to the goal to be met first, (P_1), and frozen before moving to the next priority goal, (P_2), and so on. Dobbins and Mapp (1979) refer to this approach as a "Ranked Goal Structure" formulation and identify it as representing a lexographic utility function. Lexographic utility theory requires specification of "satisfactory" levels of dominant goals (1 through n-1), then, the decision maker is assumed to maximize (or minimize) the least important goal (n), subject to "satisfactory" levels of the dominate goals (Lin, Dean and Moore, 1974).

The problem is the same as above except the objective function becomes preemptive:

Minimize $(P_i w_i u_i + P_i w_i v_i)$ where $i = 1, 2, 3, \ldots, n$ and $P_i >> P_i + 1)$ such that P_i is frozen as an equality once met.

Often this linear problem cannot be solved by the simplex method but requires a modified algorithm because there are not enough large preemptive numbers (P_i) for lots of goal constraints. In effect, the algorithm must be made so that optimizations occur in stages. Once the goal associated with P_1 is achieved, it is changed from a goal constraint to a strict equality constraint. Then optimization continues for P_z subject to a frozen P_1 constraint. The reverse slacks in this case, when multiplied by weight (w_i), form ranges around the targets (G_r). For example, if we only want to allow negative deviations from targets, a zero weight is attached to u_r and a positive weight to v_r. As there may be a number of goals in the same priority level, the relative importance with P_1 can be established by weights on u_r and v_r.

The second goal programming model presented has n levels of priorities and the first model has just one priority level which, in terms of model two, means we are just working within P_1. In both goal programming models the goal vector does not have to be in the feasible set; however, if all goal functions can be over-achieved the method yields an inferior solution (Haimes et. al., 1975 p.24).

Formulation of Study: Goal Programming

Both the described methods will work well for the linear multiobjective problem where all objectives are to be optimized, that is, each objective must be stated in terms of either maximization or minimization. If each objective is not in optimization terms, but in terms of satisfying a goal, a goal programming framework is advantageous because it reduces the relevant full efficient set to a smaller subset when a target is achieved. For example, if the national target is for 100,000 mt. of corn produced we need not be concerned with this dimension of the objective space beyond the target. A goal programming model incorporating both optimization and satisficing objective functions used in this study. The terminology of different programming frameworks is not standardized; in fact, current conceptual viewpoints on goal programming ranges from those who view goal programming as an extension of linear programming (Lee 1972; Bartlett et. al., 1976) to those (Ignizio, 1978) who view goal programming as a general framework from which single objective function problems, such as the linear case LP, are the special cases.

This study uses a single tableau land-base goal programming model. Three stages are used in the formulation of this model for analysis of trade-offs:

(1) Linear optimization of goals defined in terms of maximization and minimization.

(2) Formulation of the goal programming model.

(3) Formulation for sensitivity analysis.

When objective functions are formulated by decision makers in terms of optimization an approach to generating trade-offs is to first optimize each function individually. This generates corner points to the trade-off surface. These solutions are put in as targets in a goal programming formulation, weights on reverse slacks, are generated and the deviation between targets minimized. This has been proposed as an interactive model (Benayoun et. al., 1971; Roy, 1971). The approach used here differs because all objectives are not specified in optimization format and the model is not interactive but develops a partial trade-off set.

Step 1

Right-hand-sides (RHS) for objective functions, stated in terms of optimization, must be generated for the GP model. This can be visualized as optimizing an LP for each of these functions or as optimizing the GP model with a weight of 1 on the objective being considered and zeroes on all other objectives. Given the specification of the model optimization of a single objective function defines a corner point in R^n (space defined by n objectives) on the trade-off frontier.

Step 2

Specify the GP model allowing only negative deviations from the targets developed in Step 1 Add in objective functions specified in terms of goals allowing only negative deviations. Allowing only negative deviations greatly simplifies the model. For objectives defined in terms of optimization Step 1 assures that no larger RHS can be generated by solving the GP model. For objective functions defined in terms of goals we are only concerned with satisfying RHS so there is no need to penalize overachievement.

Step 3

Performing sensitivity analysis on the goal programming objective function by using parametric techniques can delineate the trade-offs. This is basically the approach used here.

One of the disadvantages of the GP procedure is interpreting shadow prices which are in terms of goal satisfaction (thus reflecting the effect of marginal relaxation on total goal achievement). However, Wheeler and Russel (1977) resolve, to some extent, the difficulty of not being able to put an economic value on material resources by re-constructing a particular efficient solution in LP form with a monitary based objective function and other objective functions as constraints.

Economic Interpretation of Analytic Framework

The GP approach outlined above corresponds to minimizing disutility. Utility is maximized if all targets (generated by individual objective function optimizations) are achieved simultaneously. This would be the case if there were no trade-offs between objectives, i.e., objectives are independent. In the normal case of trade-offs minimizing disutility is minimizing the sum of deviations between weighted multiple objective functions. The programming model generates an efficient set of representative points by using a series of linear tangents to possible utility functions (implicit common denominators). A linear tangent to a utility function is the slope of the function at a point which is analogous to the ratio of weights used in the GP objective function. Parametric or estimation techniques are then used to change the implicit common denominator thus developing an opportunity or efficient set.

Extensions of Analytic Framework

In this chapter the discussion has been limited to linear mathematical programming as an approach to multiple objective trade-off analysis. The standard assumptions of LP still apply to GP, as formulated above, including divisibility and linearity; however, the assumption of optimization is overcome by incorporating targets. Basic LP model adjustments, like separable programming and integer programming, fit equally well into the GP model format as LP.

Conceptually goal programming has been extended to multiple planning levels by Salih (1975) for goal conflicts. Sfeir-Younes and Bromley (1977) have conceptually extended goal programming to hierarchies of objectives for project evaluation in developing countries.

The focus of most multiobjective strategies it to interactively work with the decision makers to systematically reduce the feasible solution to a single optimum. Haimes, et. al. (1975, 1974), developed the surrogate worth trade-off method which has been used by Lindsay, et. al. (1977), and Goicoechea, et. al. (1976) for a nonlinear programming problem.

Interactively working with decision makers was not possible in this thesis.

Chapter 3

AN OVERVIEW OF COSTA RICAN AGRICULTURAL SECTOR OBJECTIVES

The Agricultural Sector

The agricultural sector has traditionally been, and continues to be, the most important sector of the Costa Rican economy. In 1975 it accounted for about 20 percent of Gross Domestic Product, 65 percent of total export earnings, and 35 percent of total employment (USAID, 1977).[1]

Agricultural exports are very important to the Costa Rican economy. Coffee and bananas are the major exports followed by sugar and beef. Coffee, sugar, and bananas collectively accounted for 57% of total exports in 1975. Coffee was surpassed in 1975 as the major export earning crop by bananas.

The total population of Costa Rica, given by the 1973 Census, was approximately 2 million. About 1 million people live in rural areas. About 225,000 people, according to USAID, are classified as "poor" farmers using the USAID poverty definition of less than $150 income per year in 1969 prices. Generally, farmers classified as "poor" are tied to small farms and do not produce

---

[1]Refers to United States Agency for International Development.

the high value, labor-intensive crops, especially coffee. Small farmers producing coffee are generally not poor.

The rural poor, by farm size, are identified (TABLE 3). It is important to note that the number and distribution of poor farmers is not highly sensitive to the definition used (USAID, 1977). Most small farmers who are not poor produce coffee or have substantial off farm employment often coffee harvesting. Farm size definitions, used alone, does not explain farm poverty in Costa Rica.

Coffee is grown by small and medium size farmers and is highly labor intensive, coffee production provides substantial employment for non-farmers. Bananas and sugar are generally grown as plantation crops and beef production is characterized as extensive.

TABLE 3.1

NUMBER OF POOR FARMS, NON-POOR FARMS AND PERCENT OF FARMS WHICH ARE POOR BY FARM SIZE

FARM SIZE	NO. OF POOR FARMS (under 1100 Colones/capita)	NO. OF NON-POOR FARMS	PERCENT OF FARMS WHICH ARE POOR
0-1 Ha.	9,018	4,275	67.8
1-2 Ha.	4,336	2,498	63.5
2-5 Ha.	6,550	5,551	54.1
5-10 Ha.	3,896	4,364	47.2
10-20 Ha.	4,079	4,607	47.0
Over 20 Ha.	0	20,045	0.0
Landless	2,870	1,320	68.5
Total	30,739	42,660	41.9

Note: 1100 colones equals $110.

Source: Adapted from 1973 Census as cited by USAID (1977).

Virtually all farms in Costa Rica are market oriented. The national average home consumption of any crop on poor farms does not exceed 6.4% of the total value of production for any farm size category (TABLE 3.1) (USAID, 1977, p.11). The highest home consumption is for beans and corn. Both commodities are major staples in the Costa Rican diet.

The agricultural sector has been characterized as being over institutionalized, meaning that numerous public agencies, quazi-public associations, and autonomous boards act with little coordination. One of the serious considerations of this study is that no basic data set at the national level has been developed. This has resulted in conflicting agricultural sector statistics. Also, there is no standard regionalization used in developing the statistics.

Sector Objectives[2]

Costa Rica's national agricultural objectives, like those of many countries, define one level of objectives within a whole pyramid of political-economic objectives. The overall societal objective is to become developed. One of the sectors feeding into this objective is agriculture. The agricultural sector has a set of objectives. This analysis is strictly concerned with the subset of multiple economic objectives related to agriculture. This is

---

[2]This section relies heavily on the agricultural sector objectives for the current planning period as documented in: OFICINA De Planificacion, Sectorial Agropecuaria Costa Rica, Plan Annual Operativo Del Sector Publico Agropecuario Para 1977, San Jose, Costa Rica, Junio de 1977.

a simplification as there are many interrelationships between objectives of different sectors. Agriculture provides important markets for non-farm products, is a major recipient of social overhead capital investments, is a major employer of human resources, and makes substantial contribution to the tax base. The contribution agriculture makes to the total economic is substantial and has been looked upon as having increased importance by the government.

In general terms the emphasis of the national agricultural policy is the improvement of rural society and expansion of agriculture's contribution to national development. The objectives have been further defined, but are still broad, and characterized as: 1) substantial increases in production for exports; 2) increasing rural employment and income; 3) substitution for imports through growth in production of currently imported commodities (self-sufficiency); 4) rational use of resources; 5) provision of inputs for national industries.

Export Crop Objective

Costa Rica has chronic balance of payment deficits which have been financed through borrowing. In 1974 the deficit was $260 million. Agricultural exports play a very important role in attempts to reduce this deficit and the need for foreign borrowing. The export dollar value of coffee, bananas and sugar in 1975 was $278 million.[3]

---

[3] See TABLE 5.1 to 5.4, Chapter V for details.

Fluctuation in export earnings have been mostly the result of prices in international coffee and sugar markets. Increasing beef exports has been part of a diversification policy. Export crops are not only important as earners of foreign exchange, but as a source of government tax revenues. Generally speaking, exports are relatively easy to effectively tax in developing countries as compared to taxing, wealth or income.

Maximizing agricultural export earnings captures much of the economic essence of the Costa Rican government's interest in agricultural exports but may not adequately reflect attempts to diversify agricultural production as a hedge against price fluctuations of exported commodities.

Employment and Income Objective

Increasing rural income opportunities through employment generation is a priority issue in Costa Rica. The age structure of the population indicates that the size of the labor force will continue to increase quite rapidly. Projections based on a study by the Instituto de Estudios Sociales en Poblacion are presented (TABLE 3.2).

The general consensus on employment is summarized by USAID (1977, p.63). Underemployment appears to be a serious problem in the agricultural sector. In recent years most new jobs have come from industry which has produced 50% more jobs than the 1973-1978 development plan target while agriculture has provided 50% less than the target. It appears doubtful that industry can continue to provide employment at its past rate of

TABLE 3.2

PROJECTION OF POSSIBLE LABOR FORCE

	1973	1976	1980	1990
POPULATION (000)	1,872	2,009	2,225	2,822
LABOR FORCE (000)	385	658	750	991
NEW JOBS NEEDED/YEAR*		24,000	24,550	21,460

*Computed on a straight line basis holding unemployment at 6.2% from 1976 to 1990.

SOURCE: M. Bogan and C. Raabe, Proyecciones Regionales de la Poblacion de Costa Rica. Universidad Nacional de Costa Rica, Heredia, September, 1976. Cited by USAID, An Assessment of The Agricultural Sector in Costa Rica (1977).

growth. This will require a higher rate of employment in agriculture if overall employment goals are to be achieved.

Two important keys to generating more employment in the agricultural sector are: 1) more intensive crop production, which is closely related to government pricing and land tenure policies, and 2) increasing production of labor intensive crops, which is currently closely tied to the export crops, especially coffee. The export crop and employment objective appear complementary as export crops are among the crops with the highest labor demands; however; demand for labor is seasonal as most labor goes into coffee harvest during November through January. USAID (1977), using their definition of poor, estimate that coffee harvest currently provides equivalent to 100,000 person-years of employment. Coefficients of labor requirements by crops for the agricultural region of Costa Rica have been developed for this analysis and are presented in Chapter V (TABLE 5.6).

Simplifying this objective into a function of maximizing employment has the limitation of not reflecting the seasonal labor demand for several crops. This simplification ignores the question of possible year-round employment through the specification of alternative crop rotations in each major agricultural area of Costa Rica.

Self-Sufficiency

One objective that is never left off any list for Costa Rica is substitution for agricultural imports through increased domestic production. The intent is to become self-sufficient in the basic grains, corn, beans, rice and sorghum. Corn, beans and rice are the staples of the average diet. Although the demand for these commodities has grown rapidly production has lagged. Imports of the basic grains and percent of consumption imported for the crop year 1975-1976 are shown (TABLE 3.3).

TABLE 3.3

1975/76 IMPORTS OF BASIC GRAINS AND IMPORTS AS A PERCENT OF TOTAL CONSUMPTION

CROP	1975/76 IMPORTS (in Kg)	IMPORTS AS A % OF TOTAL CONSUMPTION
Beans	13.9 million	46
Corn	6.2 million	6
Rice	-25.0 million (export)	--
Sorghum	-2.3 million (i.e. exports)	--

SOURCE: Adapted from USAID (1977).

Beans and corn are generally grown by small farmers. Rice is produced under dryland conditions on both large and small farms. Sorghum is used almost exclusively as animal feed and was not a significant crop in the 1973 Census.[4]

The 1985 demand estimates for the basic grains, the actual production for 1974, and the percent increases required to meet demands are shown (TABLE 3.4).

TABLE 3.4

DEMAND FOR BASIC GRAINS: ACTUAL 1975, PROJECTED 1985 AND PERCENT INCREASE REQUIRED

	Actual 1974 metric tons	Project 1985 metric tons	% Increase Required
Beans	31,580	43,900	39
Corn	147,181	212,900	45
Rice	69,682	104,026*	37

Adapted from M.J. Lord - "Market Trends and Prospects of Agricultural Commodities" IDB/IBRD/AID. Agricultural Sector Survey-Draft, Oct. 1976. Cited by USAID (1977).

*Rice - 1985 Demand is the 1973 production as shown by the Census.

Rational Use of National Resources

Within a framework of national objectives agriculture is one of the competitors for the use of natural resources such as land and water. Two broad elements are considered factors of this objective: environmental rationality and economic rationality. Balancing these two factors is part of the political process involving

[4]In the analysis done here sorghum is not included as the livestock sector was not modeled and data were not available.

critical trade-offs, but are beyond the scope of the analysis. Reference will be made to two environmental concerns with critical economic implications that will be referred to in later sections. First is the threat of coffee rust invading Costa Rica from Nicaragua. The government has discouraged the introduction of coffee production in northern areas of the Costa Rica to effectively create a buffer zone. Second, deforestation in Costa Rica has destroyed watersheds. This is especially prominant in the northern reaches of Costa Rica. In these areas land has been shifted from tropical forest to pasture for extensive livestock production. Though these two major environmental concerns are not reflected in the analytical economic model developed, they are considered in the analyses of model results. For example, validity of model results would be tempered if more coffee production in the northern reaches of Costa Rica were a model result.

Economic rationality is defined as the most efficient use of resources given the situation including, farm size, costs of production, and technology levels within a market framework. By efficiently using resources agricultural production takes place where it is most profitable and, assuming perfect competition, the result is the lowest cost to consumers. The concept relied on is comparative advantage which defines, in a relative sense, spatially where production should occur. Traditionally this is evaluated by formulating the objective function as minimization of cost.

Economic Delineation of Objectives

The objectives described in the previous sections are very interdependent. For example, export crops and high employment crops are often the same but the more area planted to these the less area available for basic grains. To study the interrelationships and trade-offs between Costa Rica's multiple objectives the following are used:

1) Maximize export earnings
2) Maximize employment
3) Satisfy 1985 domestic demand for basic grains
4) Minimize cost of agricultural production.

National Sector Planning

Institutions

The Ministry of Planning and Ministry of Agriculture (MAG) are the lead Costa Rican agencies responsible for agriculture and rural development planning, although, numerous public and quazi-public agencies, committees and organizations have programs and areas of influence. The National Agricultural Council (CAN)[5] is a group of ministers and officials set up to coordinate agricultural and rural programs. CAN does not include about 19 autonomous organization like the banks (quazi-public) and crop authorities (banana council, coffee council, etc.) that oversee production. CAN is chaired by the Minister of Agriculture and members include: The Minister of Planning; the Minister of Economy, Industry, and Commerce; the Minister of the President; the Executive President of the National Grain Production Council; the President of the Central Bank; and the President of the Institute of Lands

[5]Spanish acronyms.

and Colonization. CAN has the function of setting the direction, general policies, and objectives for the agricultural sector.

A technical support unit established for CAN was the Agricultural Sector Planning Office (OPSA).[6] OPSA works closely with CAN to implement and refine objectives and general direction policy statements into programs, projects and specific targets.

Planning Horizons and Regions

Intermediate length planning horizons are focused on by OPSA. Four year plans are developed based on broad CAN objectives, policies and programs, then specific goals such as commodity production targets are set. Currently Costa Rica is operating under an OPSA agricultural development plan for 1973-1982.

Two major agricultural planning regionalizations have been extensively used for the country. One was developed by MAG for extension purposes and the other one by the National Planning Office for sector planning purposes. The latter has been adopted by OPSA. This analysis uses a slightly modified MAG regionalization as it specifically defines agricultural regions and the Census also used it (details Chapter IV).

[6]Spanish acronyms.

Chapter 4

A LAND BASE REGIONAL MODEL

Introduction

A land base comparative advantage model and a discussion of the associated data base are presented in this Chapter. The economic concept underlying land based linear programming models is comparative advantage. Equations and model structure are presented in the next chapter.

Comparative Advantage

Theoretically comparative advantage is not a static concept though it is often formulated as such in analytical models which are based on natural advantages which affect cropping systems and yields, like climate and soils, and costs of production. Land base models are programming models that use geographic land units as the building blocks for model specification. Land base LP models formulated at the national level are often referred to as Heady models (Heady and Nicol, 1976) and regional models are illustrated by River Basin Studies (Hostetler, 1970; Putman et. al., 1977). Comparative advantage is a broad concept based on analyzing relative efficiency to allocate production. This is done by minimizing the cost of production and usually transportation, given exogenous demands. In practice, comparative advantage is affected by more than just physical conditions. Barlow (1972, p.261) says, "comparative advantage is measured by the economic ability of an area to compete with other areas in the production of particular good or services. Certain comparative advantages may stem from natural endowment. Others may involve favorable combinations of production inputs, favorable location and transportation costs, favorable institutional arrangements, or desired amenity features." Thus, comparative advantage can be associated with natural resource conditions or can be created by institutions and policy, or can be from a mix of natural resource and institution and policy conditions.

For agricultural production purposes the natural resource endowment includes factors such as climate, soils, and water which influence yield. Favorable production combinations include the availability of capital and labor which often outweigh natural advantages associated with a region. Transportation considerations can be extremely important and opening up areas of natural advantage with transportation networks can greatly influence comparative advantage. Institutional advantages are created advantages, of any administrative or political-level action, including direct or indirect public subsidies. For example, factor input price influences comparative advantage. Amenity factors such as cultural practices or values can also contribute to the comparative advantage of a region.

General Graphical Depiction

A simplified discussion of interregional location of production and comparative advantage is developed for two regions and two products Y_1 and Y_2. Assuming, that the regions trade, and zero transportation costs, each region has the same product price ratio. By also assuming factors of production are not mobile between regions the location of production can be depicted by the relative shapes of production opportunity (possibility) curves. A regional production possibility curve shows how much production could occur if just Y_1 of Y_2 were produced and all combinations of Y_1 and Y_2 that could be produced in a region given a set of inputs.

A case of absolute advantage for one product in each region is depicted (FIGURE 4.1). Production in Region 2 is the amount $Y_2 2$ of product Y_2 and $Y_1 2$ of product Y_1 (FIGURE 4.1). Specialization in production for Region 1 is depicted (FIGURE 4.1).

Comparative advantage shows that while on region may have an absolute advantage in both products specialization still occurs based on relative advantages (FIGURE 4.2). Production in Region 2 is the amount $Y_2 2$ of Y_2 and $Y_1 2$ of Y_1 (FIGURE 4.2). Specialization for Region 1 is likewise depicted.

The result of specialization due to comparative advantage is that overall production is increased and this increased production provides increased satisfaction to each region given that the price ratio is a valid measure of value. No specialization occurs if production possibility curves are identical.

FIGURE 4.1

ABSOLUTE ADVANTAGE
IN EACH REGION

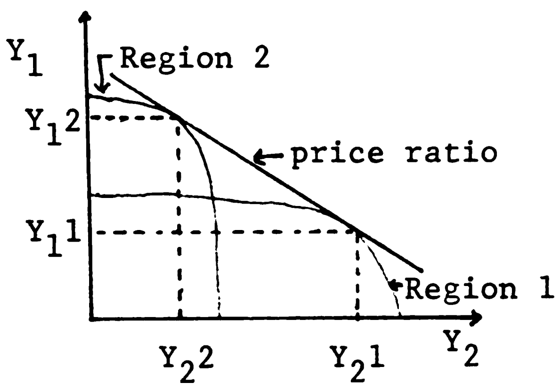
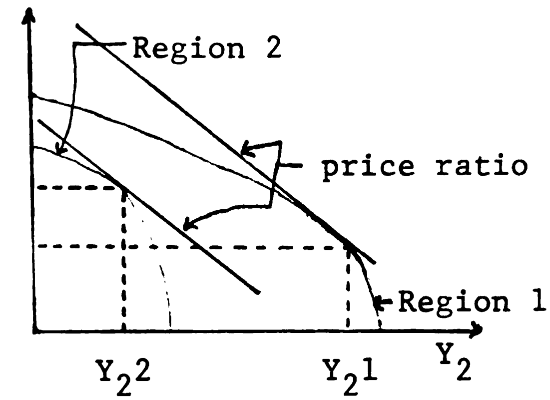


FIGURE 4.2

COMPARATIVE ADVANTAGE



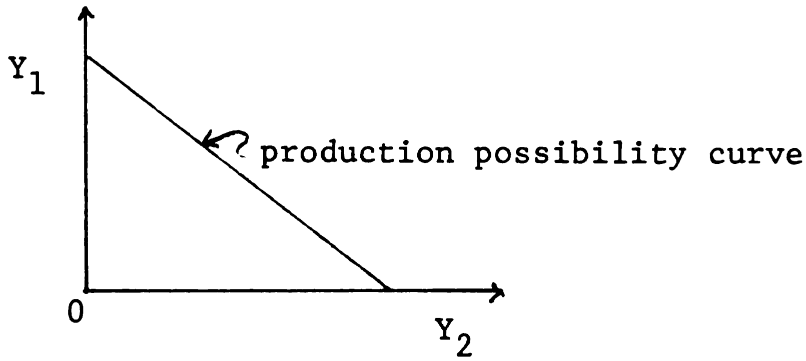
However, this is highly unlikely under situations with a number of different regions and different products. It is important to note that complete regional specialization does not occur due to increasing rates of production substitution (production possibility curves are concave to origin).

The Linear Case

Many elementary discussions of comparative advantage suppose that the marginal rate of substitution between products within a region is constant. This implies linear production possibility curves. Most mathematical programming models, including the multiobjective model used here, assume linearity. The end product of optimization using a linear production possibility curve is complete regional specialization in production. That is price ratio, except the unlikely case where the slope exactly corresponds to the production possibility curve, results in a corner solution i.e., producing either Y_1 or Y_2 (FIGURE 4.3). Complete regional specialization in agricultural production seldom exists. Linearity assumes products compete for resources at constant rates ruling out any supplementary or complementary nature existing between products.[1] The real world is much more like the non-linear case than linear. However, when solving complex optimization problems, linearity greatly facilitates solution. To achieve greater correspondence between the non-linear conditions that exist in the real world and the optimization techniques non-linear curves are segmented into a number of linear parts or the optimization models are constrained by other linear factors so complete regional specialization does not take place. In the model structure employed in this study regional constraints are employed to eliminate complete regional specialization.

FIGURE 4.3

LINEAR PRODUCTION POSSIBILITY



[1]If: (1) MRS (marginal rate of substitution) < 0: products are complementary.
(2) MRS = 0: products are substitutes.
(3) MRS > 0: products are competitive.

Objective Opportunity

The model developed in this study determines comparative advantage within a framework of multiple objectives or dimensions of performance. This might be called an objective opportunity perspective rather than comparative advantage based on opportunity possibilities. Comparative advantage, as defined in a traditional LP model, is just one of the agricultural sector objectives being analyzed here. By incorporating other sector objectives the opportunity cost of minimizing the cost of production can be defined in terms of export earnings, labor employment, and self-sufficiency.

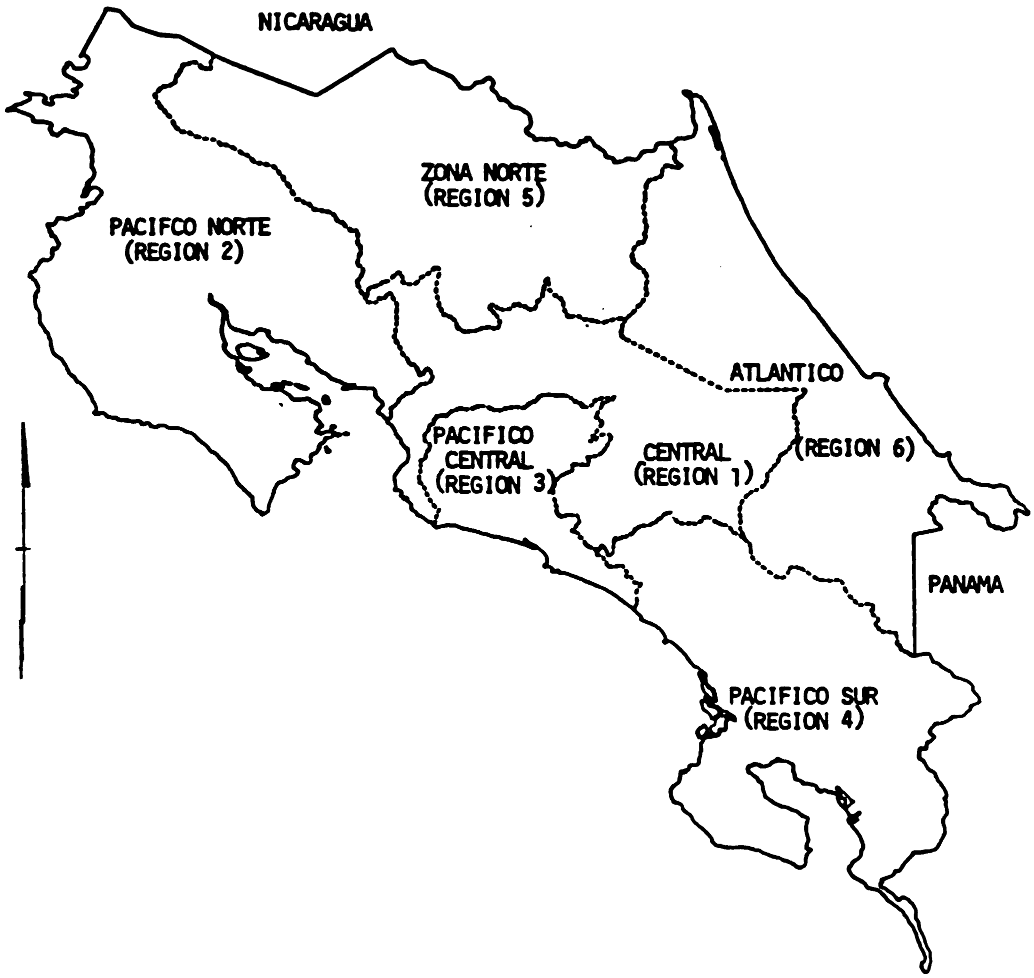
Regional Specification of the Model

Costa Rica is approximately 100 kilometers wide and 500 kilometers long with a total of approximately 51,260 square kilometers. The central north-south mountain chain separates the country into two areas. The Central and Pacific area comprises about four-fifths of the country and is characterized by rugged mountains separated by relatively large scattered flat plains. The Atlantic area, which lies on the eastern edge of the country, is relatively flat. The Ministry of Agriculture further divides the country into seven agricultural zones which have been reduced to six for this analysis (FIGURE 4.4). These regions are:

Region 1 - Central
Region 2 - Pacifico Norte
Region 3 - Pacifico Central
Region 4 - Pacifico Sur
Region 5 - Zona Norte
Region 6 - Atlantico

FIGURE 4.4

AGRICULTURAL REGIONS OF COSTA RICA



Scale Approx. 1:1,078,000 (In KM)

0 30 65 130

ADAPTED FROM: DIRECCION GENERAL DE ESTADISTICA Y CENSOS, CENSO AGROPECURAIO 1973 REGIONES AGRICOLAS. SAN JOSE, COSTA RICA - JUNIO DE 1975.

The boundaries of these agricultural regions follow the political boundaries of cantones. Agricultural regions are delineated on physical and macro-ecological characteristics.

Central Region

This region produces most of the nation's coffee, sugar cane, corn, beans, and vegetables. The topography is a rough transitional zone with elevation ranging from 600 to 1,600 meters leading to the central mesa with elevations ranging from 1,700 to 3,000 meters. There is a small coastal area included in this region.

Pacifico Norte

This is a relatively level, dry tropical region with elevations ranging from 0 to 500 meters. The area has a long dry season limiting most nonirrigated production to one crop per year. Crops produced are sorghum, corn, beans and rice (especially where irrigation water is available).

Pacifico Central

Much of this area is humid tropical forest. The most common crops are sugar cane, beans, rice and corn. Elevations range from 0 to 500 meters.

Pacifico Sur

This region is characterized as relatively level, humid tropics with elevations of 0 to 500 meters. The major crop is bananas with some coffee, beans, and corn, also grown.

Zona Norte

This region is rugged with elevations between 600 to 7,000 meters. There is relatively little agricultural production. Some bean, corn, and sugar cane, cultivation exists.

Atlantico

This region produces most of Costa Rica's bananas and cocoa. The zone is humid tropical and relatively level with elevations reaching 500 meters.

Data Base

Sources of Data

The analytical model was developed from secondary Costa Rican data. Sources include: the 1973 Census; the Central Bank (BC); the National Production Council (CNP); the crop specific associations for bananas, sugar and coffee; and the Ministry of Agriculture (MAG). Data used and developed from these sources are discussed in subsequent sections.

Crop Production

Data on production by canton for each crop are reported only in the 1973 Census. No time series data are available except at the national level. The time series national production data sources are from the Central Bank and from aggregating crop specific associations data (Aggregate). There are large differences in production levels reported for each crop depending on the source referenced. However, production trends for each particular crop tend to have the same direction of change over time among sources.

Production levels for major crops are compared for 1973 (TABLE 4.4). The discrepencies between estimates of total production among secondary data sources are easily observed, i.e., beans.

TABLE 4.4

1973 NATIONAL CROP PRODUCTION FROM CENTRAL BANK, CENSUS OF AGGREGATE (CROP SPECIFIC ASSOCIATION) DATA

Crop	Central Bank	Census	Aggregate
corn	65476	53491	64444
rice	81641	104026	97131
beans	10030	11445	5222
coffee	480530	394325	453891
sugar cane	2341295	2571505	2246111
bananas	1289401	12571505	1198064
plantain	66863	119511	82811
cocoa	5617.6	4823.5	4535.8
tobacco	2522	1586	1605
potatoes	23238	20626	20628
yucca	9959	13818	13810
minor crops	31940	35491	31940

Crop Areas

The Census is the only source depicting where all crops are grown in Costa Rica. The CNP has areas for the large regions they report data by, but only for the basic grains. Data employed in this study are cross-sectional data given by the census. Conversions from crop area to actual physical area cultivated were made by subtracting second plantings from total crop plantings.

Yields

Estimates of crop yields by region can be made if an eclectic approach is taken. Implicit yields can be calculated from various sources. The main source is the 1973 Census. MAG cost of production studies have yields for the farms studied between 1972 and 1977; these studies cover many basic crops, but not all regions of the country. Apparently the Ministry of Agriculture Surveys are only very loosely tied to any "representative" farm concepts. The CNP reports regionalized yields on the basic grains for 1973 and 1975; additionally, this source provides the only data on sorgo (grain sorghum) which has recently become a significant crop. Coffee yields by region for 1975-1976 were available from the Oficene de Cafe (Coffee Institute). Obtaining yield coefficients from these sources poses some problems as technology levels are difficult to define. Some of the MAG Cost of Production Studies have well defined technology levels. However, most data are no more detailed than implicit yields.

Costs of Production

The cost of production data set relies on BC data that cover the major crops in most regions. These data were developed for agricultural loan purposes. MAG budget data were used as a supplement and not relied heavily on because these data are not based on analysis of representative farms. Coffee costs were supplemented by the Coffee Institutes regional coefficients.

Neither the BC or MAG budgets were consistently done over time so costs were put together by source for important inputs. Labor was analyzed in two components, human and mechanical. Materials were grouped as, seed, fertilizer, and herbicides/ pesticides. Costs were updated to 1976 by the FAO consumer price index for Costa Rica. Costs were associated with regions as much as possible. Where costs couldn't be regionalized it was by coincidence fortunate that the national-level costs actually represented crops currently grown in a certain region, i.e., bananas in the region.

No data source adequately specified establishment costs for any crop. This type of information is especially necessary for perennial crops (coffee, bananas, and cocoa). Only variable costs were used in the model under the assumption variable costs are included and will be higher in areas where land has to be cleared or otherwise modified to produce new plantings of perennial crops.

Labor

Obtaining labor coefficients from the secondary data sources proved to be difficult. Both Central Bank and MAG Cost of Production studies often don't list physical units but only labor costs. By reviewing the data sources by crop, especially BC budgets for 1973 to 1976, a set of labor coefficients was developed. Most labor coefficients were assigned to agricultural regions based on yields with the underlying assumption that harvest labor is proportional to yields. Reviewing that regional data that was available, the assumption that labor use is tied to yield levels appeared to hold.

Exports

Data on national exports were available from the Central Bank and FAO. The Central Bank data were used because these data provided both exports and the amount internally consumed so ratios could be developed for national production coefficients. The export crops are coffee, bananas, sugar cane, and cocoa.

Data Calculations and Problems

Commodities Excluded

Information derived from these data sources excludes livestock activities, cotton, and sorghum due to lack of data. Cotton and sorghum have become important in Costa Rica since 1973.

Intercropping

One of the major problems with the published data sources available was determining the amount of the intercropped land. Information on intercropped land applies only to corn and beans and is very limited. Apparently census enumerators collected data on hypothetical areas that would have been planted in each crop if no intercropping had taken place. Yield ratios were applied to the implicit single crop yields (solo) derived from the census data. This ratio was also used to determine costs of production since no production costs were available for intercropped corn and beans. The relationship used was: 70% of the associated solo coefficients for both intercropped beans and corn. For example, intercropped corn yields were specified at 70% of the implicit census yields for solo planted corn. This ratio derived from experiment station studies based on standard inputs and practices (Regional Office of Central America and Panama, USAID

Mimio, 1978). It was further assumed that intercropping only allows one planting per year, i.e., no multiple cropping.

Multiple Cropping

Multiple cropping refers to the number of harvests (plantings) a farmer gets off a particular piece of land in a calendar year. No reliable sources are available that specify the amount of multiple cropping occurring in Costa Rica. Therefore, it was assumed that the census data category "second planting" reflected the amount of multiple cropping practiced. Unfortunately the 1973 Census period was a droughty year in some areas. Drought would probably reduce the practice of multiple cropping. General references suggest that not much multiple cropping occurs in Costa Rica.

Standard Units

A problem with some of the data sources is that units of measurement are not specified or are underspecified. The units were inferred by comparing data sources that had units. Products measures that would be influenced by processing and moisture content were difficult problems to handle. Coffee presented a major problem as different sources reported production at different stages of processing.

Pasture and Idle Land

Qualitatively pasture is difficult to specify, therefore, it becomes a catch-all category. Census reporting of pasture includes conditions that range from improved irrigated pasture to land with essentially no animal carrying capacity.

Large amounts of idle land were reported in the 1973 census. Again, this was probably a function of the weather conditions during 1973.

A Test of Data Sources and Set Used

Test

A test[2] was conducted comparing three basic data sets to study the sensitivity of coefficients in a L.P. model with a minimization of cost objective function. The three data sets on yields, land area, and production used from the BC, Census, and an aggregate of other sources including the crop association boards. Two sets of production costs were developed. One was developed from the BC and the other from MAG data.

The test data sets generally provided the same directions of change in comparative advantage and regional production patterns; however, the magnitudes in the directional changes differed by data set. The analysis of the data set combinations and sensitivity analyses showed the model to be highly responsive to the production cost estimates.

Data Set Used

A best set of data was gleaned from all available sources for the model developed here. Major aspects of the set were developed from:

---

[2]The work was done by Mark J. Cochran and the author during 1977-78 as part of the CRIES Project and detailed in a progress reports.

(1) Census data on yields, areas, and crop production for flexibility restraints.

(2) Costs of production and labor coefficients from the Central Bank.

(3) Yields and Production Costs for coffee were from the Coffee Institute data.

(4) For agricultural exports and export earnings Central Bank data was used.

Implications of Regions and Data

The level of aggregation implied in the regions used is closely tied to the quality of the data set obtained through reasoned-interpretation from the available secondary data sources. The desired level of aggregation depends on the purpose of the investigation. What is desired is conditioned by the data available. Agriculture in Costa Rica is heterogeneous within the regions analyzed due to institutional factors such as farm size and natural factors, especially soil and climate. Costa Rica is in one of the least homogeneous areas of the Western Hemesphere. The number of distinct vegetative types in an area is a good indicator of physical homogeneity (heterogeneity). Costa Rica ranks third behind the Amazon area of Brazil and Malaysia in the number of distinct vegetative types per hectare.[3] This would suggest disaggregating of the data beyond the production regions

[3]Personal communication from A.A. Atchley, Agronomist, SEA, USDA.

used would be desirable. Unfortunately, this would be an inappropriate use of data interpreted from the sources previously cited.

Market demand regions are not included in this analysis. Most LP spatial agricultural production models use large market regions made up of smaller more homogeneous production regions. Costa Rica is a small country so it may appear that national demands are adequate. But, a characteristic of the country is rugged topography making transportation of food difficult. No data on market demand regions are available.

Chapter 5

MODEL STRUCTURE, COEFFICIENTS, ASSUMPTIONS AND LIMITATIONS

Introduction

This chapter presents the single tableau goal programming model used to develop regional production patterns for agriculture that optimize various sector objective functions. Two planning horizons were used; a relatively short-run estimate and a medium run 1985 solution. The model, run for both planning horizons, uses 1973 as the base year. Different flexibility constraints were used to depict static trade-off associated with the two planning horizons.

Sections make up the chapter. The first section on model structure describes the general goal programming formulation including, goal constraints, objective function, national production constraints, flexibility constraints, and coefficients. The second section discusses model assumptions, limitations and usefulness.

Model Structure

The model is termed "land base" meaning activities are all tied to land availability by region. All activities come into solution on a per hectare basis (X_{ij} is the amount of land in crop i in region j). Characteristics such as farm size are not included in the model except implicitly through impacts on regional yields, costs, and type of crop produced.

The model requires the following input data (FIGURE 5.1):

(1) Land available for agriculture in each region.

(2) Yields per hectare for crops by region.

(3) Costs of production per hectare for crops by region.

(4) Labor requirements per hectare for each crop in each region.

(5) Export crop earnings per hectare in each region.

(6) Regional requirements and national demands.

The sources of information and quality of the data set was presented in the preceeding chapter, mathematical structure and model coefficients are discussed in the following subsections. The crop and regional codes are given (TABLES 5.1 and 5.2, respectively).

Goal Constraints

Each goal constraint is associated with one of the multiple objectives being analyzed. The attempt is to achieve the right-hand-side targets for these constraints allowing deviations in one direction only for each constraint.

The right-hand-sides for the goal constraints are presented (TABLE 5.3). These were derived by optimizing an LP for

FIGURE 5.1

DEPICTION OF MODEL

	row \ column	One column for each crop by region		Right-hand Side
costs specified by region →	Cost	Cost/hectare by region	=	Minimum Cost
export earnings by region →	export earnings	Earnings/hectare by region	=	Maximum Earnings
labor coefficients by region →	labor	Labor requirements/ hectares by region	=	Maximum Labor
yields by region →	self sufficiency	Yield/hectares of basic grain by region	=	1985 Demands
	crop production	one row for each crop (Yields/hectares)		National Demands
	1			Regional Production Requirements
	2			
	3			
	4			
	5			
	6			
	resource (land)	one row for each region		Total Hectares Available by Region
	1			
	2			
	3			
	4			
	5			
	6			

TABLE 5.1

CODES USED BY CROPS

Code	Crop
21	Corn
22	Rice
23	Beans
24	Coffee
25	Sugar Cane
26	Bananas
27	Plantain
28	Cocoa
29	Tobacco
30	Potatoes
31	Yucca
32	Interplanted
33	Minor Crops
70	Pasture
99	Idle Cropland

TABLE 5.2

CODES USED BY REGION

Code	Region
1	Central 1
2	Pacifico Norte 2
3	Pacifico Central 3
4	Pacifico Sur 4
5	Zona Norte 5
6	Atlantico 6

TABLE 5.3

OBJECTIVE FUNCTION AND GOAL CONSTRAINT RIGHT-HAND-SIDES FOR SHORT-RUN AND LONG-RUN MODELS

Objective Function	Goal Constraints Right-Hand-Sides	
	Short-Run	Long-Run
Maximum Labor Employment (in 10,000 of hours)	28998.	34057.
Maximum Export Earnings (in 10,000 of dollars)	32118.	40368.
Minimum Cost of Production (in 10,000 of colones)	210656.	206008.
Self Sufficiency (in metric tons)		
Corn	212900.	212900.
Beans	104026.	104026.
Rice	43900.	43900.

Export Earnings, Employment and Cost individually. Added constraints are necessary for Export Earnings because all crops do not produce export earnings. All non-export crops were given upper bounds of .1 percent over regional requirements (1973 production). Otherwise, since they have zeroes in the objective function, the labor, cost and basic grain production are much above the regional and national requirements which are greater than or equal to ($\geq$) constraints.

Labor Employment

Following is the mathematical statement for the labor employment in agricultural production goal constraint (Right-Hand-Sides, see TABLE 5.3; $LABOR_{ij}$, see TABLE 5.6):

$$\sum_j \sum_i X_{ij} LABOR_{ij} + U_2 = \text{Maximum Employment}$$

defined for each crop in each region

so $i = 21, 22, 23, \ldots, 33$ crops
$j = 1, 2, \ldots 6$ regions

Export Earnings

Following is the mathematical statement for the agricultural export earnings goal constraint (Right-Hand-Sides, see TABLE 5.3; $EXPEARN_{ij}$, see TABLE 5.11):

$$\sum_j \sum_i X_{ij} EXPEARN_{ij} + U_i = \text{Maximum Earnings}$$

defined for each export crop by region

so $i = 24, 25, 26, 28$ export crops
$j = 1, 2 \ldots 6$ regions

Cost of Production

Following is the mathematical statement for the cost of agricultural production goal constraint (Right-Hand-Sides, see

TABLE 5.2; $COST_{ij}$, see TABLE 5.14):

$$\sum_j \sum_i X_{ij} COST_{ij} + Y_1 = \text{Minimum Cost}$$

defined for each crop in each region

so i = 21, 22, 23, ... 33 crops
j = 1, 2, ... 6 regions

Self-Sufficiency

Following are the mathematical statements for the self-sufficiency in basic grains goal constraints (Right-Hand-Sides, see TABLE 5.2; Yields, see TABLE 5.13):

$$\text{Corn: } \sum_j X_{21,j}\ YC_j + U_3 = \text{1985 Demand}$$

$$\text{Rice: } \sum_j X_{22,j}\ YR_j + U_4 = \text{1985 Demand}$$

$$\text{Beans: } \sum_j X_{23,j}\ YB_j + U_5 = \text{1985 Demand}$$

YC = Yield Corn
YR = Yield Rice
YB = Yield Beans
j = 1, 2, ... 6 regions

Objective Function

An objective function in a mathematical programming context is a statement of what the model is attempting to accomplish. The model uses simple weighing factors to develop a partial set of trade-offs. Following is the statement of the objective function:

$$\text{Minimize } Z = W_1(U_1) + W_2(U_2) + W_3(N_1) + W_4(U_3 + U_4 + U_5)$$

where W's are weights (not preemptive)

Regional Land Constraints

The regional areas used in the model as right-hand-sides for cultivable area are shown (TABLE 5.4). Cultivable area is the sum of currently (1973) cultivated area and idle cropland.

TABLE 5.4

CURRENT CULTIVABLE AREA BY REGION IN HECTARES

Current Crop Land Use	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Idle Cropland	9,033.0	30,706.0	12,238.0	44,747.0	15,497.0	12,545.0
Cultivated	100,774.8	51,556.3	34,288.6	65,154.3	33,472.3	51,723.3
Total Cultivable	109,807.8	82,262.3	46,526.6	109,921.3	48,969.3	64,268.3

The equation for each regional land constraints is:

$$\sum_i X_i \leq \text{Total Cultivable Area in each Region (TABLE 5.4)}$$

$i = 21, 22, \ldots, 33, 70, 99$

This forces the cultivated area in solution to be less than or equal to that available in each region.

National Production Constraints

National production constraints are used to force the model to produce at least ($\geq$) national demands (requirements). The demands (requirements) by crops are listed (TABLE 5.5).

The equation is:

$$\sum_j \sum_i X_{ij} Y_{ij} \geq \text{National Requirements (TABLE 5.5)}$$

Y_{ij} is the yield associated with crop i in region j (see TABLE 5.13).

Note: In the model, minor crops and pasture are set as equalities and flexibility restraints in the short run model may force other crops to be equalities.

TABLE 5.5

NATIONAL REQUIREMENTS IN METRIC TONS

Crop	Requirements
Corn	53,491.0
Rice	104,026.0
Beans	11,445.0
Coffee	394,325.0
Sugar Cane	2,571,505.0
Bananas	1,251,580.0
Plantains	119,511.0
Cocoa	4,825.5
Tobacco	1,586.0
Potatoes	20,626.0
Yucca	13,818.0
Minor Crops	35,491.0*
Pasture	1,558,056.0*

*These are not demands in quantitative terms but just hectares planted with a yield of 1; they are forced solution to remove land for these crops.

Flexibility Restraints

Usability of this model rests on the flexibility restraints which are constraints that attempt to make the model more behavioral. Many methods can be used to estimate these constraints. Estimation is usually based on time series data but these procedures cannot be applied to this analysis since time series data are not available except at the national level.

The constraints used here are on regional production forcing the regional production of each crop between specified upper and lower bounds. If upper bounding is not done with flexibility constraints, unrealistic results often occur. An example is what happened in the single objective formulation that maximized export earnings. Per hectare bananas are the most profitable export crop in all regions of the country. The model, without bounds, essentially puts all idle land into bananas in all regions. This result is unrealistic from a national resource perspective because the agricultural regions are not homogeneous and regions that produce relatively little bananas get covered by banana production. From an economic perspective, shifts in agricultural production are incremental due to fixed factors of production, social and institutional constraints, imperfect mobility of resources, and risk preferences of farmers. Lower bound flexibility constraints are necessary to prevent unlogical regional specialization in production. The lower bounds are <u>not</u> analogous to regional demands.

Meister and Nichol (1975) use a lower bound on regional production of 2 percent per year and submit that upper bounds are less restrictive. Two sets of flexibility restraints were developed here to reflect both short (5 years) and medium (12 years) team analysis. For the short run model these constraints, based on the 1973 census, are:

$$90\% \text{ of } 1973 \leq 5 \text{ yr. solution} \leq 140\% \text{ of } 1973$$

To reflect lag in production of tree crops and the high cost of establishment the short run model does not allow them to change:

$$100\% \text{ of } 1973 \leq 5 \text{ yr. solution} \leq 100\% \text{ of } 1973$$

For the long run formulation the following applies to all crops:

$$75\% \text{ of } 1973 \leq 12 \text{ yrs.} \leq 140\% \text{ of } 1973$$

The upper bounds do not change because of the increased number of crops allowed into solution.

Weise (1978) states: "The positive view of these flexibility constraints is that they impose a reasonable and recognizable reality on an otherwise unrealistic abstract model. The negative view is that these are arbitrarily selected fudge factors that prevent the model from achieving a least cost solution." The net effect of these constraints is to control the magnitude of production in any region but not the direction of change in crop location between regions.

Coefficients

Coefficients in the goal programming matrix are specified for each of the six agricultural regions on a per hectare basis.

Labor Employment

Regional labor coefficients are given (TABLE 5.9). These are based on Central Bank data supplemented by Ministry of Agriculture studies.

Export Earnings

Per hectare export earnings coefficients by region (TABLE 5.11) are developed from the information on exports and internal consumption (TABLES 5.7 to 5.10). This coefficient is in terms of dollars and is calculated as follows:

(Yield) (1-Percent Consumed Internally) (Price)

The yields used are those described subsequently (TABLE 5.13).

Prices are F.O.B. New York City and USA, and these prices do not include transaction costs. The coffee price used was the average of prices presented (TABLE 5.7). The 1976 banana price was used (TABLE 5.8). Average prices were used for sugar cane and cocoa (TABLES 5.9 and 5.10).

Percent internal consumption is from averaging the national figures (TABLES 5.7 through 5.10).

TABLE 5.6

LABOR EMPLOYMENT ($LABOR_{ij}$) PER HECTARE
FOR REGIONS BY CROP

	Labor In Hours Per Hectare					
Crop	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Corn	512	471	416	416	250	613
Rice	424	250	436	303	208	188
Beans	517	455	349	430	463	286
Coffee	1555	681	606	1330	1399	575
Sugar Cane	667	700	700	373	640	208
Bananas	573	624	956	1868	1493	1561
Plantains	364	435	950	605	256	458
Cocoa	733	120	538	553	389	344
Tobacco	809		1600	1177		
Potatoes	1279	361	359	283	499	
Yucca	369	217	383	210	413	310
Interplanted (Corn/Beans)	720	648	536	634	499	629

TABLE 5.7

INFORMATION ON EXPORTS AND INTERNAL CONSUMPTION FOR COFFEE

	1972-1973	1973-1974	1974-1975	1975-1976
Dollar value of export	$90,116,700	$120,277,995	$85,894,213	$141,673,454
Volume of* export in MT	367,726	466,646	388,943	362,079
Price in Dollars	245	269	388	391
Percent Consumed Internally	10	10	11	15

*Volume in terms of fruta, statistics reported in oro using: La Oficina de Planificacion Sectorial Agropecuaria, San Jose, Costa Rica. "Medias y Equivalencies Utilizadas por la Oficina de Planificacion Sectorial Agropecuario." (1977).

SOURCE: Adapted from Banco Central de Costa Rica, Departamento de Credito de Desarrolo, Seccion de Economia Agropecuaria. "Datos Estadisticas del Sector Agropecuario Informe Trim estral a Junio de 1977." (Auosto 1977).

TABLE 5.8

INFORMATION ON EXPORTS AND INTERNAL CONSUMPTION FOR BANANAS

	1972	1973	1974	1975	1976
Dollar value of export	$82,830,292	$90,681,985	$98,253,456	$144,061,314	$144,604,127
Volume of export in MT	1,077,854	1,178,511	1,037,553	1,105,118	1,068,502
Price in Dollars	77	77	95	130	135
Percent consumed internally	**	**	**	**	**

**Essentially all banana production is exported.

TABLE 5.9

INFORMATION ON EXPORTS AND INTERNAL CONSUMPTION FOR SUGAR CANE

	1972-1973	1973-1974	1974-1975	1975-1976
Dollar value of export	$18,320,751	$28,030,291	$47,864,439	$17,265,209
Volume of* export in MT	1,075,465	986,589	761,356	592,722
Price in Dollars	17	28	63	29
Percent consumed internally	49	52	60	67

*Statistics reported in terms of processed sugar, converted into cane equivalencies by op.cit. La Oficina de Planificacion Sectorial Agropecuario equivalencies.

SOURCE: Op.cit., Banco Central

TABLE 5.10

INFORMATION ON EXPORTS AND INTERNAL CONSUMPTION FOR COCOA

	1972-1973	1973-1974	1974-1975	1975-1976
Dollar value of export	$2,815,460	$5,919,514	$6,287,176	$5,148,286
Volume of export in MT	3,757	5,087	5,309	4,108
Price in Dollars	749	1,164	1,184	1,253
Percent consumed internally	19	23	22	27

SOURCE: Op.cit., Banco Central

TABLE 5.11

INFORMATION ON EXPORTS AND INTERNAL CONSUMPTION FOR COCOA

	Dollars					
Crop	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Coffee	1240.5	543.0	483.3	1061.2	1116.0	458.3
Sugar Cane	990.8	1031.2	1039.7	553.3	950.1	308.7
Bananas	1656.5	1803.6	2744.6	5397.3	4314.6	4511.7
Cocoa	122.5	20.0	90.0	92.5	65.0	47.5

TABLE 5.12

ADJUSTED ANNUAL YIELDS PER HECTARE REFLECTING DOUBLE CROPPED PRODUCTION

Region	Crop	% of Land Double Cropped	Yield in MT/ha
Entral	Arroz	13.5	2.670
	Maiz	21.4	1.409
	Frijoles	32.0	.872
	Papa	44.0	16.189
Pacifico Norte	Arroz	17.4	1.578
	Maiz	33.2	1.296
	Frijoles	113.8	.767
	Papa	40.7	4.542
Pacifico Central	Arroz	20.2	2.747
	Maiz	13.2	1.145
	Frijoles	55.1	.588
	Papa	28.4	9.850
Pacifico Sur	Arroz	23.0	1.923
	Maiz	28.4	1.268
	Frijoles	70.9	.725
	Papa	55.5	3.586
Atlantico	Arroz	37.8	1.183
	Maiz	50.6	1.688
	Frijoles	37.6	.482
	Papa	--*	--*
Zona Norte	Arroz	4.0	1.312
	Maiz	27.1	1.225
	Frijoles	49.4	.781
	Papa	32.6	6.231

NOTES:

*/--, no production

Arroz = Rice   Maiz = Corn   Frijoles = Beans   Papa = Potatoes

SOURCE: Adapted from Direccion General de Estadistica y Censos, Censo Agropecuario 1973 Regiones Agricolas. San Jose, Costa Rica - Junio de 1975.

Yields

Using a land based model required accounting for multiple cropping patterns. In Costa Rica very few annuals are more than double cropped. Yields for multiple cropping are given by region (TABLE 5.10). The amount of land multiple cropped was calculated from the Census. Then, yields per hectare per year were calculated. When the analytical model brings into solution a hectare of land the yields reflect production for a full crop year.

Yields in metric tons by regions are listed (TABLE 5.13).

TABLE 5.13

CROP YIELDS PER HECTARE BY REGION IN METRIC TONS

	Metric Tons					
Crop	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Corn	1.41	1.3	1.15	1.27	1.33	1.69
Rice	2.67	1.58	2.75	1.92	1.31	1.18
Beans	.87	.77	.59	.73	.78	.48
Coffee	4.98	2.18	1.94	4.26	4.48	1.84
Sugar Cane	67.4	70.15	70.73	37.64	64.63	21.0
Bananas	12.27	13.36	20.33	39.98	31.96	33.42
Plantains	14.21	16.98	21.29	23.64	10.02	17.89
Cocoa	.49	.08	.36	.37	.26	.23
Tobacco	.88		1.74	1.23		
Potatoes	16.19	4.54	9.85	3.59	6.30	
Yucca	7.29	4.28	7.56	4.15	8.15	6.11
Interplanted						
A) Corn	1.03	.95	.84	.93	.97	1.23
B) Beans	.64	.56	.43	.53	.57	.35

Costs of Production

Annual costs of production on a per hectare basis are presented (TABLE 5.12). These costs only include hired labor, seed, fertilizer, machinery, and herbicides/pesticides.

TABLE 5.14

CROP COSTS OF PRODUCTION BY REGION IN COLONES

	Colones*					
Crop	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
Corn	35.57	27.31	29.09	30.82	30.89	38.10
Rice	33.90	31.80	40.75	43.14	34.11	45.20
Beans	30.89	23.10	36.29	39.99	34.96	23.20
Coffee	170.80	138.70	137.30	108.00	138.70	138.70
Sugar Cane	51.00	24.10	33.40	25.20	33.40	33.40
Bananas	25.00	25.00	25.00	25.00	25.00	25.00
Plantains	29.50	29.50	29.50	29.50	29.50	29.50
Cocoa	40.00	40.00	40.00	40.00	40.00	40.00
Tobacco	197.60	197.60	197.60	197.60	197.60	197.60
Potatoes	257.33	251.43	229.45	277.88	236.96	
Yucca	20.60	20.60	20.60	20.60	20.60	
Interplanted (Corn/Bean)	48.52	36.80	47.73	51.70	48.07	51.32

*Adjusted for inflation to 1979.

Model Assumptions, Limitations and Usefulness

As previously discussed, goal programming techniques are closely akin to linear programming. As Lee (1972) states: "Some limitations are inherent to all quantitative tools, and some are attributable to the particular characteristics of individual techniques". Numerous approaches have been developed to circumvent technique limitations.

The limitations associated with this particular model formulation are presented.

Assumptions

1) The activities are additive, linear and divisible, i.e.; the total output produced by all activities equals the sum of individual activities and the same

is true for inputs; the input/output coefficients exclude any interaction (linear); production is infinitely divisible.

2) Input prices remain at 1976 levels and quantify of input use does not affect price (perfectly elastic input supply functions).

3) National aggregate production of export crops does not affect export prices (perfectly elastic demand functions). The most critical crop with respect to this assumption is probably banana.

4) The agricultural regions are homogeneous production units. The implications of different technology levels is not approached. These could have substantial impacts on agricultural sector objectives. For example, if small farms are relatively labor intensive, optimization of a model specified by farm size could result in trade-offs between farm size and certain sector objectives, especially export earnings and minimization of cost.

5) The model is deterministic, that is, uncertainty is ignored.

6) The model is static.

The assumptions described above are limiting factors specific to this type of optimization model.

In the following section limitations not specific to the specifications of this model and conditions affecting its specification are discussed.

Limitations

Only a partial analysis of trade-offs between national agricultural sector objectives is conducted as interactions outside of the sector are not approached. Additionally, the complete agricultural sector was not modeled.

A major limitation is the absence of the livestock sector. The model set pasture as an equality constraint which does not allow increasing extensive production or the removal of pasture for cropland. This influences the models ability to reflect the Costa Rican attempt to diversify agricultural production, to diversify sources of export earnings, and to shift pasture to basic grain production. Costs Ricas' beef export market, the United States, has been strong in recent years. As Costa Rica is located north of the Food and Mouth disease zone so, it can export to fresh meat markets.

Another limitation is the exclusion of cotton and sorghum from the model. Cotton is a potential export crop. Sorghum is used exclusively as a cattle feed in Costa Rica.

A consideration in Costa Rica has been the deforestation of land to establish new pasture. This has compounded drought problems. The equality constraint on pasture does not allow the return of pasture to forest which might be expected under a minimization of production cost objective.

A substantial limitation is that the model specification abstracts from institutions and infrastructure. Especially important is the inability to reflect costs of transportation in the cost coefficients and the lack of knowledge about the ability of farmers to adapt different crops. For example, if credit and cash flow are constraints farmers may not be able to establish perennial crops. By abstracting from institutions the model is not dynamically prescriptive for policy or change in institutional structure; rather it is a status quo analysis of trade-offs. The implication is that how to achieve objectives in an administrative sense is not addressed. "How to" is a function of the amount of control the decision-makers can generate through policy tools.

As the model is a partial analysis, model results can not be interpreted as generating zero cost resource allocation adjustments through changes in regional crop production that lead to objective function values that are higher than the base (1973). The model does provide insight into regional production potential for different national objectives and the crops and regions where micro analyses may be warranted.

Usefulness: Direction of Change

It is often suggested that the direction of change be emphasized in analytical models. This point becomes especially important when the regions are fairly large and characterized by heterogeneous agriculture, when only secondary data sources are used and, when data sources are somewhat inconsistent and do not include time series. Besides data and aggregation problems the magnitude of change determined by optimization analytical models is sometimes governed by flexibility restraints. Flexibility restraints do not change the direction of change -- only the magnitude. For policy purposes this type of model may be most useful by analyzing the direction of change. But, as long as assumptions and limitations of the approach is understood, trade-offs determined by the model should shed light on the agricultural sector objectives.

Chapter 6

RESULTS OF ANALYSIS

"Quantification is an aid to thought, not a substitute for it, and so long as users treat it this way, it can be helpful to policy analysis," (Campbell and Nichols, p.566).

Introduction

Selected modeling results depicting trade-offs between the stated national agricultural sector goals for both short-run and medium-run planning horizons are presented in this Chapter. Five modeling results (representative point solutions) will be emphasized. These models were optimized for both short-run and medium-run time frames. The models used were:

Model I - maximize labor employment only

Model II - maximize export earnings only

Model III - minimize cost of production only

Model IV - equal weights on the above objective functions (10 used as base weight)

Model V - respective weights of 100, 100, 10 and 1000.

These models reflect the agricultural sector objectives which are: maximizing labor employment; maximizing export earnings;

minimizing cost of production; and self sufficiency in the basic grain (satisfying demands).

The weights can be considered implicit linear utility functions with the attributes of the objectives in the multiple objective framework quantified in the following terms:

Labor - in hours

Export Earnings - in dollars

Cost of Production - in colones

Basic Grains - in metric tons

For example, weights of 100, 100, 10, and 1000 imply a utility function that values one metric ton of basic grain as worth, 10 times more than 100 hours of employment, 10 times more than 100 dollars in export earnings and 100 times more than changing the cost of production by 10 colones.

For reference a map delineating the Agricultural regions of Costa Rica is shown (FIGURE 6.1).

Fifteen crops and six regions were included in the models discussed here. Only major regional crops and major production changes will be focused on here, complete details are in mimio form.[1] An example of the GP model output is given for medium-run model V (Appendix A).

Short-run Results

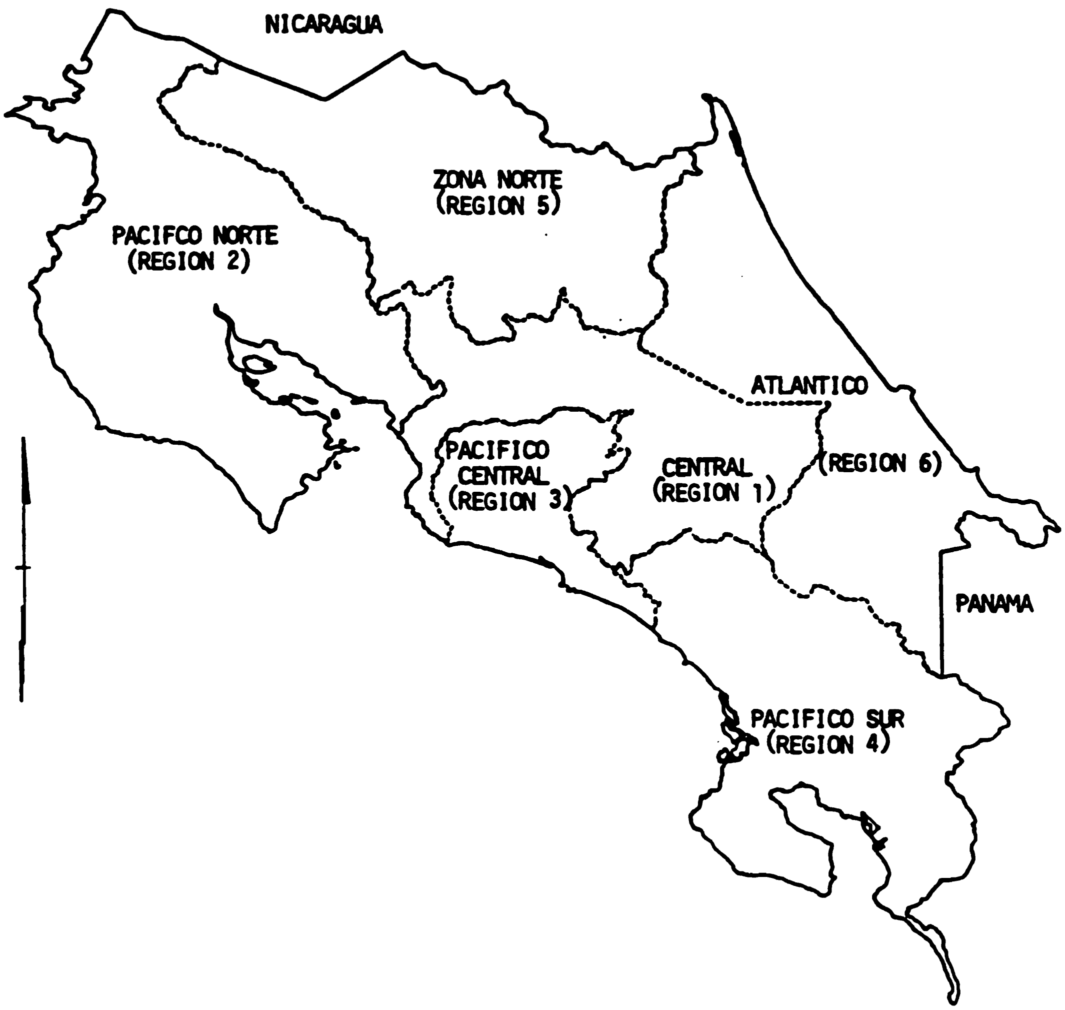
The short-run analysis depicts the case where decision makers heavily discount the future. Possibilities for increasing production are restricted to crops that do not have substantial time lags (4 to 5 years) in Costa Rica are coffee, bananas, and

---

[1] See (Robb, 1980).

FIGURE 6.1

AGRICULTURAL REGIONS OF COSTA RICA



Scale Approx. 1:1,078,000 (In KM)

0 30 65 130

ADAPTED FROM: DIRECCION GENERAL DE ESTADISTICA Y CENSOS, <u>CENSO AGROPECURAIO 1973 REGIONES AGRICOLAS</u>. SAN JOSE, COSTA RICA - JUNIO DE 1975.

cocoa. Flexibility constraints also allow less regional specialization in the short-run compared to longer term model.

Production Patterns

Agricultural production patterns that optimize associated models in the short-run are depicted (FIGURES 6.1 to 6.6). Each "+" or "-" illustrates a change of 500 to 1,499 hectares compared to the 1973 base.

Regional Activities in Solution

For Model I region 1 is the only region to use all the available idle land with 9,033 more hectares cultivated than the 1973 base. All other regions use more land than the 1973 base. The two most dramatic regional production changes are in region 1 where sugar cane increases and region 2 where bean production increases. In this model no solo bean production occurs in region 1 as all the regional bean requirement is met by intercropping. No other regions have the intercropping activity in solution.

Under Model II all regions have idle cropland. Regions 2 and 4 have more idle cropland than the 1973 base. The largest regional change in production occurs in region 1 where sugar cane production increases. No solo bean production occurs in regions 1, 2, 4, and 5.

Under Model III is the only case where region 1 has more idle land, 3662 hectares, than the 1973 base. Other regions with more idle land than in 1973 are 4, 5, and 6. The largest crop hectarage change in any region is approximately 3,000 hectares so

FIGURE 6.2

SHORT-RUN: MAXIMIZE LABOR (MODEL I)

PRODUCTION PATTERNS

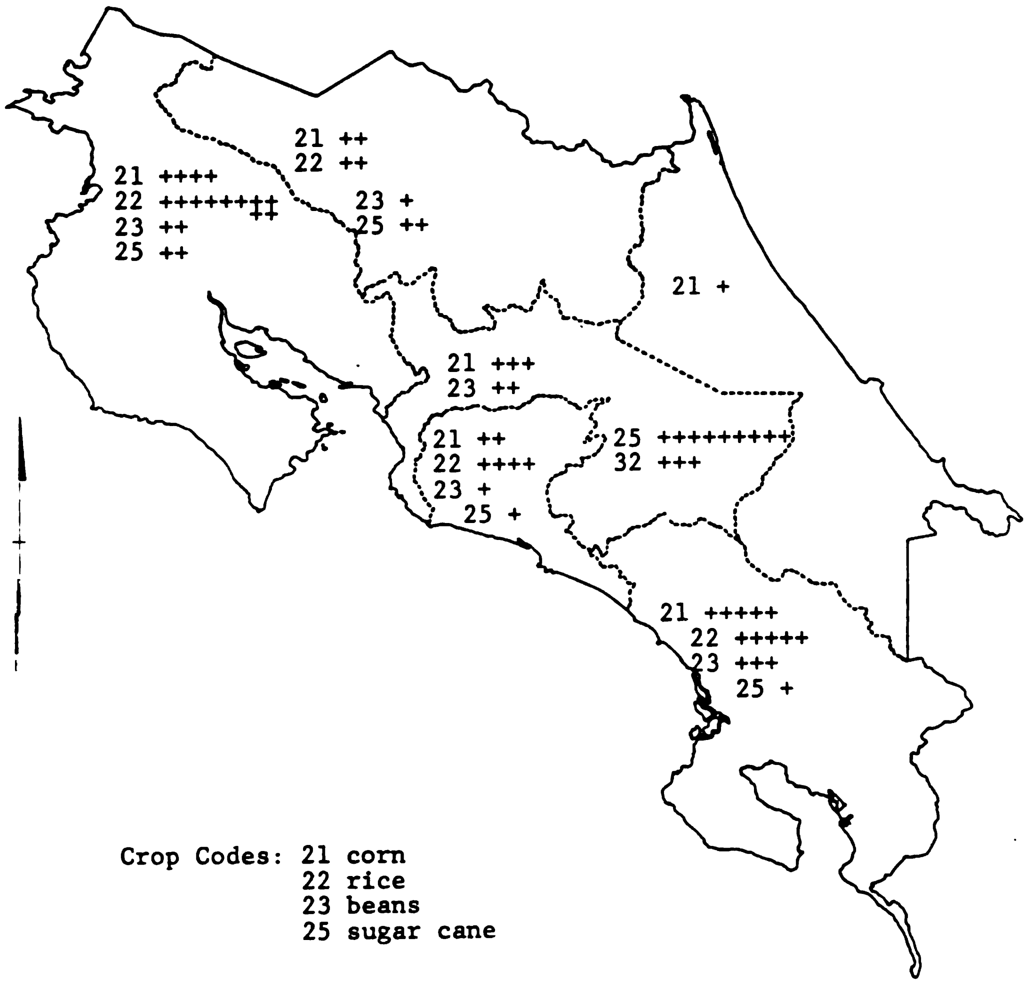


FIGURE 6.3

SHORT-RUN: MAXIMIZE EXPORT EARNINGS (MODEL II)

PRODUCTION PATTERNS

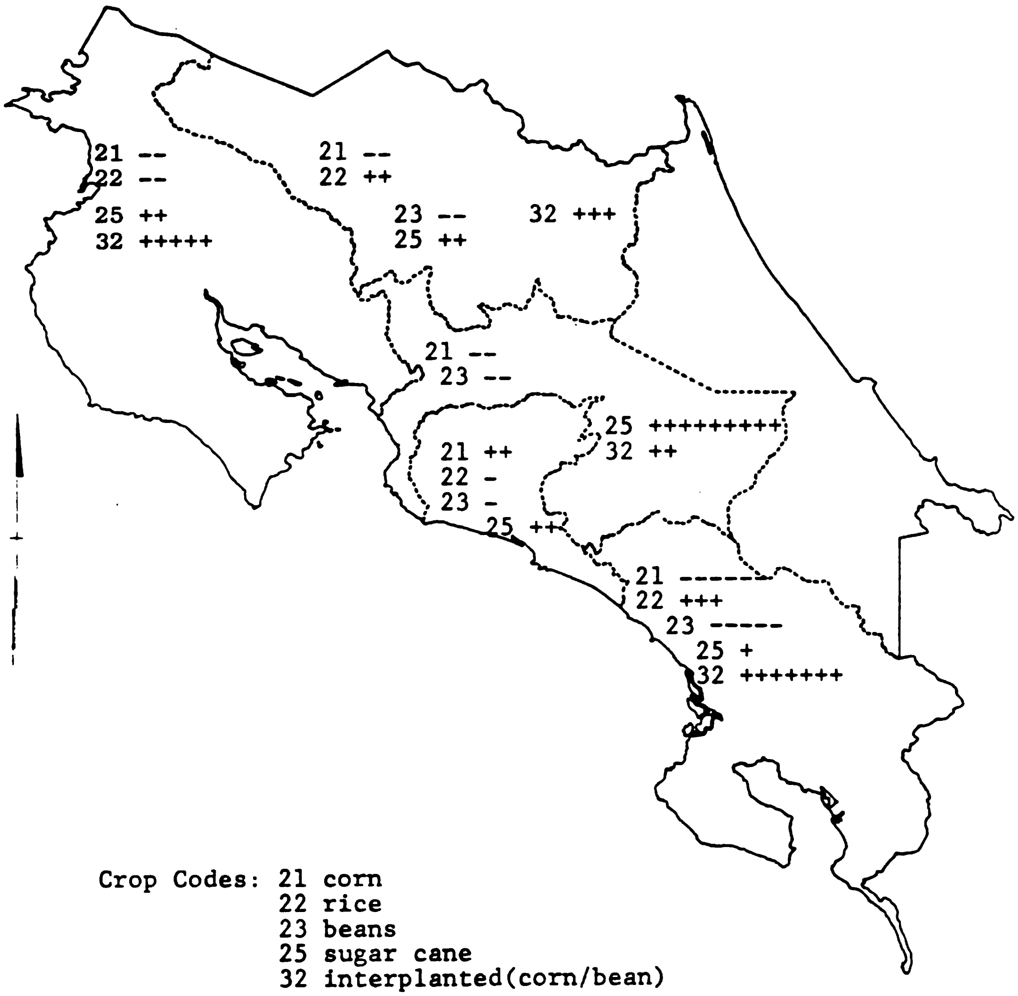


FIGURE 6.4

SHORT-RUN: MINIMIZE COST (MODEL III)

PRODUCTION PATTERNS

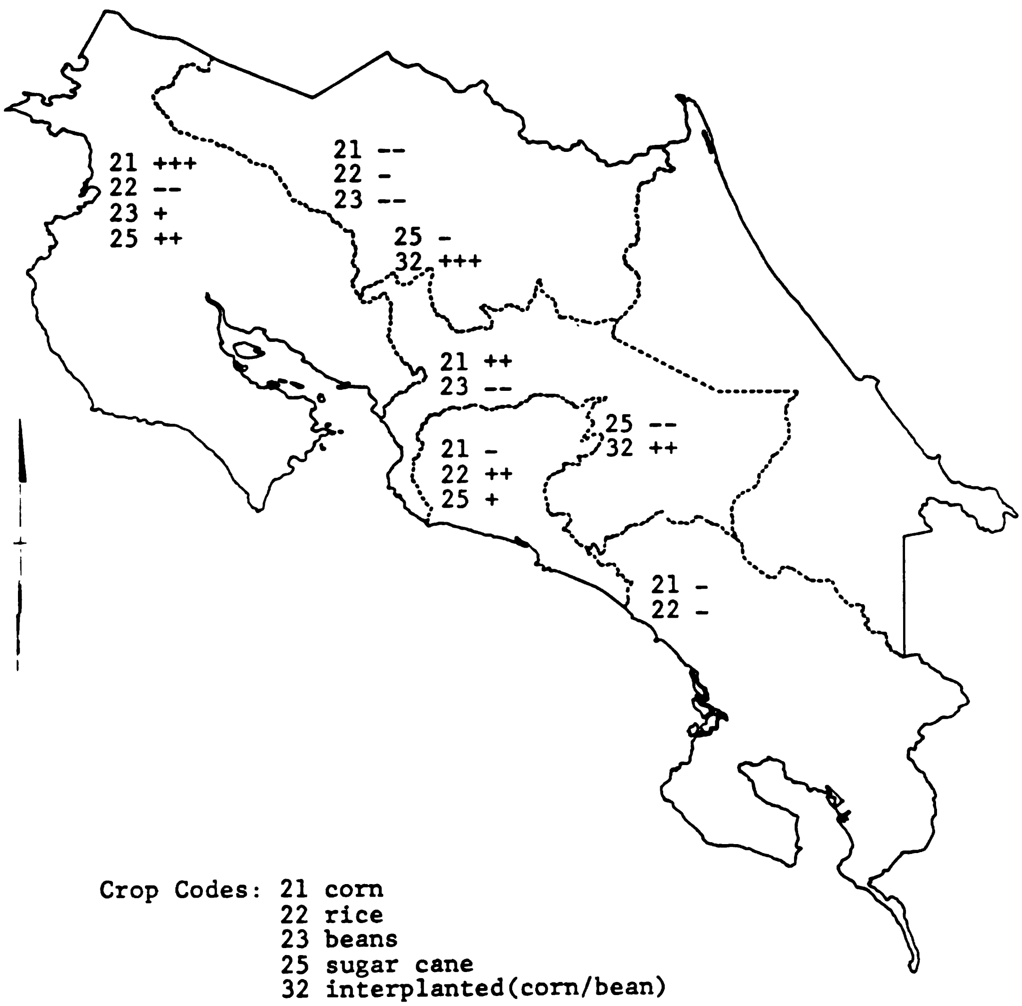


FIGURE 6.5

SHORT-RUN: EQUAL WEIGHTS (MODEL IV)

PRODUCTION PATTERNS

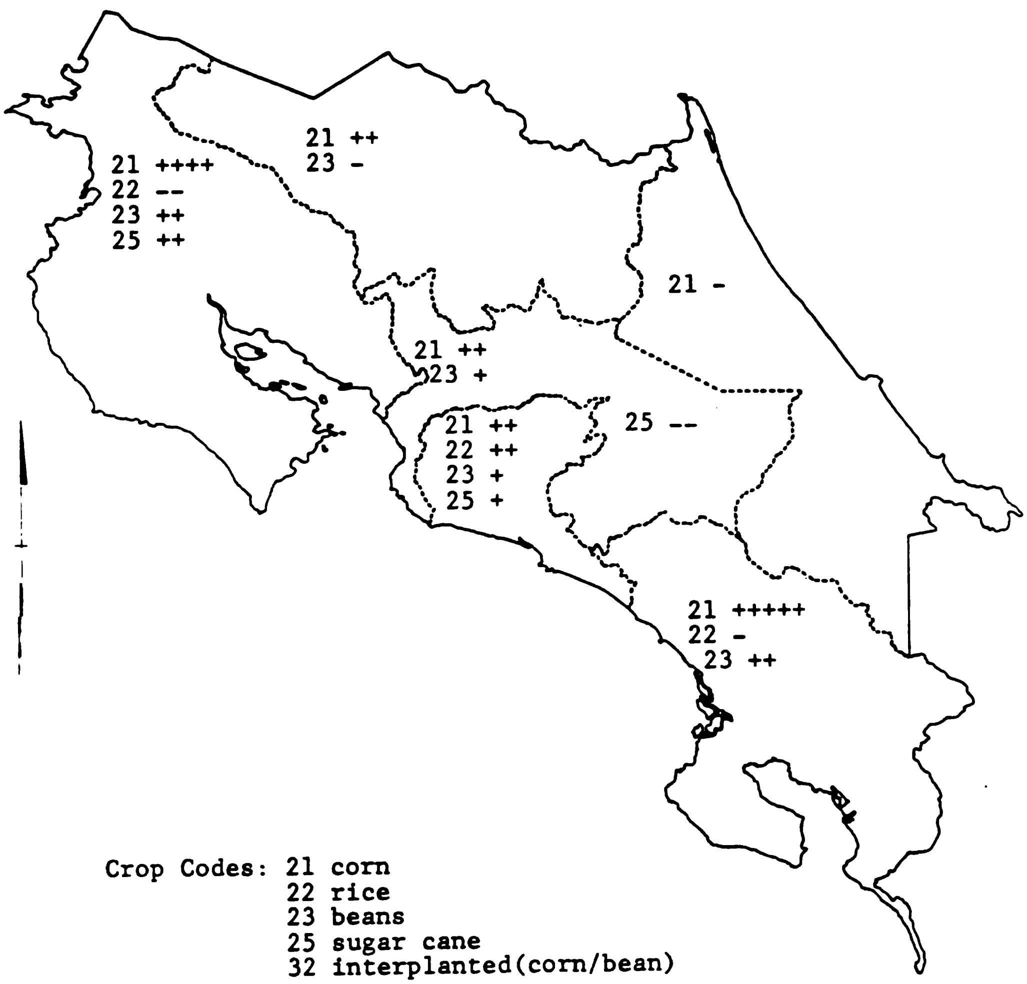
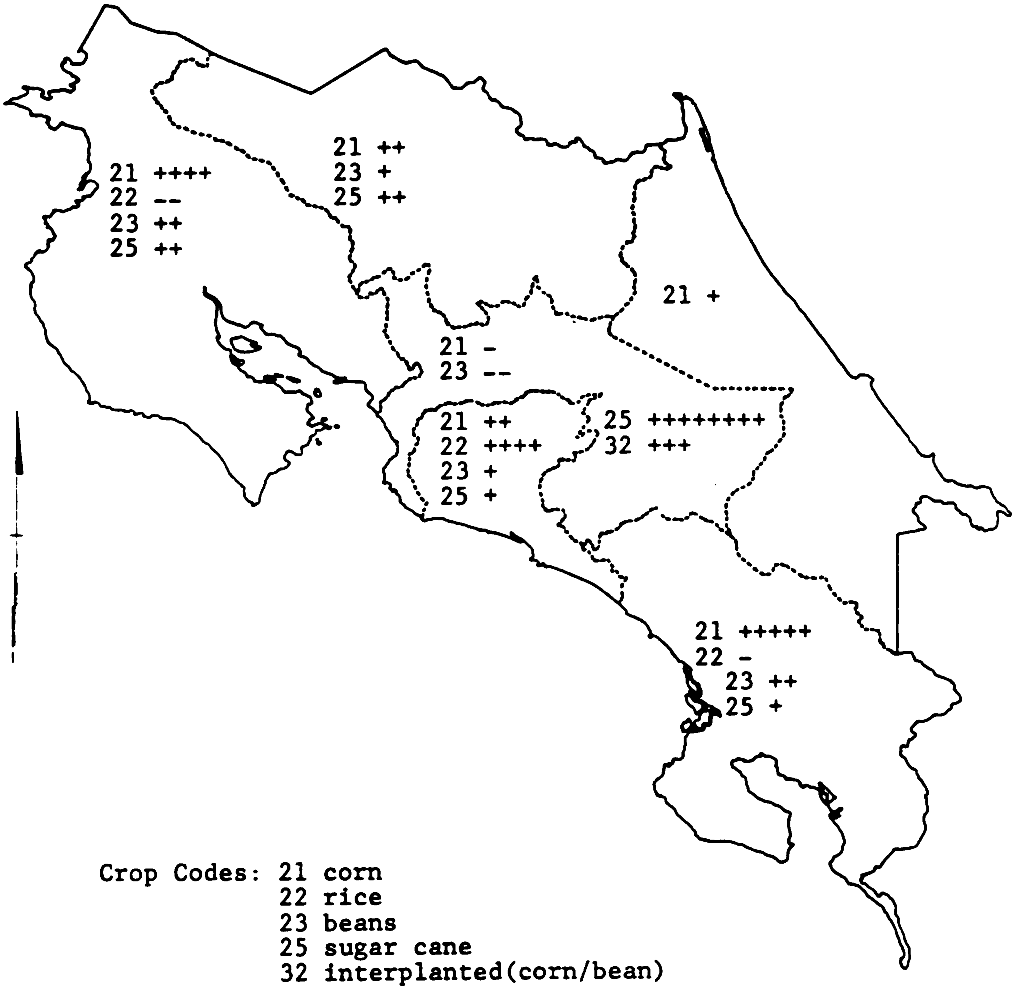


FIGURE 6.6

SHORT-RUN: WEIGHTS 100, 100, 10, 1000 (MODEL V)

PRODUCTION PATTERNS



changes are not nearly as dramatic as under other models. This reflects that, in the short-run, regional production patterns of 1973 are fairly consistent with a simple minimization of cost market solution. This is the traditional LP land base model formulation. There are many reasons why 1973 production patterns are not reflected exactly including the assumptions of the model and non simple market determinants of production.

Under Model IV all regions have more land in solution than the 1973 base, but no region uses all available cropland. No intercropping occurs in this case in any region. Under this model corn production increases on the order of 2,000 and 5,000 metric tons in each region except region 6 which decreases.

Under Model V region 1 uses all the idle cropland available in 1973. All other regions have idle land but less than the 1973 base. The national cropping pattern is similar to that under Model IV with the most significant difference in region 1 where approximately 8,000 more hectares of sugar cane over the 1973 base. All regions have intercropping in solution.

Values of Objective Functions and Sensitivity Analysis

A value-path display for the objective functions at the national level is presented (FIGURE 6.7). Cohon (p.161) attributed value path methodology to Schilling. The three basic grains are collapsed into one function (metric tons of basic grains) in the figure.

The value of objective functions and the breakdown by region for the short-run model solutions are presented (TABLE 6.1).

FIGURE 6.7

NATIONAL SHORT-RUN RESULTS:

VALUE PATH DISPLAY

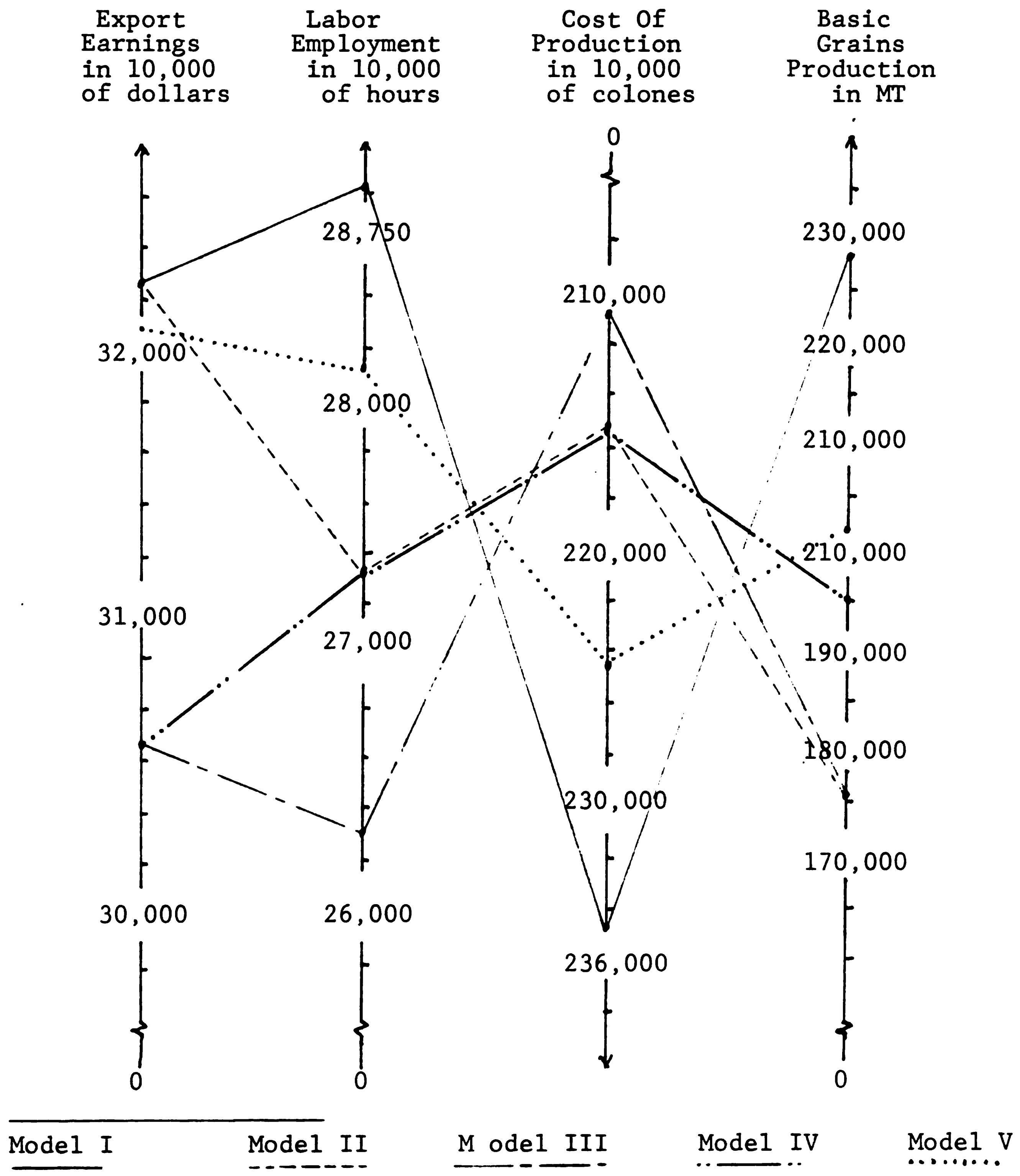


TABLE 6.1

NATIONAL AND REGIONAL VALUES OF OBJECTIVE FUNCTIONS FOR SHORT-RUN MODELS

Weights on Objectives		National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
					(Model I)			
0	1) EXPEARN	32118.	11184.	802.	553.	7012.	1864.	10703.
1	2) LABOR	28998.	12722.	2454.	1526.	5741.	1855.	4699.
0	3) COST	235884.	133896.	21129.	12376.	36962.	15139.	16382.
0	4) B GRAIN							
	CORN	72075.	6016.	20180.	8859.	21477.	7305.	8238.
	RICE	144369.	2279.	54725.	40383.	37442.	8639.	902.
	BEANS	16023.	2108.	4148.	2162.	5030.	2492.	83.
					(Model II)			
1	1) EXPEARN	32118.	11184.	802.	553.	7012.	1864.	10703.
0	2) LABOR	27332.	12586.	1882.	1292.	5256.	1730.	4586.
0	3) COST	220124.	131789.	15810.	10184.	32613.	14050.	15678.
0	4) B GRAIN							
	CORN	54026.	5675.	15693.	8859.	13807.	4696.	5296.
	RICE	105066.	2279.	35180.	25960.	32106.	8639.	902.
	BEANS	11559.	1355.	2667.	2162.	3691.	1602.	83.
					(Model III)			
0	1) EXPEARN	30620.	10025.	802.	536.	6966.	1591.	10700.
0	2) LABOR	26302.	11813.	2056.	1269.	5089.	1500.	4574.
1	3) COST	210656.	125661.	16673.	10238.	30469.	12126.	15489.
0	4) B GRAIN							
	CORN	53491.	5675.	18322.	5695.	13807.	4696.	5296.
	RICE	104026.	3545.	35180.	35098.	24070.	5554.	580.
	BEANS	11445.	1355.	3811.	1390.	3234.	1602.	53.

(Continued)

TABLE 6.1 (con't.)

Weights On Objectives		National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
					(Model IV)			
10	1) EXPEARN	30620.	10025.	802.	536.	6966.	1591.	10700.
10	2) LABOR	27317.	11980.	2144.	1429.	5473.	1608.	4683.
10	3) COST	218023.	126728.	17165.	11513.	33314.	13132.	16172.
10	4) B GRAIN							
	CORN	74887.	8828.	20180.	8859.	21477.	7305.	8238.
	RICE	104026.	3545.	35180.	35098.	24070.	5554.	580.
	BEANS	16023.	2108.	4148.	2162.	3234.	2492.	83.
					(Model V)			
100	1) EXPEARN	32010.	11077.	802.	553.	7012.	1864.	10703.
100	2) LABOR	28330.	12657.	2144.	1526.	5508.	1802.	4694.
10	3) COST	225464.	131975.	17172.	12359.	33556.	14142.	16259.
1000	4) B GRAIN							
	CORN	74887.	8828.	20180.	7704.	21477.	7305.	8238.
	RICE	108045.	2279.	35180.	14685.	24070.	5554.	580.
	BEANS	16023.	2108.	4148.	3664.	5030.	2492.	83.

The range in export earnings is \$1,498,000. This is a function of sugar cane production patterns as it is the only non-perennial export crop. The range in total metric tons of basic grains is from 25,974 metric tons to 194,936 metric tons. This is well below the 1985 total demand of 360,826 metric tons but this solution resulted from all regional production flexibility restraints being met. The range on labor is 2,696,000 hours, the low being for Model III (minimization of cost) and the high for Model I (maximization of labor). The range on cost of production, estimated as the difference between Models I and III was 25,228,000 colones. 25,228,000 colones, again determined by Models I and III.

The full trade-off surface was not generated due to the size of the model developed here and the number of objective functions involved. Representative points on the surface were selected with the aid of sensitivity analysis. Sensitivity analysis or ranging shows the bounds that a solution holds for individual objective function weight changes giving insight into robustness. Simultaneous objective function changes are constrained by the "100% rule" (explained in Chapter 2). The ranges and the types of vectors going into solution at the end points are analyzed in subsequent discussion. Analyzing the end points helps in determining robustness. For example, if the entering vectors are not crop production activities, then the solution is more robust than the ranges may suggest.

For equally weighted objectives (Model IV) the base weight is 10. The ranges are listed below:

1) Export Earnings - 5.63 to 10.70

2) Labor Employment - 5.46 to 11.16

3) Cost of Production - 9.71 to 14.80

4) Basic Grains

Corn - 2.17 to $.70 \times 10^{14}$

Rice - 1.32 to $.15 \times 10^{17}$

Beans - 6.11 to $.28 \times 10^{15}$

At both on Export Earnings a regional production constraint (maximum or minimum) is the incoming vector. For the lower bound on labor employment an intercropping vector comes into solution and at the upper board the vector is a regional production constraint. Both bounds on cost also bring in regional production constraints. The upper bounds on corn and beans bring in intercropping vectors. The upper bound on rice bring in a regional production constraint. The lower bound on rice hits the national production requirement.

When objective functions of Model V were used (weights 100, 100, 10, 1000 respectively) the following ranges hold individually:

1) Export Earnings - 97.39 to 124.15

2) Labor Employment - 99.56 to 106.79

3) Cost of Production - 9.50 to 10.04

4) Basic Grains

Corn - 7.03 to $.12 \times 10^{16}$

Rice - over achieved (not in the basis)

Beans - 2.95 to $.39 \times 10^{16}$

All the end points were limited by regional production constraints except for corn and beans which bring a intercropping vectors. Rice production overachieved the target in the model, showing the complementary between labor employment and basic grains in the short-run.

Medium-Run Model Results

In the specification of the medium-run model all crops are allowed into solution and the flexibility restraints are less restrictive.

Production Patterns

Regional production patterns defined by the number of hectares in solution compared with the 1973 Census base are depicted (FIGURES 6.8 to 6.12). Again, each "+" or "-" defines a change of 500 to 1,499 hectares. For very large changes, such as coffee, the sign depicting direction of change compared to 1973 is followed by a factor in parenthesis (ie + (17) is 17 times the upper limit on change of 1,499 hectares).

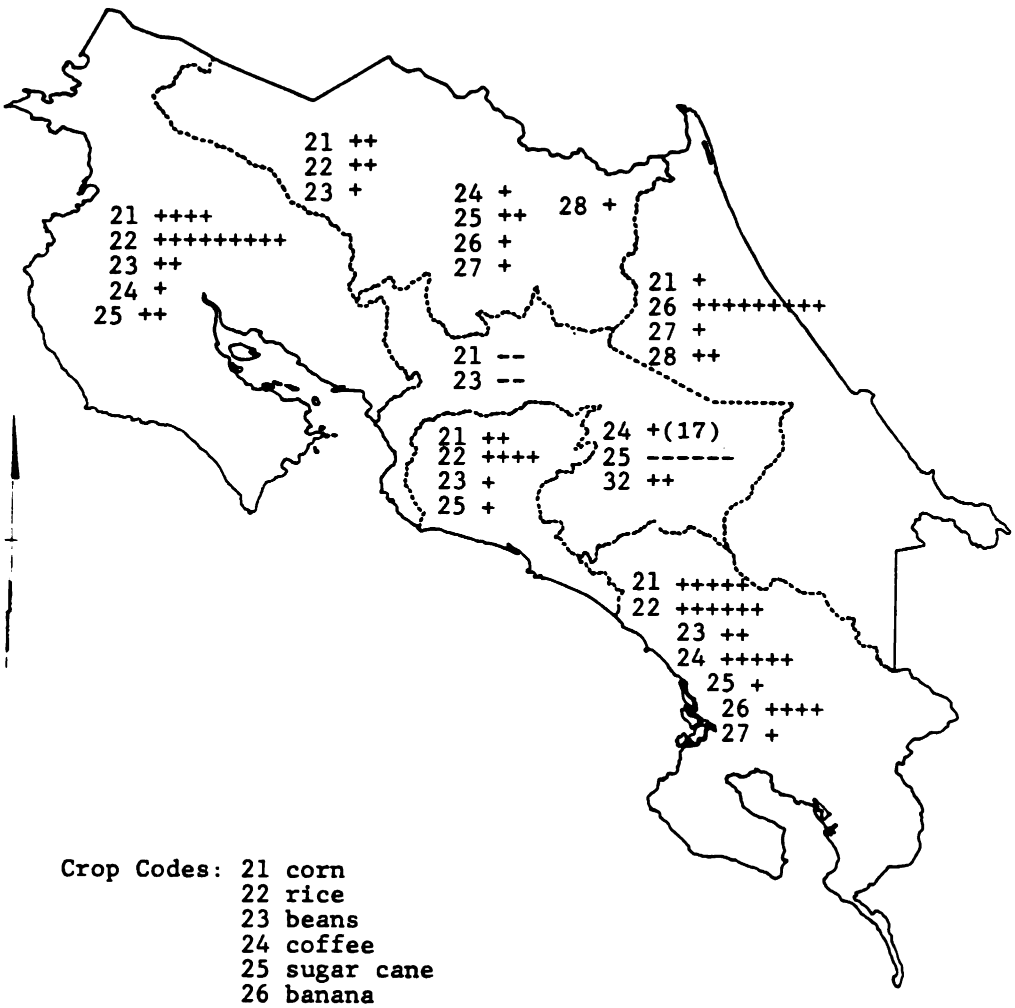
Regional Activities in Solution

Under Model I regions 1 and 6 have no idle land in solution as all available from the 1973 base is used for production. Region 1 has significant increasing hectarage of coffee, about 17,000 hectares, and significant decreasing hectarage of sugar cane, about 6,000 hectares, compared to the 1973 base. Region 2 has significant, about 9,000 hectares, of increased rice hectarage compared to 1973. Region 4 has increases on the order of 4,000 - 5,000 hectares of each corn, rice and coffee. Region 6 has about 9,000 more hectares of bananas compared to 1973. Intercropping occurs only in region 1.

FIGURE 6.8

MEDIUM-RUN: MAXIMIZE LABOR (MODEL I)

PRODUCTION PATTERNS



Crop Codes: 21 corn
22 rice
23 beans
24 coffee
25 sugar cane
26 banana
27 plantain
28 coco
32 interplanted(corn/bean)

FIGURE 6.9

MEDIUM-RUN: MAXIMIZE EXPORT EARNINGS (MODEL II)

PRODUCTION PATTERNS

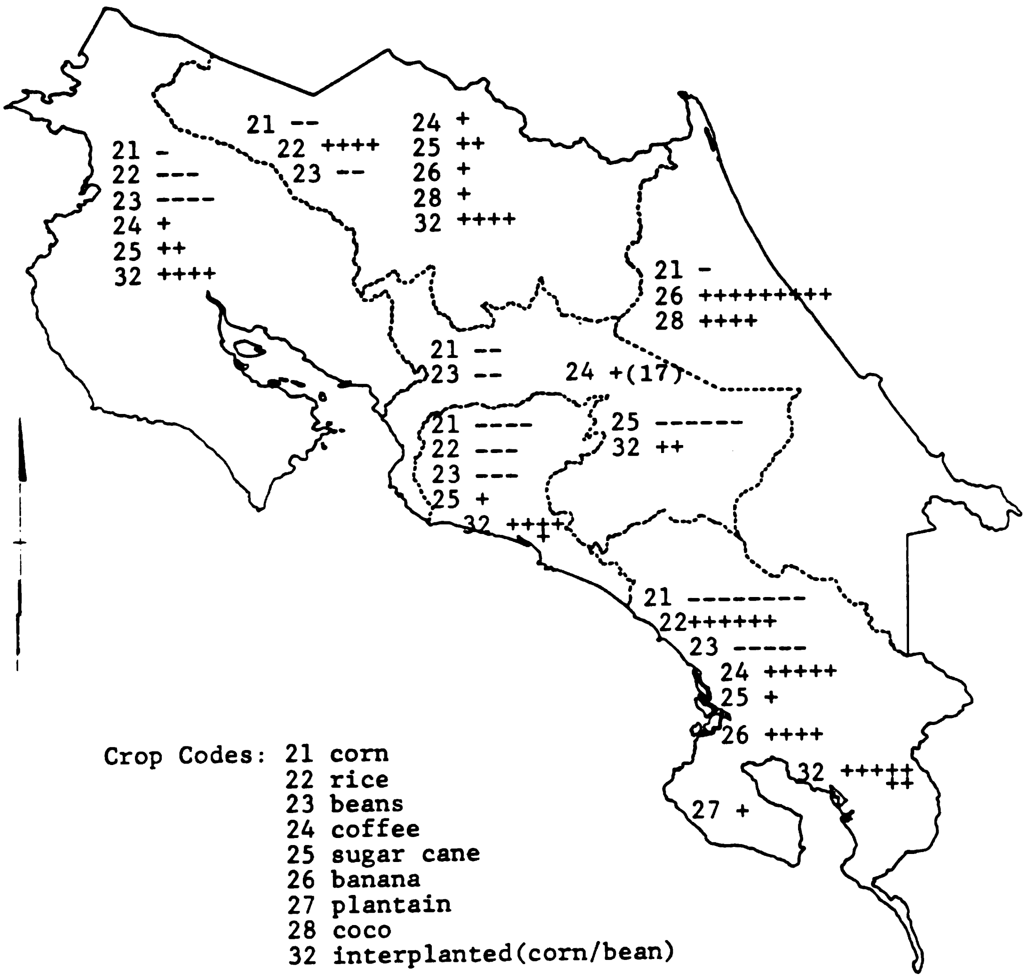
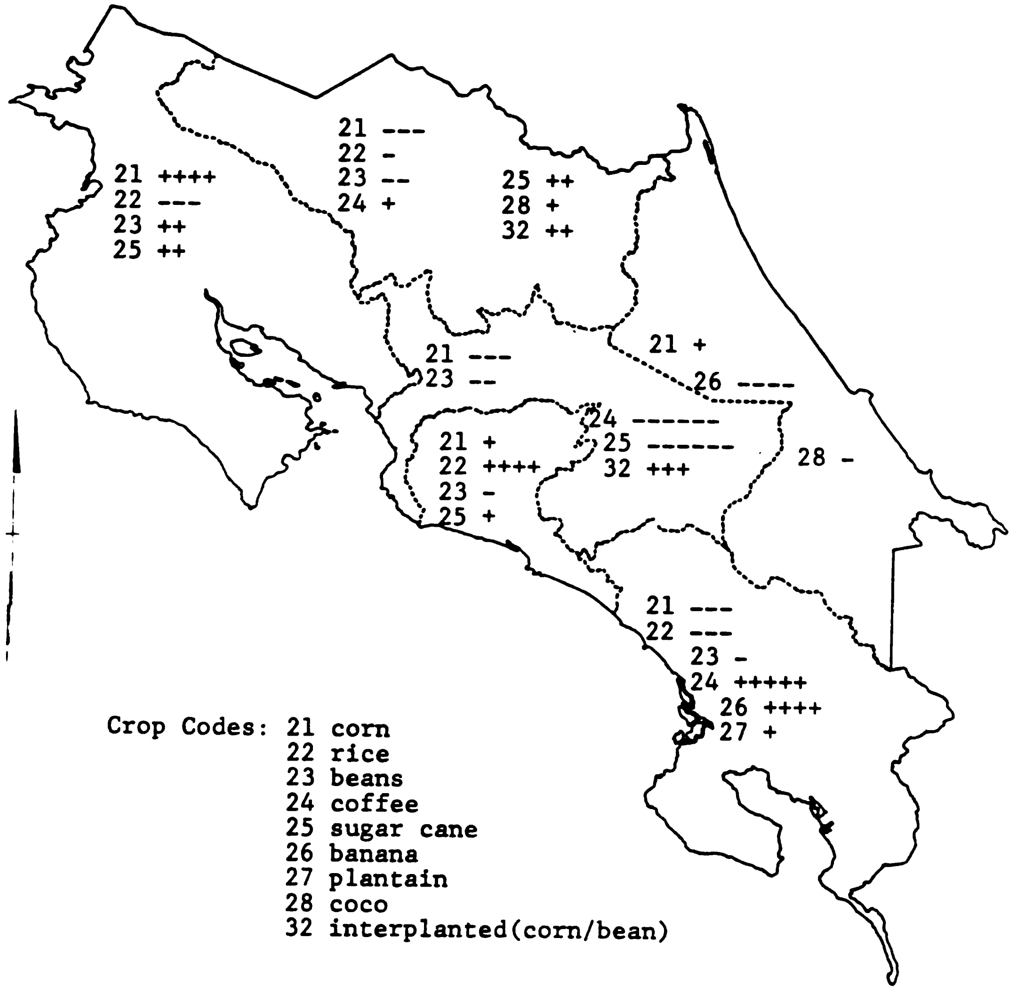


FIGURE 6.10

MEDIUM-RUN: MINIMIZE COST (MODEL III)

PRODUCTION PATTERNS



Crop Codes: 21 corn
22 rice
23 beans
24 coffee
25 sugar cane
26 banana
27 plantain
28 coco
32 interplanted(corn/bean)

FIGURE 6.11

MEDIUM-RUN: EQUAL WEIGHTS (MODEL IV)

PRODUCTION PATTERNS

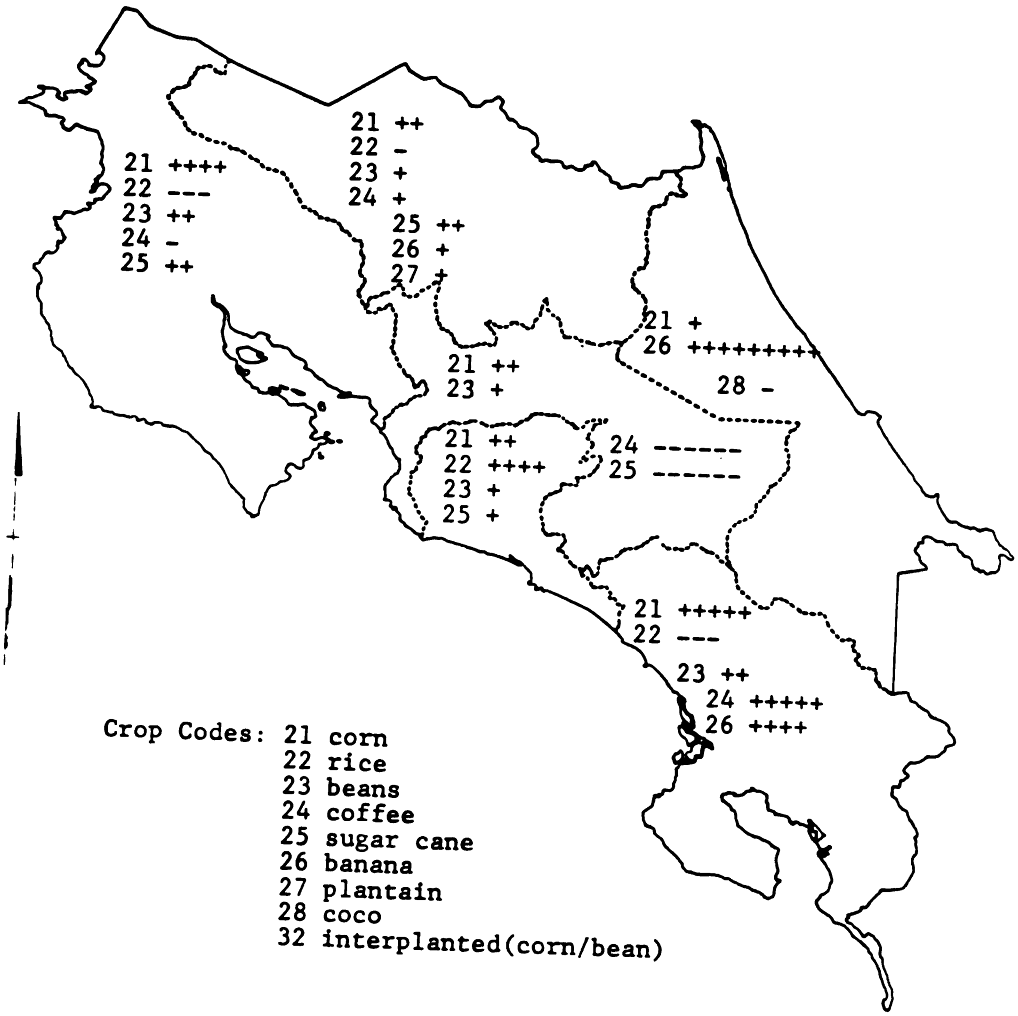
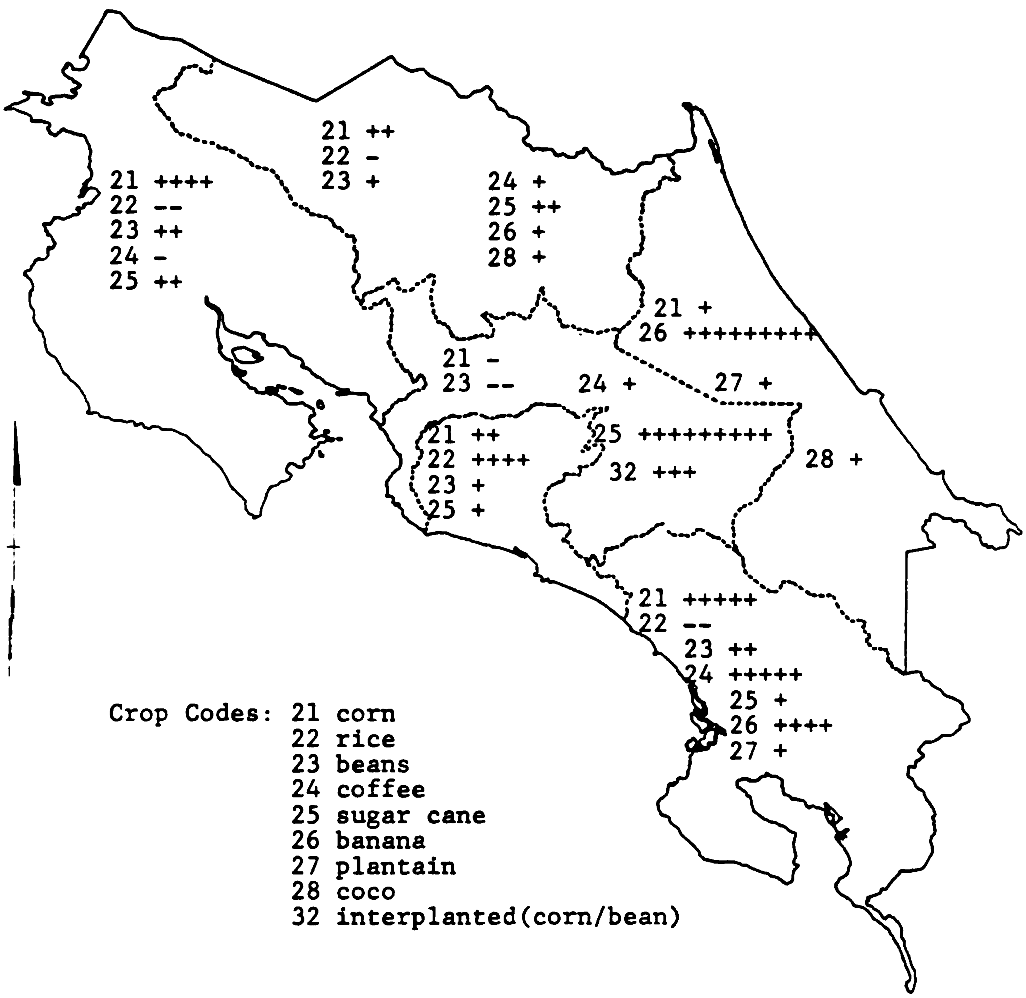


FIGURE 6.12

MEDIUM-RUN: WEIGHTS 100, 100, 10, 1000 (MODEL V)

PRODUCTION PATTERNS



Under Model II regions 1 and 6 have no idle cropland as all that available in 1973 is in production. Region 3 has more idle cropland, 2,843 hectares, than were idle in 1973. All other regions have idle cropland but less than in 1973. Region 1 has the same results as under Model I. Compared to Model I region 4 shifts from solo corn and bean production to meeting requirements by intercropping. Region 6 under this model has about 9,000 hectares more bananas than 1973, this also occurred under Model I.

Model III results in region 1 having 13,222 more hectares idle than in 1973. Region 6 has 5,358 more hectares idle than 1973. All other regions have more land in solution than the 1973 base. Region 3 is the only region to specialize in rice production. Rice production decreases in regions 2, 4, 5 and holds relatively constant in regions 1 and 6. This model has some significant changes in the spacial location of export crop production. Region 1 has decreases on the order of 6,000 hectares of coffee and sugar cane. Region 4 has increases or the order of 5,000 hectares for coffee and bananas. Region 6 has approximately 4,000 fewer hectares of bananas than the 1973 base. Only regions 1 and 4 have intercropping in solution.

Under Model IV region 1 has 8,777 more hectares idle than the 1973 base. All other regions have less idle land than the 1973 base. Under this model only region 3 tends to specialize in rice production. Coffee and sugar cane production both decrease on the order of 6,000 hectares in region 1 compared to 1973. In region 4 both corn and coffee production increase in the range of

5,000 hectares. In region 6 banana production increases on the order of 9,000 hectares. No intercropping comes into solution.

Model V results in no idle cropland in regions 1 and 6. Coffee production increases in the range of 1000 hectares, low net change compared to other models. Sugar cane production increases on the order of 9,000 hectares in region 1 compared to 1973. Coffee and corn production increase by short 5,000 hectares in region 4. Banana production increases by about 9,000 hectares in region 6. Intercropping only comes into solution in region 1.

Values of Objective Functions and Sensitivity Analysis

Medium-run national objective function results as percent increases compared to short-run results are presented (TABLE 6.2).

The values of objective functions by model with regional breakdowns are given (TABLE 6.3). The maximum labor is 34,057,000 hours (maximizing labor) and the minimum labor employed is 26,308,000 hours (minimizing cost) for a range of 7,749,000 hours. The range

TABLE 6.2

MEDIUM-RUN NATURAL RESULTS AS PERCENT OF SHORT-RUN

Model	Percent Increase			
	EXPEARN	LABOR	COST	BASIC GRAINS
I	126	117	114	98
II	126	119	114	100
III	100	100	98	100
IV	122	108	100	100
V	122	104	96	98

TABLE 6.3

MEDIUM-RUN

Weights On Objectives		National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
					(Model I)			
0	1) EXPEARN	40327.	11868.	856.	588.	9766.	2304.	14946.
1	2) LABOR	34057.	14251.	2516.	1570.	7295.	2198.	6277.
0	3) COST	269964.	153318.	22323.	12826.	44273.	17782.	19442.
0	4) B GRAIN							
	CORN	70851.	4793.	20180.	8859.	21477.	7305.	8238.
	RICE	143602.	1924.	54725.	40383.	37442.	8639.	489.
	BEANS	15059.	1145.	4148.	2162.	5030.	2492.	83.
					(Model II)			
1	1) EXPEARN	40368.	11887.	856.	588.	9766.	2304.	14967.
0	2) LABOR	32501.	14205.	2072.	1118.	6801.	2153.	6153.
0	3) COST	257250.	152638.	17693.	9176.	40728.	17447.	19568.
0	4) B GRAIN							
	CORN	54026.	4793.	20180.	5618.	11659.	7305.	4472.
	RICE	105066.	1924.	34649.	21922.	37442.	8639.	489.
	BEANS	11559.	1145.	2252.	2162.	3465.	2492.	45.
					(Model III)			
0	1) EXPEARN	30620.	8977.	770.	532.	9755.	1855.	8730.
0	2) LABOR	26308.	10708.	2097.	1293.	6481.	1811.	3919.
1	3) COST	206007.	114167.	16322.	10445.	36315.	14659.	14100.
0	4) B GRAIN							
	CORN	53491.	4793.	20180.	4809.	11659.	3966.	8085.
	RICE	104026.	1924.	34593.	40383.	20325.	4690.	489.
	BEANS	11445.	1145.	4148.	1173.	2731.	1353.	45.

(Continued)

TABLE 6.3 (con't.)

Weights On Objectives		National	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6
					(Model IV)			
10	1) EXPEARN	37289.	8977.	770.	568.	9755.	2304.	14916.
10	2) LABOR	29633.	10872.	2097.	1542.	6955.	2101.	6067.
10	3) COST	217421.	115231.	16322.	12206.	39870.	16205.	17587.
	4) B GRAIN							
	CORN	74887.	8828.	20180.	8859.	21477.	7305.	8238.
	RICE	104026.	3545.	34593.	40383.	20325.	4690.	489.
	BEANS	16023.	2108.	4148.	2162.	5030.	2492.	83.
					(Model V)			
100	1) EXPEARN	34454.	11101.	782.	568.	9766.	2304.	14933.
100	2) LABOR	31571.	12564.	2131.	1544.	7012.	2106.	6214.
10	3) COST	234855.	130514.	16697.	12216.	40188.	16229.	19011.
1000	4) B GRAIN							
	CORN	74887.	8828.	20180.	8859.	21477.	7305.	8238.
	RICE	104026.	1924.	36214.	40383.	20325.	4690.	489.
	BEANS	16023.	2108.	4148.	2162.	5030.	2492.	83.

of export earnings is $9,746,000. The range of cost is 48,935,000 colones. The total metric tons of basic grains range from 229,612 metric tons, which is much less than the 1985 demands, to a minimum of 168,962 metric tons.

For equally weighted objectives (Model IV) the base chosen was 10. The ranges over which weights on objectives hold are:

1) Export Earnings - 5.63 to 10.40
2) Labor Employment - 7.24 to 11.16
3) Cost of Production - 9.71 to 13.82
4) Basic Grains

Corn - 7.03 to $.2 \times 10^{16}$

Rice - not in Basis (overachieved)

Beans - 2.95 to $.39 \times 10^{16}$

The ranges are larger in the long-run model than the short-run model for corn and beans. All vectors entering the bases are the same as in the short-run presented previously.

Conflicts Between Time Horizons

Comparative statics are used in this section to analyze apparent conflicts between short-run and medium-run time horizons. Given the models constraints, conflicts will result where land resources are the most limiting. Regions with substantial idle land will be able to produce equal to the short-run objective function results for non-perennial crops as well as produce perennial crops. An index showing the magnitude of objective function change between the short-run and medium-run formulations was previously presented (Table 6.2). In the following subsections conflicts within models that result from different planning horizons are presented.

In the short-run any increase in export earnings is due to sugar cane which is the only non-perennial exported. Labor in the short-run is closely tied to the basic grains and sugar cane. In the medium-run both more export earnings and employment are generated through perennial export crops so that perennials generally go to the maximums allowed by flexibility restraints. Then basic grains and sugar cane are brought into solution.

Time horizon conflicts are a result of the flexibility restraints, crops allowed into solution, and land resource availability by region. The model assumes land resource availability does not change over time. The following discussion focuses on regions where conflicting optimal production results between short and medium-run formulations. Regions where the direction of change from the short-run do not change and the available land resources allow increasing perennial production in the medium-run are not considered regions of time horizons' conflict.

<u>Model I: Maximize Labor</u>

Under Model I only region 1 has conflicting production between the time horizons analyzed. In the short-run this region produces, <u>more</u> solo corn and beans, more intercropping, and about 9,000 hectares <u>more</u> sugar cane than the 1973 base. In the medium-run this region produces <u>less</u> solo corn and beans, <u>more</u> (but less than the short-run model) interplanted, and about 6,000 hectares less sugar cane than the 1973 base. In the medium-run this region specializes in coffee production with about 17,000 more hectares than the 1973 base. The medium-run formulation results in: \$6,840,000 more in export earnings; 15,290,000 more hours of employment, and in 194,220,000 colones higher cost of production compared to the short-run in region 1.

Model II: Maximize Export Earnings

Under Model II three regions 1, 2, and 3 have conflicting production between the two time horizons.

In the short-run region 1 specializes in sugar cane production with about 9,000 more hectares than the 1973 base. In the medium-run this region has the same crops being produced as with maximizing labor (Model I) with specialization in coffee and 9,000 fewer hectares of sugar cane than the base. Other crops (corn, beans, and intercropped) are the same for both time horizons. The difference in objective function values between the two time horizons: \$8,250,000 more export earnings; 5,169,000 more hours of labor; and 37,126,000 colones higher cost of production in the medium-run.

For region 2 the difference between short-run and the medium-run (medium-run minus short-run) is: +1,000 hectares of corn; -1,000 hectares of rice; -4,000 hectares of beans; and -1,000 hectares of interplanted. The difference in objective function values for the region between the two time horizons is: \$540,000 more of export earnings; 1,900,000 more hours of employment; and 18,830,000 colones higher cost of production in the medium-run.

Under the short-run formulation region 3 produces approximately 2,000 more hectares of solo corn and sugar cane over the 1973 base and 1,000 hectares less rice and beans. With the medium-run formulation about 4,000 less hectares of corn, 3,000 less hectarage of rice and solo beans are in solution compared to 1973. About 1,000 fewer hectares of sugar cane are in production compared to the short-run and intercropping comes into solution with about 5,000 hectares. The difference between short and medium-run objective function (medium-run minus short-run) region 3 are: export earnings + $750,000, labor hours of employment - 1,740,000 hours: and total cost of production drop by 10,080,000 colones.

Model III: Minimization of Cost

Under this model magnitude in cost of production is the only major change between the short and medium-run models. The difference in cost is 4,649,000 colones less in the medium-run.

Model IV: Equal Weights

Under this model major conflicts betwen time horizons are not generally apparent, although, compared to the 1973 base many more crops have significant hectarage changes.

Model V: Weights 100, 100, 10, 1000

Under this model major regional conflicts in crop production between the time horizons are not apparent.

Partial Opportunity Costs of Sector Objectives

As discussed in Chapter 4 the optimal solutions of the land base model do not give zero cost regional resource adjustments that result in higher utility defined in terms of given objective functions. Therefore, the analysis of opportunity costs is partial. The value of multiobjective analysis over the traditional land base LP is that it reflects better the nature of policy considerations and helps to bring opportunity costs to the forefront.

Opportunity costs can be defined between the models presented in terms of any of the objective functions used. In this section the minimization of cost objective function (Model III) is used as the base. This objective function approximately depicts the perfect competition equilibrium solution to regional crop production patterns (given the underlying assumptions of the model). The difference between the minimization of cost model and other models can be interpreted as how much adjustment cost and benefit, in terms of objective function achievement could be derived from not allowing free market solutions not including the costs of inducement. The national relationships for the short-run and medium-run are shown (TABLE 6.4 and 6.5, respectively) in the form of differences (model under study minus model III).

Some Implications: Magnitude of Change For Basic Grains, Self-Sufficiency and Labor Employment

Flexibility constraints control the amount of regional specialization allowed in crop production and thus the magnitude

TABLE 6.4

SHORT-RUN OPPORTUNITY COST OF NON-PERFECT COMPETITION FORMULATION

Model	EXPEARN (in $10,000)	LABOR (in 10,000 hours)	COST (in 10,000 colones)	B GRAINS (in metric tons)
I	+1,498	+2,696	+25,228	+63,505
II	+1,498	+1,030	+ 9,468	+ 1,689
IV	0	+1,015	+ 7,367	+25,974
V	+1,390	+2,028	+14,808	+29,993

TABLE 6.5

MEDIUM-RUN OPPORTUNITY COST OF NON-PERFECT COMPETITION FORMULATION

Model	EXPEARN (in $10,000)	LABOR (in 10,000 hours)	COST (in 10,000 colones)	B GRAINS (in metric tons)
I	+9,707	+7,749	+63,957	+60,550
II	+9,748	+6,193	+51,243	+ 1,689
IV	+6,669	+3,325	+11,414	+25,974
V	+8,834	+5,263	+28,848	+25,974

of objective function achievement. This is why direction of change is emphasized in most macro land base models. Realizing these limitations, this section discusses the apparent (assuming flexibility constraints are correct) ability to generate substantial new employment in the sector and to satisfy 1985 demands for the basic grains through changes in regional production patterns.

Self sufficiency requirements for the basic grains in 1985 were given (TABLE 3.4). The aggregated demands are never approached under any model. The maximum aggregate production is under short-run Model I (maximizing labor) due to the complementarity between labor and basic grains under this formulation. Rice production exceeds demand by 40,343 mt. under Model I (as demands are equal to 1973 production).[2] The maximum corn production is under Model IV and Model V (both short and medium-run) with production 138,013 mt. less than requirements. Bean supply is maximized under Model I (short-run) and under models IV and V (both short and medium-run) but they underproduce demands by 27,887 mt. This seems to imply that changing production patterns will not meet demands. Demands could only be met by substantial annual yield increases per hectare.

The projected number of jobs needed per year was given (TABLE 3.2). The average for the 1976, 1980, and 1990 projections is 23,337 jobs per year. The difference between the short-run Model III, which has little change from the 1973 base, and the medium-run maximization of labor employment (Model I) is 38,775 jobs[3] [(77,550,000 hours of employment) ÷ (40 hours per week)

---

[2]Note: The country traditionally has had exceeded self sufficiency demands for rice; see TABLE 3.3.

[3]Note that export earnings, costs of production, and basic grains production also increase.

(50 weeks)]. The analytical model suggests that jobs can be generated by changing crop production patterns but not enough jobs would be created to keep up with the annual increase in demand for jobs. As in the case of basic grains, increases in annual yields per hectare would apparently be required to generate more jobs.[4]

---

[4]As described in Chapter 4 employment is tied to yields within specific crops.

Chapter 7

SUMMARY AND CONCLUSIONS

Review of Problem and Objectives

National agricultural sector objectives and goals do not fit well into undimensional objective function optimization techniques. For Costa Rica the agricultural sector objective include non-commensurable functions of: maximization of labor employment; maximization of export earnings; minimization of costs of production; and self sufficiency in the basic grains. The degree of competiveness between these functions defines trade-offs. Defining trade-offs resulting from different regional crop production activities was the role of this analysis leaving decision makers with the burden of making value judgements to determine the "best" solution.

The objectives of this study were to: 1) Study mathematical programming optimization techniques that could be used to quantify conflicts (trade-offs) between objectives and then employ a demonstration land base model for the stated agricultural sector objectives of Costa Rica; 2) Analyze the implications and direction of change in crop production between regions in both short and medium term planning horizons; 3) Compare the multiobjective approach to the traditional minimization of production costs land base linear programming formulation.

Review of Analytical Model

A single tableau regional goal programming model (GP) was developed for Costa Rica that treats several national agricultural sector objectives simultaneously. The GP framework used here is conceptually analogous to minimizing disutility. Maximizing utility is defined by achieving all individual targets on goal functions. This is done by minimizing the deviation between weighted objectives given targets.

The GP model developed here is an extension of traditional land base LP models which minimize the cost of production given exogenous demands. Land base models define regional production activities for each crop in a per hectare basis. The GP model developed for Costa Rica incorporates objectives (eg. maximizing export earnings) and satisfying specific goals (eg. 43900 metric tons of rice). By incorporating satisfying objective functions the size of the trade-off surface can be reduced to a more applicable set from which point selections can be generated. The GP model is flexible, for example, if decision makers reformulate the maximization of labor objective into a goal of "X" hours only the right-hand side of the goal function needs to be changed.

The GP model is a normative efficiency model with the same basic assumptions of a traditional land base LP. The model is not behavioral. The relatively simple model developed for Costa Rica does not prescribe policy but does bring to the forefront ideas of conflict in formulating objective functions through a partial analyses of potential regional agricultural production adjustments.

Summary of Results

Selected objective functions on the trade-off surface between objectives were generated to depict trade-offs. The results are regional crop production activities that optimize implicit utility functions. The models analyzed were:

Model I - maximize labor employment

Model II - maximize export earnings

Model III - minimize costs of production

Model IV - equally weighted objective on, labor employment, export earnings, cost of production, and basic grains self sufficiency.

Model V - weights of: 100 on labor employment and export earnings; 10 on cost of production; and 1000 on basic grains self sufficiency.

Selected results of this analysis are given below.

1. The short-run minimization of cost model (Model III) results in relatively little change in regional crop production activities compared to the 1973 base.

Implying that a short-run market solution to regional production activities could have determined the base years solution.

2. There are significant short-run trade-offs between national sector objective functions in both activities in solution and levels of goal function achievement. Labor and basic grains production are closely related in the short-run.
3. Conflicts between objective functions are apparent under the medium-run model both in activities in solution and levels of goal function achievement. Labor and export crops are closely related in the medium-run.
4. Region 1 is the major area of conflict between models. Under both time horizons this region ranges from having no idle land (Models I and II) to much more idle land than the 1973 base (Model III). Crops specialized in vary greatly by the objective function used in this region.
5. Conflicting production between time horizons is greatest in Region 1. Conflicts are not nearly as great in other regions as idle land is more often in solution.
6. The potential to meet self sufficiency and national labor employment demands by changing regional crop production activities appears limited although

large gains compared to 1973 apparently can be made. More drastic changes in institutions and productivity are implied. An option includes more intensive production of basic grains which could make simultaneous movement toward both self sufficiency and labor employment possible.

Of the various programming model approaches to incorporating multiple objectives the GP approach, as used here, is relatively easy to develop and use.

The land base cost minimization LP model was a component of the GP model developed for this study. These two formulations are complementary so the costs in terms of time and effort were not much greater for the GP. For example, coefficients for labor employment come out of farm budgets studies necessary for LP.

The insight generated appears to be a valuable input into the decision making processes. The philosophy that decision makers are best able to make subjective value judgements in trading off objectives is used in the GP approach used here. The traditional LP generates just a one point deterministic solution that decision makers can either accept or reject and does not give information on trade-offs. Neither the land base LP nor the GP help in defining institutions to achieve national level sector objectives. But, the GP makes more accessible the implications of what could be possible, under current natural resources and technology, and brings to the forefront conflicts between objective functions and the resulting opportunity set.

Additional Useful Research

The Formulated GP Model

Data problems limit how much analysis can be performed on the Costa Rican agricultural sector. The secondary data sources available were used to their potential in developing this partial regional analysis. Data by more homogeneous regions would strengthen analysis of production potential under alternative objective functions greatly. This includes specification of present and alternative technologies of production and micro constraints to adoption.

The land base model developed here does not consider institutional structure within the sector. Implications of objective functions related to the rural poor and farm size were not included in this study.

Finally, to fully effectively evaluate trade-offs the agricultural sector, it can not be partitioned from the broader economy.

Analytical Methods

Increasing the number of objective functions under study results in dimensionality problems. Constructing efficient sets in more than two dimensions is computationally difficult and requires better estimation methods. One approach would be extension of Cohon's (1979) Noninferior Set Estimation Method beyond two dimensions. If it is possible to interact with decision makers Surrogate Worth Trade-off methods could be used (Haimes, et. al. 1975, 1974) to reduce the size of the efficient under study.

Better efficient set estimation techniques should also lead to concern about the sensitivity of the whole efficient set being depicted (Schurle and Erven 1979 (a), (b)).

APPENDIX A

EXAMPLE GP MODEL OUTPUT: MEDIUM RUN WEIGHTS 100, 100, 10, 1000 (MODEL V)

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION CENTRAL 1

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	4472.00	3854.75	8828.39	4792.56	1.41
RICE	TM	948.00	720.72	1924.32	1924.32	2.67
BEANS	TM	1731.00		2108.40	1144.56	.87
COFFEE	TM	63011.00	61953.24	308527.06	238484.19	4.98
SUGAR CANE	TM	23403.00	32764.18	2208305.00	1198795.00	67.40
BANANAS	TM	729.50	1021.30	12531.39	6802.76	12.27
PLANTAIN	TM	169.00	128.41	1824.76	1824.76	14.21
COCOA	TM	48.00	37.22	18.24	18.24	.49
TOBACCO	TM	879.00	668.45	588.24	588.24	.88
POTATOES	TM	1193.30	1212.69	19633.44	14683.20	16.19
YUCCA	TM	161.00	122.39	892.24	892.24	7.29
INTERPLANTED	HA		3294.37	*		
MINOR CROPS	HA	4030.00	4030.00	4030.00	4030.00	1.00
PASTURE	HA	230866.00	230866.00	230866.00	230866.00	1.00
IDLE CROPLAND	HA	9033.00				
TOTAL		340673.75	340673.44			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION CENTRAL 1

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		197.36	1371.13	.36
RICE	TM		30.56	244.32	.34
BEANS	TM				.31
COFFEE	TM	7685.30	9633.73	105816.06	1.71
SUGAR CANE	TM	3246.27	2185.37	16709.73	.51
BANANAS	TM	169.18	58.52	255.33	.25
PLANTAIN	TM		4.67	37.83	.29
COCOA	TM	.46	2.73	14.89	.40
TOBACCO	TM		54.08	1320.86	1.93
POTATOES	TM		155.10	3120.61	2.57
YUCCA	TM		4.52	25.21	.21
INTERPLANTED	HA		237.19	1598.43	.49
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		11101.20	12563.81	130514.19	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

--MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO NORTE 2

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	11087.50	15522.76	20179.58	10954.64	1.30
RICE	TM	24740.00	22920.16	36213.85	29707.64	1.58
BEANS	TM	3847.90	5387.27	4148.19	2251.88	.77
COFFEE	TM	2106.00	1600.53	3489.16	3489.16	2.18
SUGAR CANE	TM	4624.00	6473.61	454123.38	246524.19	70.15
BANANAS	TM	110.70	154.98	2070.60	1124.04	13.36
PLANTAIN	TM	118.00	165.23	2805.60	1523.04	16.98
COCOA	TM	6.00	4.75	.38	.38	.08
TOBACCO	TM					
POTATOES	TM	18.20	13.89	63.08	63.08	4.54
YUCCA	TM	71.00	99.44	425.60	231.04	4.28
INTERPLANTED	HA			*		
MINOR CROPS	HA	4827.00	4827.00	4827.00	4827.00	1.00
PASTURE	HA	594389.00	594389.00	594389.00	594389.00	1.00
IDLE CROPLAND	HA	30706.00	25092.62			
TOTAL		676651.25	676651.13			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUNO5
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO NORTE 2

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	11087.50	15522.76	20179.58	10954.64	1.30
RICE	TM	24740.00	22920.16	36213.85	29707.64	1.58
BEANS	TM	3847.90	5387.27	4148.19	2251.88	.77
COFFEE	TM	2106.00	1600.53	3489.16	3489.16	2.18
SUGAR CANE	TM	4624.00	6473.61	454123.38	246524.19	70.15
BANANAS	TM	110.70	154.98	2070.60	1124.04	13.36
PLANTAIN	TM	118.00	165.23	2805.60	1523.04	16.98
COCOA	TM	6.00	4.75	.38	.38	.08
TOBACCO	TM					
POTATOES	TM	18.20	13.89	63.08	63.08	4.54
YUCCA	TM	71.00	99.44	425.60	231.04	4.28
INTERPLANTED	HA			*		
MINOR CROPS	HA	4827.00	4827.00	4827.00	4827.00	1.00
PASTURE	HA	594389.00	594399.00	594389.00	594389.00	1.00
IDLE CROPLAND	HA	30705.00	25092.62			
TOTAL		676651.25	676651.13			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL-- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUNS05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO NORTE 2

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		731.12	4239.26	.27
RICE	TM		573.00	7288.61	.32
BEANS	TM		245.12	1244.46	.23
COFFEE	TM	86.91	107.00	2219.94	1.39
SUGAR CANE	TM	667.56	453.15	1560.14	.24
BANANAS	TM	27.95	9.67	38.75	.25
PLANTAIN	TM		7.19	48.74	.29
COCOA	TM	.01	.06	1.90	.40
TOBACCO	TM				
POTATOES	TM		.50	34.93	2.51
YUCCA	TM		2.16	20.48	.21
INTERPLANTED	HA				.37
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		782.43	2130.97	16697.20	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL-- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO NORTE 2

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		731.12	4239.26	.27
RICE	TM		573.00	7288.61	.32
BEANS	TM		245.12	1244.46	.23
COFFEE	TM	86.91	107.00	2219.94	1.39
SUGAR CANE	TM	667.56	453.15	1560.14	.24
BANANAS	TM	27.95	9.67	38.75	.25
PLANTAIN	TM		7.19	48.74	.29
COCOA	TM	.01	.06	1.90	.40
TOBACCO	TM				
POTATOES	TM		.50	34.93	2.51
YUCCA	TM		2.16	20.48	.21
INTERPLANTED	HA				.37
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		782.43	2130.97	16697.20	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO CENTRAL 3

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	5503.00	7703.65	8859.19	4809.28	1.15
RICE	TM	10489.00	14684.72	40382.98	21922.20	2.75
BEANS	TM	2616.90	3663.73	2161.60	1173.44	.59
COFFEE	TM	670.00	509.28	988.00	988.00	1.94
SUGAR CANE	TM	3196.00	4474.39	316473.88	171800.25	70.73
BANANAS	TM	201.90	282.69	5746.99	3119.80	20.33
PLANTAIN	TM	512.00	716.77	15259.98	8284.00	21.29
COCOA	TM	8.00	11.67	4.20	2.28	.36
TOBACCO	TM	57.00	67.59	117.60	63.84	1.74
POTATOES	TM	14.80	11.26	110.96	110.96	9.85
YUCCA	TM	74.00	103.52	782.60	424.84	7.56
INTERPLANTED	HA			*		
MINOR CROPS	HA	10946.00	10946.00	10946.00	10946.00	1.00
PASTURE	HA	242195.00	242195.00	242195.00	242195.00	1.00
IDLE CROPLAND	HA	12238.00	3351.30			
TOTAL		288721.56	288721.44			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL-   --MINIMIZE DEVIATION. LONG RUN MODEL,CBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO CENTRAL 3

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		320.47	2240.99	.29
RICE	TM		640.25	5984.02	.41
BEANS	TM		127.86	1329.57	.36
COFFEE	TM	24.61	30.86	699.24	1.37
SUGAR CANE	TM	465.20	313.21	1494.45	.33
BANANAS	TM	77.59	27.02	70.67	.25
PLANTAIN	TM		68.09	211.45	.29
COCOA	TM	.10	.63	4.67	.40
TOBACCO	TM		10.81	133.55	1.98
POTATOES	TM		.40	25.85	2.29
YUCCA	TM		3.96	21.32	.21
INTERPLANTED	HA				.48
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		567.51	1543.59	12215.75	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO SUR 4

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION*	REQUIREMENT	YIELD
CORN	TM	12079.30	16911.32	21477.37	11659.16	1.27
RICE	TM	13929.00	10536.16	20325.42	20325.44	1.92
BEANS	TM	4921.80	6890.68	5030.19	2730.68	.73
COFFEE	TM	13718.00	19205.29	81814.50	44413.64	4.26
SUGAR CANE	TM	1631.00	2283.41	85947.31	46657.16	37.64
BANANAS	TM	10052.00	14072.80	562630.31	305428.00	39.98
PLANTAIN	TM	2611.00	3655.40	86413.50	46910.24	23.64
COCOA	TM	445.00	624.32	231.00	125.40	.37
TOBACCO	TM	569.00	687.63	880.16	553.28	1.28
POTATOES	TM	13.70	10.37	37.24	37.24	3.59
YUCCA	TM	355.00	496.92	2062.20	1119.48	4.15
INTERPLANTED	HA			*		
MINOR CROPS	HA	4829.00	4829.00	4329.00	4829.00	1.00
PASTURE	HA	184307.00	184307.00	184307.00	184307.00	1.00
IDLE CROPLAND	HA	44767.00	29667.95			
TOTAL		294223.25	294228.06			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL— —MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION PACIFICO SUR 4

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		779.61	5212.07	.31
RICE	TM		320.76	4566.87	.43
BEANS	TM		296.30	2755.58	.40
COFFEE	TM	2038.07	2554.30	20741.70	1.08
SUGAR CANE	TM	126.34	85.17	575.42	.25
BANANAS	TM	7595.50	2622.80	3518.20	.25
PLANTAIN	TM		221.15	1078.34	.29
COCOA	TM	5.77	34.53	249.73	.40
TOBACCO	TM		80.93	1358.75	1.98
POTATOES	TM		.29	28.83	2.73
YUCCA	TM		10.44	102.36	.21
INTERPLANTED	HA				.52
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		9765.63	7012.27	40187.32	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL-- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUNO5
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION ZONA NORTE 5

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	3923.40	5492.63	7305.19	3965.68	1.33
RICE	TM	4711.00	3530.12	4689.95	4689.96	1.31
BEANS	TM	2281.80	3194.87	2492.00	1352.80	.78
COFFEE	TM	3417.00	4783.75	21431.18	11634.08	4.48
SUGAR CANE	TM	5758.00	8061.21	520995.69	282826.38	64.63
BANANAS	TM	1623.00	2272.20	72619.31	39421.96	31.96
PLANTAIN	TM	1467.00	1114.89	11171.23	11171.24	10.02
CACAO	TM	2574.00	3602.31	936.60	508.44	.26
TOBACCO	TM					
POTATOES	TM	163.10	124.01	781.28	781.28	6.30
YUCCA	TM	815.00	1140.96	9298.79	5047.92	8.15
INTERPLANTED	HA			*		
MINOR CROPS	HA	6739.00	6739.00	6739.00	6739.00	1.00
PASTURE	HA	234507.00	234507.00	234507.00	234507.00	1.00
IDLE CROPLAND	HA	15497.00	8863.31			
TOTAL		283476.25	283476.13			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL— ——MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION ZONA NORTE 5

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		137.32	1696.67	.31
RICE	TM		74.47	1221.18	.34
BEANS	TM		147.92	1116.93	.35
COFFEE	TM	533.87	669.25	6635.05	1.39
SUGAR CANE	TM	765.90	515.92	2692.44	.33
BANANAS	TM	980.36	339.24	568.05	.25
PLANTAIN	TM		28.54	328.89	.29
COCOA	TM	23.41	140.13	1440.92	.40
TOBACCO	TM				
POTATOES	TM		6.19	293.86	2.37
YUCCA	TM		47.12	235.04	.21
INTERPLANTED	HA				.48
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		2303.54	2106.09	16229.02	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL-   --MINIMIZE DEVIATION. LONG RUN MODEL,CPJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION ATLANTICO 6

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	YIELD
CORN	TM	3481.50	4874.32	8237.59	4471.84	1.69
RICE	TM	546.00	414.78	489.44	489.44	1.18
BEANS	TM	123.80	172.08	82.60	44.84	.48
COFFEE	TM	435.00	368.43	677.92	677.92	1.84
SUGAR CANE	TM	151.00	211.40	4439.39	2409.96	21.00
BANANAS	TM	23439.00	32814.57	1096662.00	595331.50	33.42
PLANTAIN	TM	1553.00	2174.19	38896.13	21115.08	17.89
COCOA	TM	17224.00	18278.47	4204.05	3011.12	.23
TOBACCO	TM					
POTATOES	TM					
YUCCA	TM	600.00	840.00	5132.39	2786.16	6.11
INTERPLANTED	HA			*		
MINOR CROPS	HA	4120.00	4120.00	4120.00	4120.00	1.00
PASTURE	HA	71792.00	71792.00	71792.00	71792.00	1.00
IDLE CROPLAND	HA	12545.00				
TOTAL		136060.25	136060.19			

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

REGION ATLANTICO 6

CROPS		EXPORT EARNING ***	LABOR **	TOTAL COST *	COST/HA *
CORN	TM		298.80	1857.11	.38
RICE	TM		7.80	187.48	.45
BEANS	TM		4.92	55.41	.32
COFFEE	TM	16.89	21.18	511.02	1.39
SUGAR CANE	TM	6.53	4.40	70.61	.33
BANANAS	TM	14804.95	5122.35	8203.64	.25
PLANTAIN	TM		99.58	641.38	.29
COCOA	TM	105.10	628.78	7311.39	.40
TOBACCO	TM				
POTATOES	TM				
YUCCA	TM		26.04	173.04	.21
INTERPLANTED	HA				.51
MINOR CROPS	HA				
PASTURE	HA				
IDLE CROPLAND	HA				
TOTAL		14933.45	6213.84	19011.07	

* COST IS IN UNITS OF 10,000 COLONES.
** LABOR IS IN UNITS OF 10,000 HOURS.
***EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL- --MINIMIZE DEVIATION. LONG RUN MODEL,GBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

NATIONAL SUMMARY

MINIMUM DEVIATION= H008

CROPS	UNI	ORIGINAL AREA	OPTIMAL AREA	PRODUCTION *	REQUIREMENT	EXPORT EARNING +++	LABOR ***	TOTAL COST **
CORN	TM	40547.20	54359.42	74887.25	53491.00		2464.68	16617.23
RICE	TM	55363.00	52906.66	104025.83	104026.00		1646.84	19492.46
BEANS	TM	15523.19	19308.62	16022.97	11445.00		822.13	6501.94
COFFEE	TM	93407.00	88420.38	416927.63	394325.00	10385.63	13018.31	136622.81
SUGAR CANE	TM	38763.00	54268.19	3590282.00	2571505.00	5277.79	3557.22	23102.77
BANANAS	TM	36156.10	50618.54	1752260.00	1251580.00	23655.52	8185.60	12654.63
PLANTAIN	TM	6430.00	7954.88	156371.13	119511.00		429.22	2346.69
COCOA	TM	20305.00	22558.74	5394.46	4823.50	134.86	806.85	9023.49
TOBACCO	TM	1505.00	1423.67	1586.00	1586.00		145.83	2813.16
POTATOES	TM	1403.10	1372.23	20625.99	20626.00		162.49	3504.08
YUCCA	TM	2076.00	2803.22	18593.82	13818.00		94.24	577.46
INTERPLANTED	HA		3294.37	*			237.19	1593.43
MINOR CROPS	HA	35491.00	35491.00	35491.00	35491.00			
PASTURE	HA	1558056.00	1558056.00	1558056.00	1558056.00			
IDLE CROPLAND	HA	124786.00	66975.13					
TOTAL		2019811.00	2019810.00			39453.80	31570.57	234854.94

* THE PRODUCTION OF INTERPLANTED HAS BEEN ALLOCATED TO THE PRODUCTION OF CORN AND BEANS.
** COST IS IN UNITS OF 10,000 COLONES.
***LABOR IS IN UNITS OF 10,000 HOURS.
+++EXPORT EARNING IS IN UNITS OF 10,000 DOLLARS

5/31/79

COSTA RICAN GOAL PROGRAMMING MODEL— ——MINIMIZE DEVIATION. LONG RUN MODEL,OBJ RUN05
DATA FROM 1973 COSTA RICAN NATIONAL CENSUS AND
BANCO CENTRAL DE COSTA RICA

LEVELS TO WHICH GOALS WERE ATTAINED.

GOALS	TARGET	UNDER	OVER	SOLUTION
EXPORT EARNINGS	40368.0	914.2		39453.8
LABOR	34057.0	2486.4		31570.6
COST	206008.0		28847.6	234855.6
CORN	212900.0	138012.6		74887.4
RICE	104026.0			104026.0
BEANS	43900.0	27877.0		16023.0

BIBLIOGRAPHY

BIBLIOGRAPHY

Barlow, R. Land Resource Economics: The Economics of Real Property. New Jersey: Prentice-Hall, Inc., 1972.

Bartlett, E.T., Bottoms, K.E. and Pope, R.P. "Goal-Multiple Objective Programming." Colorado State University Range Science Series Wo. 21, Colorado, 1976.

Benayoun, R., de Montgolfier, J. and Tergny, J. "Linear Programming with Multiple Objective Functions: Step Method (STEM)." Mathematical Programming 1 (1971):366-375.

Bradley, S.P., A.C. Hay and T.L. Magnanti, Applied Mathematical Programming: Addison-Wesley Pub. Co., 1977.

Brill, Downey E. "The Use of Optimization Models in Public-Sector Planning." Management Science 25 (May 1979):415-422.

Campbell, V.W. and Nichols, D.G. "Setting Priorities Among Objectives." Policy Analysis, 3 (1977):561-578.

Chandler, W. and Boehlje, M. "Use of Linear Programming in Capital Budgeting with Multiple Goals." American Journal of Agricultural Economics, 53 (1971): 325-330.

Charnes, A. and Cooper, W. Management Models and Industrial Applications of Linear Programming. New York: John Wiley & Sons, Inc., 1961.

Charnes, A. and Cooper, W.W. "Goal Programming and Multiple Objective Optimization." European Journal of Operations Research 1 (1977):39-54.

Cohon, Jared L. Multiobjective Programming and Planning. New York: Academic Press, 1978.

Cohon, J.L. and Marks, D.H. "A Review and Evaluation of Multiobjective Programming Techniques." Water Resources Research 11 (1975):208-220.

Dauer, Jerald P. and Krueger, Robert J. "An Interactive Approach to Goal Programming." Operations Research Quarterly 28 (1977):671-681.

De Veer, Jan. "Extension and Administrative Needs in Application." In Economic Models and Quantitative Methods for Decisions and Planning in Agriculture: Proceedings of an East-West Seminar, edited by E.O. Heady, pp. 489-497, Iowa State University Press, Ames Iowa (1971).

Dekluyver, C.A. "An Exploration of Various Goal Programming Formulation with Application to Advertising Media Scheduling." Journal of Operational Research Society, 30 (1979): 167-171.

Dobbins, C.L. and Mapp, H.P. "A Recursive Interactive Goal Programming Model for the Analysis of Farm Entry-Exit Coordination." Presented at the annual meetings of the Southern Agricultural Economics Association, 1979.

Ecker, J.G. "Modeling with Multiple Objectives." In Energy: Mathematics and Models, edited by F.S. Roberts, 1975.

Goicoechen, A., Duckstein, L. and Fogel, M.M. "Multiobjective Programming in Watershed Management: A Study of the Charleston Watershed." Water Resources Research 12 (1976):1085-1092.

Haimes, Y.Y. and W.A. Hall. "Multiobjectives in Water Resource Systems Analysis: The Surrogate Worth Trade-Off Method." Water Resources Research, 10 (August 1974):615-624.

Haimes, Yacon Y., Hall, Warren A. and Freeman, Herbert T. Multiobjective Optimization in Water Resources Systems: The Surrogate Worth Trade-Off Method. Amsterdam: Elsevier Scientific Publishing Co., 1975.

Haverly Systems Inc., "Seasonal Production Planning and Other Fish." Mimio (1977).

Heady, Earl O. and Nichol, Kenneth J. "Models of Agricultural Water, Land Use and the Environment." In Economic Modeling for Water Policy Evaluation Vol. 3, pp. 29-57. North-Holland Pub. Co., 1976.

Hostetler, John. "Sensitivity Analysis of Selected Linear Programming Assumptions: A Study of the Stability of Agricultural Projections in River Basin Research." Unpublished Ph.D. Thesis, Michigan State University, 1970.

Ignizio, James P. "A Review of Goal Programming: A Tool for Multiobjective Analysis." Journal of Operations Research Society 29 (1978):1109-1119.

Ijiri, Y. Management Goals and Accounting for Control. Amsterdam: North-Holland Publishing, 1965.

Johnson, G.L. "Contributions of Economists to a Rational-Decision-Making Process in the Field of Agricultural Policy." In Decision-Making and Agriculture, pp. 25-46. University of Nebraska Press, 1977.

Keeney, Ralph L. and Raifta, Howard. Decisions with Multiple Objectives: Preferences and Value Trade-Offs. New York: John Wiley & Sons, Inc., 1976.

Koopmans, T.C. Activity Analysis of Production and Allocation. New York: Wiley, 1951.

Lee, Sang M. Goal Programming for Decision Analysis. Philadelphia Auerback Publishers, Inc., 1972.

Lin, W., Dean, G.W. and Moore, C.V. "An Empirical Test of Utility Versus Profit Maximization in Agricultural Production." American Journal of Agricultural Economics 56 (1974): 497-508.

Lindsay, B.E., R.O. Porlack and C.E. Willis. "Decisions with Competing Objectives: An Application to Sludge Disposal Alternatives in Massachusetts." Journal of Northeastern Agricultural Economics Council, 6 (1977):31-40.

Markowitz, H.M. Portfolio Selection: Efficient Diversification of Investment. New York: John Wiley & Sons, Inc., 1959.

Meisel, W.S. "Trade-Off Decisions in Multiple Criteria Decision-Making." In Multiple Criteria Decision-Making. Edited by J.L. Cochrane and M. Zeleney, Columbia SC: University of South Carolina Press, Columbia, 1973.

Meister, Anton D. and Nichol, Kenneth J. "A Documentation of the National Water Assessment Model of Regional Agricultural Production, Land and Water Use, and Environmental Interaction." Center for Agricultural and Rural Development Miscellaneous Report, Iowa State University, Ames, December 1975.

Orne, D.L., Rao, A. and Wallace, W.A. "Profit Maximization with the Aid of Goal Programming for Speculative Housing Estate Developers." Operations Research Quarterly 26 (1975):813-826.

Putman, John, Stipe, Sterling and McDivitt, James. "A Model of the Linear Programming Analysis for the Maumee Leval B River Basin Study." Working Paper U.S.D.A. NRE-ERS, January 1977.

Quade, E.S. Analysis for Public Decisions. New York: American Elsevier Pub. Co., 1975.

Regional Office of Central America and Panama: USAID "Projecto de Sistemas de Cultivo Para Pequenas Agricultores." Mimio, 1978.

Robb, James G. "Selected GP Model Output for Costa Rica." CRIES Project Mimio, East Lansing, 1980.

Roy, B. "Problems and Methods with Multiple Objective Functions." Mathematical Programming 1 (1971):234-266.

United States Agency for International Development. "An Assessment of the Agricultural Sector in Costa Rica." United States Aid Mission to Costa Rica, San Jose, February 1977.

Salih, Kamal. "Goal Conflicts in Pluralistic Multi-Level Planning for Development." International Regional Science Review, 1 (1975):49-72.

Saygideger, O., Vocke, G.F. and Heady, E.O. "A Multigoal Linear Programming Analysis of Trade-Offs Between Production Efficiency and Soil Loss Control in U.S. Agriculture." Center for Agricultural and Rural Development Report 76, Iowa State University, Ames, 1977.

Schurle, Bryan and Erven, Bernard L. "Sensitivity of Efficient Frontiers Developed for Farm Enterprise Decisions." American Journal of Agricultural Economics 61 (August 1979a):506-511.

Schurle, Bryan W. and Erven, Bernard. "The Trade-Off Between Return and Risk Farm Enterprise Choice." North Central Journal of Agricultural Economics 1 (1979b):15-21.

Sfeir-Younis, Alfredo and Bromley, Daniel W. Decision-Making in Developing Countries: Multiobjective Formulation and Evaluation Methods. New York: Praeger Publishers, 1977.

Wheeler, B.M. and J.R.M. Russell. "Goal Programming and Agricultural Planning." Operational Research Quarterly, 28 (1977):21-32.

Weisz, R.N. "A Method for Merging the Results of Normative and Positive Models." Working Paper U.S.D.A. NRE-ERS No. 62, August 1978.

Zeleney, M. Linear Multiobjective Programming. New York: Springer-Verlag, 1974.