A linear programming analysis of irrigated agriculture on the island of Santiago, Republic of Cape Verde

Item Type	text; Thesis-Reproduction (electronic)
Authors	Sellen, Daniel Marc, 1959-
Publisher	The University of Arizona.
Rights	
Download date	
Link to Item	http://hdl.handle.net/10150/277065

INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book. These are also available as one exposure on a standard 35mm slide or as a 17" x 23" black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700 800/521-0600

A linear programming analysis of irrigated agriculture on the island of Santiago, Republic of Cape Verde

Sellen, Daniel Marc, M.S

The University of Arizona, 1989

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

A LINEAR PROGRAMMING ANALYSIS OF IRRIGATED AGRICULTURE ON THE ISLAND OF SANTIAGO, REPUBLIC OF CAPE VERDE

by

Daniel Marc Sellen

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 8 9

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interests of scholarship. In all other instances, permission must be obtained from the author.

SIGNED: Daniel Solley

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Gary D. Thompson	6-16-89
G. D. Thompson Assistant Professor of Agricultural Economics	Date

ACKNOWLEDGEMENTS

This thesis builds upon an many years of research on agriculture in Cape Verde, particularly from researchers at the University of Arizona. Without this work this thesis could not have been written.

I am very grateful to my thesis director Gary Thompson, who took great interest in my research and myself as a student, and who taught me all I know (and a lot I still do not know) about mathematical programming. I am also indebted to Mark Langworthy, who patiently provided many hours of help, particularly with the data. Special thanks go to Timothy Finan, who, apart from valuable advice on this thesis, provided me with encouragement and help in entering the field of Agricultural Economics, a decision I have not regretted.

TABLE OF CONTENTS

Page

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

TABLE OF CONTENTS -- Continued

CHAPTER FOUR Page

CHAPTER FIVE

CHAPTER SIX

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS -- Continued

LIST OF TABLES

ABSTRACT

Agriculture in Cape Verde is severely constrained by a harsh physical environment, and large amounts of foreign aid are required to meet demand for food. Policy-makers believe that the development of irrigated farming offers the most potential for increasing food production, requiring a transition from the dominant irrigated crop, sugar cane, to food crops. Linear programming techniques are used to model a representative farm on the island of Santiago. Water constraints are varied parametrically, showing that revenues are extremely sensitive to frequency of irrigation, and that the dominance of low-profit crops is explained by unreliable and long watering intervals. The shift from cane to more profitable food crops will therefore require water reform aimed at increasing irrigation frequency and improving its reliability. Significant improvements in food production and farm incomes can be achieved even considering present supplies of water and land.

-CHAPTER ONE-

1. Introduction

Despite separation from the African mainland, the Republic of Cape Verde experiences the same climatic conditions as its Sahelian neighbours to the east. Food production is insufficient to support the nation's inhabitants, typical of many regions in the Sahel, and this has resulted in dependency on foreign food subsidies. According to a USDA report (1987) Cape Verde ranked second in the world for 1987/8 in terms of per capita additional food needed.[1] Cape Verde has received large amounts of agricultural research support, in addition to financial and technical assistance, over the past decade. Foreign and domestic policy-makers have had to make important decisions on how best to conserve and employ limited and fragile resources to promote productive and sustainable farming systems.

Water management warrants special attention by those charged with improving agricultural productivity in these arid conditions. As the model presented in this paper will show, water is the critical constraint in the irrigated farming sector in Cape Verde. Few, if any, farmers receive as much water as they need, when they want it. The irrigated sector is thought to offer the most potential for development, because rainfed farming is too severely constrained by climate to entertain the possibility of crop diversification or consistently marketable yields.

---

[1] Ranking is based on a status quo need basis, calculated from the country's recently achieved level of consumption. The assumption is that additional food supplies are needed to prevent consumption from falling below recent levels.

Linear programming (LP) techniques are used here to model a "representative" farm, i.e. one that possesses the physical characteristics described as typical in the literature on Cape Verdean agriculture. Model parameters assume that the farmer has access to both rainfed and irrigated land (rainfed is included to better estimate labour requirements and total revenues). Only the island of Santiago is considered. This island has most of the nation's agricultural land, about forty per cent of the irrigated land, and about half the nation's population. Extensive crop budgets for irrigated and rainfed agriculture on Santiago and other islands were prepared in 1987 and 1988 by researchers at the University of Arizona in cooperation with the National Agricultural Institute of Cape Verde (Food Crops Research Project/INIA).

The model provides insight into three questions. First, how can farmers maximise revenues from their small plots of irrigated land with the present limitations of water, land, and labour availabilities, in conjunction with agronomic and household consumption constraints? It will be enlightening to compare the revenues and crop mix produced by the model with empirical evidence from Santiago today. If the model produces a reasonable reflection of current farming practices, further analysis will reveal how higher incomes may be obtained by adjusting prices or input supplies. If the model does not reflect the data, it will be instructive to identify what parameters were inaccurate and redesign the model accordingly.

Second, for policy considerations, how does the optimal farm plan change if the water distribution system is modified? Evidence is strong that unreliable water resources have adverse effects on the adoption of profitable crops and improved farming practices (see Bromley et al. 1980, for a bibliography of examples). By altering water parameters in the model according to water supply and irrigation frequency, we might expect to identify conditions that explain current farmer behaviour, and point to ways in which farming productivity and profitability may be improved. One study maintains that "The most promising improvement available now in irrigation practices is to adapt the cropping pattern to the present water supply..." (Food Strategy Study, vol.2 1982). It will be argued that the reverse may also be true, that the water supply can be adapted to promote the desired cropping pattern.

Finally, can improvements be made in irrigation water usage without having to locate additional supplies of water? The development literature on Cape Verde focuses exclusively on the expansion of irrigated land by somehow accessing more water. This thesis will present analysis showing that significant gains in employment, farm income, and food production are possible without having to locate more water or augment the area of irrigated land.

The first chapter of this paper describes Santiago's agricultural system, paying particular attention to water usage, and includes a review of the relevant literature. The second and third chapters describe the structure of the LP model and the corresponding basic solution. Chapter Four proposes alternative methods of supplying water to irrigated plots, incorporates these methods into the original model, and discusses the economic implications. Chapter Five assembles the previous results into a model that investigates the possibility of increasing revenues, food production, and employment with present levels of water and land. The final chapter summarises and concludes by relating these implications to feasibility within policy and social contexts.

2. Characteristics of Agriculture on Santiago

The ten islands that make up the Cape Verdean archipelago lie six hundred kilometers off the coast of Senegal in West Africa (see **Figure 1a**). The population density of Cape Verde is the highest of all Sahelian countries. Over half of the population of 340,000 is directly involved in agriculture.

Farm productivity in Cape Verde is severely limited by the harsh physical environment. Most of the land is rocky, steep, and infertile. Soils are composed largely from volcanic rock. There are some good soils in the valleys and in higher altitudes where conditions are more humid and cooler. Soil studies on Santiago have been carried out, but not specifically in regard to agricultural potential (for maps and tables on soils see Freeman et al. 1978, pp.56-65). The area of cultivated land (at any one time) is estimated at about 60,000 hectares for the whole country, of which Santiago has about half. This national figure is probably twenty-five per cent smaller due to the present drought and some estimates are that only 5,000 hectares in the whole country are currently suitable for corn and bean cultivation, the staples of the Cape Verdean diet (Food Strategy Study vol.1 1982 p.15) . **Figure 1b** shows areas of isohumic soils (brown to reddish brown sandy or clayey soils) and isohumic soils with a higher proportion of coarse and rocky soils (lithosols and vertisols). Together, the shaded areas roughly correspond to the land planted in rainfed crops in good years. Erosion is a serious problem and is getting worse as more rainfed land is abandoned due to the drought (Food Strategy Study vol. 2 1982, p.xii).

Precipitation and groundwater are scarce, due to the Sahelian climate. The rainy season generally begins in late June and ends in November, although this varies considerably from year to year. During this time rain tends to fall torrentially on the higher elevations, and is often carried down the slopes in the form of devastating floods. Most surface water is thus lost to the sea; very little is absorbed as groundwater. Precipitation is extremely scarce during the rest of the year. Drought has been a common occurrence since colonisation by the Portuguese five hundred years ago. Recurring famines have periodically reduced the population from fifteen to forty per cent, even well into this century (Moran 1982, p.71). These cyclical droughts typically last several years, but the present drought has been unusually long, beginning in the late 1960s. Groundwater cannot be depended on to sufficiently compensate for the lack of rainfall, since it is largely limited to the valley floors and is ultimately dependent on rainfall for recharge. Rains were good in 1987 in terms of both quantity and timing, but gave little reason for optimism about years to come.

a) Rainfed farming:

Two general farming systems can be distinguished in Cape Verde: rainfed and irrigated. The great majority of agricultural land is rainfed. On Santiago in 1978, 97% of the total of 31,980 hectares of agricultural land fell into this category. Virtually all rural families have access to some rainfed land, on which they grow the traditional subsistence crops of corn and beans. The average size of these parcels is 1.2 hectares (Finan and Belknap 1985, p.22). Despite this large proportion of land devoted to the staple crops, it rarely enough to supply the nation's needs because yields are so very low. Domestic production supplies an average of only five per cent of national cereal consumption (USDA 1987, p.38).

Dryland farming in Cape Verde is labour-intensive using very simple technology. Planting, which must coincide with the first rains, consists of making holes with a hoe and dropping in the corn and bean seeds. No pesticides or fertilisers, chemical or organic, are used. This technology is homogeneous across the nation. Yields are poor and often insufficient to feed the family, a problem exacerbated by the present drought.

Family and community labour are employed in rainfed farming, with women, men, and children all contributing. According to a survey carried out on Santiago farming systems in 1984, women contributed 43% of the hours of rainfed family agricultural labour, and men 26% (Finan and Belknap 1985, p16). This difference is due to men's dominance in irrigated farming, a disproportionate number of women in Cape Verde (due to male out-migration), and to the great number of female-headed households, which subsist on rainfed farming. These latter households represent about two-fifths of those sampled in the Santiago survey, and have been discussed in detail elsewhere (Finan and Henderson 1988). The remaining 31% of the labour is supplied by children and *djunta-mon* community labour. *Djunta-mon* is a reciprocal relationship between households that enables farm families to avoid labour bottlenecks, especially at harvest time.

b) Irrigated farming:

Many farmer households also practice irrigated farming on the valley floors (called *ribeiras*) and on upland terraced slopes, wherever water is available. There are about one thousand hectares of irrigated land on Santiago. Irrigated plots are generally small; the average size is about one-tenth of a hectare (Finan and Belknap 1985, p.22). This plot size roughly corresponds to one "liter" in local terminology [2]. Since most farmers who have access to such land also have rainfed land, crops destined for market are grown on the irrigated plots (although not exclusively) if the water supply permits. Irrigation makes the

---

[2] A liter describes the amount of land that can be sown with one liter of corn (about 1,000 square meters).

diversification into more profitable crops such as potatoes, bananas, and vegetables possible. Smaller irrigated plots are often planted in a higher percentage of consumption crops, such as sweet potato and manioc, reflecting the tendency of subsistence farmers to attend to household consumption needs first. Larger plots are typically planted in sugar cane or bananas. Most of Cape Verde's irrigated land, about sixty per cent, is devoted to sugar cane.

Irrigated plots require seven times the labour (per liter) needed for rainfed farming, although the crop season is only six to eight months long. Eighty to ninety per cent of this labour is supplied by males, and some wage labour is used on larger farms. Labour demand, however, tends to be much more uniform throughout the year than in dryland farming with irrigated crops needing to be continually weeded and watered.

Technology is also simple in irrigated farming, but varies according to the crop and type of irrigation system used. Organic fertiliser is typically applied to consumption crops (manioc and sweet potato). Bananas, tomatoes, onions, cabbages, potatoes, and other vegetables may receive chemical fertiliser and pesticide. In general, the small quantity of purchased inputs means that production costs are very low.

c) Water distribution:

Water for irrigation is available from three different systems. Many farmers use hand-excavated wells (*pocos*) where groundwater is not too far from the surface. These may be built and maintained by single farmers or groups. Another system consists of capturing water from natural springs (*nascentes*) with small dams (*captacoes*), which are built on bedrock in gullies or *ribeiras* . Water intercepted in *captacoes* is diverted to fields or reservoirs via aquaducts called *levadas*. More recently, tubewells (*furos*), which go farther down into the alluvium, have been constructed by the government, and serve larger areas of farm land. On Santiago, *pocos* and *furos* are the most common sources of water. *Nascentes*, *captacoes*, and *levadas* are typical of Santo Antao, another major agricultural island.

Collectively, these water sources are not dependable; it is estimated that only one third of irrigated plots have reliable water supply, meaning sources from which farmers may expect a constant supply. Hand dug wells risk silting up when floods come down the *ribeiras*. Salt accumulation may also occur during extended dry periods. Pump breakdown is also common, and since the machinery is not locally manufactured, replacement of parts may take several weeks.

There is little documentation on water distribution practices in Cape Verde, apart from very general descriptions in the literature. These practices depend on the quality and type of water source available. Most wells are privately owned and maintained, and some are state property, particularly the new tubewells. The 1984 survey of Santiago agriculture shows that an average of four hours of water per month were available to farmers with access to *nascentes* and *pocos*, representing 93% of all irrigated households sampled (Finan and Belknap 1985, p.34). Tubewells supplied almost twice as much water per month, and shorter intervals could be scheduled between watering.

With private water distribution systems, farmers mutually appoint a water distributor (*merim* or *meirinho*) to control allotments of the water, although this is more common on Santo Antao. For public wells, typical on Santiago, farmers pay for fuel and also a small fee to a government water distributor. Water allotments from these systems are traditionally distributed as follows. A rotation system for the farmers is established, whereupon each plot is allotted as much water as the farmer considers necessary. That farmer will not receive water until his turn comes up again, although some "borrowing" arrangements may occur between neighbouring plots. The time between turns is determined by the condition of the pump and water availability, i.e. the time it takes the groundwater or runoff to replenish the well or *captacoe*. This could take days, weeks, or even months. The implications of this system and its irregularity are discussed further in Chapters Four and Five. More recently, fixed application schedules have become more common on Santiago, although the irrigation intervals are still ulimately dependent on rates of groundwater recharge.

d) Marketing:

The marketing system on Santiago may also be a significant constraint to agricultural development. Unfortunately there is also very little written on this; no specific studies have been carried out to date. Furthermore, no standardised systematic process of price recording exists. The marketing infrastructure in Santiago is best viewed as efficient yet limited. It is limited in the sense that it extends only as far as the island itself. No longer are crops exported abroad, with the exception of some bananas to Portugal. There is some inter-island trade using small boats, but most of Santiago's produce goes to the capital, Praia. At harvest times, hundreds of women rent trucks, transport the crops, and retail them. There may be heavy losses of perishable crops between the field and the market; one group of researchers estimates an average loss of fifty per cent (Food Strategy Study 1982, vol.1 p.95), although no documentation is presented. Despite these apparent limitations, a comparison of Santiago prices for the summer of 1988 reveals that producer prices average as much as 83% of consumer prices (see prices data in Table 1). This reflects low transportation costs and a high level of efficiency in local marketing by the many petty entrepreneurs, who are the only intermediaries between the farmer and the consumer.

e) Cape Verdean Agricultural Policy:

The priorities of the Cape Verdean government in agriculture have remained relatively unchanged since independence, corresponding to the urgent need to alleviate the chronic food shortages and stabilise the vulnerable resources of water and land. Therefore the thrust of development policy has been to maintain and expand the area of irrigated land with soil and water conservation, and to encourage the production of food crops at the expense of sugar cane.

The government is involved in the creation and operation of public agricultural enterprises such as farm cooperatives and irrigation systems, and public works programs. These latter programs are financed by foreign transfers; donated food is sold on the market at fixed levels that represent current world prices and the revenues go to pay participants of the work fronts. Work fronts are thus critical for creating rural employment and income in drought years, as well as providing for infrastructural improvements. These are primarily the construction of soil and water conservation projects. A research station, the National Agricultural Institute of Cape Verde, opened in 1980 to facilitate such projects and conduct agricultural research.

The government's plan for the 1980s is to bring more land into production with improved soil and water conservation practices, including groundwater exploitation and reforestation. The government's goal is to eventually have 10,000 hectares of irrigated land in production nationally (U.S.AID 1980, pp.5-6). This is five times the present level. Another study speculates that groundwater development may make possible an expansion to 8,000 hectares (Freeman et al. 1978, p.212). These figures are probably very long term if realistic at all; a recent assessment of the agricultural sector predicts that if current efforts to increase water supply are successful, an expansion of irrigable land by 600 to 800 hectares could be possible in the next ten years (MASI 1986, p.42). This newly irrigated land will be public and utilised by cooperatives organised by the government. Although domestic food production has the highest priority, the new land will probably produce a large portion of non-staple crops. Considering the low yields of corn in Cape Verde in the best of years, it is thought that the irrigated land should produce more highly profitable crops for export. The foreign exchange generated from export crops could then be used to acquire corn from abroad.

Another focus of the government's strategy is to reduce the area planted in sugar cane, which occupies most of Cape Verde's irrigated land. Cane production is discouraged for two reasons. First, it is used to produce the very popular local version of rum, called *grogue*, which is viewed to have detrimental effects on the health of the population. Second, cane occupies land which might be used for growing food crops. Since independence in 1975, the government has attempted to alter the situation by taxing cane land and production at the *grogue* manufacturing stage, and simultaneously providing price incentives for food crops, efforts which have proved unsuccessful (Langworthy and Hillman 1989). Despite these efforts, however, sugar cane production has not decreased relative to other crops. In fact, for the period 1982-1985 cane production has actually increased relative to food crops (Langwortthy and Hillman 1989, p.11).

3. Literature Review

Sources used for this thesis are selected from the literature on agriculture in Cape Verde, operations research applications in agriculture, and studies of irrigation systems. The following resources and others are cited in the bibliography.

a) Cape Verdean Agriculture:

Much of the literature on agriculture in the Cape Verde islands originates from the work of international donor organisations during the past ten years. Most describe the economy, indicate constraints to development, and make recommendations for planning and further research. These reports are valuable compilations of statistical information in the absence of recent and reliable national account statistics. Their recommendations for the rural sector are generally very similar, differing only in the finer points or emphases. To summarise, they advocate the maximization of staple food production, development of water resources, establishment of sound conservation practices, generation of energy from local sources, and creation of employment alternatives.

An excellent reference and starting point for examining information on Cape Verde up to the mid-seventies is Cape Verde: Assessment of the Agricultural Sector (Freeman et al. 1978) a report prepared by a multi-disciplinary team for U.S.AID. The purpose of the report is to provide AID with a rationale for continuing assistance, and guidelines for implementing it. The scope and content of the report are comprehensive, containing detailed descriptions of Cape Verde's natural resources and food production, and compiling data which, according to the authors, are from scarce documents. This report was updated for AID in 1985 (MASI 1986).

A ten-volume report called Food Strategy Study (1982) was produced as part of a bilateral aid program between the Netherlands and Cape Verde, with the purpose of designing an economic plan to promote Cape Verde's self-sufficiency in food. The study is comprehensive, well-documented, and contains many maps and photographs. The first two volumes pertain most to this thesis, entitled "General Outline of the Study", and "Water Resources and Irrigation". The latter is probably the best exostong resource on that topic.

Much of the recent literature on agriculture in Cape Verde comes from the University of Arizona. Two studies, Characteristics of Santiago Agriculture (Finan and Belknap 1985), and Study on Food and Agricultural Statistics in the Context of a National Information System (Hillman, Finan, and Langworthy 1986), provided much of the background material for this thesis. The former, mentioned several times above, is the report based on the survey of 239 (of 1802 farm households) farming households on Santiago, and is hereafter referred to as the Santiago survey. The survey provides social and economic data to technical experts at the national experimental station of the *Centro de Estudos Agrarios* (CEA). Similar surveys have been done for other islands. The second study pulls together statistics from the surveys and other sources, discusses the methodology, and addresses implications of the information to future agricultural policy in Cape Verde.

As previously mentioned, the University of Arizona, in cooperation with the National Agricultural Institute of Cape Verde (INIA), has prepared crop budgets for irrigated and rainfed crops on Santiago and Santo Antao (1987, 1988). These provide the empirical foundation for this paper. Many of the price data came from Estudo da Evolucao Absoluta dos Precos de Produtos Agricolas: Junho-Agosto/1988, compiled by the Ministry of Rural Development and Fisheries in Cape Verde, which documents consumer and producer prices in several *conselhos* (districts) on Santiago for most of the crops considered in the following model. Data on watering frequencies previously mentioned came from unpublished records for the Ribeira Seca irrigation network for 1988.

Academic literature has focussed on explaining how farming practices and rural Cape Verdean society have adapted to the harsh physical environment and agricultural mismanagement under the colonial regime. A journal article, The Evolution of Cape

Verde's Agriculture (Moran 1982), turns attention away from drought as an explanatory variable in the islands' agricultural poor development, focusing instead on the role of the colonial experience and consequent socio-economic disparities in land tenure and production.

Two in five farm families on Santiago are headed by single mothers. The Logic of Cape Verdean Female-Headed Households: Social Response to Economic Scarcity (Finan and Henderson 1988) explains how this familial institution came about and why it persists. The explanation is based on economic factors (a lack of alternative employment) and social factors (access to productive factors necessitates family formation).

The Farming System Under Duress: Agricultural Adaptation the Cape Verde Islands (Finan 1988) contrasts the irrigated and rainfed farming systems on Santiago, discusses the economic, technological, and social adaptations to drought and puts these adaptations within the larger context of arid land farming in developing countries. This multi-faceted approach represents the Farming Systems Research and Extension (FSRE) methodology, which, the author suggests, must take into account both subsistence and market-oriented strategies if effective recommendations are to be made.

b) Other Sources:

The most valuable resource for methodology in this paper (graduate advisors aside) was Mathematical Programming for Economic Analysis in Agriculture, by Hazell and Norton (1986). This book was extremely useful in describing the strengths and weaknesses of linear programming, and linking the technique to modelling at the farm level. A collection of studies entitled Linear Programming and Agricultural Policy: Micro Studies of the Pakistan Punjab, by Carl Gotsch et al. (1975), provided many interesting examples of how linear programming models could illuminate aspects of the irrigated agricultural sector in a developing country. An excellent starting point for examining issues related to irrigation reform is a 1980 journal article by Bromley, Taylor, and Parker, called Water Reform and Economic Development: Institutional Aspects of Water Management in Developing Countries. The authors discuss why and how distortions in efficiency and equity arise in irrigated farming systems. Social and economic considerations to establishing a more equitable water management system are provided, with an example from the Philippines. Footnotes contain a thorough review of the relevant literature.

- CHAPTER TWO -

1. The Model

The model presented in this chapter will be used to generate prescriptive information on an optimal farm plan, using parameters of crop input requirements, resource availabilities, and price data, in order to describe a "representative" farm in the irrigated sector on Santiago. The information generated will list which crops should be grown, when they should be planted, and how much should be planted in a given year.

Farmers on Santiago make decisions on what and how much to plant based on many factors. They realise from experience that only certain crops will grow on their land, uncertain yields may be expected due to the unpredictable water supply, and that there are a limited number of cropping patterns possible. The choice of crops will depend on what prices the crops will fetch at market, and may also depend on the consumption demands of their families. Farmers consider how much to plant based on how much land, labour, and water they own or have access to. The model developed in this thesis assumes profit-maximising behaviour on the part of the Santiago farmer, compromised with the need for a certain degree of subsistence security. In other words, the representative farmer will plant a certain amount with the aim of taking care of some household consumption needs, and plant the remainder in order to obtain the highest possible level of net revenues.

Linear programming (LP) is a mathematical technique used for solving inequality-constrained optimisation problems in which both constraints and objective function (the equation to be maximised or minimised) are linear. Constraints are expressed as inequalities to reflect the fact that the farm plan does not need to exhaust all available resources. In the context of the farm, an LP model provides a way to arrive at a profit-maximising or cost-minimising solution subject to a set of constraints, evaluating opportunities available in a situation with multiple yet finite number of inputs and outputs. In the model presented here, the solution describes the area to be devoted to each crop selected for the optimal farm plan, or "basis".

The LP model used in this thesis is introduced with mathematical notation and then described in more detail. It follows a standard profit maximisation construction for the objective function, and imposes detailed constraints to account for resource availabilities, water transfer possibilities, household consumption demand, and agronomic restrictions. The object to is find the farm plan with the highest net returns, while simultaneously satisfying all the constraining conditions.

Although most LP problems involve a high number of complex calculations, a computer can usually solve them in a short period of time. For the computer to arrive at a solution, all cropping options (activities) are specified together with their resource requirements and production restrictions, if any. Also included are the fixed resource constraints and the expected financial returns for each activity with variable costs netted out. Inputs must be defined as fixed or variable in the context of an LP model. The costs of variable inputs (seed, water, pump fuel, fertiliser, and pesticide, where applicable) are subtracted from the gross revenues, so that the solution represents a maximisation of net returns. Labour and land are considered as fixed inputs in this model. It is not strictly accurate to consider these as fixed, because the option to rent land and hire labour exists. However, for labour, most rural Santiago families rely on their own resources, with the exception of resorting to the *djunta-mon* institution. Land and labour costs are excluded to allow consideration of the shadow prices generated by the model wherever land or labour constraints are binding.

Matrix notation is first used to describe the model:

$$
\begin{array}{lll}
(1) & \text{maximise} & Z = \mathbf{c}'\mathbf{x} \\
 & \text{subject to:} & \mathbf{Ax} \le \mathbf{b} \\
 & & \mathbf{Nx} \le \mathbf{r} \\
 & & \mathbf{Fx} \le \mathbf{g} \\
 & & \mathbf{Kx} + \mathbf{Dy} \le \mathbf{0} \\
 & & \mathbf{Ey} \le \mathbf{h} \\
 & & \mathbf{x}, \mathbf{y} \ge 0
\end{array}
$$

where Z = total net revenue, the value to be maximised (C.V. esc)
$\mathbf{c}$ = a vector of gross revenues less variable costs for rainfed and irrigated crops measured in C.V. esc per liter (C.V. esc/liter)
$\mathbf{x}$ = a vector of land allocation activities for each crop (liters)
$\mathbf{A}$ = a matrix of monthly irrigated land requirements (liters)
$\mathbf{b}$ = a vector of monthly irrigated land availabilities (liters)
$\mathbf{N}$ = a matrix of monthly rainfed land requirements (liters)
$\mathbf{r}$ = a vector of monthly rainfed land availabilities (liters)
$\mathbf{F}$ = a matrix of monthly labour requirements (person/days)
$\mathbf{g}$ = a vector of monthly labour availabilities (person/days)
$\mathbf{y}$ = a vector of weekly water use activities (hours)
$\mathbf{K}$ = a matrix of weekly irrigated water requirements (hours)
$\mathbf{D}$ = a diagonal matrix with -1 elements associating weekly water use to monthly water availability
$\mathbf{h}$ = a vector of monthly water availability (hours)
$\mathbf{E}$ = a matrix that sums weekly water use for each month

In addition, the following constraints are imposed:

$\mathbf{x} \ge \mathbf{0.1}$ liters (for sugar cane activities only)
$\mathbf{x} \ge \mathbf{0.075}$ liters (for sweet potato/manioc activities only)
$\mathbf{x} \le \mathbf{0.5}$ liters (for vegetable activities only)

The remainder of the chapter details the assumptions made for specifying gross margins, cropping possibilities, resource availabilities, and household demand, and agronomic restrictions:

a) The Objective Function: The following cropping activities are already in the crop mix of farms on Santiago:

Irrigated:	low and high yield manioc intercropped sweet potato and manioc sweet potato low and high yield tomato low and high yield sugar cane onion cabbage Irish potato low and high yield banana
Rainfed:	intercropped corn and beans

This is not an exhaustive list of crops grown in Cape Verde, although it represents the great majority, and is sufficient for modelling a representative farm. Several types of fruit trees are grown, for example, but these are sparsely located, and the decision to plant and manage them is not an important part of the farmers' strategy for what and how much to plant. Sweet potato, pigeon peas, and peanuts may be grown on rainfed land with exceptionally humid conditions, but corn and beans are by far the dominant rainfed crops. High and low yield crops differ in the amount of inputs they receive, particularly water. These differences in yields, inputs, and variable costs are described in **Tables 1** to **6**.

Seasonality is a critical component of the model. Cape Verdean farmers need not restrict their planting schedules to specific weeks or even months; they may choose to plant as early as November or late as May: at any other time the risk of loss to heat or flooding is too great. This flexibility also reflects the ability of the farmer to coordinate plantings to avoid potential bottlenecks in resource use of irrigated crops. Monthly and even weekly recordings in the Santiago crop budgets permit specification of seasonal activities. Seven monthly activities have been included for each irrigated crop; the model assumes that plantings may occur in any month from November to May. Rainfed crops must be planted in July to take advantage of the first rains (if they come at all).

Another reason for incorporating seasonality is because prices of marketed produce vary from month to month. Farmers want to avoid surpluses at the marketplace, and may stagger plantings accordingly. **Table 1** shows variation in producer and consumer prices in the four months of April to July in 1988 in the *conselhos* (districts) of Praia, Santa Cruz, and Tarrafal on Santiago. These data have been used to calculate average monthly producer prices. In the few cases where producer prices were absent, estimates were made based on consumer prices. With comparable data, it was found that producer prices averaged 83% of consumer prices, although proportions vary across crops and separate figures were used for each crop in calculating net revenues.

Prices for manioc, sweet potato, corn, beans, and banana vary little over time. Bean and corn prices (both import commodities) are fixed by the government and remain fairly constant. Also, long harvest periods enable greater flexibility for timing the marketing and storing of these crops. The average prices for these crops correspond very closely to the prices used in the Santiago crop budgets. These are referred to as "price-constant" crops henceforth. Prices for tomatoes, potatoes, onions, and cabbages respond to market conditions and are highly variable. The monthly averages show that prices are generally lowest in April, and increase through to July. These producer price estimates, rather than those included in the crop budgets, were used in the model. These are labelled as "price-variable" crops.

The seven monthly activities for each crop also had to take into account that <u>yields</u> would vary for the price-variable crops over the course of the growing season. The later the planting, the higher the probability that high summer temperatures or floods would damage yields, particularly those of tomatoes. To simulate this uncertainty, fractions of the average yields supplied in the Santiago crop budgets were used. Although agronomic data are lacking, estimates on the fractions were made in consultation with agricultural economists working in the area. **Table 2** relates the planting and marketing schedule with expected yields for the price-variable crops. The latter is obtained by multiplying the average yield by a percentage representing that which can be expected to be harvested.

Tables 3a and **3b** show how the **c** (net revenue) values in the objective function were derived. They represent revenues expected for one liter of each crop, with variable costs of water, fertiliser, pump fuel, and other inputs netted out. The Santiago crop budgets are constructed assuming that water comes from a public well, with farmers paying a small amount for the water. To repeat, land and labour are treated as fixed costs in this model in order that the dual prices (the change in total revenue from adding an extra unit of the scarce resource) of binding constraints will shed light on shadow prices. The expected prices and yields are taken from the previous tables, and the costs are from the Santiago crop budgets (Food Crops Research Project 1987) .

b) <u>Land Constraints</u>: Since we are attempting to model a representative farm, the irrigated plot size is assumed to be one liter (0.1 hectare). The amount of rainfed land is twelve times larger (1.2 hectares). These are slight underestimations of the actual averages recorded in the Santiago Survey; the mean rainfed plot was recorded at 12.7 liters, and the irrigated plots at 1.04 liters (Finan and Belknap 1985, p.22). The integer figures were chosen for ease of exposition.

Table 4 shows a simplified matrix for the land constraints, illustrating only the "typical" planting schedules from the Santiago crop budgets. In general, the first indication of land use corresponds to the ploughing/land preparation stage, and the last to harvesting. Tomatoes, cabbages, and onions are started as seedlings in nurseries, and transplanted after two or three months.

c) Labour Constraints: Weekly data on labour use per crop is aggregated by months and measured in person-days. This is displayed in **Table 5.** The data detail the number of person-days required for each task (e.g. irrigation, planting, weeding) for each crop.

A representative farm will be worked by a family of "average" size. The 1984 survey of agriculture in Santiago , which sampled 239 of 1802 farm households, records an average family size of 5.7 members (Finan and Belknap 1985, p.7). Census results report a very similar figure (MASI 1986, p.42). For the model parameters we assume that there are three members of the household who are each able to commit twenty days per month to agriculture. The right-hand side (resource availability) for the monthly labour constraints is therefore set at sixty person/days.

d) Domestic Consumption Constraints: It was judged necessary to incorporate some household demand constraints in order to model two behavioural attributes of the Cape Verdean farm family relating to risk aversion. First, the constraints take into account the tendency of Santiago subsistence farmers, like those around the world, to meet the consumption needs of the family before committing resources to highly profitable yet risky crops such as vegetables which may never get to market due to drought, floods, pests, or marketing obstacles. Second, the constraints reflect reliance on the traditional consumption crops, which by no coincidence are the most resistant to drought. Also, rural markets for subsistence crops are small, and the option to buy certain crops is not always there.

These traditional crops are manioc, sweet potato, corn, beans, and sugar cane (all price-constant crops). The dryland crops, corn and beans, are at the mercy of the rains and yields vary accordingly. Manioc, intercropped with sweet potato, and sugar cane are grown on irrigated plots, particularly on those with poor or unreliable water availability. These crops are relatively drought resistant, and sparse irrigation intervals may just retard their growth, not kill the plants. Sugar cane merits special attention. It is obviously not a nutritious crop, nor is it very profitable (it has by far the lowest profit margin per liter of all irrigated crops). However Cape Verdean farmers give it high priority -- about sixty per cent of irrigated land is planted in cane --because sugar cane is drought resistant and able to survive variability in watering schedules, although adverse conditions can reduce yields considerably. Nevertheless, there remains some potential for marketable yields even in the worst of years.

Quantities of the sweet potato and manioc "required" by the average family were converted from estimates in kilograms to the land required to grow as much. This seemed appropriate, because due to uncertain weather conditions, the farmer will make his or her best guess upon deciding on how much land to plant. If it is assumed that a family of five is to have 0.33 kilos of sweet potato and 0.66 kilos of manioc per member per day, then 0.075 of the irrigated liter must be planted with that intercropped activity. Corn and beans, also staples, do not have to be constrained in the model, since they do not have to compete with other crops for the rainfed land. A small portion of land is allotted to cane (0.1 liter). This figure is arbitrary to some extent. It is smaller than the national percentage of irrigated land planted in cane because it is generally the larger farms that concentrate in cane production. However, for the two reasons listed in the previous paragraph, it was decided not to completely omit this crop from the model.

The above constraints assume that farmers adjust planting to expected yields. This is a valid assumption in subsistence situations. Hammer's article on farm allocation decisions in neighbouring Senegal shows how farmers choose between subsistence crops (millet) and cash crops (groundnuts) (Hammer 1986). Using a standard inventory control model, he shows empirically the intertemporal characteristic of farm planning, where millet land allocation varies negatively to the previous year's production. Groundnut allocation varies positively with the previous year's millet production, presumably because stores of the consumption crop enable concentration on the cash crop. Similarly, Cape Verdean farmers will make decisions on use of their irrigated plots for consumption and marketable crops based on what yields they expect--expectations based on the production of previous years. Thus, the consumption constraints simulate the riskiness of devoting all the land to cash crops.

Finally, it should be noted that it is debatable whether over-constraining the model with consumption restrictions is a good substitute for dealing with risk-aversion using the traditional approach of quadratic programming with a matrix of variance and co-variance coefficients. Musser, McCarl, and Smith (1982), who criticise previous research for over-emphasing risk and slighting constraint specification, make the case that both methods may yield similar optimal solutions. In the Santiago case there is little choice, since reliable data on the variability of water inputs, frequency of pump breakdowns, and marketing of output are currently lacking. Therefore these constraints are considered justified.

e) <u>Single-Cropping Constraint</u>: The model inserts a ceiling on the amount of land that can be put into production of tomatoes, cabbage, onions, and potatoes. This is done because there are agronomic reasons why double cropping of the same crop cannot take place (growth of nematodes, pest and weed control, etc.). Therefore, the model stipulates that a maximum of 0.5 liters of each of these vegetables over the year may be planted as such. As will be shown, this constraint is binding in very few of the farm models to be considered (only farms with access to plenty of water and at very frequent intervals). Note that there is no reason why the harvest of one vegetable cannot be followed by the planting of another vegetable if all other constraints permit.

This set of constraints serves a dual purpose. By imposing a limit on the area devoted to any one vegetable crop, avoidance of market risk is simulated. As seen in section 1a. of this chapter, producer prices for vegetables are highly variable. Santiago farmers might therefore be averse to committing large amounts of resources to a single risky crop.

f) Water Constraints: Water applications are measured in hours. An hour refers to the length of time that the irrigation system's pump is left on, and is roughly equivalent to twenty cubic meters, although this varies from pump to pump. Data in the crop budgets are for irrigation applications on a weekly basis from public wells. These can be seen in **Table 6**. A monthly availability of three hours of water has been chosen as an average allotment available per liter per month for the initial model, although this is varied parametrically in Chapter Four. Three hours is below the average of four recorded in the Santiago survey (Finan and Belknap 1985, p.34), but closer to median values (see Chapter Four).

A watering frequency of once every week has been chosen, to allow for the possibility of growing vegetables, some of which require weekly waterings in the early stages of growth. As Hazell and Norton have pointed out, models that incorporate seasonality on such a detailed basis should have a mechanism that reflects the farmer's ability to avoid resource use bottlenecks, to "smooth out" usage of the input (Hazell and Norton 1986, pp.43-44). In order to reflect this flexibility in using the available groundwater for irrigation within the month, water transfer activities and constraints are included for each month. With this component, farmers may use variable amounts of water per irrigation application, as long as the total used in each month does not exceed the monthly availability of water. This simulates the practice of "water borrowing" among Santiago farmers, where one farmer may request some of the water from a neighbour's turn, with the understanding that it will be repayed in kind later.

g) Non-negativity constraints: The final constraint ($x, y \geq 0$) simply stipulates that cropping activities and water transfer activities may not be operated at a negative level (e.g. one cannot plant a negative amount of land, nor apply a negative amount of water). While this is intuitively obvious, the model requires this specification for accurate solution by the computer.

- CHAPTER THREE -

1. The Basic Solution

The basic solution lists the cropping activities chosen for the optimal farm plan , that which maximises revenue for the representative irrigated farm subject to the constraints described previously. The model in equation (1) of Chapter 2 was run on the "GAMS" software package (BDM-LP, version 1.01). The command file computer input from GAMS can be found in Appendix 3. There are 124 activities (72 for crops, 52 for weekly water transfer) and 83 constraints (12 each for monthly land and labour requirements, 52 for weekly water requirements, 12 for water transfer, and 7 for consumption and agronomic constraints). Note that the numerical suffixes of the cropping activities in the model code correspond to the month in which the planting of that crop takes place. For example, "ONION11" and "SWTPOT04" represent onions planted in November and sweet potatoes planted in April, respectively. Note also that "N" and "X" are used to represent intensive and extensive activities. "MANOCN12" and "TOMATX12", for example, are the December plantings of high yield manioc and low yield tomatoes. The reader is referred to **Tables 3a** and **3b** for a complete list. The computer output is included in Appendix 4.

a) Revenues and Crop Mix: The value of the objective function (Z) was computed at 253,014 Cape Verdean escudos, or \$3,615 (70 CV esc. ≈ \$1US). Recall that this total revenue figure represents returns from both irrigated and rainfed plots, and does not include implicit costs of labour or land. Revenue from the twelve liters of rainfed land amount to about eighteen per cent of the total revenue, although it is assumed that the corn and beans produced here will be consumed domestically and never reach market. Therefore income from the irrigated liter amounts to just over 208,000 C.V. esc ($2,970). **Figure 2** illustrates how each "basic" crop, those crops chosen as part of the optimal farm plan, contributed to the value of total revenue. The chart clearly shows a preference by the representative farmer for the profitable vegetables, high yield tomatoes and onions, which account for almost two thirds of total revenue. The agronomic constraint specified in the model was binding for tomatoes but not for onions; i.e. the single-cropping restriction prevented more tomatoes from being grown. The high yield manioc activity is also included in the basis.

Note that the constraints for the two consumption activities included in the model (sweet potato/manioc and sugar cane) are binding. These activities contribute only 4.1% of the farm revenue, although they occupy 17.5% of the land. The dual price (the change in the optimal value of the objective function from relaxing the constraint by one unit) of the cane constraint is 66,890 C.V. esc ($956), and that for the sweet potato/manioc constraint is 53,650 C.V. esc ($766). In other words, if these constraints were omitted, total net revenue would rise by those amounts. This suggests that farmers in this farm plan have a lot to gain by giving up these activities in favour of buying grogue and sweet potatoes on the market and planting something else in their place.

b) <u>Land Use</u>: The optimal farm plan indicates that irrigated land be used intensively. The cropping intensity is 118%. This was calculated by multiplying total land area available for cultivation by that actually cultivated in the year times one hundred. **Figure 3** illustrates the cropping calendar for the irrigated plot. Several sequential activities appear in the basis for tomatoes and onions. Staggering plantings is necessary due to the heavy water requirements of these vegetables; they must receive water each week of the first month. Note that about one quarter of the land is double-cropped in the year, with tomatoes, then onions, or vice-versa. Two of the onion activities are accommodated when tomato land becomes available. Aside from avoiding water use bottlenecks, double-cropping helps even out labour use. It also keeps more land in a soil-holding crop, which reduces soil erosion and nutrient losses through leaching, and aids in controlling pests and weeds.

Ten and one half of the twelve liters of rainfed land are planted in corn and beans in this farm plan. Full utilisation does not occur because some of the labour is drawn into more profitable irrigated production during the critical month of January, when the labour-intensive harvest of rainfed corn and beans occurs (see next section on labour use).

c) Labour Use: **Figure 4a** contrasts labour use for rainfed and irrigated plots. Peak labour use in January corresponds to the harvest of corn and beans; January is the only month in which the labour constraint is binding (at sixty person-days) in this model. The dual price of labour is only 851 C.V. esc ($12.16) for this month. The dual price of labour indicates that if one more person-day of labour were available in January, total net revenue would rise by 851 C.V. esc. The cost of a day's labour, which includes salary and non-monetary expenses, is 250 C.V. esc ($3.57) for men and 150 C.V. esc ($2.14) for women (Santiago Crop Budgets 1988, p.28). This suggests that it would not be worthwhile to hire labour in this month. In reality, the harvest period may last longer than labour use specifications indicated in the crop budgets and even if family labour is fully utilised, the family could take advantage of the *djunta mon* (reciprocal inter-household labour) system to avoid this potential bottleneck on rainfed land and the need to hire labour.

Figure 4b details the labour demands for irrigated crops in the farm plan. In general, the larger sections of the bars correspond to planting stages, while the smaller sections indicate weeding or watering tasks. It is not surprising that the model indicates so much slack labour for most of the year. We would not expect labour to be binding in Cape Verde's agricultural sector, in which an average of over seventy per cent of the labour force is unemployed (USAID 1980, p.21). This labour surplus corresponds with a high level of male out-migration and very low wage rates in agriculture.

d) Water Use: As expected, water is the critical binding constraint in this model. **Figure 4c** shows that all three hours of available water are used in six months of the year. The dual prices of water, which represent the extra revenue that would be generated if one more hour of water were available, for these months are indicated in the same figure. They range from a low of 1,467 ($21) to a high of 15,493 ($221) in May. The latter amount represents the potential of late plantings of vegetables, suggesting that substantial revenue could be gained from small increases in water in November, February, and May. Water is not binding in the rainy season months (July to October), because the peak demands of the late vegetable crops come earlier. Water is not binding in January because the model did not select any January plantings of the water-intensive vegetables (their net revenue values were relatively lower than for other months).

2. Sensitivity Analysis on Prices:

It is useful to analyse effects of producer price changes on the model for two related reasons. First, sensitivity analysis provides information on how much such prices must change in order to make non-basic crop activities enter the optimal farm plan. Second, sensitivity analysis provides a test of validity on the model. If small increases in producer prices of non-basic crops were to make the crops basic, then we could not be confident about the crop choice of the model's optimal farm plan, because small changes in prices could make the model results inapplicable.

For non-basic activities, higher producer price levels are calculated so that they could be included in the optimal farm plan. This information is displayed in **Tables 7a** and **7b**, which show the "reduced cost" for each non-basic crop. The reduced cost is defined as the change in net revenue, or **c** value, needed to bring that activity into the basis These values were calculated by GAMS and are listed in the appended output. Further calculation arrived at the producer price required to achieve a net revenue which represents the initial **c** value plus the reduced cost. **Figure 5** summarises these tables by showing the <u>mean</u> percentage increase in producer price needed for the <u>non-basic</u> crop activities to enter the farm plan.

Not surprisingly, the lowest price increases correspond to the four crops which are already represented in the basis in certain months. Potato and cabbage prices must rise considerably to be included. Sugar cane and banana prices must jump from four to six and a half times their present value in order for them to become profitable relative to other cropping possibilities. These large reduced costs for cane and banana support the idea that there may be strong extra-economic forces operating in their favour. For bananas, farmers may be reluctant to cut down well established trees, perhaps in the hope that the export market will grow to previous levels. Cane may be preferred for *grogue*, the *palha* by-product , or as will be argued later, technical constraints may leave the farmers few alternatives to this hardy crop.

The magnitude of the price changes required for the non-basic crop activities to enter the basis suggests that we can be reasonably confident about the validity of the model in terms of the crops selected in the model's solution. Major changes in Santiago prices will have to take place in order for the model results to differ significantly.

3. Model Validation with empirical evidence

The most common experiment for validating LP models is the "prediction experiment", which compares the solution values of the primal variables (x) with real world values (McCarl and Apland 1986). For comparison, data on actual crop selection for permanently irrigated areas in Cape Verde (Freeman et al. 1978, p.103) are contrasted with the modelled results.

	Actual(%)	Modelled(%)
Cane	57	10
Banana	9	0
Manioc	0	22
Swt Pot/Manioc	12	8
Potato	7	0
Tomato	1	30
Onion	2	30
Other Vegetables	12	0
	100	100

(Note: other vegetables=carrots, cauliflower, peppers, garlic, cabbage)

Obviously the model has selected a crop mix for a representative farm that bears little resemblance to the aggregate quantities being grown. The most obvious disparities are between sugar cane and the vegetables. If the sugar cane land were somehow converted to tomatoes and onions, the two columns would appear much more similar. Note however that the "actual" figures do not represent a "typical" farm but aggregated data on land under cultivation. Therefore the data are not strictly comparable, unless we could assume that all farms in Cape Verde grow similar proportions of crops. Evidence presented in the next chapter, however, shows that Santiago farmers are not homogeneous with respect to their access to productive resources, particularly water.

The income generated by the optimal farm plan also suggests that there is serious mispecification in the model. Annual revenues of 253,000 C.V. esc a year, about $3,600, is an enormous sum for a Cape Verdean farmer. In 1985 the national per capita income was 25,000 C.V. esc, less than a tenth of that calculated for the "representative" farmer (The Economist 1988, p.63). Land rental prices on Santiago--about 7,000 C.V. esc per liter (Food Crops Research Project 1982, p.20)--are insignificant compared to this figure.

In sum, the price sensitivity analysis supports the model's choice of cropping activities, but empirical evidence suggests that the model is deficient in one or more aspects.[3] Chapter Four assumes that the disparity is caused by the water parameters used in the model, and investigates the effects of varying water supply and irrigation frequency.

---

[3] One disturbing result of the model and the sensitivity analysis is that potatoes were not selected, even though it is apparent from the empirical evidence that these crops are culivated more than onions and tomatoes. Perhaps this is because potatoes are relatively drought resistant (although their optimal water needs are high compared to manioc, sweet potato, and cane) and the harvest and storage periods can be extended to avoid surpluses at the market.

-CHAPTER FOUR-

1. Manipulating water distribution

Changes in irrigation practices can take place across two dimensions: quantity and frequency of water applied. In this section, model parameters are varied on these dimensions, and observations are then made on the impact on crop mix, scheduling, input use, and farm revenues. Of course, the way in which these manipulations of irrigation water take place is not simply a technical or resource issue; altering the quantity and frequency involves economic and social considerations. These are addressed in the final chapter.

To measure effects of quantity changes, water supply (**h**) is varied parametrically in the linear model. Computer runs of the model were made with one, two, three, four, five, and six hours of water available each month of the year. This range encompasses the vast majority of irrigated farms on Santiago, from the driest to the most advantaged.

For frequency effects, total monthly water supply is held constant for specified periods, and then the number of applications each irrigated plot receives is varied. As described earlier, the current linear model assumes that the farmer may apply the available monthly water supply (three hours) on a weekly basis. In other words, the application frequency is four times a month. This option is not available to many farmers on Santiago. Some plots may receive similar amounts, but only twice or once a month. In extreme cases, irrigations may only occur once every 45 days or more. To simulate the effects of this variability in watering frequency on the optimal farm plan, the model was run several times with watering frequencies of every one, two, three, four, and six weeks.

Figure 6a summarises the results in terms of total revenue of 36 versions of the optimal farm plan, with water supply (on the x-axis) and irrigation interval (each line) varied parametrically. The optimal farm plan described in the previous chapter is represented by point A. Note that with an irrigation frequency of greater than six weeks, there is assumed to be no income from the irrigated plot, just from rainfed corn and beans (this is not absolutely true in reality; small yields of sugar cane may be produced at longer intervals). The bases associated with each of the lines shown in **Figure 6a** are described below. Results in terms of land use patterns and revenues by crop summarised in **Tables 8** and **9**, portrayed graphically in **Figures 7a to 11b. Figure 6b** is constructed in the same way as **6a**, but includes information on the annual labour demands of each of the farm plans.

a) Watering every week: There are no basis changes as water supply is varied from 1 to 6 hours a month (see **Figure 7a**); the combination of cane, sweet potato/manioc, high yield manioc, high yield tomatoes, and onions persists. More water, however, allows more of the latter three crops to be grown, to a point where the single-cropping constraint is binding for onions and tomatoes as plenty of water becomes available. Compared to the revenue breakdown (**Figure 7b**) for the six optimal farm plans, the lucrative tomatoes contribute disproportionately to total revenues.

The flattening out of the revenue function with this watering interval after three hours of water availability is significant. Doubling water availability (from three to six hours) only results in a twelve per cent increase in revenues. This is because land becomes a binding constraint after three hours, suggesting that three hours of water a month should be sufficient for farmers with only a liter of irrigated land. This result could have important implications on water management practices and land reform efforts.

b) Watering every 2 weeks: Optimal farm plans under this situation follow a very similar pattern to that described above (see **Figures 8a** and **8b**). The major difference is that tomato and cabbage production is infeasible, since these crops demand weekly watering in the initial month. Without tomatoes, optimal farm plans focus on onions and high yield manioc, and corresponding optimal revenue values for the irrigated plot are twenty-five to thirty-one percent lower than with weekly waterings (thirteen to twenty-five per cent lower with rainfed included). The same flattening out of the revenue graph occurs as the land and onion single-cropping restriction become binding after the three hours level. Farmers can expect revenues of about 160,000 C.V. esc from their irrigated plot at a level of three or more hours.

c) Watering every 3 weeks: With this interval, tomatoes, onions, cabbage, potatoes, and bananas are no longer candidates for the optimal farm plan. Selection is limited to sugar cane, low yield manioc, sweet potato, and the intercropped sweet potato/manioc. The latter activity becomes the most profitable, and dominates the farm plans, with the exception of the 0.1 liter of sugar cane (**Figures 9a** and **9b**). Expected revenues from irrigated crops are just under fifty per cent lower than the bi-monthly case above, about 106,000 C.V. esc per year. Revenues cease to increase after four hours because land is binding at that point.

d) Watering every 4 weeks: The sweet potato/manioc consumption constraint imposed on the above models was dropped at this point to prevent solution infeasibility, since the activity requires water every three weeks. The optimal basis now includes only low yield manioc and the minimum portion of sugar cane (see **Figures 10a** and **10b**). Land becomes binding when three hours of water are available per month. At this water supply level or greater, expected revenue is about 75,000 C.V. esc for irrigated crops and 51,000 for rainfed crops.

e) Watering every 6 weeks: With this interval, only low yield sugar cane production is feasible. Land is binding at 3 hours per month. Revenues are very low; with the full liter of land planted in cane, farmers can expect under 1,500 C.V. esc per year (see **Figures11a** and **11b**).

Two interesting conclusions arise from the scenarios. First, they show that diminishing returns to the water input occur after three hours of water are available. Second, they show clearly that choices of crops for the optimal farm plan depend much less on how much water is available, and much more on the frequency of irrigation. In general, smaller amounts of water, *ceteris paribus*, mean that smaller areas are cultivated and/or reduced areas of crops with high water demand are planted. Together, these conclusions suggest that net gains might be achieved by cutting back the water supply of more advantaged farms in favour of increasing irrigation frequency for the system as a whole. This possibility is considered in the final two chapters.

In order to test the significance of irrigation frequency on Santiago farms, it will be useful to return to the validation experiment introduced in the third section of Chapter Three. The results regarding frequency of irrigation water are again compared with present farming practices in Cape Verde (see **Figure 12**). Holding water supply constant at three hours, the crop mixes at various frequencies (i.e. the farm plan at point A in **Figure 6a** and the points directly below it) are compared to the same data presented in the previous chapter (Freeman et al. 1978, p.103) which represents estimates on the percentage of irrigated land under cultivation in Cape Verde as a whole. Unfortunately data for Santiago alone are not available. The data do not represent the crop mix found on a "typical" farm, so again the two data series are not strictly comparable.

Clearly the empirical information still does not match any of the results generated by the model. The "actual" data display a more varied choice of crops, with a larger percentage of land in sugar cane. Bananas, potato, and "other vegetables", do not appear at all in the modelled farm plans. In order to compare the modelled farm plans with the "actual" cropping patterns, we need to estimate the number of farms that have access to the particular irrigation frequencies, and from there construct sectoral estimates which weight theses modelled crop mixes by the percentages of farms receiving particular irrigation intervals.

2. Empirical Evidence on Irrigation Frequencies:

Estimates of irrigation intervals are available from two sources. One is the Santiago survey (Finan and Belknap 1985). The other is recent documentation from the Ribeira Seca irrigation system on Santiago (see **Figure 1b** for its location). These data are discussed separately below and then compared together with the national data on area under cultivation.

a) Santiago Survey Data: Ninety of the 239 households sampled in the 1984 report had access to irrigated land, of which 88 responded to a question on frequency of irrigation. The land in question amounted to 85 liters. Whether the answers are expressed per respondent or converted to per liter terms, the answers are very similar.

The following table summarises the information.

Irrigation Interval	(per liter) %	(per respondent) %
every week or less	5.1	8.0
every two weeks	19.0	19.3
every three weeks	6.6	6.8
every four weeks	10.0	8.0
more than four weeks	59.3	57.9
	100.0	100.0

b) Ribeira Seca Data: Fourteen months of records (from January 1988 to February 1989) exist for the Ribeira Seca irrigation system on Santiago. These were kept by a bureaucrat who manages the distribution of tubewell water to all the farms in that valley. They record the name of the farmer, the date, and the number of hours allotted. Regrettably, neither the size of plots nor the crops grown thereon were listed, making conclusions on water supply per unit of land difficult. However, the records do shed some light on what a "typical" watering amounts and intervals might be.

Table 10 displays the information for the 56 Ribeira Seca farms (arranged in arbitrary order); figures represent hours of water applied per week per farmer. For simplicity data were aggregated per week; in a few cases two or three waterings were applied in certain weeks. Adding these figures horizontally across the page, and aggregating the sums into months gives an idea on how much water was available from the tubewell in that year. **Figure 13** plots these results. The supply appears highly irregular. However, there were rains in late July and late October in 1988, which probably accounts for the small allotments in those months. The reason for the similarly small quantities toward the end of the period is unknown.

How equitable was the distribution of this water? Adding the figures from **Table 10** down the columns may give an idea of how equitably the water was distributed, although, to repeat, there is no indication of how large the plots are, so measurements in hours per liter are impossible to calculate. **Figure 14** plots the distribution of water by farm. The disparity in distribution is clear. Whether this skewed distribution is a indication of the size of land allotments or distortions in the water allotment for other reasons is an important question, but must remain unanswered at this time. The median value is about 25 hours for the 14 months, under two hours of water per month. If this value corresponds to "average" sized farms of one liter as indicated in the Santiago survey, we would conclude (from model results in **Figure 6a**) that the land is being under-utilised due to lack of water. However, it is necessary to relate plot size in Ribeira Seca compared to the rest of Santiago before accepting this conclusion.

The Ribeira Seca data are more useful in giving an idea of water frequency intervals for those farms. **Table 11** is identical to **Table 10** except that numbers were changed to X's to aid in visualising the watering interval experienced by each farmer (by reading down the table). The striking feature of this table is the apparent arbitrary nature of the distribution. Some farms appear to be very fortunate (e.g. farms #1,#10,#30,#55), with water made available weekly for sustained periods. Others received water at intervals up to months apart.

In an attempt to quantify this interval distribution, the number of times in which irrigation water was received was counted for each farm (calculations are presented in **Table 12**). These values were compared with the time span during which the water was applied. Since there were some very long periods with an absence of applications, the period concerned was defined by the time between the first and last weekly record. This was to avoid including periods when land might have lain fallow. **Table 12** displays the mean number of irrigations per month, as well as the mean duration (in weeks) between irrigations. The figures may be biased downward slightly considering the times when rain made irrigation unnecessary. These weekly intervals were sorted and appear graphed in **Figure 15**. Like the Santiago survey data, the graph clearly shows that only a very few farms enjoy the option of growing high-profit crops, i.e. those who were getting water on a weekly or biweekly basis. Only about a third of the farms were doing better than water every three weeks. The rest were most likely involved in cultivation of sugar cane or low yield manioc, considering the low irrigation frequency.

The following tale summarises and compares the interval data for the Santiago survey and the Ribeira Seca data.

	Santiago		Ribeira Seca
	(per liter)	(per respondent)	(per respondent)
Irrigation Interval	%	%	%
every week or less	5.1	8.0	7.4
every two weeks	19.0	19.3	7.4
every three weeks	6.6	6.8	18.5
every four weeks	10.0	8.0	9.3
more than four weeks	59.3	57.9	57.4
	100.0	100.0	100.0

c) Modelling Crop Mix on a Sectoral Basis

The comparison between actual and modelled crop mixes displayed in **Figure 12** can be reformulated to incorporate the interval results presented in the previous section and arrive at sectoral comparison at the level of Ribeira Seca and Santiago as a whole, as opposed to simply modelling a representative farm. This is done by first multiplying the percentages displayed above by the crop mix proportions found at each of the intervals (from Chapter Four). The weighted crop mixes are then added for each crop. This gives an inductive, "sectoral" estimate, which assumes that farmers produce the optimal farm plans based on the irrigation frequency they receive. Thus the estimate is more suitable for comparison to the data on estimated cropland for Cape Verde.

The weighted and "actual" crop mixes are displayed in **Figure 16**. The first column is identical to that in **Figure 12**, and represents the estimates on irrigated area under cultivation for Cape Verde as a whole from the U.S.AID report. The second column infers a crop mix based on the watering intervals from the Santiago survey, and the final does the same using the Ribeira Seca data.

The results of this validation procedure offer a strong support for arguing the significance of irrigation intervals in the cropping choices of Santiago farmers. The most obvious similarity between modelled and actual estimates is the area planted in sugar cane; the model departs from the empirical evidence by only a few percentage points. Among the differences is the emphasis on bananas in the actual situation. This perhaps reflects the fact that, despite the low net revenues of bananas seen in the sensitivity analysis, farmers are unwilling to destroy the trees that once supplied a significant source of export revenues.

-CHAPTER FIVE-

1. Increasing Water Supply

This thesis has shown that in order to effect the transition from cane to food crops, Santiago farmers must have timely access to irrigation water. This can come about in two ways. The first assumes an increased supply of water through development of water resources or improvement of the technical efficiency of present systems. This will have the effect of decreasing the time between irrigation turns for farmers, since the water source will be recharged more quickly. The other way, which assumes a constant supply of water and development of improved distribution practices, is discussed in the second part of this chapter.

Access to more water may be achieved by either better weather conditions (which replenish groundwater and holding tanks and increase the amount of surface water that may be captured), or by locating new sources of groundwater. The first alternative is uncertain; good rains in 1987 gave little reason to believe that the drought is coming to an end. Consensus in the literature is that improvement of the management of the ground and surface water has the greatest potential. The recommendations of the Dutch study (Food Strategy Study 1982, vol.2) are to improve water catchment and storage structures, particularly in those upland areas. This would have the combined effect of controlling erosion and capturing groundwater that ordinarily flows through the alluvium and out to sea. One estimate is that 140 million cubic meters of surface and groundwater annually could be developed; 30 million cubic meters are presently being utilised (Freeman et al. 1978, p.195). About two-thirds of this potential would come from renewable groundwater, and the remainder from intercepting surface flows. This optimistic report provides only vague indications of how this is to be achieved. Obviously there are considerable costs involved in achieving this goal. However, an in-depth discussion of the potential and costs of developing new sources of water supply and improving existing sources is beyond the scope of this thesis (see Food Strategy Study 1982, vol. 2 pp.55-63 for details on such costs).

There may also be some potential for improving the technical efficiency of present irrigation systems by reducing seepage losses, particularly with the upland irrigated terraces. The overall water efficiency use of upland systems is very low because of seepage through earth-lined levadas and heavy losses when water flows from one terrace down to the next. In contrast, *ribeira* systems tend to be highly efficient, with well maintained concrete levadas. Upland systems average about 30% efficiency, and the ribeiras 90% (see Food Strategy Study 1982, vol. 2 pp.28-32, for a detailed description on how irrigation efficiencies are calculated). However, improvement of the upland delivery systems would probably have a negligible effect on irrigated farming as a whole, because, considering low upland system efficiency and high river basin efficiency, any improvement in upland systems would simply reduce the amount of water in the ribeiras lower down.

2. Increasing Irrigation Frequency

None of the recommendations contained in the development literature on Cape Verde address the possibility of improving the allocative efficiency of irrigation systems under present conditions of land and water supply. To investigate this possibility a simple LP model is constructed. The Santiago data are used again, which record watering intervals from 90 farms comprising 85 liters of land. For modelling purposes, these farms are assumed here to be members of a single irrigation system. The model is designed so that the objective function maximises expected revenue for the 85 liters, solving for an optimal combination of irrigation intervals. The coefficients represent the optimal values of per liter net revenue that were calculated in Chapter Four (see **Table 3**) for each interval. Land receiving weekly watering is labelled x1, that with two week intervals is x2, and so on, with x5 land receiving intervals of greater than four weeks. To estimate the total water available annually for these 85 liters, an estimated number of applications per year (52 divided by the recorded intervals) is multiplied by an assumed average application quantity of three hours per liter. The resulting estimate is 3,973 hours of irrigation water per year. Coefficients in the water constraint are measures of how many water applications each type of land requires annually. For example, x1 land requires 52 weekly applications of 3 hours of water (156 hours) annually. The model takes the following form:

$$\begin{aligned} &\text{maximise} && 208029x1 + 153614x2 + 84475x3 + 74000x4 + 1485x5 \ \ (\text{C.V. esc}) \\ &\text{subject to:} && x1 + x2 + x3 + x4 + x5 \leq 85 \ (\text{liters}) \\ & && 156x1 + 78x2 + 52x3 + 39x4 + 27x5 \leq 3973 \ (\text{hours}) \end{aligned}$$

Total net revenue is maximised at 7.83 million C.V. esc, with only 50.9 liters of land irrigated at two week intervals. In short, if cropping patterns are to be adapted to the water supply with profit maximisation as the collective goal, then irrigated land is perhaps not a limiting factor in Santiago irrigated agriculture. For political and social reasons, however, the abandonment of 40% of this irrigated land will not be a popular alternative. With this in mind this model was rerun several times, each time forcing a particular watering interval into the basis in order to observe revenue and land use levels. The results are displayed in **Figures 17a** and **17b**. The first graph contrasts the Santiago data, which show a dominance of land watered at the lowest frequency (x5), with modelled results. If water were only available on a strict weekly basis, water supply would only allow 25.5 liters to be in production. Land must also be under-used if water is supplied once every two or three weeks. Longer intervals allow full use of the available land.

Expected net revenues from each of these scenarios are shown in **Figure 17b**. With present water supply, revenues are greatest when land is under-used, and irrigated at two week intervals (see dark bars). This is 71% greater than the estimated revenue from current practices. The one, two and four week interval scenarios respectively generate 16%, 41%, and 38% higher net revenues. In order to produce a variety of crops, a combination of these watering intervals would be selected for various amounts of land. Clearly, significant increases in collective revenue could be achieved using the vast majority of irrigated land with no change in the present water supply.

If more water were to be found, the potential is much higher still. **Figure 17b** also shows expected revenues if, somehow, enough water were to become available so that <u>all</u> 85 liters could be sustained with the various frequencies.

Gains in farm income and food production would be accompanied by increased demand for labour on irrigated farms since food crops require more labour than sugar cane. This difference was illustrated in **Figure 6b**, which shows that almost three times the person-days per year are required for the representative irrigated farm plan (with frequent irrigation) than with the area planted in cane (with infrequent irrigation).

-CHAPTER SIX-

1. Summary

The first chapter pointed to water scarcity as the greatest obstacle to the growth of food production on Santiago, and described domestic and foreign efforts to overcome the problem. Chapter 3 showed that the irrigated farm plan produced by the "representative" linear model described in the Chapter 2 was very profitable and produced a high proportion of food crops, but did not resemble data on current farming practices. Chapter 4 attempted to explain and correct this disparity by manipulating the water variable on the dimensions of water supply and irrigation interval. A water supply of three hours per month appeared to be an adequate amount to realise most of the potential of a liter of irrigated land. Crop mix and farm revenues proved to be more sensitive to watering frequency than to water supply. Irrigation schedules show that Santiago farms are heterogeneous with respect to the irrigation intervals they receive. By adjusting the modelled results for the various intervals found in the irrigation schedules, a sectoral model produced results similar to current farming practices, i.e. with about sixty per cent of land devoted to sugar cane and a relatively small amount planted with high-profit food crops. Chapter Five demonstrated that gains in employment, farm income, and food production might be achieved by redistributing the present supply of water on the present area of irrigated land.

2. Policy Implications

The results regarding intervals in irrigation shed light on why the Cape Verdean government's policies to reduce the area cultivated in cane in favour of food crops have been ineffective. Price supports for vegetables and taxes on *grogue* production will probably not change cropping patterns because sugar cane production remains the only feasible cropping alternative for the many farmers who receive water at long and unreliable intervals. This supports the hypothesis presented by other researchers (Langworthy and Hillman, in print), who recognise this technical constraint and argue that the *grogue* tax simply reduces returns to cane producers.

Consideration of this technical constraint as the sole explanatory variable may be simplistic. Risk, in terms of input supplies and output prices is likely an important factor in farm planning that this model has omitted. The only exception to lack of risk considerations is the imposition of the consumption constraints, which account for risk by assuming a risk-averse farmer takes steps to ensure some subsistence security. Risk factors were not specified explicitly in this thesis because the data were lacking. However, further research which incorporates such risk in a quadratic programming framework would likely produce results similar to the empirical evidence on crop mix. Existing data certainly give a good idea on how uncertain water availability has been in the past few years. If this could be measured and incorporated into the model, results would likely favour cane and other hardy, low-risk crops such as manioc and sweet potato. Riskiness of output prices might also confirm and help to explain current cropping practices. Recall that crops were divided into two groups ("price-variable" and "price-constant") based on producer price data. There were not enough data to make possible a variance-covariance matrix that would account for variability in net revenues in all the activities included in this model. However, farmers would probably tend to favour crops that will fetch a dependable price at market. Musser, McCarl, and Smith (1986) have shown that thorough specification of constraints can produce a crop mix identical to a less fully constrained quadratic programming model that incorporates output price risk.

Water reform will be needed to transform the present irrigation patterns to a more regulated one that recognises the importance of frequent irrigation applications. Bromley, Taylor and Parker define water reform as "institutional modifications which alter current patterns of water allocation among farmers" (1980, p.368). They observe that this reform is most easily attained when a) there is homogeneity of economic power and social status among water users, b) intercommunity factionalism is small, and c) there is a parallel development of institutional arrangements for water use and construction of the irrigation works themselves.

Do these conditions exist on Santiago? The first criterion is not met among irrigated farmers, although in rainfed farming cultural institutions exist that provide ways for rural families to share access to productive resources (Finan 1988). Nineteen percent of the population on Santiago own all the land; the remainder are wage workers or sharecroppers (Freeman et al. 1978, p.204). Eighty per cent of the irrigated farms cultivate only forty per cent of the irrigated land (Finan 1988, p.115). Ethnographic research is needed to examine how socio-economic differences are manifest with respect to irrigation privileges. Intercommunity factionalism is not likely relevant to the Santiago situation as it would be, say, on a flood plain, where communities compete for the same water in the same irrigation network. On Santiago the topography isolates communities and the adjoining irrigation networks. Parallel development of water use practices and the infrastructure may occur with the creation of new government-sponsored tubewell projects. Many such projects are planned for the coming decades. This suggests potential for centrally controlled and more equitable water distribution, although clearly central control is not the sufficient condition for improved distribution, as the Ribeira Seca data indicate.

Should the allocation of water be handled privately or publicly? While attending to the immediate requirements of the present population, chronic drought and overdraft mean that water management in Santiago must account for projected future use. Public management of water distribution would be more capable of fostering long term efficient use of water where numerous farms are linked to the same irrigation network. Individual profit-maximisers, striving for short-run gain in the face of uncertainty about future water availability, may use present resources beyond the long run capacities of the aquifer, and do so at the expense of their neighbours. Presently farmers receive as much water as they want when their turn comes up. There is incentive to use more than is necessary, in anticipation of a long wait until the next turn. Excessive waterings are especially wasteful because of the coarse soils, which drain quickly, and uneven distributions. The diminishing marginal returns presented in **Figure 6a** suggest that increases in water supply over three hours per month result in only small increases in farm revenue. A centralised authority, with access to accurate hydrological information on the water availability and rates of recharge would coordinate equitable allotments and withdrawal from wells, and adjust for seasonal variation. Another reason for public development of water resources is that irrigation strictures such as tubewells are prohibitively expensive for private farmers. So far 90% of money invested in such projects has come from foreign aid (Food Strategy Study 1982 vol. 2, p.xiv).

Public irrigation programs could choose between institutional or pricing policies to allocate the water. The former means that water continues to be provided free but on a strict schedule that preserves the resource and allows for more frequent intervals. Price policies could accomplish this indirectly, with marginal cost pricing that reflects the scarcity of the resource (Seagraves and Easter 1983). Marginal cost pricing would discourage the tendency to over-water.

The approach developed in this thesis would greatly benefit from further research on agriculture in Cape Verde. More information is needed on the hydrology of irrigated areas, specifically the determination the rate of groundwater recharge in order that water usage practices can develop to provide sustained and reliable access. This information can then be inserted into sectoral models that simultaneously treat the economics of agricultural production with the hydrology of the areas (see Duloy and O'Mara 1984, for an example). More price data will help to estimate the role of risk in the farmers' decision-making. This model has ignored market demand as a constraining influence, other than to acknowledge and incorporate seasonal variation in some producer prices. Widespread transition from cane to food crops would certainly have an impact on prices, given the small size of the market. Ethnographic research is needed to shed light on irrigation practices and determine how the present systems of water allocation operate and why they exist. It appears that certain farmers receive water in greater amounts and at shorter intervals. This disparity could be the result of differences in productive resources, entrepreneurship, or socio-political influence. Many projects fail when the status quo is disrupted, and ultimately the success of any water reform will depend on its compatibility with the target population.

APPENDIX 1: ILLUSTRATIONS

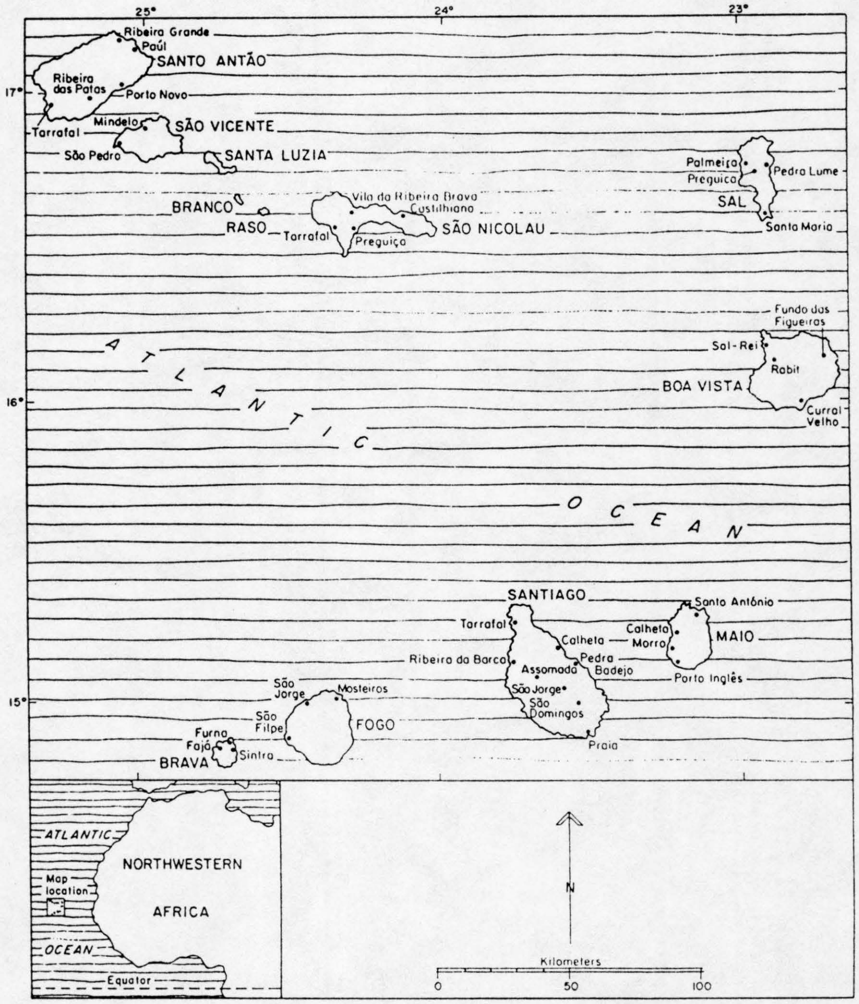


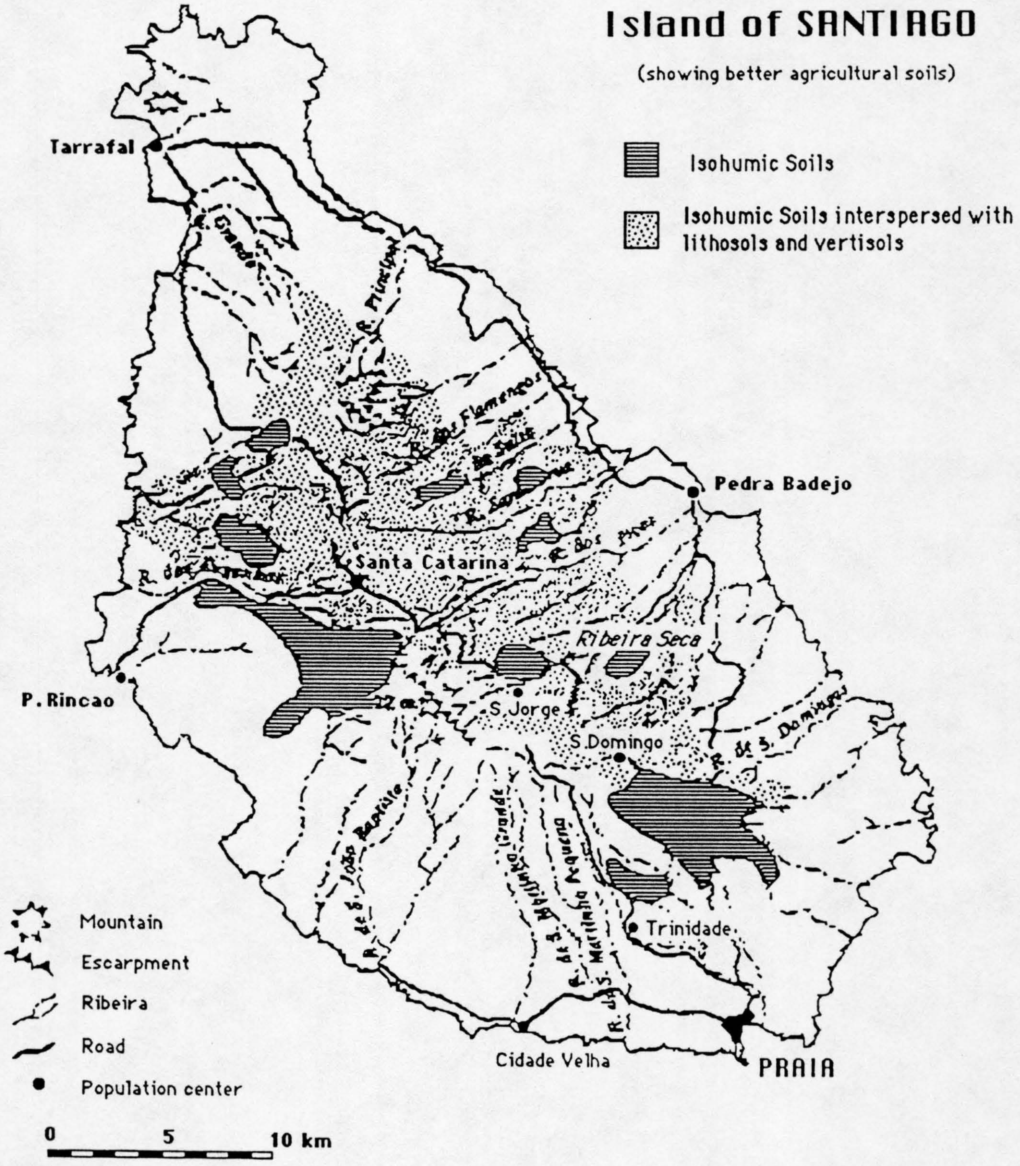
Figure la: The Republic of Cape Verde

Source: Finan and Henderson, 1988, p.90

Figure 1b:

Island of SANTIAGO

(showing better agricultural soils)



Source: Freeman et al., 1978, p.63.

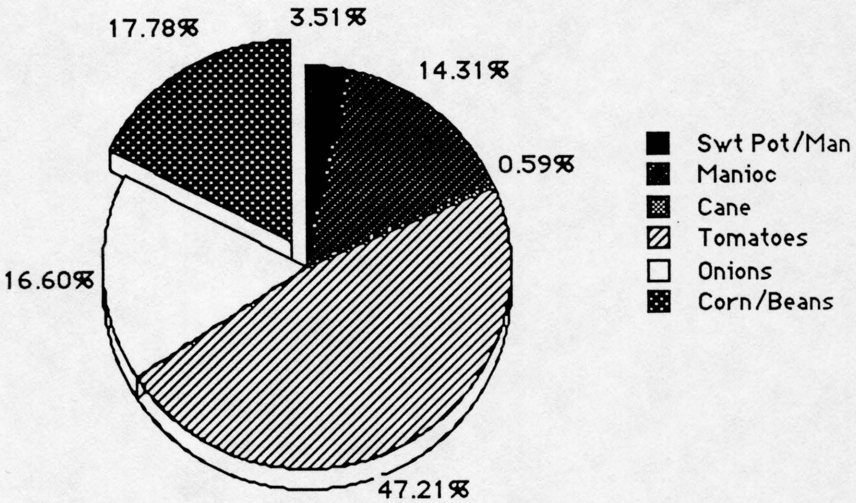


Figure 2: Revenue by crop for optimal farm plan

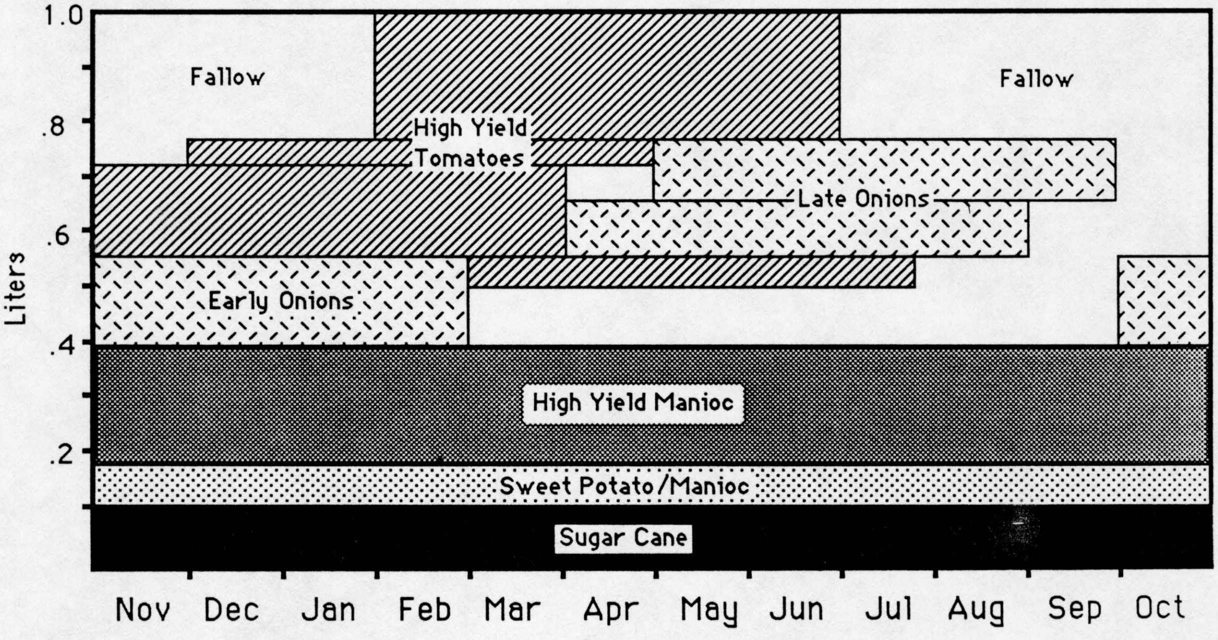


Figure 3: Crop calendar for optimal farm plan.

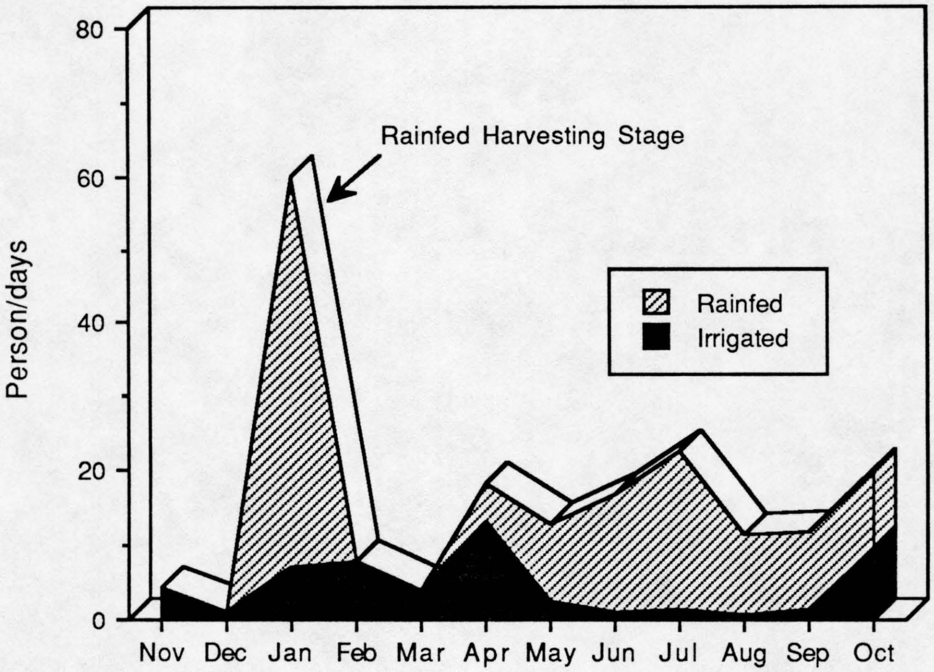


Figure 4a: Total monthly labour use for optimal farm plan

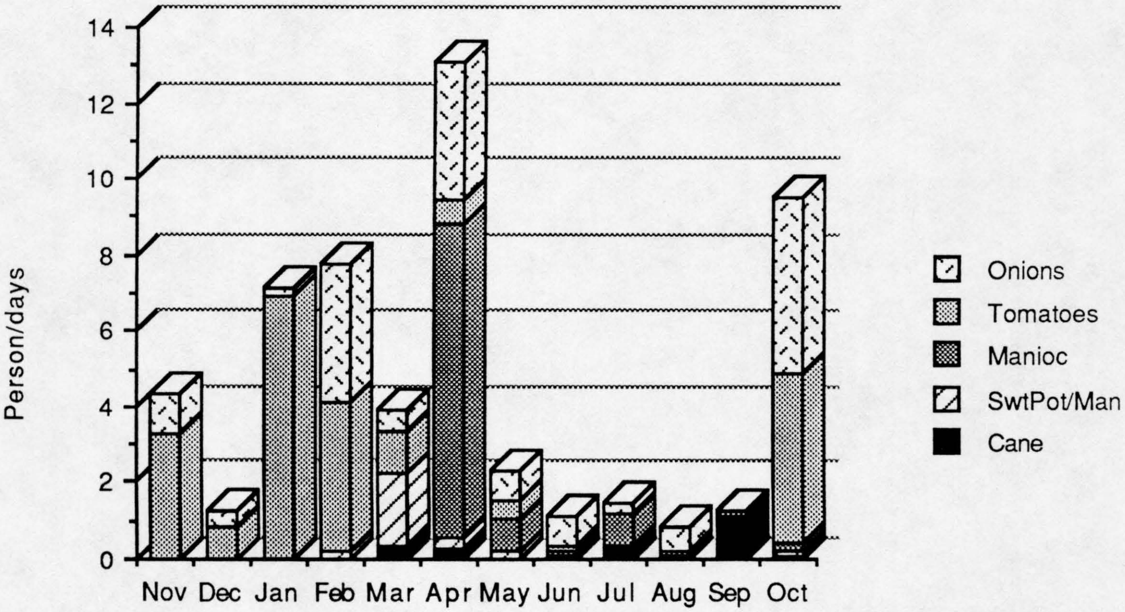


Figure 4b: Labour use by crop on irrigated land for optimal farm plan

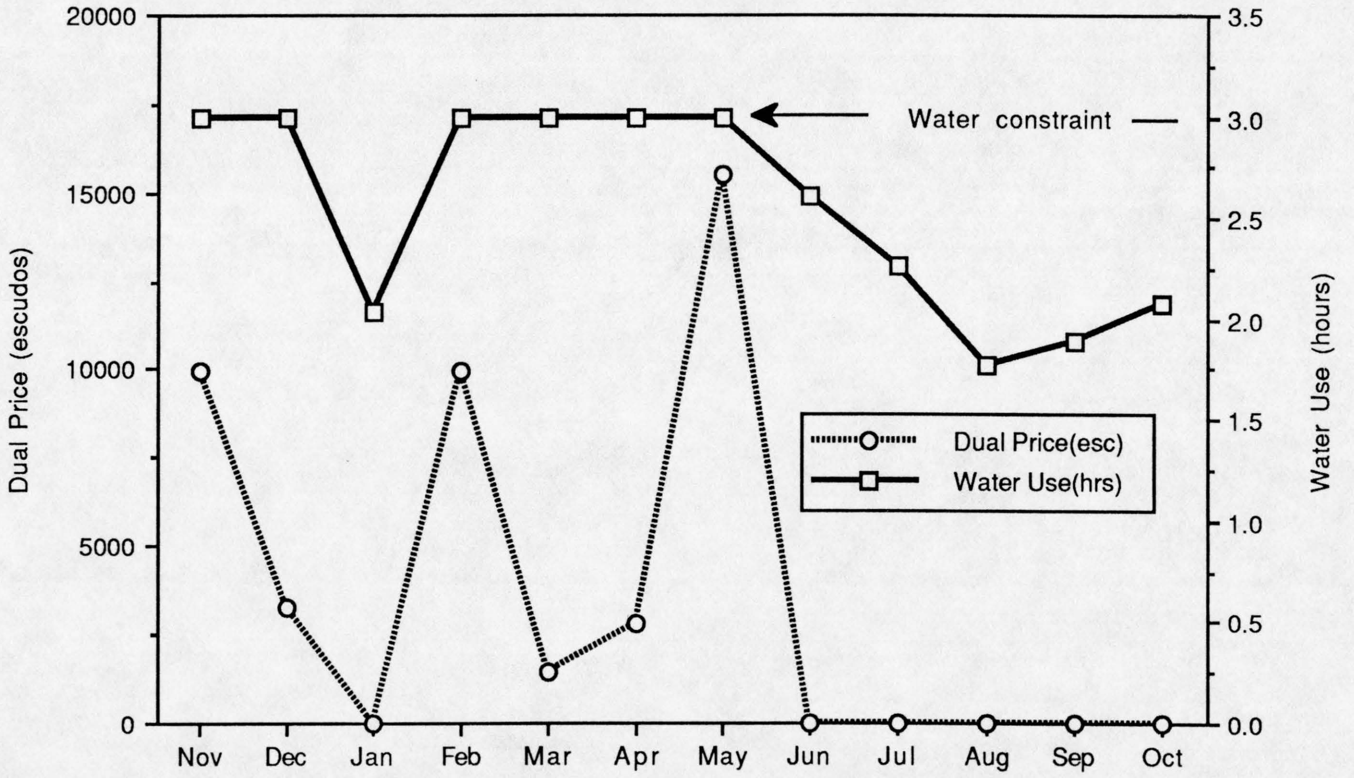


Figure 4c: Water use and dual price for optimal farm plan

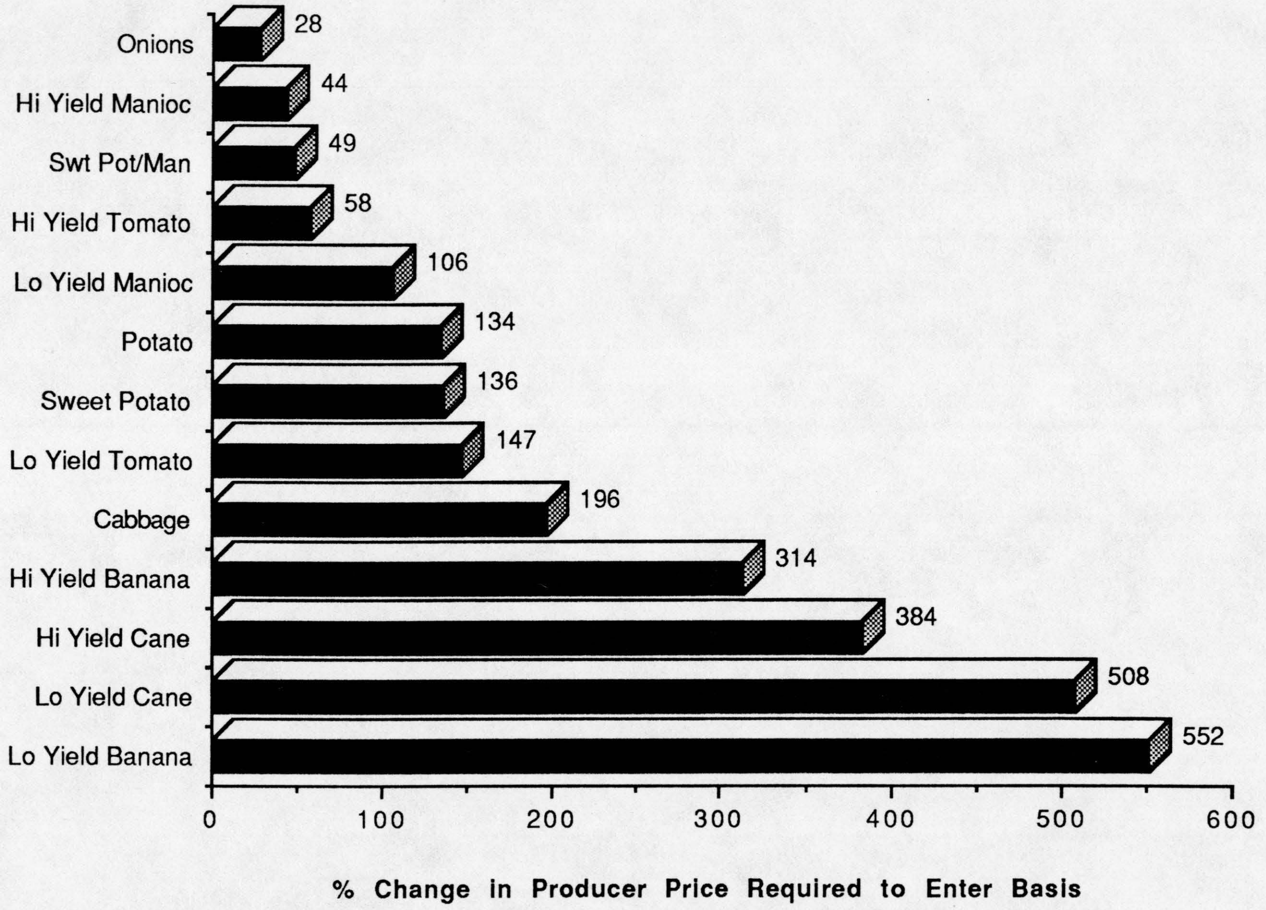


Figure 5: Percentage change in producer price required
for non-basic activities to enter basis, by crop

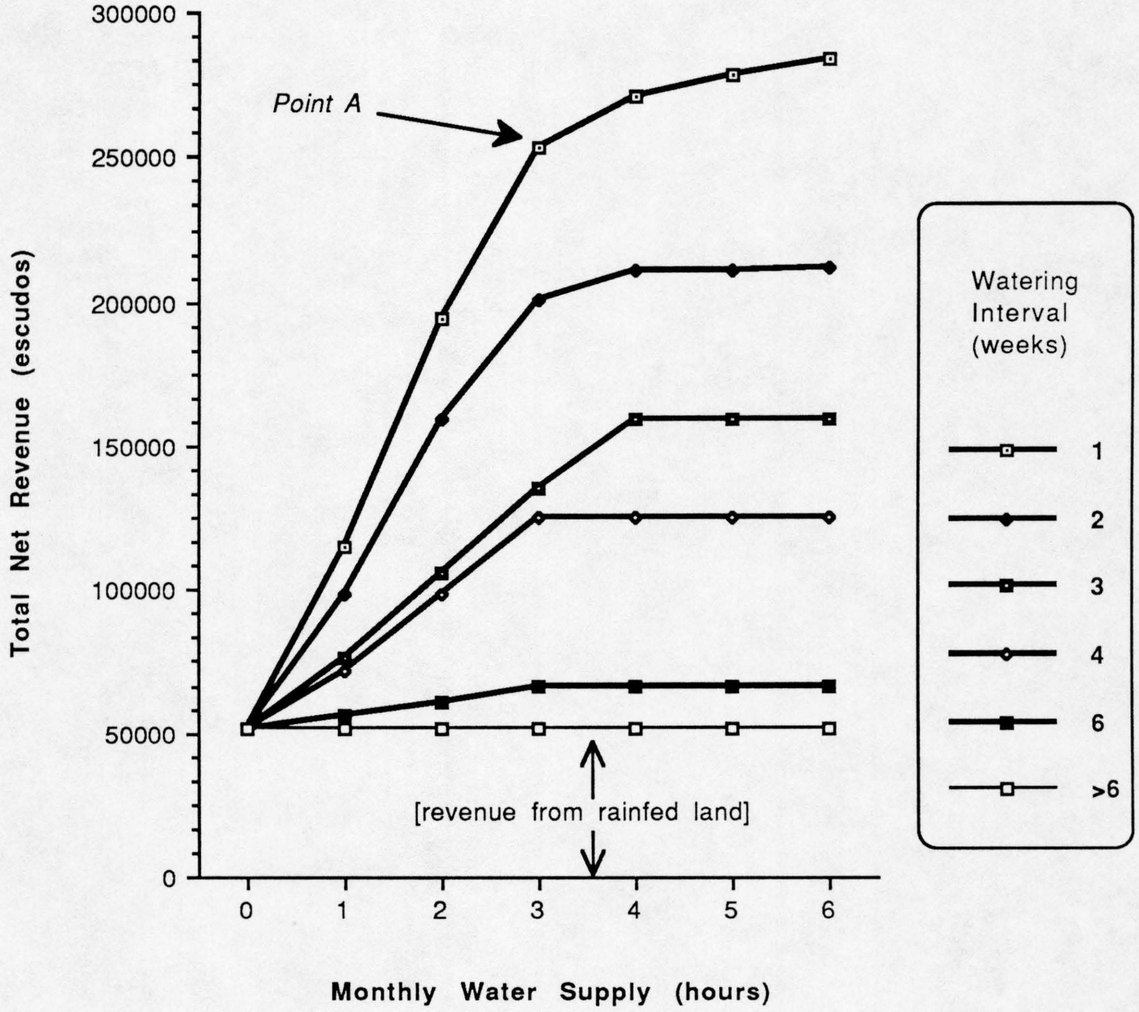


Figure 6a: Farm Revenue as a function of water supply and watering frequency

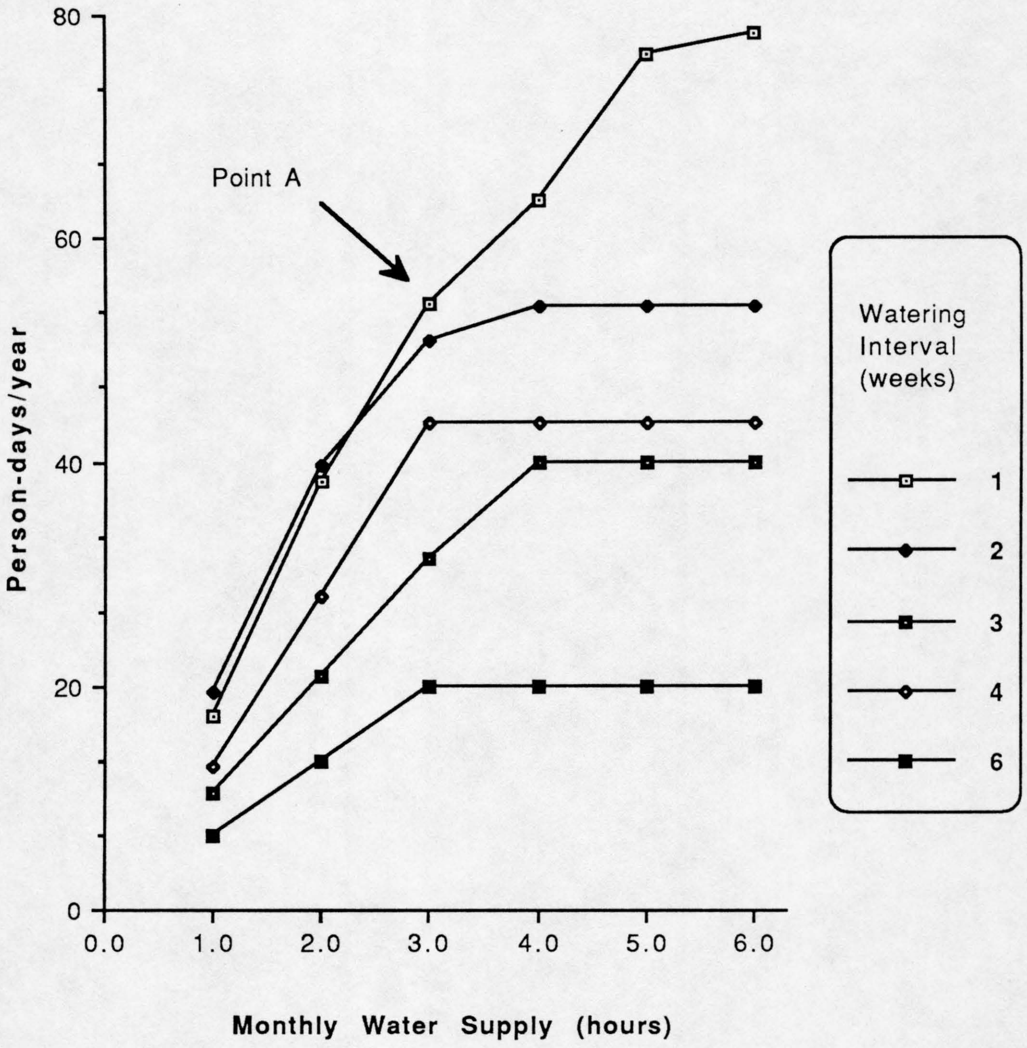


Figure 6b: Annual labour use as a function of water supply and watering frequency

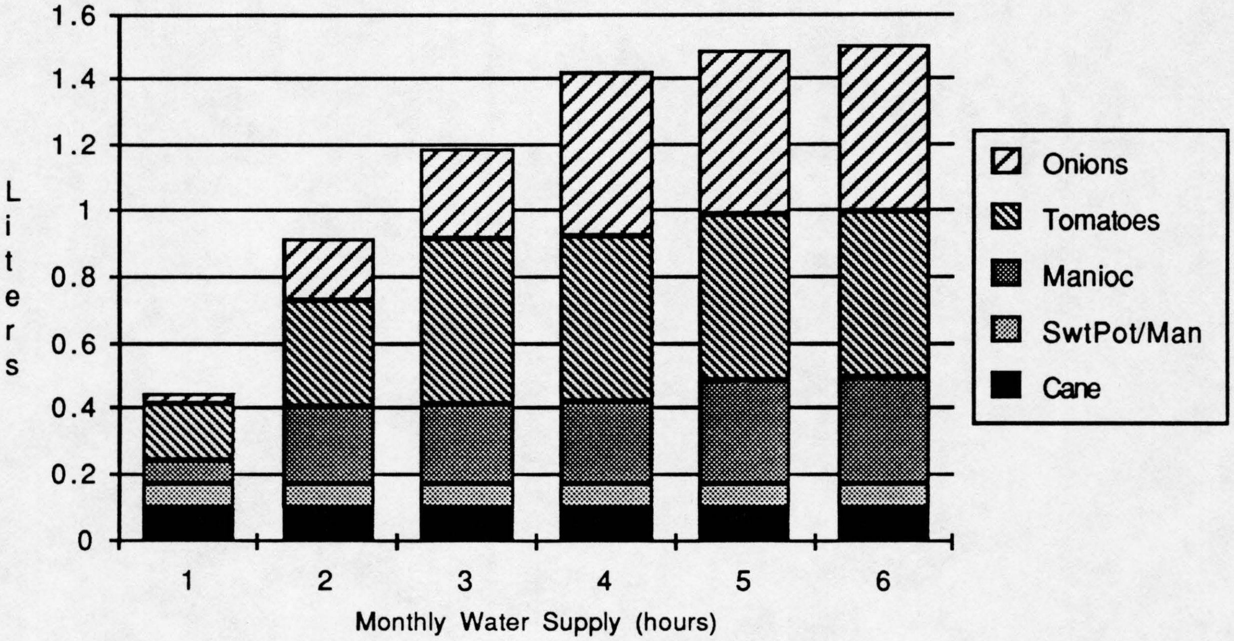


Figure 7a: Irrigated land use by crop for optimal farm plan (watering every week)

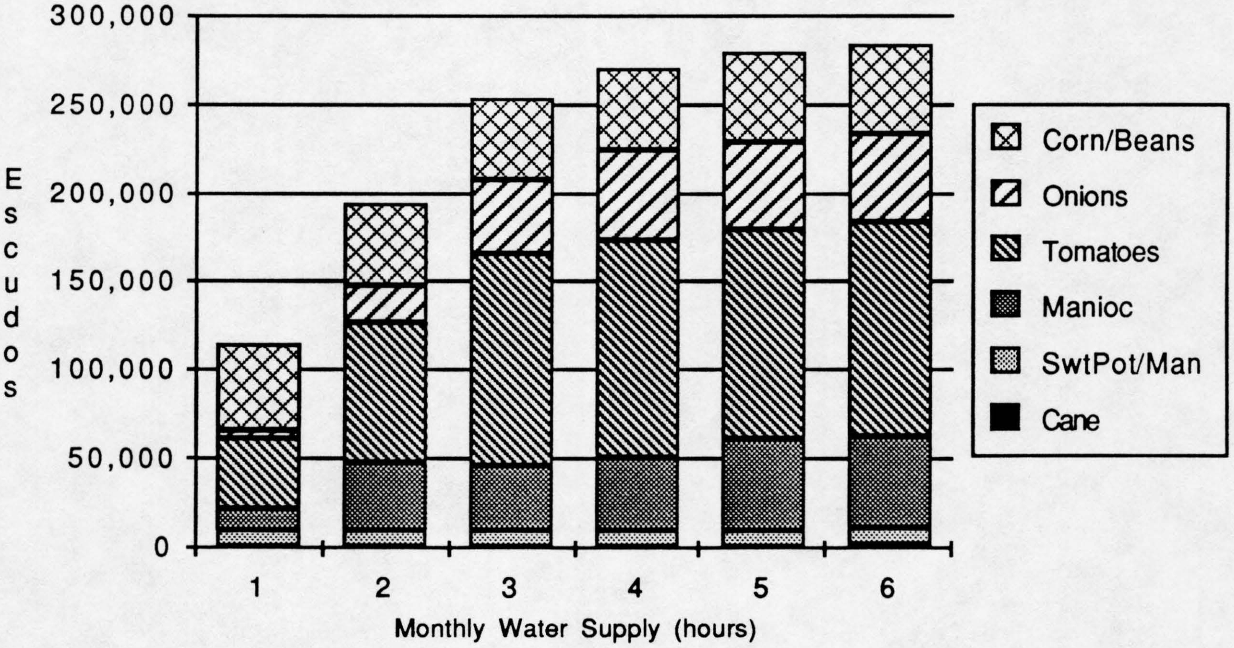


Figure 7b: Revenue by crop for optimal farm plans (watering every week)

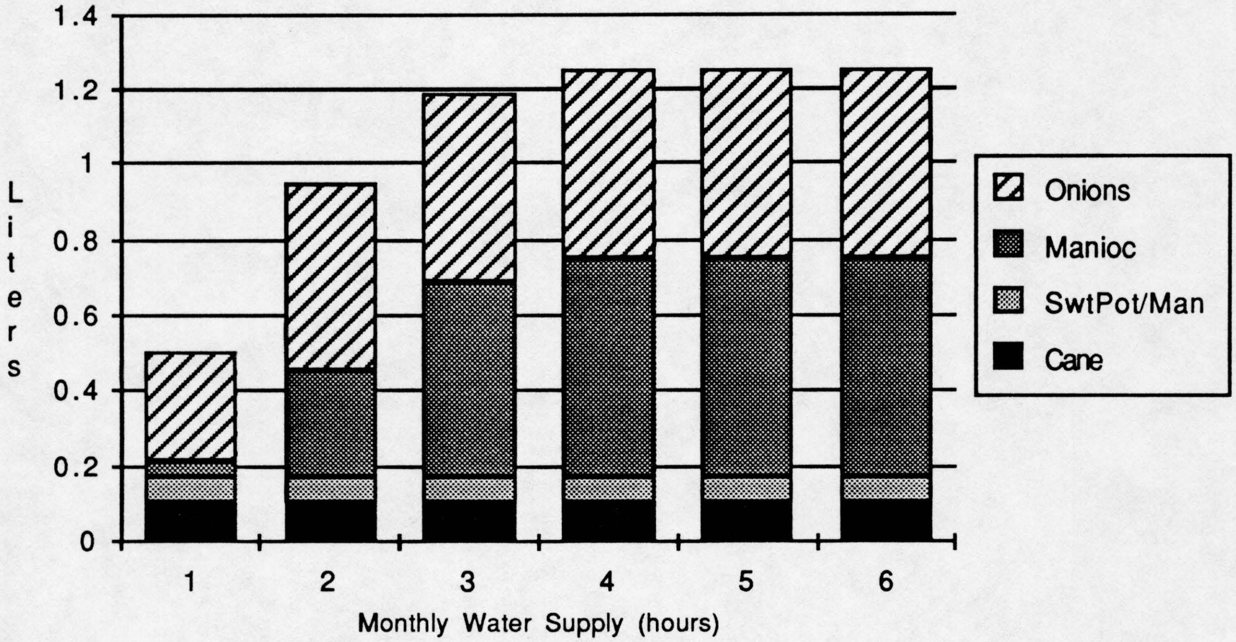


Figure 8a: Irrigated land use by crop for optimal farm plans (watering every 2 weeks)

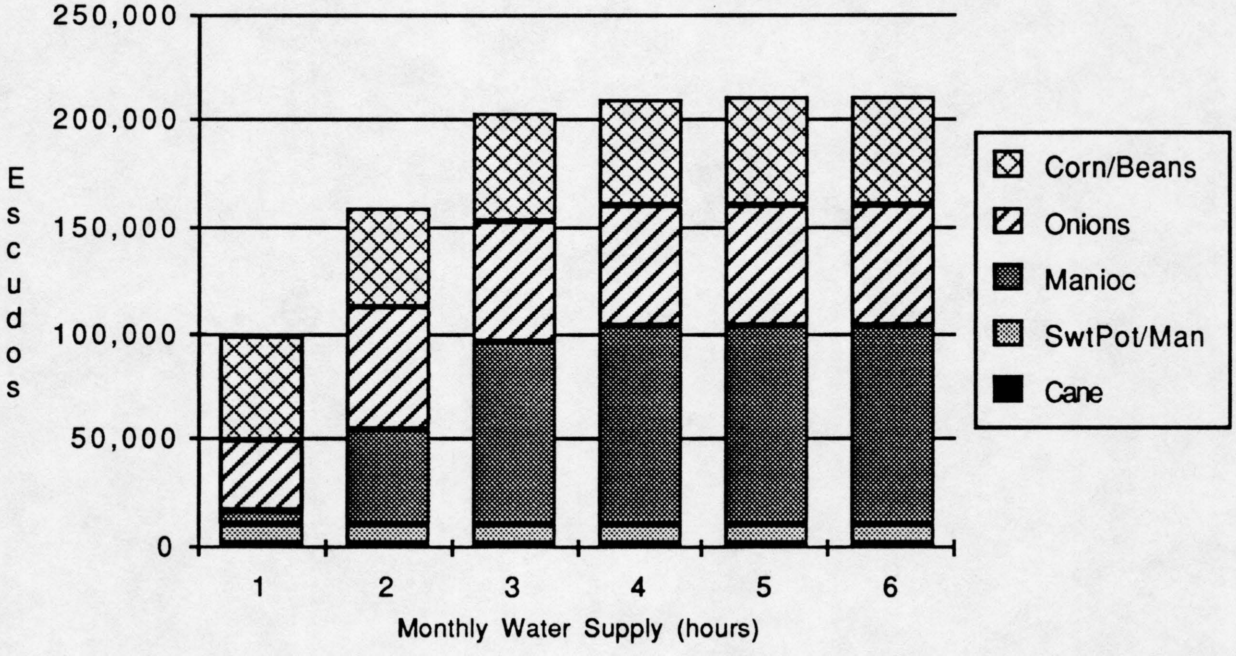


Figure 8b: Revenue by crop for optimal farm plans (watering every 2 weeks)

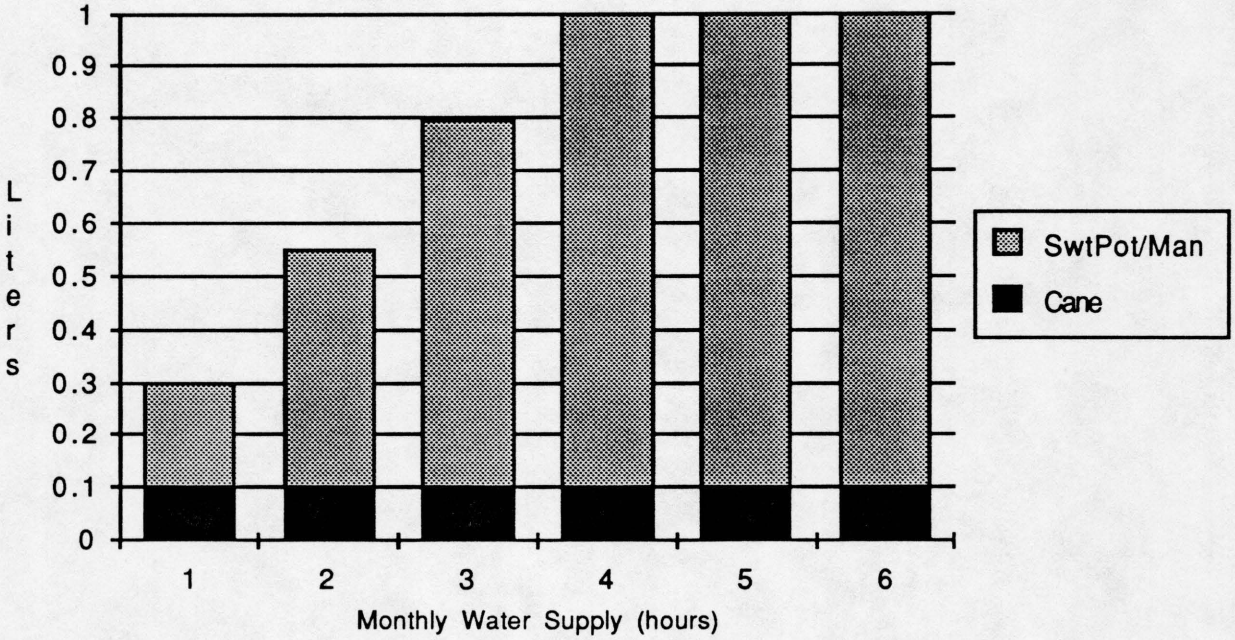


Figure 9a: Irrigated land use by crop for optimal farm plans (watering every 3 weeks)

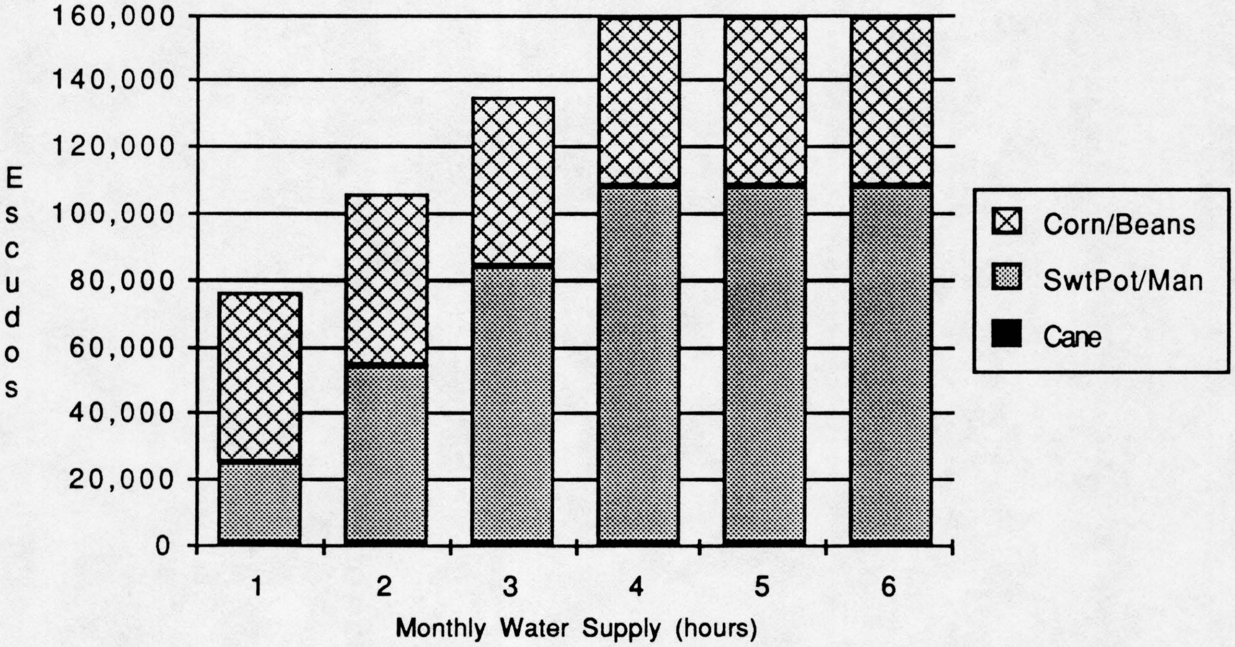


Figure 9b: Revenue by crop for optimal farm plans (watering every 3 weeks)

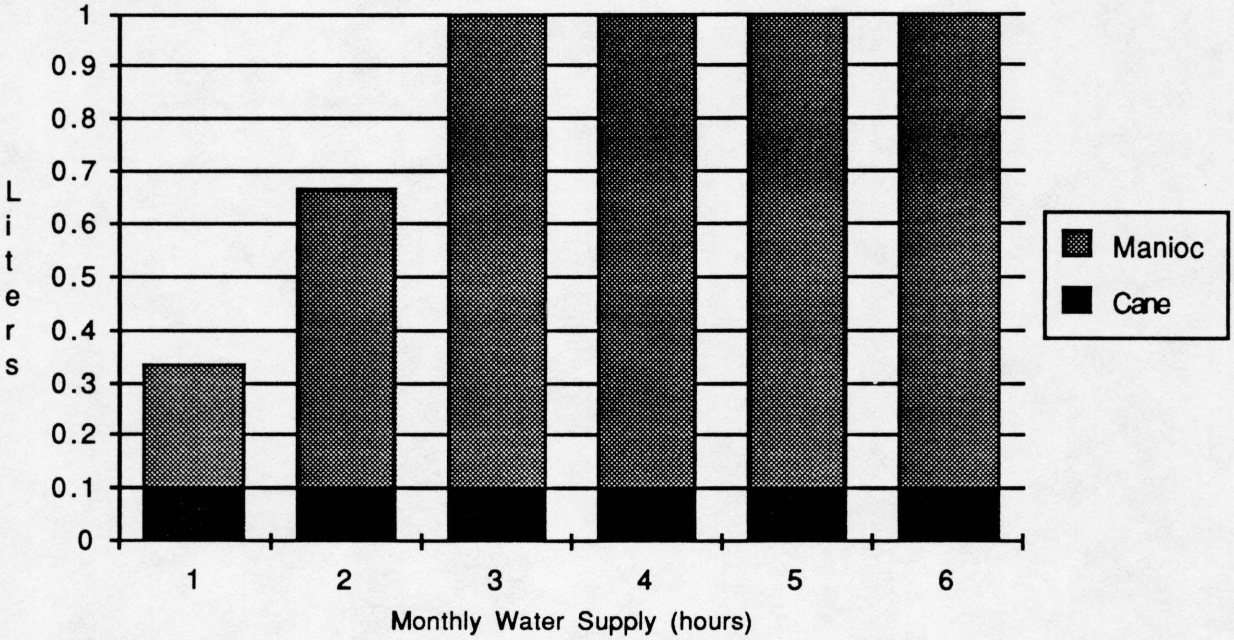


Figure 10a: Irrigated land use by crop for optimal farm plans (watering every 4 weeks)

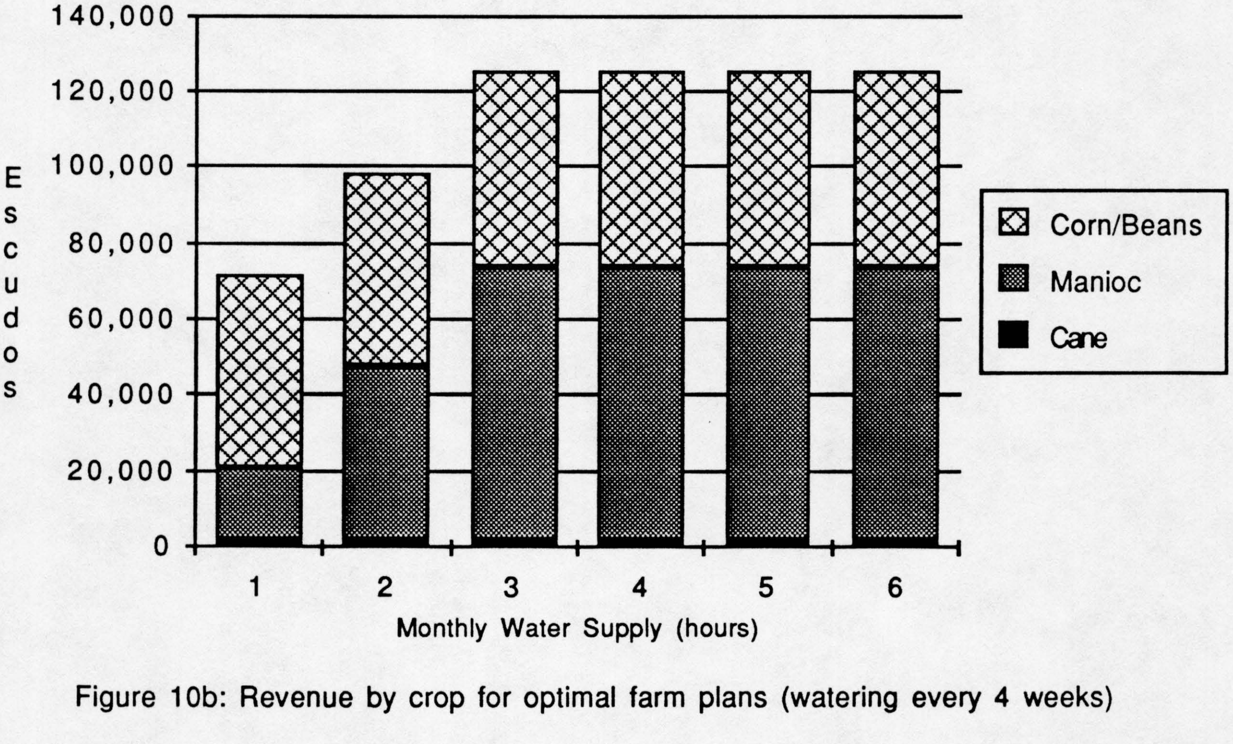


Figure 10b: Revenue by crop for optimal farm plans (watering every 4 weeks)

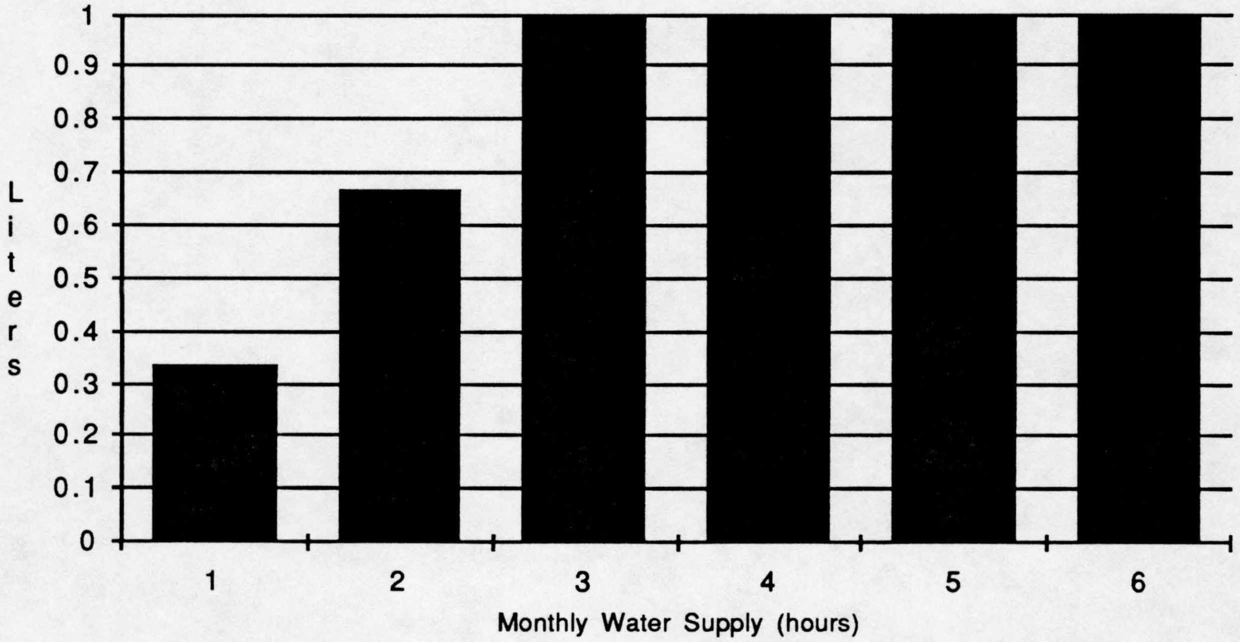


Figure 11a: Irrigated land use by crop for optimal farm plans (watering every 6 weeks)

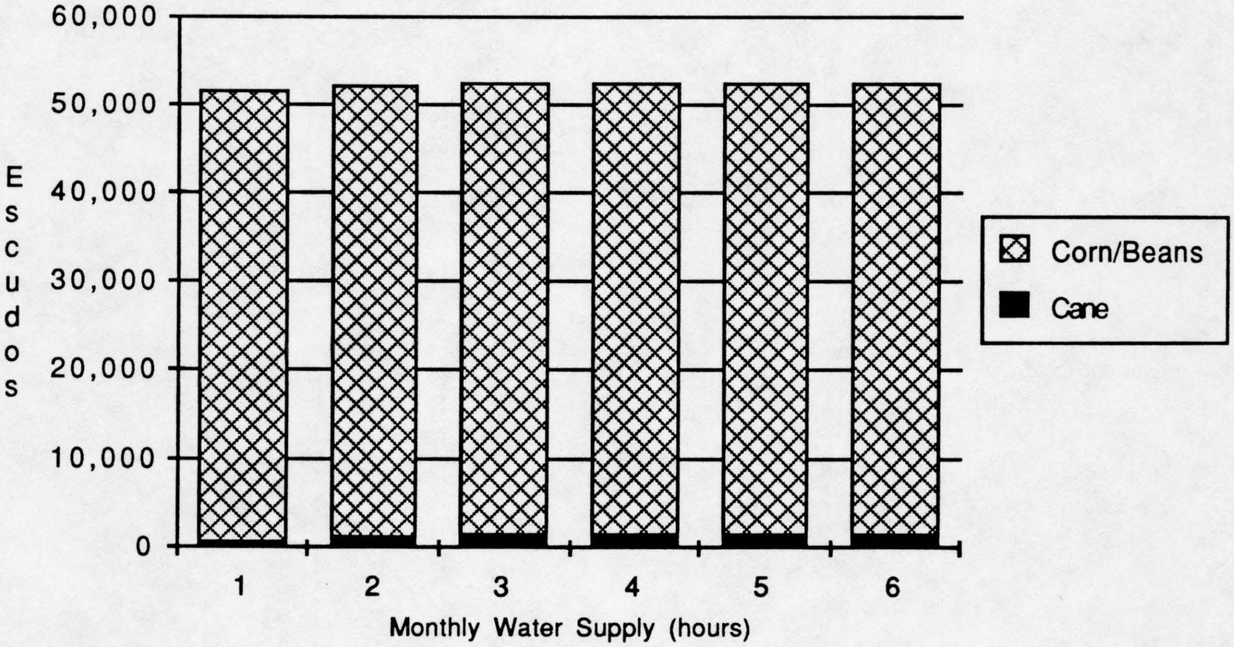


Figure 11b: Revenue by crop for optimal farm plans (watering every 6 weeks)

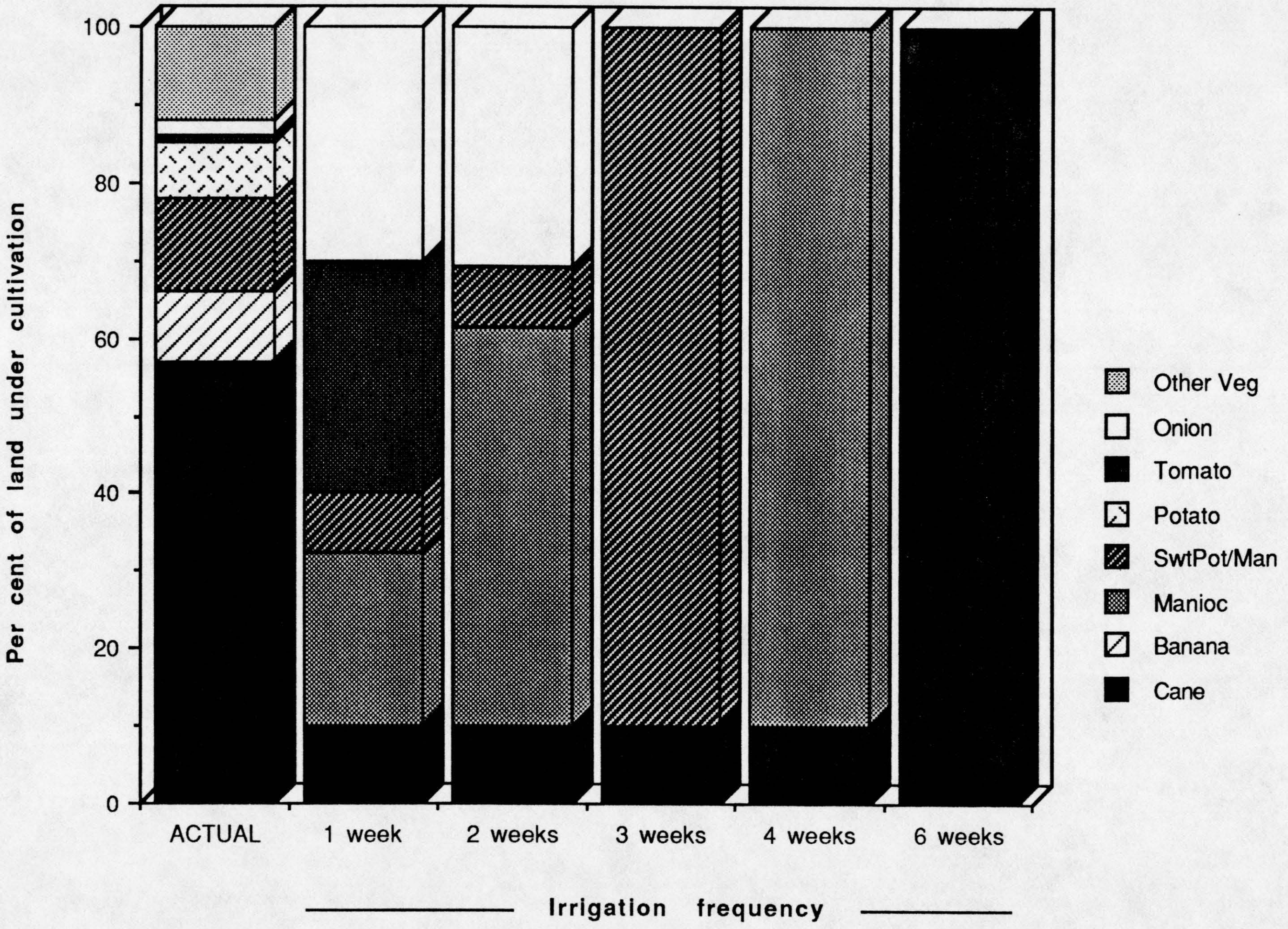


Figure 12: Actual crop mix compared to modelled crop mix, by watering frequency, with three hours monthly water availability

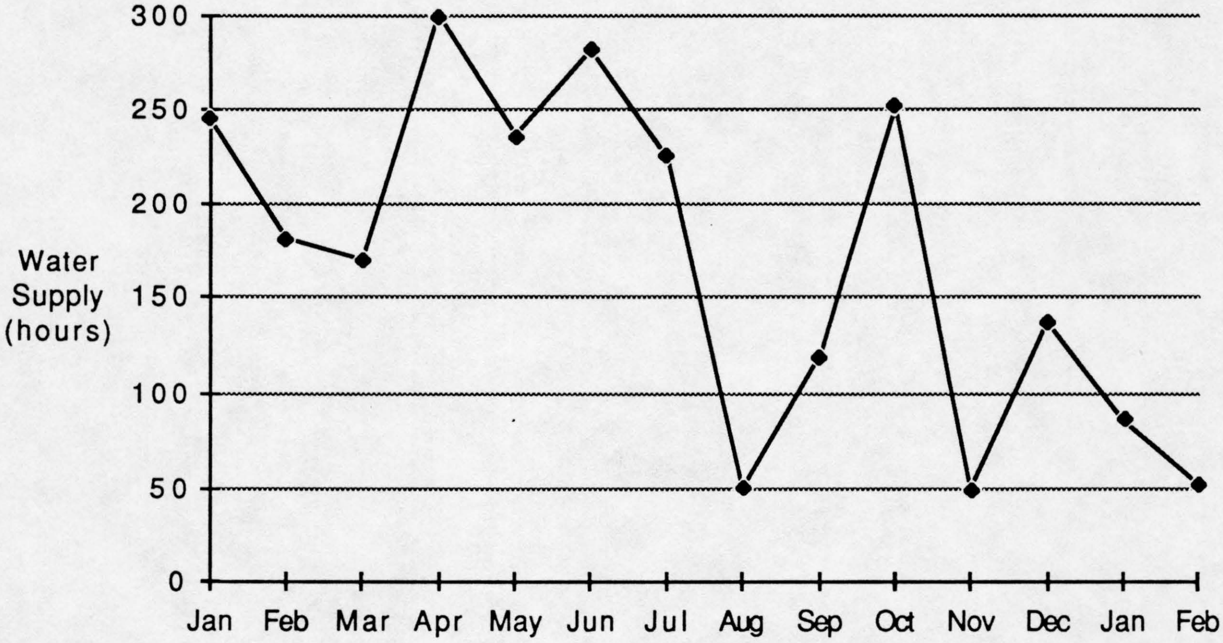


Figure 13: Monthly water supply for Ribeira Seca irrigation system (January 1988 to February 1989)

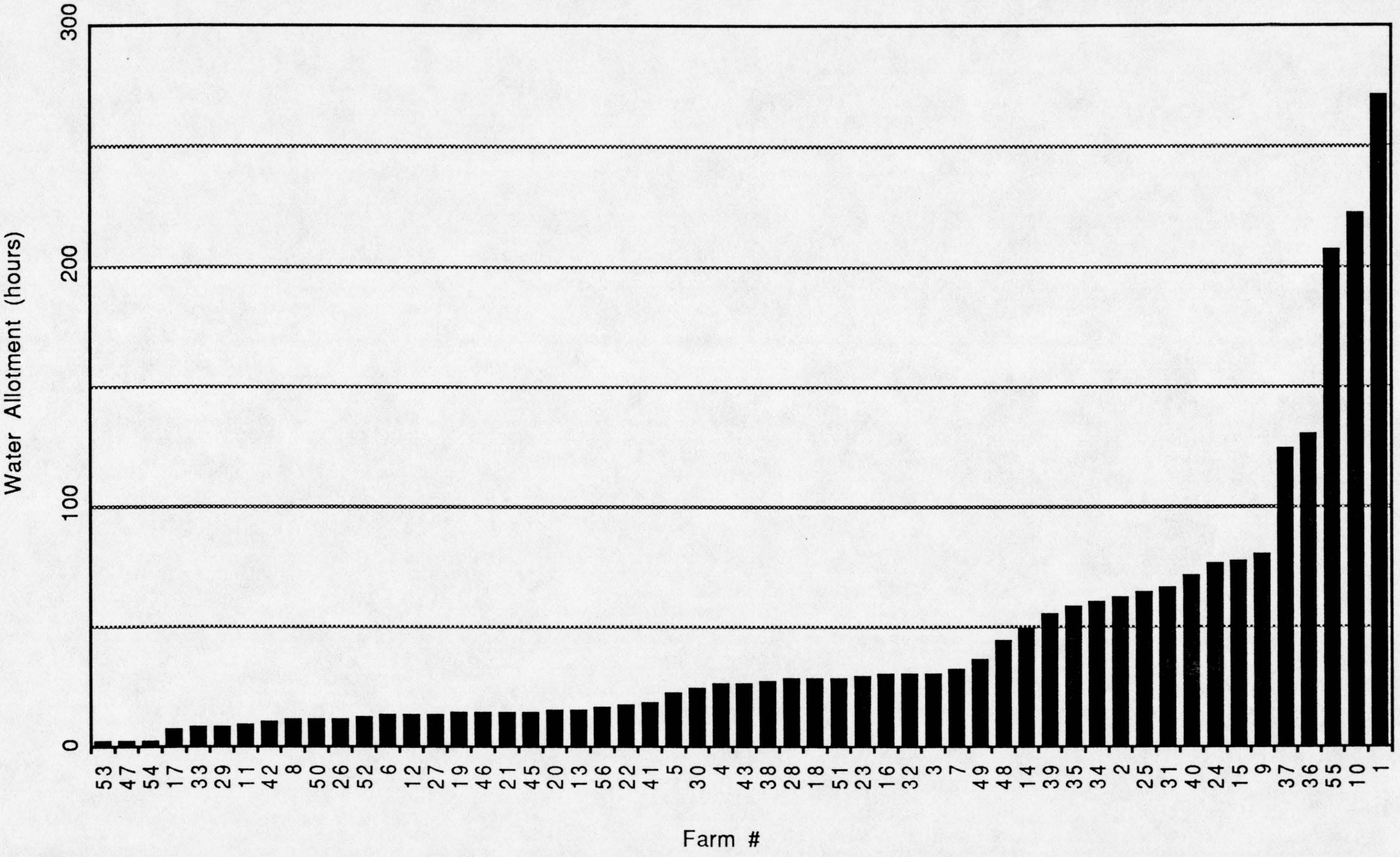


Figure 14: Water Allotments by farm for Ribeira Seca (Jan. 1988 to Feb. 1989)

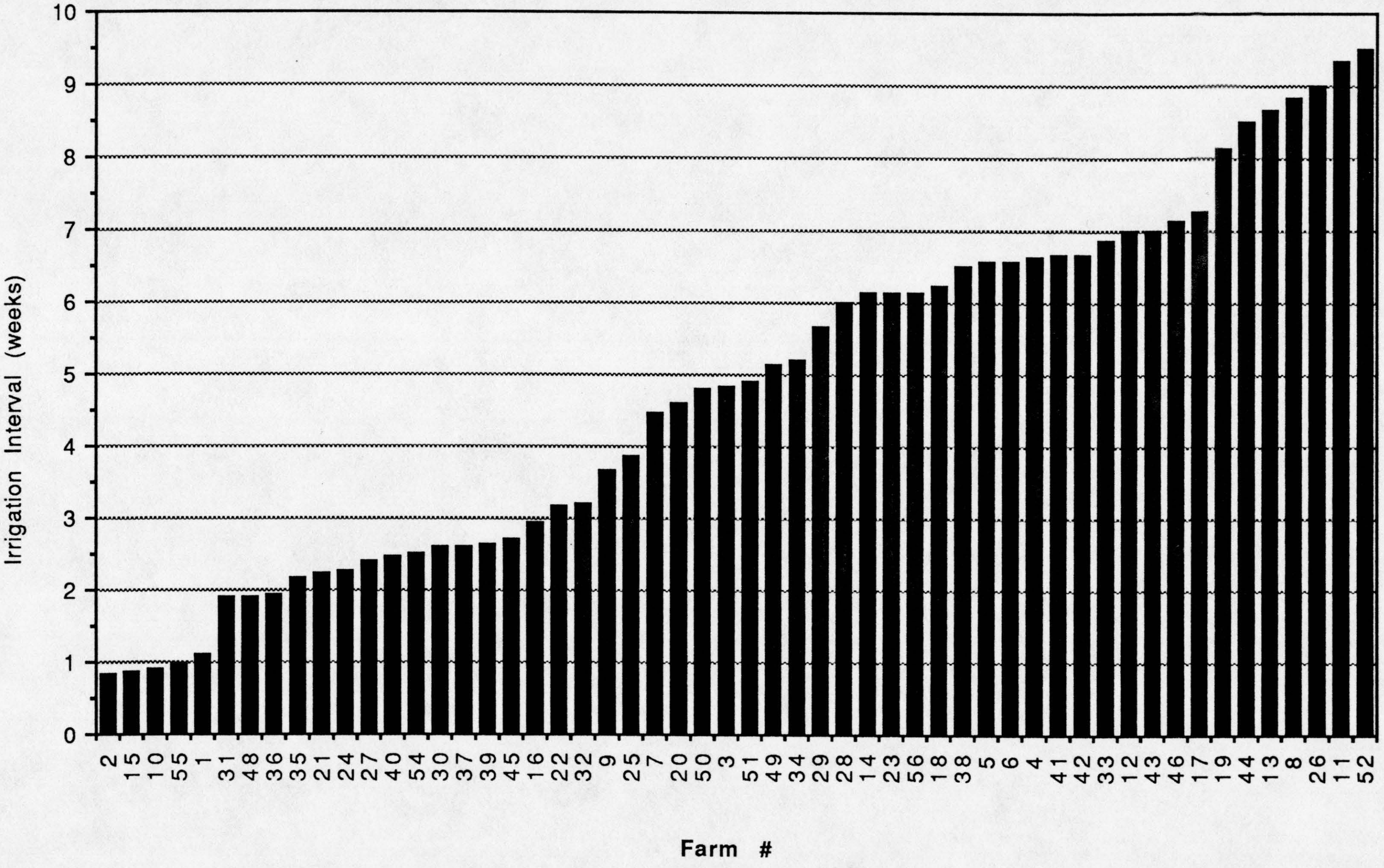


Figure 15: Mean irrigation intervals by farm for Ribeira Seca

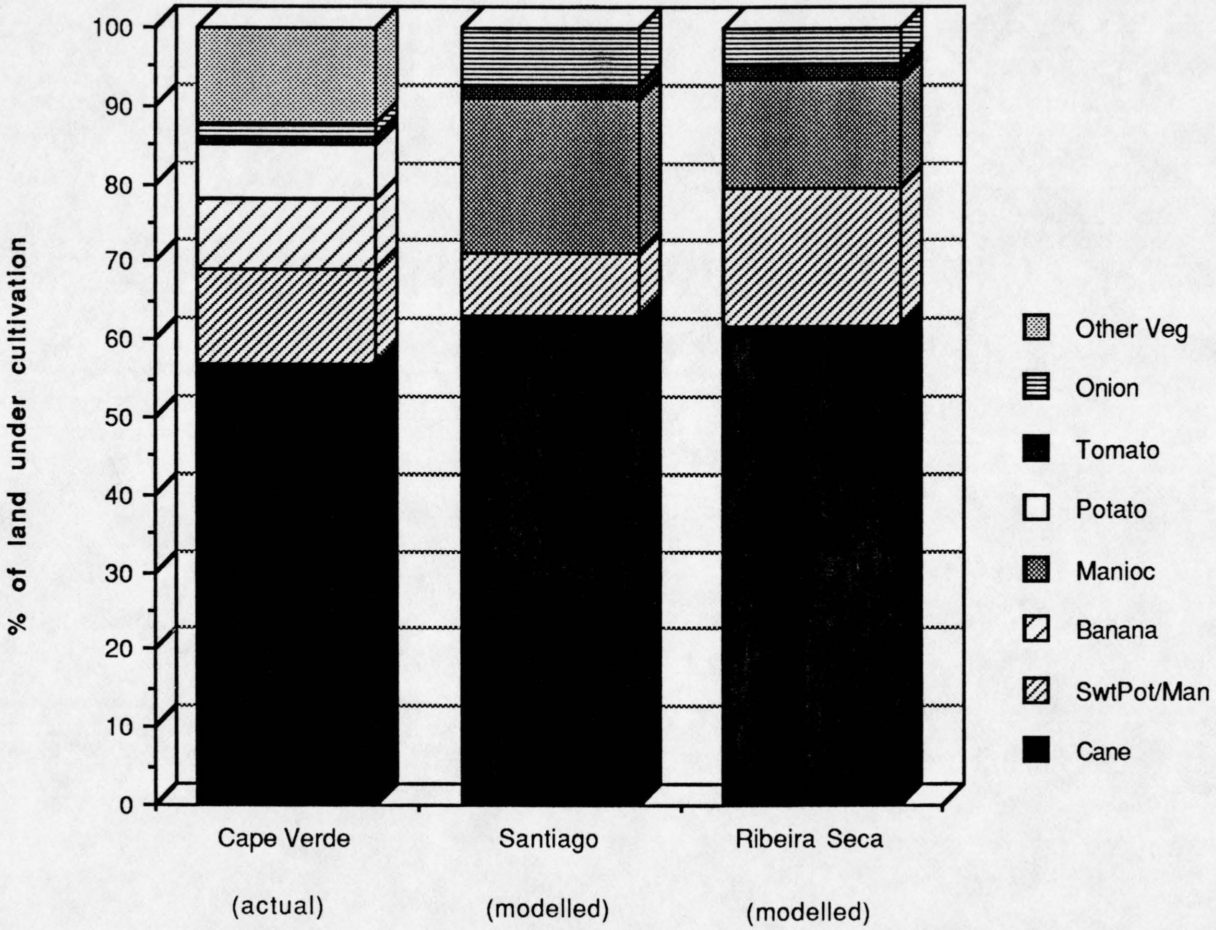


Figure 16: Actual vs. modelled "sectoral" crop mixes

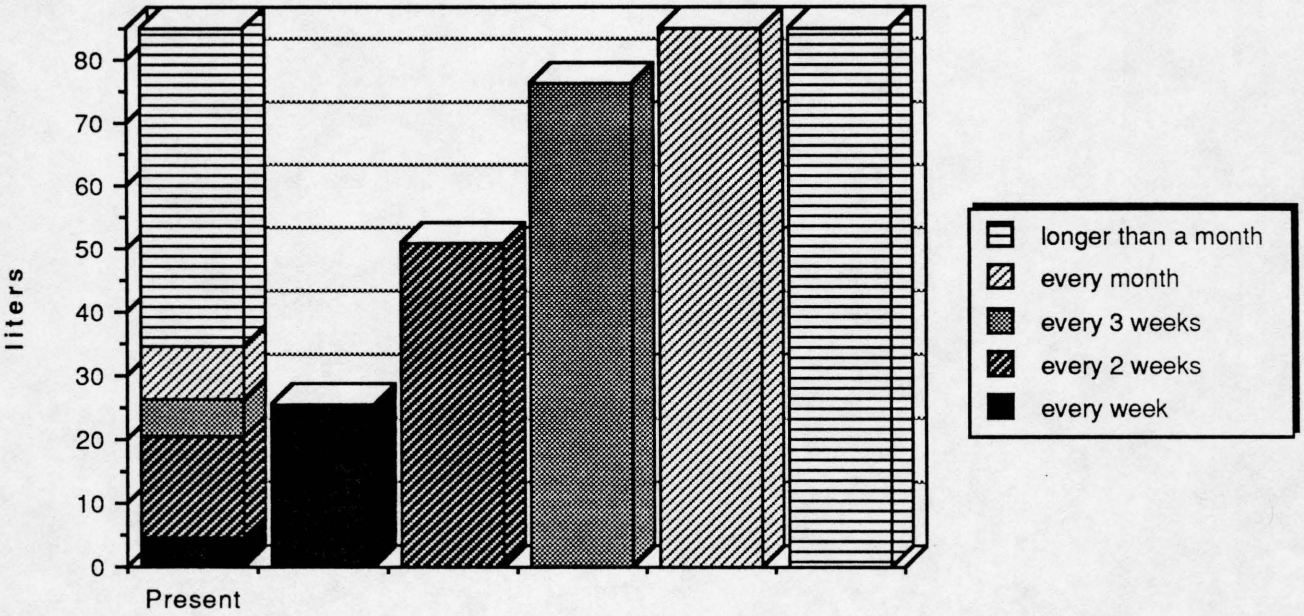


Figure 17a: Land use, by water interval, for Santiago data and modelled estimates.

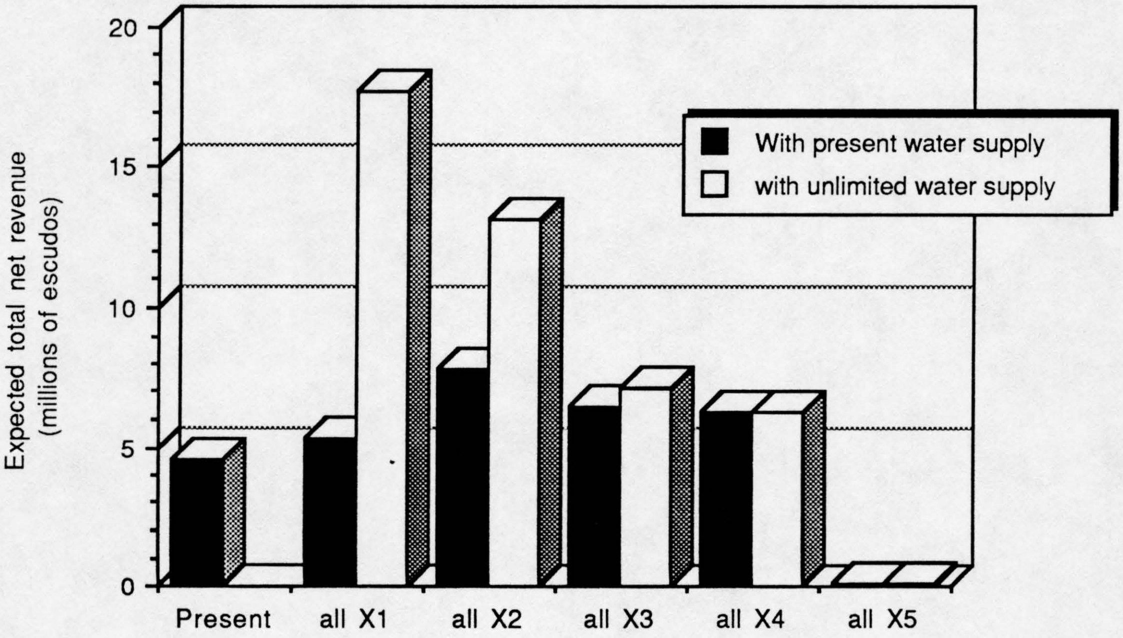


Figure 17b: Expected net revenues from Santiago data, by water interval, with present and unlimited water supply

APPENDIX 2: TABLES

Table 1: Producer and Consumer Prices on Santiago

CROPS	MARKET	April			May			June			July			Monthly Average				Average
		Pr	*Sc*	*Ta*	*Pr*	*Sc*	*Ta*	*Pr*	*Sc*	*Ta*	*Pr*	*Sc*	*Ta*	Apr	May	Jun	Jul	
Manioc	Producer	30	30	50	*34*	33	40	40	40	50	*46*	30	50	37	36	43	42	39
	Consumer	45	42.5	50	41.5	42.5	50	58.1	51.5	50	56.5	50	45	46	45	53	51	49
Swt Potato	Producer	*50*	35	52.5	*46*	35	57.5	40	*47*	38.5	*49*	35	45	46	46	42	43	44
	Consumer	54.5	42.5	52.5	49.7	40	52.5	47.3	51.5	38.5	52.8	47.5	46.5	50	47	46	49	48
Tomato	Producer	47.5	40	35	*102*	60	*64*	60	75	60	*100*	48	60	41	75	65	69	63
	Consumer	50.5	29	46	111	52.5	70	109	80	60	109	80	62.5	42	78	83	84	72
Onion	Producer	35	37.5	50	*41*	50	46	*43*	53.3	70	*73*	*55*	*75*	41	46	55	67	52
	Consumer	51.8	68.8	56.5	54.2	61.3	70	57.3	66.5	80.	96.7	73	100	59	62	68	90	70
Cabbage	Producer	17.5	26.3	34	26	27.5	52.5	50	20	35	*75*	60	*50*	26	35	35	62	39
	Consumer	27	25	31	41.5	35	45	60.5	50	40	90.4	*80*	60	28	41	50	77	49
Potato	Producer	35.5	35	41	30	35	43	40	35	55	40	46	50	37	36	43	45	40
	Consumer	45	40	54.3	42.6	45	56	46.1	51.5	62.5	65.3	55	70	46	48	53	63	53
Banana	Producer	*12*	9	10	12	10.8	10	*12*	10.7	*10*	*13*	11.5	10	10	11	11	12	11
	Consumer	15	10.8	12.5	14.2	11.8	13	15	14	12.5	16.4	13.5	15.5	13	13	14	15	14
Corn	Producer	*21*	*17*	*20*	*22*	*18*	-	*22*	28	*20*	*21*	*20*	*21*	19	20	23	21	21
	Consumer	24.8	20	23.5	26.8	22	-	26.4	22	23.5	25.3	24	25	23	24	24	25	24
Beans	Producer	*32*	*17*	*24*	*31*	*12*	*25*	*32*	*15*	*27*	*27*	*17*	*26*	24	23	25	23	24
	Consumer	38.8	20	29	37.6	15	30	38.3	18	32.5	33	20	31	29	28	30	28	29

Conselhos: Pr=Praia, Sc=Santa Cruz, Ta=Tarrafal

Producers prices shown in italics are estimates calculated by subtracting average % difference from consumer prices for each crop.

(Ave. % difference: Manioc 28%, Swt Potato 11%, Tomato 18%, Onion 37%, Cabbage 33%, Potato 31%, Banana 26%, Corn/Beans 33%)

Other figures represent averages of up to five sites within the three conselhos.

Source: Estudo da evolucao absoluta dos precos de produtos agricolas, Junho - Agosto/1988.

Table 2: Correlation of planting and marketing schedules for price-variable crops with expected yields and price variability.

	Planting time	Marketing time	Average Yield (kg/liter)	Expected percentage (%)	Expected Yield (kg/liter)	Expected Price (esc/kg)
Lo Yield Tomato	Nov	Feb	2000	*100*	2000	*60*
	Dec	Mar	2000	*100*	2000	*50*
	Jan	Apr	2000	*100*	2000	41
	Feb	May	2000	*90*	1800	75
	Mar	Jun	2000	*70*	1400	65
	Apr	Jul	2000	*50*	1000	69
	May	Aug	2000	*30*	600	*70*
Hi Yield Tomato	Nov	Feb	4000	*100*	4000	*60*
	Dec	Mar	4000	*100*	4000	*50*
	Jan	Apr	4000	*100*	4000	41
	Feb	May	4000	*90*	3600	75
	Mar	Jun	4000	*70*	2800	65
	Apr	Jul	4000	*50*	2000	69
	May	Aug	4000	*30*	1200	*70*
Onions	Nov	Feb	2500	*100*	2500	*50*
	Dec	Mar	2500	*100*	2500	*45*
	Jan	Apr	2500	*100*	2500	41
	Feb	May	2500	*90*	2250	46
	Mar	Jun	2500	*70*	1750	55
	Apr	Jul	2500	*60*	1500	67
	May	Aug	2500	*50*	1250	*75*
Cabbage	Nov	Feb	2000	*100*	2000	*45*
	Dec	Mar	2000	*100*	2000	*35*
	Jan	Apr	2000	*100*	2000	26
	Feb	May	2000	*90*	1800	35
	Mar	Jun	2000	*70*	1400	35
	Apr	Jul	2000	*50*	1000	62
	May	Aug	2000	*30*	600	*65*
Potato	Nov	Feb	2000	*100*	2000	*45*
	Dec	Mar	2000	*100*	2000	*40*
	Jan	Apr	2000	*100*	2000	37
	Feb	May	2000	*90*	1800	36
	Mar	Jun	2000	*70*	1400	43
	Apr	Jul	2000	*60*	1200	45
	May	Aug	2000	*50*	1000	*47*

Note: Percentages are estimates of the proportion of average yields expected from later plantings. Prices in italics are estimates based on extrapolations from data in Table 1. Other prices are monthly averages from Table 1.

Table 3a: Derivation of net revenue values (per liter) for price and yield variable crops.

	Planting (Model Code)	Price (esc/kg)	* Yield (kg/liter)	= Total Revenue (esc.)	- Var. Cost (esc.)	= Net Revenue (esc.)
Lo Yield Tomato	TOMATX11	60	2000	120000	240	119,760
	TOMATX12	50	2000	100000	240	99,760
	TOMATX01	41	2000	82000	240	81,760
	TOMATX02	75	1800	135000	240	134,760
	TOMATX03	65	1400	91000	240	90,760
	TOMATX04	69	1000	69000	240	68,760
	TOMATX05	70	600	42000	240	41,760
Hi Yield Tomato	TOMATN11	60	4000	240000	469	239,531
	TOMATN12	50	4000	200000	469	199,531
	TOMATN01	41	4000	164000	469	163,531
	TOMATN02	75	3600	270000	469	269,531
	TOMATN03	65	2800	182000	469	181,531
	TOMATN04	69	2000	138000	469	137,531
	TOMATN05	70	1200	84000	469	83,531
Onions	ONION11	50	2500	125000	110	124,890
	ONION12	45	2500	112500	110	112,390
	ONION01	41	2500	102500	110	102,390
	ONION02	46	2250	103500	110	103,390
	ONION03	55	1750	96250	110	96,140
	ONION04	67	1500	100500	110	100,390
	ONION05	75	1250	93750	110	93,640
Cabbage	CABBAG11	45	2000	90000	132	89,868
	CABBAG12	35	2000	70000	132	69,868
	CABBAG01	26	2000	52000	132	51,868
	CABBAG02	35	1800	63000	132	62,868
	CABBAG03	35	1400	49000	132	48,868
	CABBAG04	62	1000	62000	132	61,868
	CABBAG05	65	600	39000	132	38,868
Potato	POTAT11	45	2000	90000	712	89,288
	POTAT12	40	2000	80000	712	79,288
	POTAT01	37	2000	74000	712	73,288
	POTAT02	36	1800	64800	712	64,088
	POTAT03	43	1400	60200	712	59,488
	POTAT04	45	1200	54000	712	53,288
	POTAT05	47	1000	47000	712	46,288

Source: see Table 3b.

Table 3b: Derivation of net revenue variables (per liter) for price and yield constant crops.

	Planting (Model Code)	Price (esc/kg)	* Yield (kg/liter)	= Total Revenue (esc.)	- Var. Cost (esc.)	= Net Revenue (esc.)
LoYield Manioc	MANOCX.	40	2000	80000	167	79,833
HiYield Manioc	MANOCN..	40	4050	162000	190	161,810
(Swtpot)		43	900	38700		
(Manioc)		40	2000	80000		
SwtPotato/Manioc	SWTMAN..			118700	143	118,557
Sweet Potato	SWTPOT..	43	1600	68800	142	68,658
(Cane)		150	90	13500		
(Straw)		80	25	2000		
Lo Yield Cane	CANEX.			15500	652	14,848
(Cane)		150	128	19200		
(Straw)		80	32	2560		
Hi Yield Cane	CANEN..			21760	652	21,108
Lo Yield Banana	BANANX..	11	3000	33000	5102	27,898
Hi Yield Banana	BANANN..	11	5000	55000	1677	53,323
(Corn)		12	80	960		
(Beans)		24	40	960		
(Palha)		40	60	2400		
Corn and Beans	DRCRNBNS			4320	63	4,257

Sources: Prices and expected yields were derived in the previous tables. Total variable costs are from the Santiago crop budgets, and do not include implicit costs of land or labour.

Table 4: Monthly land use requirements of crops (typical planting schedule)

	LoYield Manioc	HiYield Manioc	SwPot/ Manioc	Sweet Potato	LoYield Cane	HiYield Cane	LoYield Tomato	HiYield Tomato	Onion	Cabbage	Irish Potato	LoYield Banana	HiYield Banana	(Rainfed) Corn & Beans
Nov	•	•	•		•	•	•	•			•	•	•	•
Dec	•	•	•		•	•	•	•			•	•	•	•
Jan	•	•	•	•	•	•	•	•			•	•	•	
Feb	•	•	•	•	•	•	•	•		•	•	•	•	
Mar	•	•	•	•	•	•		•	•	•		•	•	
Apr	•	•	•	•	•	•			•	•		•	•	
May	•	•	•	•	•	•			•	•		•	•	
Jun	•	•	•	•	•	•			•	•		•	•	
Jul	•	•	•	•	•	•			•			•	•	•
Aug	•	•	•		•	•						•	•	•
Sep	•	•	•		•	•						•	•	•
Oct	•	•	•		•	•					•	•	•	•

Source: Crop Budgets for Santiago

Table 5: Labour requirements for one liter of crops in person/days per month (typical planting schedule)

	LoYield Manioc	HiYield Manioc	SwPot/ Manioc	Sweet Potato	LoYield Cane	HiYield Cane	LoYield Tomato	HiYield Tomato	Onion	Cabbage	Irish Potato	LoYield Banana	HiYield Banana	(Rainfed) Corn & Beans
Nov	3.375	3.75	4.05		3.375	3.375					4.625	0.75	1.45	
Dec	0.375	0.75	2.775		2.625	2.625			0.8		6.75	0.375	0.75	
Jan	3.375	3.75	0.375	28.48		0.375					1.25	0.375	1.45	5
Feb	0.375	0.75	1.575	1.975	0.375	0.375	28.9	30.15		28.8	9	0.75	0.75	
Mar	0.375	0.75	0.75	3.15	2.625	2.625	6.38	7.13	28	6		4.475	1.45	
Apr	0.375	0.75	0.375	0.375		0.375	1.21	2.13	5.5	2.75		4.125	4.5	0.5
May	0.375		2.85	0.375	10.63	10.63	1.21	2.13	2.25	1.25		0.75	1.45	1
Jun	0.375		0.375	0.375	0.375	0.375	1.98	1.88	0.875			4.85	0.75	1.5
Jul			0.375	2.1					5			11.8	14.1	2
Aug			0.375											1
Sep														1
Oct	37	37	28.1								28			1

Source: Crop Budgets for Santiago

Table 6: Water requirements per liter (in hours per week) of irrigated crops (typical planting schedule)

		LoYield Manioc	HiYield Manioc	SwPot/ Manioc	Sweet Potato	LoYield Cane	HiYield Cane	LoYield Tomato	HiYield Tomato	Onion	Cabbage	Irish Potato	LoYield Banana	HiYield Banana
Nov	1	3	3	3		3	3					3	3	3
	2											3		
	3		3									3		3
	4			3									3	
Dec	1	3	3				3					3		3
	2													
	3		3	3		3						3	3	3
	4													
Jan	1	3	3				3					3		3
	2			3									3	
	3		3									3		3
	4				3									
Feb	1	3	3	3		3	3						3	3
	2				3									
	3		3											3
	4				3								3	
Mar	1	3	3	3			3	3	3		3			3
	2				3			3	3		3			
	3		3			3		3	3		3		3	3
	4			3	3			3	3		3			
Apr	1	3	3				3			3				3
	2			3	3			3	3		3		3	
	3		3							3				3
	4							3	3		3			
May	1	3		3		3	3			3			3	3
	2				3			3	3		3			
	3									3			3	3
	4			3				3	3		3			
Jun	1	3					3			3			3	3
	2				3									
	3			3		3							3	3
	4													
Jul	1												3	3
	2			3										
	3												3	3
	4													
Aug	1			3										
	2													
	3													
	4													

Source: Crop Budgets for Santiago

Table 7a: Price sensitivity analysis for non-basic crops in optimal farm plan (in escudos)

	Planting (Model Code)	Net Revenue	Reduced Cost	Net Rev required	Present ProdPrice	Price Required	% change required
Lo Yield Tomato	TOMATX11	119,760	-95,103	214,863	60	107	79
	TOMATX12	99,760	-98,987	198,747	50	99	99
	TOMATX01	81,760	-90,998	172,758	41	86	110
	TOMATX02	134,760	-133,706	268,466	75	149	99
	TOMATX03	90,760	-90,771	181,531	65	129	99
	TOMATX04	68,760	-88,248	157,008	69	157	127
	TOMATX05	41,760	-174,264	216,024	70	360	414
Hi Yield Tomato	TOMATN11	239,531	-9,866	249,397	60	62	4
	TOMATN04	137,531	-19,477	157,008	69	78	13
	TOMATN05	83,531	-132,494	216,025	70	180	157
Onions	ONION12	112,390	-7,756	120,146	45	48	7
	ONION01	102,390	-35,153	137,543	41	55	34
	ONION02	103,390	-66,154	169,544	46	75	64
	ONION04	100,390	-9,540	109,930	67	73	9
Cabbage	CABBAG11	89,868	-95,142	185,010	45	92	105
	CABBAG12	69,868	-100,084	169,952	35	85	143
	CABBAG01	51,868	-90,460	142,328	26	71	173
	CABBAG02	62,868	-166,240	229,108	35	127	263
	CABBAG03	48,868	-102,556	151,424	35	108	209
	CABBAG04	61,868	-65,033	126,901	62	127	104
	CABBAG05	38,868	-147,049	185,917	65	310	376
Potato	POTATO11	89,288	-65,712	155,000	45	77	71
	POTATO12	79,288	-84,271	163,559	40	81	104
	POTATO01	73,288	-67,869	141,157	37	70	90
	POTATO02	64,088	-143,724	207,812	36	115	220
	POTATO03	59,488	-87,534	147,022	43	105	143
	POTATO04	53,288	-65,127	118,415	45	98	118
	POTATO05	46,288	-93,150	139,438	47	139	195
Lo Yield Manioc	MANOCX11	79,833	-120,630	200,463	40	100	150
	MANOCX12	79,833	-88,286	168,119	40	84	110
	MANOCX01	79,833	-81,041	160,874	40	80	101
	MANOCX02	79,833	-109,669	189,502	40	95	137
	MANOCX03	79,833	-48,385	128,218	40	64	60
	MANOCX04	79,833	-73,773	153,606	40	77	92
	MANOCX05	79,833	-75,087	154,920	40	77	93
Hi Yield Manioc	MANOCN11	161,810	-74,752	236,562	40	58	46
	MANOCN12	161,810	-105,575	267,385	40	66	65
	MANOCN01	161,810	-88,532	250,342	40	62	54
	MANOCN02	161,810	-116,841	278,651	40	69	72
	MANOCN03	161,810	-25,776	187,586	40	46	16
	MANOCN04	161,810	-16,971	178,781	40	44	10

Source: See following table.

Table 7b: Price sensitivity analysis for non-basic crops in optimal farm plan (in escudos).

	Planting (Model Code)	Net Revenue	Reduced Cost	Net Rev required	Present ProdPrice	Price Required	% change required
SwtPotato Manioc *	SWTMAN11	118,557	-106,371	224,928	42	78	85
	SWTMAN12	118,557	-16,236	134,793	42	46	11
	SWTMAN01	118,557	-35,718	154,275	42	53	27
	SWTMAN02	118,557	-69,287	187,844	42	65	54
	SWTMAN05	118,557	-89,080	207,637	42	72	70
Sweet Potato	SWTPOT11	68,658	-142,344	211,002	43	132	206
	SWTPOT12	68,658	-116,025	184,683	43	115	168
	SWTPOT01	68,658	-99,509	168,167	43	105	144
	SWTPOT02	68,658	-189,847	258,505	43	161	276
	SWTPOT03	68,658	-63,963	132,621	43	83	93
	SWTPOT04	68,658	-18,677	87,335	43	54	27
	SWTPOT05	68,658	-24,301	92,959	43	58	35
Lo Yield Cane	CANEX11	14,848	-107,365	122,213	150	1351	800
	CANEX12	14,848	-12,033	26,881	150	291	94
	CANEX01	14,848	-74,732	89,580	150	988	559
	CANEX02	14,848	-67,775	82,623	150	911	507
	CANEX04	14,848	-71,867	86,715	150	956	538
	CANEX05	14,848	-73,181	88,029	150	971	547
Hi Yield Cane	CANEN11	21,108	-109,910	131,018	150	1018	579
	CANEN12	21,108	-82,035	103,143	150	801	434
	CANEN01	21,108	-72,874	93,982	150	729	386
	CANEN02	21,108	-70,001	91,109	150	707	371
	CANEN03	21,108	-40,219	61,327	150	474	216
	CANEN04	21,108	-65,607	86,715	150	672	348
	CANEN05	21,108	-66,921	88,029	150	683	355
Lo Yield Banana	BANANX11	27,898	-276,063	303,961	11	100	806
	BANANX12	27,898	-154,421	182,319	11	59	437
	BANANX01	27,898	-139,226	167,124	11	54	391
	BANANX02	27,898	-206,364	234,262	11	76	594
	BANANX03	27,898	-164,304	192,202	11	62	467
	BANANX04	27,898	-183,582	211,480	11	69	525
	BANANX05	27,898	-223,137	251,035	11	82	645
Hi Yield Banana	BANANN11	53,323	-247,240	300,563	11	60	443
	BANANN12	53,323	-214,062	267,385	11	53	383
	BANANN01	53,323	-195,061	248,384	11	49	349
	BANANN02	53,323	-193,826	247,149	11	49	346
	BANANN03	53,323	-134,263	187,586	11	37	238
	BANANN04	53,323	-125,458	178,781	11	35	222
	BANANN05	53,323	-121,173	174,496	11	35	214

Source: Net revenues and present producer prices from Tables 3a and 3b. Reduced costs from GAMS output. "Price required" is that price which would bring net revenues to a level where that activity would enter the basis, where

Price Required = (Total Revenue Required -Variable Costs)/Yield.

* Assumes producer prices for both crops will rise proportionally.

Table 8: Irrigated land use by crop (in liters) for optimal farm plans.

Watering Interval	**Basic Crop**	------Monthly Water Supply (hours)------					
		1	**2**	**3**	**4**	**5**	**6**
Every week	Cane	0.100	0.100	0.100	0.100	0.100	0.100
	SwtPot/Man	0.075	0.075	0.075	0.075	0.075	0.075
	Manioc	0.075	0.233	0.244	0.246	0.313	0.325
	Tomatoes	0.166	0.324	0.500	0.500	0.500	0.500
	Onions	0.032	0.187	0.267	0.500	0.500	0.500
	Total	0.448	0.919	1.186	1.421	1.488	1.500
Every 2 weeks	Cane	0.100	0.100	0.100	0.100	0.100	0.100
	SwtPot/Man	0.075	0.075	0.075	0.075	0.075	0.075
	Manioc	0.043	0.277	0.516	0.574	0.576	0.576
	Onions	0.289	0.500	0.500	0.500	0.500	0.500
	Total	0.507	0.952	1.191	1.249	1.251	1.251
Every 3 weeks	Cane	0.100	0.100	0.100	0.100	0.100	0.100
	SwtPot/Man	0.200	0.450	0.700	0.900	0.900	0.900
	Total	0.300	0.550	0.800	1.000	1.000	1.000
Every 4 weeks	Cane	0.100	0.100	0.100	0.100	0.100	0.100
	Manioc	0.233	0.567	0.900	0.900	0.900	0.900
	Total	0.333	0.667	1.000	1.000	1.000	1.000
Every 6 weeks	Cane	0.333	0.667	1.000	1.000	1.000	1.000

Table 9: Revenue breakdown by crop (in escudos) for optimal farm plans.

Watering	**Basic**	---------Monthly	Water	Supply	(hours)-----------		
Interval	**Crop**	**1**	**2**	**3**	**4**	**5**	**6**
	Cane	1,485	1,485	1,485	1,485	1,485	2,111
	SwtPot/Man	8,892	8,892	8,892	8,892	8,892	8,892
	Manioc	12,120	37,736	36,218	39,913	50,700	52,588
Every week	Tomatoes	39,221	78,387	119,445	122,499	117,832	119,765
	Onions	3,483	20,382	41,989	51,448	49,987	50,195
	Corn/Beans	49,436	47,230	44,986	46,172	49,390	50,000
	Total	114,637	194,112	253,015	270,409	278,286	283,551
	Cane	1,485	1,485	1,485	2,111	2,111	2,111
	SwtPot/Man	8,892	8,892	8,892	8,892	8,892	8,892
Every 2 weeks	Manioc	6,892	44,828	86,302	93,041	93,041	93,041
	Onions	33,026	57,045	56,935	56,321	56,321	56,321
	Corn/Beans	48,613	47,012	50,010	49,933	50,525	50,898
	Total	98,908	159,262	203,624	210,298	210,890	211,263
	Cane	1,485	1,485	1,485	1,485	1,485	1,485
Every 3 weeks	SwtPot/Man	23,711	53,351	82,990	106,701	106,701	106,701
	Corn/Beans	51,020	50,940	50,860	50,797	50,797	50,797
	Total	76,216	105,776	135,335	158,983	158,983	158,983
	Cane	2,111	2,111	2,111	2,111	2,111	2,111
Every 4 weeks	Manioc	18,628	45,239	71,850	71,850	71,850	71,850
	Corn/Beans	51,084	51,084	51,084	51,084	51,084	51,084
	Total	71,823	98,434	125,045	125,045	125,045	125,045
Every 6 weeks	Cane	495	990	1,485	1,485	1,485	1,485

Table10: Irrigation supply and frequency by farm for Ribeira Seca irrigation system, January 1988 to February 1989.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	45	46	48	49	50	51	52	54	55	56
Jan 1	15		3.5	3	2	2.3					1.5	2			4									2.3				3.5		1													1.3	4	1.5						3	
2	5			1.5			1			8.3			3		9.8	2.8		4	2					3.8						0.5		1		2		5.8									1.3		2.3	3.3	2.8		2.3	2.8
3	2							2.3		2.8					0.5							1	2.8	3		2					1					13				5.3	3.8	1.8	3.5	1.3			5					5.5	
4	9.3					0.5			9.3	4				2.5	2.8						0.5												1.8		8.5	7.5		6	4.5	4							3.3			1			8.8	
Feb 1	5.3						2.8			2.8				5.5	1						0.8							3	1							4.5	3							1		2.8						1	
2	7.5		2		2	2.5	1	2	2	3	1.5				6							1.5	2.8	7.5					0.8	1.5						0.5												2.3				12	2.3
3	2.8									8.3														3.5						1.5					18			2	7			3.8			2						1.8	
4	7.3											2.3			7.8			3							3.5													6.3							1.5							4.8	
Mar 1				4											2.5	1.5																					3.5														
2	23									10					6.5						0.5		3.8													4	6									2.5						3.5	
3			3.3		2		2.3							6.8	4.5													3.5			0.8	2.8	1.5	1.5		0.5	3.5	10		3.5	6.5				1.5		2.8							
4										5.8					9														2.5		1		1.5				6.5															2.3		12	
Apr 1	12								11							2						1			6.5						2.8			9					1							3.5						5.5	
2				2.5		2.3			0.5	12						1		3.5							4.5	8.8					5.5				5.3	17		4.5	1		3	1.5		1		0.8		2	3				2.5
3	4.5						2					1.8			2	0.3			2				3	1.5		2	4.3	3	1.5		2		0.5	8.8		7.3			4	6			2.8	1		1.5	5					4	
4	12		4		2.8		2.8			9.5		0.5	3		11						1.8			5	0.3					2		2	0.5				9						1		4	1.5			1			19	
May 1									11	3				8	5	2		3													2					3							1						1	5	
2										7.5										3									1		1.5	1.8				15			1		3	2				2.3							
3	4.3									8					3.5	1.5							4.5	0.5	9			4		1	3							4.5	4.5				1.3			6					1.3	
4	13			4.3		2	2		1.5	11					1.3	2		2				0.3		11		2	0.5				5		0.8		5.3	1			0.5	6			2.5	1		2			3.8			16	
Jun 1	4.8		4.3		2.5			1.5		13	1.5			7							1	1.8						2.5		2										1					1	1		2	0.5		1	5.5	2.3
2		7.5					2.5		10	9								1	3	4.8				0.8			5				2.3					12		4.8			3.3	1.5				1.3						4.8	
3	3.5	6.5								1			2.5			1	1.5				0.5			1.3	9					1.5				9		2.3	8.5		5	1			3.5			0.8	5		3			8	
4	18	4.3		3.5					2.5	16		2				2						0.3		4.5					2.5			3	1.3	1							4.3					1					1.8		7	2
Jul 1	2.5	0.8	2.5		2		2.5	2			1.5		1.5					3							4.3						2.5	3				5					2						1.5		2.3	2			4.5	
2	4.3	9.3							7	4.3									2	3.5	1.3			6.8								0.5		3.5		18		4			3	2				1	5						
3	9.5	5.5	3.5							4.5							1.8									9	2.3				0.5					6.5		8.5		4	2.5			3.5			1.8			3					
4	1	0.5					3			7											1	2								1.5	1.3	0.8		5																		16	
Aug 1																																	2.3					5.5									1.3									
2	4.3	2.3								2.5											1	0.5								0.5				1.3	0.8		3.5							1.5							0.8	
3		0.5																			1											2.3	3.3			1.5					3.8						5.5	1.5						
4	3.5																																																				
Sep 1		0.3								4.8																1						2.3	2.8			1					2.3				1.3								
2	9	0.5								4											1	1							0.5	1				1	0.8		3.5										0.8	2					0.8	
3	17	2														0.5									1											1.5				1	3.3													1	
4	5.5	0.5								8.3						0.5					1	1								0.5	2.5	3.8			8.3					2.8													16	
Oct 1		5.8			2.5				11	3						3.3					1	0.5		11					1.5		7.3	2.8								2.8													1.5	
2	22	0.5	1				4.3			4.8		1.5		8.8				4.5			1				9.3				0.5	0.5			1.3	7.5	0.5					3									4.5			0.5	
3		5.8	0.5		2			2		7.5		1		2		0.5			2				4.5					4							3.3		8	4.8	5	4	2.5	1.5			1.8		6					4.5	2.3
4				3.5						9.3	1.5		2.5			2.8	1.8			3.5		0.5				2						1.5				2								3.5									12	
Nov 1	16									9																			2	1.5									3													5.5	2
2																																																					
3										3												1																																
4																															2				2.3																	2	
Dec 1	15									5												1								0.8		1.5			1.5		2															1	
2										9.5						2									1.3						0.3	2.3						4		1.8	1													8	
3	7	9.8					3.5		2.3	1													1	3.5								3.5	3			3		5.5		2													1.5	
4	5		3												8.5								1		1.3						0.5	3.5						6		2.5													2	
Jan 1													2.5			2														1																							2			
2				3.5	2.3	1.5			2									2					1			8.5			2.5									3	6		3.5															
3								1															1							0.5					6.5					2										3	1			
4									2.8		1.5	2										1				1				2.8			1.5			2.5	5		4	3.5					0.5								
Feb 1																				4							5					0.5							4									2							
2			3						7.5											3																			4		3				2.5		2					2			
3					2	2	3										2																																					

Table 11: Irrigation frequency by farm for Ribeira Seca Irrigation system, January 1988 to February 1989.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	45	46	47	48	49	50	51	52	53	54	55	56
Jan 1	X		X	X	X	X					X	X			X	X								X				X		X														X	X		X							X	
2	X			X			X			X			X		X	X		X	X					X							X		X		X		X									X		X	X	X			X	X
3	X							X		X					X							X	X	X		X					X					X				X	X	X	X	X				X						X	
4	X					X			X	X				X	X						X											X		X	X		X	X	X								X			X				X	
Feb 1	X						X			X				X	X						X							X	X							X	X						X			X							X	
2	X		X		X	X	X	X	X	X	X				X							X	X	X					X	X						X												X					X	X
3	X									X														X							X					X			X	X			X				X							X	
4	X											X			X			X							X											X						X										X	
Mar 1				X											X	X																				X																	
2	X									X					X						X		X												X	X							X						X	
3			X		X		X							X	X											X			X	X	X	X		X	X	X		X	X				X			X							
4										X					X												X		X		X				X														X			X	
Apr 1	X								X							X					X			X							X			X					X							X							X	
2				X		X			X	X						X		X						X	X						X				X	X		X	X		X	X		X			X		X	X					X
3	X						X					X			X	X			X				X	X		X	X	X	X		X		X	X		X			X	X			X	X			X	X						X	
4	X		X		X		X			X		X	X		X						X			X	X					X		X	X	X			X						X		X		X			X				X	
May 1									X	X				X	X	X		X													X					X								X									X	X	
2										X										X									X		X	X				X			X	X	X	X					X								
3	X									X					X	X							X	X	X			X		X	X							X	X					X				X						X	
4	X			X		X	X		X	X					X	X		X				X		X		X	X				X		X		X	X			X	X			X	X			X			X		X		X	
Jun 1	X		X		X			X		X	X			X							X	X						X		X										X					X		X		X	X			X	X	X
2		X					X		X	X		X						X	X	X				X			X				X					X		X			X	X	X				X							X	
3	X	X								X			X			X	X				X			X	X					X				X		X	X		X	X			X			X	X	X		X				X	
4	X	X		X					X	X		X				X					X		X					X			X	X	X							X					X						X			X	X
Jul 1	X	X	X		X	X	X	X	X		X		X					X						X						X	X				X					X	X						X		X	X				X	
2	X	X					X		X	X			X						X	X	X			X								X		X		X		X			X	X					X	X							
3	X	X	X							X							X								X	X				X					X		X		X	X			X				X			X					
4	X	X					X			X											X	X								X	X	X		X																				X	
Aug 1																																X					X										X								
2	X	X								X											X	X								X				X	X		X							X										X	
3		X																			X									X	X	X			X				X	X							X	X							
4	X																								X																													
Sep 1		X								X															X						X	X			X					X				X											
2	X	X								X											X	X							X	X				X	X		X										X	X						X	
3	X	X														X						X			X										X				X	X														X	
4	X	X								X						X					X	X								X	X	X			X					X														X	
Oct 1		X			X				X	X						X					X	X		X					X		X	X								X														X	
2	X	X	X				X			X		X		X				X			X				X				X	X			X	X	X					X										X				X	
3		X	X		X			X		X		X		X		X			X				X					X							X		X	X	X	X	X	X			X			X						X	X
4				X						X	X		X	X		X	X			X		X				X					X				X								X											X	
Nov 1	X									X																				X	X									X														X	X
2																																																							
3										X												X																																	
4																															X				X																			X	
Dec 1	X									X												X								X		X			X		X																	X	
2										X						X								X						X	X						X		X	X														X	
3	X	X					X		X	X												X	X								X	X			X		X		X															X	
4	X		X											X								X		X						X	X						X		X															X	
Jan 1													X			X													X																					X				
2				X	X	X			X								X					X			X			X								X	X		X															
3								X														X							X					X					X										X	X				
4									X		X	X										X				X				X			X			X	X		X	X					X									
Feb 1																		X							X					X							X									X								
2			X						X										X																	X		X				X		X						X				
3					X	X	X									X																																						

Table 12: Irrigation interval calculations, by farm, from Ribeira Seca data.

farm #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
#waterings	47	31	12	8	9	9	13	6	15	56	6	8	6	8	23	20	4	9
#weeks	52	26	58	53	59	59	58	53	55	50	56	56	52	49	20	59	29	56
#months	13.0	6.5	14.5	13.3	14.8	14.8	14.5	13.3	13.8	12.5	14.0	14.0	13.0	12.3	5.0	14.8	7.3	14.0
wat/month	3.6	4.8	0.8	0.6	0.6	0.6	0.9	0.5	1.1	4.5	0.4	0.6	0.5	0.7	4.6	1.4	0.6	0.6
interval	1.1	0.8	4.8	6.6	6.6	6.6	4.5	8.8	3.7	0.9	9.3	7.0	8.7	6.1	0.9	3.0	7.3	6.2

farm #	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
#waterings	7	5	17	17	8	23	13	6	5	9	9	22	27	15	8	10	23	26
#weeks	57	23	38	54	49	52	50	54	12	54	51	57	51	48	55	52	50	54
#months	14.3	5.8	9.5	13.5	12.3	13.0	12.5	13.5	3.0	13.5	12.8	14.3	12.8	12.0	13.8	13.0	12.5	13.5
wat/month	0.5	0.9	1.8	1.3	0.7	1.8	1.0	0.4	1.7	0.7	0.7	1.5	2.1	1.3	0.6	0.8	1.8	1.9
interval	8.1	4.6	2.2	3.2	6.1	2.3	3.8	9.0	2.4	6.0	5.7	2.6	1.9	3.2	6.9	5.2	2.2	2.1

farm #	37	38	39	40	41	42	43	44	45	46	48	49	50	51	52	54	55	56
#waterings	22	6	21	22	6	6	8	6	13	8	29	8	5	11	6	2	53	7
#weeks	57	39	55	54	40	40	56	51	35	57	57	41	24	54	57	5	52	43
#months	14.3	9.8	13.8	13.5	10.0	10.0	14.0	12.8	8.8	14.3	14.3	10.3	6.0	13.5	14.3	1.3	13.0	10.8
wat/month	1.5	0.6	1.5	1.6	0.6	0.6	0.6	0.5	1.5	0.6	2.0	0.8	0.8	0.8	0.4	1.6	4.1	0.7
interval	2.6	6.5	2.6	2.5	6.7	6.7	7.0	8.5	2.7	7.1	2.0	5.1	4.8	4.9	9.5	2.5	1.0	6.1

#waterings = number of times in which irrigation water was received during recorded period
#weeks = number of weeks from first irrigation to last (inclusive)
#months = number of months from first irrigation to last
wat/month = mean number of irrigations per month
interval = mean duration in weeks between irrigations

Note: two farms with only one recorded irrigation were omitted.

APPENDIX 3: COMPUTER INPUT

```
$TITLE CAPE VERDE AGRICULTURE PROBLEM-REPRESENTATIVE MODEL
SETS
J  crops /
   MANOCN11, MANOCN12, MANOCN01, MANOCN02, MANOCN03, MANOCN04, MANOCN05,
   MANOCX11, MANOCX12, MANOCX01, MANOCX02, MANOCX03, MANOCX04, MANOCX05,
   SWTMAN11, SWTMAN12, SWTMAN01, SWTMAN02, SWTMAN03, SWTMAN04, SWTMAN05,
   SWTPOT11, SWTPOT12, SWTPOT01, SWTPOT02, SWTPOT03, SWTPOT04, SWTPOT05,
   CANEN11,  CANEN12,  CANEN01,  CANEN02,  CANEN03,  CANEN04,  CANEN05,
   CANEX11,  CANEX12,  CANEX01,  CANEX02,  CANEX03,  CANEX04,  CANEX05,
   TOMATX11, TOMATX12, TOMATX01, TOMATX02, TOMATX03, TOMATX04, TOMATX05,
   TOMATN11, TOMATN12, TOMATN01, TOMATN02, TOMATN03, TOMATN04, TOMATN05,
   ONION11,  ONION12,  ONION01,  ONION02,  ONION03,  ONION04,  ONION05,
   CABBAG11, CABBAG12, CABBAG01, CABBAG02, CABBAG03, CABBAG04, CABBAG05,
   POTATO11, POTATO12, POTATO01, POTATO02, POTATO03, POTATO04, POTATO05,
   BANANX11, BANANX12, BANANX01, BANANX02, BANANX03, BANANX04, BANANX05,
   BANANN11, BANANN12, BANANN01, BANANN02, BANANN03, BANANN04, BANANN05,
   DRYCRNBNS /

W water transfer activities  /
  NOV1*NOV4, DEC1*DEC4, JAN1*JAN4, FEB1*FEB4, MAR1*MAR4, APR1*APR4,
  MAY1*MAY4, JUN1*JUN4, JUL1*JUL4, AUG1*AUG4, SEP1*SEP4, OCT1*OCT4 /

LND  irrigated land requirements
            / LNDNOV, LNDDEC, LNDJAN, LNDFEB, LNDMAR, LNDAPR,
              LNDMAY, LNDJUN, LNDJUL, LNDAUG, LNDSEP, LNDOCT /

DRY  rainfed land requirements
            / DRYNOV, DRYDEC, DRYJAN, DRYFEB, DRYMAR, DRYAPR,
              DRYMAY, DRYJUN, DRYJUL, DRYAUG, DRYSEP, DRYOCT /

LAB  labour requirements
            / LABNOV, LABDEC, LABJAN, LABFEB, LABMAR, LABAPR,
              LABMAY, LABJUN, LABJUL, LABAUG, LABSEP, LABOCT /

WAT  water requirements /
 WATNOV1*WATNOV4, WATDEC1*WATDEC4, WATJAN1*WATJAN4, WATFEB1*WATFEB4,
 WATMAR1*WATMAR4, WATAPR1*WATAPR4, WATMAY1*WATMAY4, WATJUN1*WATJUN4,
 WATJUL1*WATJUL4, WATAUG1*WATAUG4, WATSEP1*WATSEP4, WATOCT1*WATOCT4 /

TRN water transfer constraints / T01 * T12 /;

PARAMETERS
    C(J)  mean net revenue for crop j in escudos per liter of land
/MANOCN11  161810, SWTMAN11  118557, CANEN11 21108,  TOMATX11  119760,
 MANOCN12  161810, SWTMAN12  118557, CANEN12 21108,  TOMATX12   99760,
 MANOCN01  161810, SWTMAN01  118557, CANEN01 21108,  TOMATX01   81760,
 MANOCN02  161810, SWTMAN02  118557, CANEN02 21108,  TOMATX02  134760,
 MANOCN03  161810, SWTMAN03  118557, CANEN03 21108,  TOMATX03   90760,
 MANOCN04  161810, SWTMAN04  118557, CANEN04 21108,  TOMATX04   68760,
 MANOCN05  161810, SWTMAN05  118557, CANEN05 21108,  TOMATX05   41760,
```

```
 TOMATN11  239531,  ONION11  124890, CABBAG11  89648, POTATO11  89288,
 TOMATN12  199531,  ONION12  112390, CABBAG12  69868, POTATO12  79288,
 TOMATN01  163531,  ONION01  102390, CABBAG01  51868, POTATO01  73288,
 TOMATN02  269531,  ONION02  103390, CABBAG02  62868, POTATO02  64088,
 TOMATN03  181531,  ONION03   96140, CABBAG03  48868, POTATO03  59488,
 TOMATN04  137531,  ONION04  100390, CABBAG04  61868, POTATO04  53288,
 TOMATN05   83531,  ONION05   93640, CABBAG05  38868, POTATO05  46288,

 BANANX11  27898, BANANN11   53323, MANOCX11 79833, SWTPOT11 68658,
 BANANX12  27898, BANANN12   53323, MANOCX12 79833, SWTPOT12 68658,
 BANANX01  27898, BANANN01   53323, MANOCX01 79833, SWTPOT01 68658,
 BANANX02  27898, BANANN02   53323, MANOCX02 79833, SWTPOT02 68658,
 BANANX03  27898, BANANN03   53323, MANOCX03 79833, SWTPOT03 68658,
 BANANX04  27898, BANANN04   53323, MANOCX04 79833, SWTPOT04 68658,
 BANANX05  27898, BANANN05   53323, MANOCX05 79833, SWTPOT05 68658,

 CANEX11 14848,
 CANEX12 14848,
 CANEX01 14848,
 CANEX02 14848,
 CANEX03 14848,
 CANEX04 14848,
 CANEX05 14848, DRYCRNBNS 4257 /

B(LND)  available irrigated land
  / LNDNOV 1, LNDDEC 1, LNDJAN 1, LNDFEB 1, LNDMAR 1, LNDAPR 1,
    LNDMAY 1, LNDJUN 1, LNDJUL 1, LNDAUG 1, LNDSEP 1, LNDOCT 1 /

R(DRY) available rainfed land
  / DRYNOV 12, DRYDEC 12, DRYJAN 12, DRYFEB 12, DRYMAR 12, DRYAPR 12,
    DRYMAY 12, DRYJUN 12, DRYJUL 12, DRYAUG 12, DRYSEP 12, DRYOCT 12 /

G(LAB)  available labour
  / LABNOV 60, LABDEC 60, LABJAN 60, LABFEB 60, LABMAR 60, LABAPR 60,
    LABMAY 60, LABJUN 60, LABJUL 60, LABAUG 60, LABSEP 60, LABOCT 60 /

M(WAT)
  / WATNOV1 * WATNOV4 0, WATDEC1 * WATDEC4 0, WATJAN1 * WATJAN4 0,
    WATFEB1 * WATFEB4 0, WATMAR1 * WATMAR4 0, WATAPR1 * WATAPR4 0,
    WATMAY1 * WATMAY4 0, WATJUN1 * WATJUN4 0, WATJUL1 * WATJUL4 0,
    WATAUG1 * WATAUG4 0, WATSEP1 * WATSEP4 0, WATOCT1 * WATOCT4 0 /

H(TRN) monthly water availability / T01 * T12 3 /;

TABLE  D(WAT,W)  water transfer activities constraint matrix

        NOV1 NOV2 NOV3 NOV4 DEC1 DEC2 DEC3 DEC4 JAN1 JAN2 JAN3 JAN4
WATNOV1  -1
WATNOV2       -1
WATNOV3            -1
WATNOV4                 -1
```

```
WATDEC1                      -1
WATDEC2                           -1
WATDEC3                                -1
WATDEC4                                     -1
WATJAN1                                          -1
WATJAN2                                               -1
WATJAN3                                                    -1
WATJAN4                                                         -1
   +    FEB1 FEB2 FEB3 FEB4 MAR1 MAR2 MAR3 MAR4 APR1 APR2 APR3 APR4
WATFEB1  -1
WATFEB2       -1
WATFEB3            -1
WATFEB4                 -1
WATMAR1                      -1
WATMAR2                           -1
WATMAR3                                -1
WATMAR4                                     -1
WATAPR1                                          -1
WATAPR2                                               -1
WATAPR3                                                    -1
WATAPR4                                                         -1
     +  MAY1 MAY2 MAY3 MAY4 JUN1 JUN2 JUN3 JUN4 JUL1 JUL2 JUL3 JUL4
WATMAY1  -1
WATMAY2       -1
WATMAY3            -1
WATMAY4                 -1
WATJUN1                      -1
WATJUN2                           -1
WATJUN3                                -1
WATJUN4                                     -1
WATJUL1                                          -1
WATJUL2                                               -1
WATJUL3                                                    -1
WATJUL4                                                         -1
     +  AUG1 AUG2 AUG3 AUG4 SEP1 SEP2 SEP3 SEP4 OCT1 OCT2 OCT3 OCT4
WATAUG1  -1
WATAUG2       -1
WATAUG3            -1
WATAUG4                 -1
WATSEP1                      -1
WATSEP2                           -1
WATSEP3                                -1
WATSEP4                                     -1
WATOCT1                                          -1
WATOCT2                                               -1
WATOCT3                                                    -1
WATOCT4                                                         -1;

TABLE

   E(TRN,W) sums weekly water use to monthly water availability
```

```
    NOV1 NOV2 NOV3 NOV4 DEC1 DEC2 DEC3 DEC4 JAN1 JAN2 JAN3 JAN4
T11  1    1    1    1
T12                      1    1    1    1
T01                                          1    1    1    1
 +  FEB1 FEB2 FEB3 FEB4 MAR1 MAR2 MAR3 MAR4 APR1 APR2 APR3 APR4
T02  1    1    1    1
T03                      1    1    1    1
T04                                          1    1    1    1
 +  MAY1 MAY2 MAY3 MAY4 JUN1 JUN2 JUN3 JUN4 JUL1 JUL2 JUL3 JUL4
T05  1    1    1    1
T06                      1    1    1    1
T07                                          1    1    1    1
 +  AUG1 AUG2 AUG3 AUG4 SEP1 SEP2 SEP3 SEP4 OCT1 OCT2 OCT3 OCT4
T08  1    1    1    1
T09                      1    1    1    1
T10                                          1    1    1    1  ;

TABLE
        N(DRY,J) unit requirements of rainfed land for crop j
           DRYCRNBNS
DRYNOV       1
DRYDEC       1
DRYJUL       1
DRYAUG       1
DRYSEP       1
DRYOCT       1 ;

TABLE
        A(LND,J) unit requirements of irrigated land for crop j
       MANOCN11 MANOCN12 MANOCN01 MANOCN02 MANOCN03 MANOCN04 MANOCN05
LNDNOV        1        1        1        1        1        1        1
LNDDEC        1        1        1        1        1        1        1
LNDJAN        1        1        1        1        1        1        1
LNDFEB        1        1        1        1        1        1        1
LNDMAR        1        1        1        1        1        1        1
LNDAPR        1        1        1        1        1        1        1
LNDMAY        1        1        1        1        1        1        1
LNDJUN        1        1        1        1        1        1        1
LNDJUL        1        1        1        1        1        1        1
LNDAUG        1        1        1        1        1        1        1
LNDSEP        1        1        1        1        1        1        1
LNDOCT        1        1        1        1        1        1        1
   +   MANOCX11 MANOCX12 MANOCX01 MANOCX02 MANOCX03 MANOCX04 MANOCX05
LNDNOV        1        1        1        1        1        1        1
LNDDEC        1        1        1        1        1        1        1
LNDJAN        1        1        1        1        1        1        1
LNDFEB        1        1        1        1        1        1        1
LNDMAR        1        1        1        1        1        1        1
LNDAPR        1        1        1        1        1        1        1
LNDMAY        1        1        1        1        1        1        1
LNDJUN        1        1        1        1        1        1        1
```

```
LNDJUL          1         1         1         1         1         1         1
LNDAUG          1         1         1         1         1         1         1
LNDSEP          1         1         1         1         1         1         1
LNDOCT          1         1         1         1         1         1         1
   +     SWTMAN11  SWTMAN12  SWTMAN01  SWTMAN02  SWTMAN03  SWTMAN04  SWTMAN05
LNDNOV          1         1         1         1         1         1         1
LNDDEC          1         1         1         1         1         1         1
LNDJAN          1         1         1         1         1         1         1
LNDFEB          1         1         1         1         1         1         1
LNDMAR          1         1         1         1         1         1         1
LNDAPR          1         1         1         1         1         1         1
LNDMAY          1         1         1         1         1         1         1
LNDJUN          1         1         1         1         1         1         1
LNDJUL          1         1         1         1         1         1         1
LNDAUG          1         1         1         1         1         1         1
LNDSEP          1         1         1         1         1         1         1
LNDOCT          1         1         1         1         1         1         1
   +     SWTPOT11  SWTPOT12  SWTPOT01  SWTPOT02  SWTPOT03  SWTPOT04  SWTPOT05
LNDNOV          1         1                                             1
LNDDEC          1         1         1
LNDJAN          1         1         1         1
LNDFEB          1         1         1         1         1
LNDMAR          1         1         1         1         1         1
LNDAPR          1         1         1         1         1         1         1
LNDMAY                    1         1         1         1         1         1
LNDJUN                              1         1         1         1         1
LNDJUL                                        1         1         1         1
LNDAUG                                                  1         1         1
LNDSEP                                                            1         1
LNDOCT          1                                                 1         1
    +     CANEN11   CANEN12   CANEN01   CANEN02   CANEN03   CANEN04   CANEN05
LNDNOV          1         1         1         1         1         1         1
LNDDEC          1         1         1         1         1         1         1
LNDJAN          1         1         1         1         1         1         1
LNDFEB          1         1         1         1         1         1         1
LNDMAR          1         1         1         1         1         1         1
LNDAPR          1         1         1         1         1         1         1
LNDMAY          1         1         1         1         1         1         1
LNDJUN          1         1         1         1         1         1         1
LNDJUL          1         1         1         1         1         1         1
LNDAUG          1         1         1         1         1         1         1
LNDSEP          1         1         1         1         1         1         1
LNDOCT          1         1         1         1         1         1         1
    +     CANEX11   CANEX12   CANEX01   CANEX02   CANEX03   CANEX04   CANEX05
LNDNOV          1         1         1         1         1         1         1
LNDDEC          1         1         1         1         1         1         1
LNDJAN          1         1         1         1         1         1         1
LNDFEB          1         1         1         1         1         1         1
LNDMAR          1         1         1         1         1         1         1
LNDAPR          1         1         1         1         1         1         1
LNDMAY          1         1         1         1         1         1         1
```

```
LNDJUN        1        1        1        1        1        1        1
LNDJUL        1        1        1        1        1        1        1
LNDAUG        1        1        1        1        1        1        1
LNDSEP        1        1        1        1        1        1        1
LNDOCT        1        1        1        1        1        1        1
  +    TOMATX11 TOMATX12 TOMATX01 TOMATX02 TOMATX03 TOMATX04 TOMATX05
LNDNOV        1
LNDDEC        1        1
LNDJAN        1        1        1
LNDFEB        1        1        1        1
LNDMAR                 1        1        1        1
LNDAPR                          1        1        1        1
LNDMAY                                   1        1        1        1
LNDJUN                                            1        1        1
LNDJUL                                                     1        1
LNDAUG                                                              1
  +    TOMATN11 TOMATN12 TOMATN01 TOMATN02 TOMATN03 TOMATN04 TOMATN05
LNDNOV        1
LNDDEC        1        1
LNDJAN        1        1        1
LNDFEB        1        1        1        1
LNDMAR        1        1        1        1        1
LNDAPR                 1        1        1        1        1
LNDMAY                          1        1        1        1        1
LNDJUN                                   1        1        1        1
LNDJUL                                            1        1        1
LNDAUG                                                     1        1
LNDSEP                                                              1
   +     ONION11  ONION12  ONION01  ONION02  ONION03  ONION04  ONION05
LNDNOV        1
LNDDEC        1        1
LNDJAN        1        1        1
LNDFEB        1        1        1        1
LNDMAR                 1        1        1        1
LNDAPR                 1        1        1        1        1
LNDMAY                          1        1        1        1        1
LNDJUN                                   1        1        1        1
LNDJUL                                            1        1        1
LNDAUG                                                     1        1
LNDSEP                                                              1
LNDOCT        1
   +   CABBAG11 CABBAG12 CABBAG01 CABBAG02 CABBAG03 CABBAG04 CABBAG05
LNDNOV        1
LNDDEC        1        1
LNDJAN        1        1        1
LNDFEB        1        1        1        1
LNDMAR                 1        1        1        1
LNDAPR                 1        1        1        1        1
LNDMAY                          1        1        1        1        1
LNDJUN                                   1        1        1        1
LNDJUL                                            1        1        1
```

```
LNDAUG                                                      1        1
LNDSEP                                                               1
LNDOCT         1
  +     POTATO11 POTATO12 POTATO01 POTATO02 POTATO03 POTATO04 POTATO05
LNDNOV         1
LNDDEC         1        1
LNDJAN         1        1        1
LNDFEB         1        1        1        1
LNDMAR                  1        1        1        1
LNDAPR                  1        1        1        1        1
LNDMAY                           1        1        1        1        1
LNDJUN                                    1        1        1        1
LNDJUL                                             1        1        1
LNDAUG                                                      1        1
LNDSEP                                                               1
LNDOCT         1
  +     BANANX11 BANANX12 BANANX01 BANANX02 BANANX03 BANANX04 BANANX05
LNDNOV         1        1        1        1        1        1        1
LNDDEC         1        1        1        1        1        1        1
LNDJAN         1        1        1        1        1        1        1
LNDFEB         1        1        1        1        1        1        1
LNDMAR         1        1        1        1        1        1        1
LNDAPR         1        1        1        1        1        1        1
LNDMAY         1        1        1        1        1        1        1
LNDJUN         1        1        1        1        1        1        1
LNDJUL         1        1        1        1        1        1        1
LNDAUG         1        1        1        1        1        1        1
LNDSEP         1        1        1        1        1        1        1
LNDOCT         1        1        1        1        1        1        1
  +     BANANN11 BANANN12 BANANN01 BANANN02 BANANN03 BANANN04 BANANN05
LNDNOV         1        1        1        1        1        1        1
LNDDEC         1        1        1        1        1        1        1
LNDJAN         1        1        1        1        1        1        1
LNDFEB         1        1        1        1        1        1        1
LNDMAR         1        1        1        1        1        1        1
LNDAPR         1        1        1        1        1        1        1
LNDMAY         1        1        1        1        1        1        1
LNDJUN         1        1        1        1        1        1        1
LNDJUL         1        1        1        1        1        1        1
LNDAUG         1        1        1        1        1        1        1
LNDSEP         1        1        1        1        1        1        1
LNDOCT         1        1        1        1        1        1        1;

TABLE   F(LAB,J) labour requirements for crop j

         DRYCRNBNS
LABJAN        5
LABAPR         .5
LABMAY        1
LABJUN        1.5
LABJUL        2
```

```
LABAUG      1
LABSEP      1
LABOCT      1
  +    MANOCN11 MANOCN12 MANOCN01 MANOCN02 MANOCN03 MANOCN04 MANOCN05
LABNOV     3.75     37
LABDEC     0.75     3.75     37
LABJAN     3.75     0.75     3.75     37
LABFEB     0.75     3.75     0.75     3.75     37
LABMAR     0.75     0.75     3.75     0.75     3.75     37
LABAPR     0.75     0.75     0.75     3.75     0.75     3.75     37
LABMAY              0.75     0.75     0.75     3.75     0.75     3.75
LABJUN                       0.75     0.75     0.75     3.75     0.75
LABJUL                                0.75     0.75     0.75     3.75
LABAUG                                         0.75     0.75     0.75
LABSEP                                                  0.75     0.75
LABOCT   37                                                      0.75
  +    MANOCX11 MANOCX12 MANOCX01 MANOCX02 MANOCX03 MANOCX04 MANOCX05
LABNOV    3.375   37                                    .375     .375
LABDEC     .375    3.375   37                                    .375
LABJAN    3.375     .375    3.375   37
LABFEB     .375    3.375     .375    3.375   37
LABMAR     .375     .375    3.375     .375    3.375   37
LABAPR     .375     .375     .375    3.375     .375    3.375   37
LABMAY     .375     .375     .375     .375    3.375     .375    3.375
LABJUN     .375     .375     .375     .375     .375    3.375     .375
LABJUL              .375     .375     .375     .375     .375     .375
LABAUG                       .375     .375     .375     .375     .375
LABSEP                                .375     .375     .375     .375
LABOCT  37                                     .375     .375     .375
  +    SWTMAN11 SWTMAN12 SWTMAN01 SWTMAN02 SWTMAN03 SWTMAN04 SWTMAN05
LABNOV     4.05     28.1             0.375    0.375    0.375     2.85
LABDEC    2.775     4.05     28.1             0.375    0.375    0.375
LABJAN    0.375    2.775     4.05     28.1             0.375    0.375
LABFEB    1.575    0.375    2.775     4.05     28.1             0.375
LABMAR     0.75    1.575    0.375    2.775     4.05     28.1
LABAPR    0.375     0.75    1.575    0.375    2.775     4.05     28.1
LABMAY     2.85    0.375     0.75    1.575    0.375    2.775     4.05
LABJUN    0.375     2.85    0.375     0.75    1.575    0.375    2.775
LABJUL    0.375    0.375     2.85    0.375     0.75    1.575    0.375
LABAUG    0.375    0.375    0.375     2.85    0.375     0.75    1.575
LABSEP             0.375    0.375    0.375     2.85    0.375     0.75
LABOCT     28.1             0.375    0.375    0.375     2.85    0.375
  +    SWTPOT11 SWTPOT12 SWTPOT01 SWTPOT02 SWTPOT03 SWTPOT04 SWTPOT05
LABNOV   1.975    28.475
LABDEC   3.15      1.975    28.475
LABJAN    .375     3.15      1.975    28.475
LABFEB    .375      .375     3.15      1.975    28.475
LABMAR    .375      .375      .375     3.15      1.975    28.475
LABAPR   2.1        .375      .375      .375     3.15      1.975    28.475
LABMAY             2.1        .375      .375      .375     3.15      1.975
LABJUN                       2.1        .375      .375      .375     3.15
```

```
LABJUL                                   2.1        .375       .375     .375
LABAUG                                              2.1        .375     .375
LABSEP                                                         2.1      .375
LABOCT 28.475                                                         2.1
   +      CANEN11   CANEN12   CANEN01   CANEN02   CANEN03   CANEN04   CANEN05
LABNOV      3.375                                             0.375    10.625
LABDEC      2.625     3.375                                             0.375
LABJAN      0.375     2.625     3.375
LABFEB      0.375     0.375     2.625     3.375
LABMAR      2.625     0.375     0.375     2.625     3.375
LABAPR      0.375     2.625     0.375     0.375     2.625     3.375
LABMAY     10.625     0.375     2.625     0.375     0.375     2.625     3.375
LABJUN      0.375    10.625     0.375     2.625     0.375     0.375     2.625
LABJUL                0.375    10.625     0.375     2.625     0.375     0.375
LABAUG                          0.375    10.625     0.375     2.625     0.375
LABSEP                                    0.375    10.625     0.375     2.625
LABOCT                                              0.375    10.625     0.375
   +      CANEX11   CANEX12   CANEX01   CANEX02   CANEX03   CANEX04   CANEX05
LABNOV      3.375                                             0.375    10.625
LABDEC      2.625     3.375                                             0.375
LABJAN                2.625     3.375
LABFEB      0.375               2.625     3.375
LABMAR      2.625     0.375               2.625     3.375
LABAPR                2.625     0.375               2.625     3.375
LABMAY     10.625               2.625     0.375               2.625     3.375
LABJUN      0.375    10.625               2.625     0.375               2.625
LABJUL                0.375    10.625               2.625     0.375
LABAUG                          0.375    10.625               2.625     0.375
LABSEP                                    0.375    10.625               2.625
LABOCT                                              0.375    10.625
  +      TOMATX11  TOMATX12  TOMATX01  TOMATX02  TOMATX03  TOMATX04  TOMATX05
LABNOV       6.38      28.9
LABDEC       1.21      6.38      28.9
LABJAN       1.21      1.21      6.38      28.9
LABFEB       1.98      1.21      1.21      6.38      28.9
LABMAR                 1.98      1.21      1.21      6.38      28.9
LABAPR                           1.98      1.21      1.21      6.38      28.9
LABMAY                                     1.98      1.21      1.21      6.38
LABJUN                                               1.98      1.21      1.21
LABJUL                                                         1.98      1.21
LABAUG                                                                   1.98
LABSEP
LABOCT       28.9
  +      TOMATN11  TOMATN12  TOMATN01  TOMATN02  TOMATN03  TOMATN04  TOMATN05
LABNOV       7.13     30.15
LABDEC       2.13      7.13     30.15
LABJAN       2.13      2.13      7.13     30.15
LABFEB       1.88      2.13      2.13      7.13     30.15
LABMAR                 1.88      2.13      2.13      7.13     30.15
LABAPR                           1.88      2.13      2.13      7.13     30.15
LABMAY                                     1.88      2.13      2.13      7.13
```

```
LABJUN                                         1.88     2.13     2.13
LABJUL                                                  1.88     2.13
LABAUG                                                           1.88
LABSEP
LABOCT    30.15
  +     ONION11  ONION12  ONION01  ONION02  ONION03  ONION04  ONION05
LABNOV     5.55       28                         .8
LABDEC     2.25     5.55       28                         .8
LABJAN    0.875     2.25     5.55       28                         .8
LABFEB        5    0.875     2.25     5.55       28
LABMAR                 5    0.875     2.25     5.55       28
LABAPR                          5    0.875     2.25     5.55       28
LABMAY                                   5    0.875     2.25     5.55
LABJUN                                            5    0.875     2.25
LABJUL       .8                                            5    0.875
LABAUG                .8                                            5
LABSEP                         .8
LABOCT       28                         .8
  +    CABBAG11 CABBAG12 CABBAG01 CABBAG02 CABBAG03 CABBAG04 CABBAG05
LABNOV        6       28
LABDEC     2.75        6       28
LABJAN     1.25     2.75        6       28
LABFEB              1.25     2.75        6       28
LABMAR                       1.25     2.75        6       28
LABAPR                                1.25     2.75        6       28
LABMAY                                         1.25     2.75        6
LABJUN                                                  1.25     2.75
LABJUL                                                           1.25
LABAUG
LABSEP
LABOCT       28
  +    POTATO11 POTATO12 POTATO01 POTATO02 POTATO03 POTATO04 POTATO05
LABNOV    4.625       28
LABDEC     6.75    4.625       28
LABJAN     1.25     6.75    4.625       28
LABFEB        9     1.25     6.75    4.625       28
LABMAR                 9     1.25     6.75    4.625       28
LABAPR                          9     1.25     6.75    4.625       28
LABMAY                                   9     1.25     6.75    4.625
LABJUN                                            9     1.25     6.75
LABJUL                                                     9     1.25
LABAUG                                                              9
LABSEP
LABOCT   28
  +    BANANX11 BANANX12 BANANX01 BANANX02 BANANX03 BANANX04 BANANX05
LABNOV     0.75                                11.8     4.85     0.75
LABDEC    0.375     0.75                                11.8     4.85
LABJAN    0.375    0.375     0.75                                11.8
LABFEB     0.75    0.375    0.375     0.75
LABMAR    4.475     0.75    0.375    0.375     0.75
LABAPR    4.125    4.475     0.75    0.375    0.375     0.75
```

```
LABMAY     0.75    4.125    4.475     0.75    0.375    0.375     0.75
LABJUN     4.85     0.75    4.125    4.475     0.75    0.375    0.375
LABJUL     11.8     4.85     0.75    4.125    4.475     0.75    0.375
LABAUG              11.8     4.85     0.75    4.125    4.475     0.75
LABSEP                       11.8     4.85     0.75    4.125    4.475
LABOCT                                11.8     4.85     0.75    4.125
  +    BANANN11 BANANN12 BANANN01 BANANN02 BANANN03 BANANN04 BANANN05
LABNOV     1.45                                14.9     0.75     1.45
LABDEC     0.75     1.45                                14.9     0.75
LABJAN     1.45     0.75     1.45                                14.9
LABFEB     0.75     1.45     0.75     1.45
LABMAR     1.45     0.75     1.45     0.75     1.45
LABAPR      4.5     1.45     0.75     1.45     0.75     1.45
LABMAY     1.45      4.5     1.45     0.75     1.45     0.75     1.45
LABJUN     0.75     1.45      4.5     1.45     0.75     1.45     0.75
LABJUL     14.9     0.75     1.45      4.5     1.45     0.75     1.45
LABAUG              14.9     0.75     1.45      4.5     1.45     0.75
LABSEP                       14.9     0.75     1.45      4.5     1.45
LABOCT                                14.9     0.75     1.45      4.5;

TABLE K(WAT,J) water requirements for crop j

       MANOCN11 MANOCN12 MANOCN01 MANOCN02 MANOCN03 MANOCN04 MANOCN05
WATNOV1       3
WATNOV3       3
WATDEC1       3        3
WATDEC3       3        3
WATJAN1       3        3        3
WATJAN3       3        3        3
WATFEB1       3        3        3        3
WATFEB3       3        3        3        3
WATMAR1       3        3        3        3        3
WATMAR3       3        3        3        3        3
WATAPR1       3        3        3        3        3        3
WATAPR3       3        3        3        3        3        3
WATMAY1                3        3        3        3        3        3
WATMAY3                3        3        3        3        3        3
WATJUN1                         3        3        3        3        3
WATJUN3                         3        3        3        3        3
WATJUL1                                  3        3        3        3
WATJUL3                                  3        3        3        3
WATAUG1                                           3        3        3
WATAUG3                                           3        3        3
WATSEP1                                                    3        3
WATSEP3                                                    3        3
WATOCT1                                                             3
WATOCT3                                                             3
   +   MANOCX11 MANOCX12 MANOCX01 MANOCX02 MANOCX03 MANOCX04 MANOCX05
WATNOV1       3                                            3        3
WATDEC1       3        3                                            3
WATJAN1       3        3        3
```

```
WATFEB1       3        3        3        3
WATMAR1       3        3        3        3        3
WATAPR1       3        3        3        3        3        3
WATMAY1       3        3        3        3        3        3        3
WATJUN1       3        3        3        3        3        3        3
WATJUL1                3        3        3        3        3        3
WATAUG1                         3        3        3        3        3
WATSEP1                                  3        3        3        3
WATOCT1                                           3        3        3
  +    SWTMAN11 SWTMAN12 SWTMAN01 SWTMAN02 SWTMAN03 SWTMAN04 SWTMAN05
WATNOV1       3                          3                          3
WATNOV2                                           3
WATNOV3                                                    3
WATNOV4       3                                                     3
WATDEC1                3                          3
WATDEC2                                                    3
WATDEC3       3                                                     3
WATDEC4                3
WATJAN1                         3                          3
WATJAN2       3                                                     3
WATJAN3                3
WATJAN4                         3
WATFEB1       3                          3                          3
WATFEB2                3
WATFEB3                         3
WATFEB4                                  3
WATMAR1       3        3                          3
WATMAR2                         3
WATMAR3                                  3
WATMAR4       3                                   3
WATAPR1                3        3                          3
WATAPR2       3                          3
WATAPR3                                           3
WATAPR4                3                                   3
WATMAY1       3                 3        3                          3
WATMAY2                3                          3
WATMAY3                                                    3
WATMAY4       3                 3                                   3
WATJUN1                3                 3        3
WATJUN2                         3                          3
WATJUN3       3                                                     3
WATJUN4                3                 3
WATJUL1                         3                 3        3
WATJUL2       3                          3                          3
WATJUL3                3
WATJUL4                         3                 3
WATAUG1       3                          3                 3        3
WATAUG2                3                          3
WATAUG3                         3
WATAUG4                                  3                 3        3
WATSEP1                3                          3
```

```
WATSEP2                         3                          3
WATSEP3                                  3
WATSEP4                                           3                 3
WATOCT1                         3                          3
WATOCT2                                  3                          3
WATOCT3                                           3
WATOCT4                                                    3
  +    SWTPOT11 SWTPOT12 SWTPOT01 SWTPOT02 SWTPOT03 SWTPOT04 SWTPOT05
WATNOV1       3
WATNOV4       3
WATDEC1                3
WATDEC3       3
WATDEC4                3
WATJAN1                         3
WATJAN2       3
WATJAN3                3
WATJAN4                         3
WATFEB1       3                          3
WATFEB2                3
WATFEB3                         3
WATFEB4       3                          3
WATMAR1                3                          3
WATMAR2                         3
WATMAR3                                  3
WATMAR4       3        3                          3
WATAPR1                         3                          3
WATAPR2                                  3
WATAPR3                                           3
WATAPR4       3        3        3                          3
WATMAY1                                  3                          3
WATMAY2                                           3
WATMAY3                                                    3
WATMAY4                3        3        3                          3
WATJUN1                                           3
WATJUN2                                                    3
WATJUN3                                                             3
WATJUN4                         3        3        3
WATJUL1                                                    3
WATJUL2                                                             3
WATJUL4                                  3        3        3
WATAUG1                                                             3
WATAUG4                                           3        3        3
WATSEP4                                                    3        3
WATOCT4                                                             3
   +    CANEN11  CANEN12  CANEN01  CANEN02  CANEN03  CANEN04  CANEN05
WATNOV1       3                                            3        3
WATDEC1       3        3                                            3
WATJAN1       3        3        3
WATFEB1       3        3        3        3
WATMAR1       3        3        3        3        3
WATAPR1       3        3        3        3        3        3
```

```
WATMAY1       3        3        3        3        3        3        3
WATJUN1       3        3        3        3        3        3        3
WATJUL1                3        3        3        3        3        3
WATAUG1                         3        3        3        3        3
WATSEP1                                  3        3        3        3
WATOCT1                                           3        3        3
   +    CANEX11  CANEX12  CANEX01  CANEX02  CANEX03  CANEX04  CANEX05
WATNOV1       3                                                     3
WATNOV3                                                    3
WATDEC1                3
WATDEC3       3                                                     3
WATJAN1                         3
WATJAN3                3
WATFEB1       3                          3
WATFEB3                         3
WATMAR1                3                          3
WATMAR3       3                          3
WATAPR1                         3                          3
WATAPR3                3                          3
WATMAY1       3                          3                          3
WATMAY3                         3                          3
WATJUN1                3                          3
WATJUN3       3                          3                          3
WATJUL1                         3                          3
WATJUL3                3                          3
WATAUG1                                  3                          3
WATAUG3                         3                          3
WATSEP1                                           3
WATSEP3                                  3                          3
WATOCT1                                                    3
WATOCT3                                           3
   +   TOMATX11 TOMATX12 TOMATX01 TOMATX02 TOMATX03 TOMATX04 TOMATX05
WATNOV1       3
WATNOV2       3
WATNOV3       3
WATNOV4       3
WATDEC1                3
WATDEC2       3        3
WATDEC3                3
WATDEC4       3        3
WATJAN1                         3
WATJAN2       3        3        3
WATJAN3                         3
WATJAN4       3        3        3
WATFEB1                                  3
WATFEB2                3        3        3
WATFEB3                                  3
WATFEB4                3        3        3
WATMAR1                                           3
WATMAR2                         3        3        3
WATMAR3                                           3
```

```
WATMAR4                         3        3        3
WATAPR1                                                    3
WATAPR2                                  3        3        3
WATAPR3                                                    3
WATAPR4                                  3        3        3
WATMAY1                                                             3
WATMAY2                                           3        3        3
WATMAY3                                                             3
WATMAY4                                           3        3        3
WATJUN1
WATJUN2                                                    3        3
WATJUN3
WATJUN4                                                    3        3
WATJUL1
WATJUL2                                                             3
WATJUL3
WATJUL4                                                             3
   +   TOMATN11 TOMATN12 TOMATN01 TOMATN02 TOMATN03 TOMATN04 TOMATN05
WATNOV1       3
WATNOV2       3
WATNOV3       3
WATNOV4       3
WATDEC1                3
WATDEC2       3        3
WATDEC3                3
WATDEC4       3        3
WATJAN1                         3
WATJAN2       3        3        3
WATJAN3                         3
WATJAN4       3        3        3
WATFEB1                                  3
WATFEB2                3        3        3
WATFEB3                                  3
WATFEB4                3        3        3
WATMAR1                                           3
WATMAR2                         3        3        3
WATMAR3                                           3
WATMAR4                         3        3        3
WATAPR1                                                    3
WATAPR2                                  3        3        3
WATAPR3                                                    3
WATAPR4                                  3        3        3
WATMAY1                                                             3
WATMAY2                                           3        3        3
WATMAY3                                                             3
WATMAY4                                           3        3        3
WATJUN1
WATJUN2                                                    3        3
WATJUN3
WATJUN4                                                    3        3
WATJUL1
```

```
WATJUL2                                                             3
WATJUL3
WATJUL4                                                             3
  +     ONION11  ONION12  ONION01  ONION02  ONION03  ONION04  ONION05
WATNOV1       3
WATNOV3       3
WATDEC1       3        3
WATDEC3       3        3
WATJAN1       3        3        3
WATJAN3                3        3
WATFEB1                3        3        3
WATFEB3                         3        3
WATMAR1                         3        3        3
WATMAR3                                  3        3
WATAPR1                                  3        3        3
WATAPR3                                           3        3
WATMAY1                                           3        3        3
WATMAY3                                                    3        3
WATJUN1                                                    3        3
WATJUN3                                                             3
WATJUL1                                                             3
  +    CABBAG11 CABBAG12 CABBAG01 CABBAG02 CABBAG03 CABBAG04 CABBAG05
WATNOV1       3
WATNOV2       3
WATNOV3       3
WATNOV4       3
WATDEC1                3
WATDEC2       3        3
WATDEC3                3
WATDEC4       3        3
WATJAN1                         3
WATJAN2       3        3        3
WATJAN3                         3
WATJAN4       3        3        3
WATFEB1                                  3
WATFEB2                3        3        3
WATFEB3                                  3
WATFEB4                3        3        3
WATMAR1                                           3
WATMAR2                         3        3        3
WATMAR3                                           3
WATMAR4                         3        3        3
WATAPR1                                                    3
WATAPR2                                  3        3        3
WATAPR3                                                    3
WATAPR4                                           3        3
WATMAY1                                                             3
WATMAY2                                           3        3        3
WATMAY3                                                             3
WATMAY4                                           3        3        3
WATJUN1
```

```
WATJUN2                                                    3        3
WATJUN3
WATJUN4                                                    3        3
WATJUL1
WATJUL2                                                             3
WATJUL3
WATJUL4                                                             3
  +    POTATO11 POTATO12 POTATO01 POTATO02 POTATO03 POTATO04 POTATO05
WATNOV1       3
WATNOV2       3
WATNOV3       3
WATDEC1       3        3
WATDEC2                3
WATDEC3       3        3
WATJAN1       3        3        3
WATJAN2                         3
WATJAN3       3        3        3
WATFEB1                3        3        3
WATFEB2                                  3
WATFEB3                3        3        3
WATMAR1                         3        3        3
WATMAR2                                           3
WATMAR3                         3        3        3
WATAPR1                                  3        3        3
WATAPR2                                                    3
WATAPR3                                  3        3        3
WATMAY1                                           3        3        3
WATMAY2                                                             3
WATMAY3                                           3        3        3
WATJUN1                                                    3        3
WATJUN2
WATJUN3                                                    3        3
WATJUL1                                                             3
WATJUL2
WATJUL3                                                             3
   +   BANANX11 BANANX12 BANANX01 BANANX02 BANANX03 BANANX04 BANANX05
WATNOV1       3                                   3        3        3
WATNOV3                                           3        3        3
WATNOV4       3
WATDEC1                3                                   3        3
WATDEC3       3                                            3        3
WATDEC4                3
WATJAN1                         3                                   3
WATJAN2       3
WATJAN3                3                                            3
WATJAN4                         3
WATFEB1       3                          3
WATFEB2                3
WATFEB3                         3
WATFEB4       3                          3
WATMAR1                3                          3
```

```
WATMAR2                         3
WATMAR3       3                          3
WATMAR4                3                          3
WATAPR1                         3                          3
WATAPR2       3                          3
WATAPR3                3                          3
WATAPR4                         3                          3
WATMAY1       3                          3                          3
WATMAY2                3                          3
WATMAY3       3                 3                          3
WATMAY4                                  3                          3
WATJUN1       3        3                          3
WATJUN2                         3                          3
WATJUN3       3        3                 3                          3
WATJUN4                                           3
WATJUL1       3        3        3                          3
WATJUL2                                  3                          3
WATJUL3       3        3        3                 3
WATJUL4                                                    3
WATAUG1                3        3        3                          3
WATAUG2                                           3
WATAUG3                3        3        3                 3
WATAUG4                                                             3
WATSEP1                         3        3        3
WATSEP2                                                    3
WATSEP3                         3        3        3                 3
WATOCT1                                  3        3        3
WATOCT2                                                             3
WATOCT3                                  3        3        3
   +   BANANN11 BANANN12 BANANN01 BANANN02 BANANN03 BANANN04 BANANN05
WATNOV1       3                                   3        3        3
WATNOV3       3                                            3        3
WATDEC1       3        3                                            3
WATDEC3       3        3
WATJAN1       3        3        3
WATJAN3       3        3        3
WATFEB1       3        3        3        3
WATFEB3       3        3        3        3
WATMAR1       3        3        3        3        3
WATMAR3       3        3        3        3        3
WATAPR1       3        3        3        3        3        3
WATAPR3       3        3        3        3        3        3
WATMAY1       3        3        3        3        3        3        3
WATMAY3       3        3        3        3        3        3        3
WATJUN1       3        3        3        3        3        3        3
WATJUN3       3        3        3        3        3        3        3
WATJUL1       3        3        3        3        3        3        3
WATJUL3       3        3        3        3        3        3        3
WATAUG1                3        3        3        3        3        3
WATAUG3                3        3        3        3        3        3
WATSEP1                         3        3        3        3        3
```

```
WATSEP3                         3        3        3        3        3
WATOCT1                                  3        3        3        3
WATOCT3                                  3        3        3        3;

VARIABLES
        X(J)   crop activities measured in liters (one-tenth hectare)
        Y(W)   water activities measured in hours
        Z      total revenue in escudos;

POSITIVE VARIABLE X ;
POSITIVE VARIABLE Y ;

EQUATIONS
        REVENUE          the objective function
        IRRLAND(LND)     land constraints
        DRYLAND(DRY)     rainfed land constraints
        LABOUR(LAB)      labour constraints
        WATER(WAT)       water constraints
        TRANSFER(TRN)    water transfer constraints
        CANECONS         cane consumption constraint
        SWTMANCONS       swt. potato & manioc consumption constraint
        TOMMONO          tomato single cropping constraint
        ONMONO           onion single cropping constraint
        CAMONO           cabbage single cropping constraint
        POMONO           potato single cropping constraint;

REVENUE ..       Z =E= SUM((J), C(J) * X(J)) ;
IRRLAND(LND) ..  SUM(J, A(LND,J)*X(J)) =L= B(LND) ;
DRYLAND(DRY) ..  SUM(J, N(DRY,J)*X(J)) =L= R(DRY) ;
LABOUR(LAB) ..   SUM(J, F(LAB,J)*X(J)) =L= G(LAB) ;
WATER(WAT) ..    SUM(J, K(WAT,J)*X(J)) + SUM(W,D(WAT,W)*Y(W)) =L= M(WAT);
TRANSFER(TRN) .. SUM(W, E(TRN,W)*Y(W)) =L= H(TRN);
CANECONS ..      X('CANEX11')+X('CANEX12')+X('CANEX01')+X('CANEX02')
                +X('CANEX03')+X('CANEX04')+X('CANEX05')
                +X('CANEN11')+X('CANEN12')+X('CANEN01')+X('CANEN02')
                +X('CANEN03')+X('CANEN04')+X('CANEN05') =G= .1;
SWTMANCONS ..    X('SWTMAN11')+X('SWTMAN12')+X('SWTMAN01')+X('SWTMAN02')
                +X('SWTMAN03')+X('SWTMAN04')+X('SWTMAN05') =G= .075;
TOMONO    ..     X('TOMATX11')+X('TOMATX12')+X('TOMATX01')+X('TOMATX02')
                +X('TOMATX03')+X('TOMATX04')+X('TOMATX05')
                +X('TOMATN11')+X('TOMATN12')+X('TOMATN01')+X('TOMATN02')
                +X('TOMATN03')+X('TOMATN04')+X('TOMATN05') =L= .5;
ONMONO    ..     X('ONION11')+X('ONION12')+X('ONION01')+X('ONION02')
                +X('ONION03')+X('ONION04')+X('ONION05') =L= .5;
CAMONO    ..     X('CABBAG11')+X('CABBAG12')+X('CABBAG01')+X('CABBAG02')
                +X('CABBAG03')+X('CABBAG04')+X('CABBAG05') =L= .5;
POMONO    ..     X('POTATO11')+X('POTATO12')+X('POTATO01')+X('POTATO02')
                +X('POTATO03')+X('POTATO04')+X('POTATO05') =L= .5;

MODEL   CAPEVLP linear programming model
     /REVENUE, IRRLAND, DRYLAND, LABOUR, WATER, TRANSFER,
```

```
      CANECONS, SWTMANCONS, TOMONO, ONMONO, CAMONO, POMONO / ;

SOLVE     CAPEVLP USING LP MAXIMIZING Z;

DISPLAY X.L, X.M ;
DISPLAY Y.L, Y.M ;

PARAMETER OPTLND(LND,J) monthly breakdown of land use by crop j;
OPTLND(LND,J) = X.L(J) * A(LND,J);
DISPLAY OPTLND;

PARAMETER OPTLAB(LAB,J) monthly breakdown of labour use by crop j;
OPTLAB(LAB,J) = X.L(J) * F(LAB,J);
DISPLAY OPTLAB;

PARAMETER OPTWAT(WAT,J) weekly breakdown of water use by crop j;
OPTWAT(WAT,J) = X.L(J) * K(WAT,J);
DISPLAY OPTWAT;

PARAMETER OPTREV(J)  breakdown of total revenue;
OPTREV(J) = C(J)*X.L(J);
DISPLAY OPTREV;
```

APPENDIX 4: COMPUTER OUTPUT

```
CAPE VERDE AGRICULTURE PROBLEM (REPRESENTATIVE MODEL)
SOLUTION REPORT     SOLVE CAPEVLP USING LP FROM LINE 1227

               S O L V E     S U M M A R Y

     MODEL   CAPEVLP             OBJECTIVE  Z
     TYPE    LP                  DIRECTION  MAXIMIZE
     SOLVER  BDMLP               FROM LINE  1227

**** SOLVER STATUS     1 NORMAL COMPLETION
**** MODEL STATUS      1 OPTIMAL
**** OBJECTIVE VALUE           253014.0146

 RESOURCE USAGE, LIMIT          2.600     1000.000
 ITERATION COUNT, LIMIT        28         1000

 BDM - LP  VERSION 1.01

 A. Brooke, A. Drud, and A. Meeraus,
 Analytic Support Unit,
 Development Research Department,
 World Bank,
 Washington, D.C. 20433, U.S.A.

 WORK SPACE NEEDED (ESTIMATE)    --    12386 WORDS.
 WORK SPACE AVAILABLE            --    51712 WORDS.

 EXIT -- OPTIMAL SOLUTION FOUND.

                       LOWER     LEVEL     UPPER    MARGINAL

---- EQU REVENUE         .         .         .         1.000

  REVENUE     THE OBJECTIVE FUNCTION

---- EQU IRRLAND     LAND CONSTRAINTS

          LOWER     LEVEL     UPPER    MARGINAL

LNDNOV     -INF      0.713     1.000        .
LNDDEC     -INF      0.787     1.000        .
LNDJAN     -INF      0.787     1.000        .
LNDFEB     -INF      1.000     1.000 44966.284
LNDMAR     -INF      1.000     1.000 23884.836
LNDAPR     -INF      0.852     1.000        .
LNDMAY     -INF      0.901     1.000        .
LNDJUN     -INF      0.901     1.000        .
LNDJUL     -INF      0.688     1.000        .
```

```
LNDAUG     -INF      0.522     1.000       .
LNDSEP     -INF      0.522     1.000       .
LNDOCT     -INF      0.564     1.000       .

---- EQU DRYLAND     RAINFED LAND CONSTRAINTS

          LOWER     LEVEL     UPPER    MARGINAL

DRYNOV     -INF     10.568    12.000       .
DRYDEC     -INF     10.568    12.000       .
DRYJUL     -INF     10.568    12.000       .
DRYAUG     -INF     10.568    12.000       .
DRYSEP     -INF     10.568    12.000       .
DRYOCT     -INF     10.568    12.000       .


---- EQU LABOUR      LABOUR CONSTRAINTS

          LOWER     LEVEL     UPPER    MARGINAL

LABNOV     -INF      4.324    60.000       .
LABDEC     -INF      1.246    60.000       .
LABJAN     -INF     60.000    60.000   851.400
LABFEB     -INF      7.757    60.000       .
LABMAR     -INF      3.890    60.000       .
LABAPR     -INF     18.403    60.000       .
LABMAY     -INF     12.910    60.000       .
LABJUN     -INF     16.998    60.000       .
LABJUL     -INF     22.590    60.000       .
LABAUG     -INF     11.407    60.000       .
LABSEP     -INF     11.843    60.000       .
LABOCT     -INF     20.082    60.000       .

---- EQU WATER       WATER CONSTRAINTS

           LOWER     LEVEL     UPPER    MARGINAL

WATNOV1     -INF       .         .      9930.142
WATNOV2     -INF       .         .      9930.142
WATNOV3     -INF       .         .      9930.142
WATNOV4     -INF       .         .      9930.142
WATDEC1     -INF       .         .      3266.314
WATDEC2     -INF       .         .      3266.314
WATDEC3     -INF       .         .      3266.314
WATDEC4     -INF       .         .      3266.314
WATJAN1     -INF       .         .          EPS
WATJAN2     -INF       .         .          EPS
WATJAN3     -INF       .         .           .
```

```
WATJAN4     -INF       .         .         EPS
WATFEB1     -INF       .         .     9927.304
WATFEB2     -INF       .         .     9927.304
WATFEB3     -INF       .         .     9927.304
WATFEB4     -INF       .         .     9927.304
WATMAR1     -INF       .         .     1467.460
WATMAR2     -INF       .         .     1467.460
WATMAR3     -INF       .         .     1467.460
WATMAR4     -INF       .         .     1467.460
WATAPR1     -INF       .         .     2828.494
WATAPR2     -INF       .         .     2828.494
WATAPR3     -INF       .         .     2828.494
WATAPR4     -INF       .         .     2828.494
WATMAY1     -INF       .         .    15493.147
WATMAY2     -INF       .         .    15493.147
WATMAY3     -INF       .         .    15493.147
WATMAY4     -INF       .         .    15493.147
WATJUN1     -INF       .         .         EPS
WATJUN2     -INF       .         .         EPS
WATJUN3     -INF       .         .         EPS
WATJUN4     -INF       .         .         .
WATJUL1     -INF       .         .         EPS
WATJUL2     -INF       .         .         .
WATJUL3     -INF       .         .         EPS
WATJUL4     -INF       .         .         EPS
WATAUG1     -INF       .         .         EPS
WATAUG2     -INF       .         .         EPS
WATAUG3     -INF       .         .         EPS
WATAUG4     -INF       .         .         EPS
WATSEP1     -INF       .         .         EPS
WATSEP2     -INF       .         .         EPS
WATSEP3     -INF       .         .         EPS
WATSEP4     -INF       .         .         EPS
WATOCT1     -INF       .         .         EPS
WATOCT2     -INF       .         .         .
WATOCT3     -INF       .         .         EPS
WATOCT4     -INF       .         .         EPS

---- EQU TRANSFER    WATER TRANSFER CONSTRAINTS

       LOWER     LEVEL     UPPER    MARGINAL

T01     -INF      2.037     3.000      .
T02     -INF      3.000     3.000  9927.304
T03     -INF      3.000     3.000  1467.460
T04     -INF      3.000     3.000  2828.494
T05     -INF      3.000     3.000 15493.147
T06     -INF      2.610     3.000      .
```

```
T07     -INF      2.260     3.000      .
T08     -INF      1.772     3.000      .
T09     -INF      1.889     3.000      .
T10     -INF      2.072     3.000      .
T11     -INF      3.000     3.000  9930.142
T12     -INF      3.000     3.000  3266.314

                       LOWER     LEVEL     UPPER    MARGINAL

---- EQU CANECONS       0.100     0.100     +INF  -6.689E+4
---- EQU SWTMANCONS     0.075     0.075     +INF  -5.365E+4
---- EQU TOMONO         -INF      0.500     0.500 30106.802

  CANECONS    CANE CONSUMPTION CONSTRAINT
  SWTMANCONS  SWT. POTATO & MANIOC CONSUMPTION CONSTRAINT
  TOMONO      TOMATO SINGLE CROPPING CONSTRAINT

---- VAR X           CROP ACTIVITIES MEASURED IN LITERS (ONE-TENTH HECTARE)

             LOWER     LEVEL     UPPER    MARGINAL

MANOCN11       .         .        +INF  -7.475E+4
MANOCN12       .         .        +INF  -1.056E+5
MANOCN01       .         .        +INF  -8.853E+4
MANOCN02       .         .        +INF  -1.168E+5
MANOCN03       .         .        +INF  -2.578E+4
MANOCN04       .         .        +INF  -1.697E+4
MANOCN05       .        0.224     +INF       .
MANOCX11       .         .        +INF  -1.206E+5
MANOCX12       .         .        +INF  -8.829E+4
MANOCX01       .         .        +INF  -8.104E+4
MANOCX02       .         .        +INF  -1.097E+5
MANOCX03       .         .        +INF  -4.839E+4
MANOCX04       .         .        +INF  -7.377E+4
MANOCX05       .         .        +INF  -7.509E+4
SWTMAN11       .         .        +INF  -1.064E+5
SWTMAN12       .         .        +INF  -1.624E+4
SWTMAN01       .         .        +INF  -3.572E+4
SWTMAN02       .         .        +INF  -6.929E+4
SWTMAN03       .        0.007     +INF       .
SWTMAN04       .        0.068     +INF       .
SWTMAN05       .         .        +INF  -8.908E+4
SWTPOT11       .         .        +INF  -1.423E+5
SWTPOT12       .         .        +INF  -1.160E+5
SWTPOT01       .         .        +INF  -9.951E+4
SWTPOT02       .         .        +INF  -1.898E+5
SWTPOT03       .         .        +INF  -6.396E+4
SWTPOT04       .         .        +INF  -1.868E+4
```

```
SWTPOT05       .        .       +INF   -2.430E+4
CANEN11        .        .       +INF   -1.099E+5
CANEN12        .        .       +INF   -8.204E+4
CANEN01        .        .       +INF   -7.287E+4
CANEN02        .        .       +INF   -7.000E+4
CANEN03        .        .       +INF   -4.022E+4
CANEN04        .        .       +INF   -6.561E+4
CANEN05        .        .       +INF   -6.692E+4
CANEX11        .        .       +INF   -1.074E+5
CANEX12        .        .       +INF   -1.203E+4
CANEX01        .        .       +INF   -7.473E+4
CANEX02        .        .       +INF   -6.778E+4
CANEX03        .      0.100     +INF       .
CANEX04        .        .       +INF   -7.187E+4
CANEX05        .        .       +INF   -7.318E+4
TOMATX11       .        .       +INF   -9.510E+4
TOMATX12       .        .       +INF   -9.899E+4
TOMATX01       .        .       +INF   -9.100E+4
TOMATX02       .        .       +INF   -1.337E+5
TOMATX03       .        .       +INF   -9.077E+4
TOMATX04       .        .       +INF   -8.825E+4
TOMATX05       .        .       +INF   -1.743E+5
TOMATN11       .      0.148     +INF       .
TOMATN12       .      0.074     +INF       .
TOMATN01       .        .       +INF   -9865.984
TOMATN02       .      0.213     +INF       .
TOMATN03       .      0.064     +INF       .
TOMATN04       .        .       +INF   -1.948E+4
TOMATN05       .        .       +INF   -1.325E+5
ONION11        .      0.166     +INF       .
ONION12        .        .       +INF   -7756.568
ONION01        .        .       +INF   -3.515E+4
ONION02        .        .       +INF   -6.615E+4
ONION03        .      0.101     +INF       .
ONION04        .        .       +INF   -9539.846
ONION05        .      0.124     +INF       .
CABBAG11       .        .       +INF   -9.514E+4
CABBAG12       .        .       +INF   -1.001E+5
CABBAG01       .        .       +INF   -9.046E+4
CABBAG02       .        .       +INF   -1.662E+5
CABBAG03       .        .       +INF   -1.026E+5
CABBAG04       .        .       +INF   -6.503E+4
CABBAG05       .        .       +INF   -1.470E+5
POTATO11       .        .       +INF   -6.571E+4
POTATO12       .        .       +INF   -8.427E+4
POTATO01       .        .       +INF   -6.787E+4
POTATO02       .        .       +INF   -1.437E+5
POTATO03       .        .       +INF   -8.753E+4
```

```
POTATO04        .         .        +INF  -6.513E+4
POTATO05        .         .        +INF  -9.315E+4
BANANX11        .         .        +INF  -2.761E+5
BANANX12        .         .        +INF  -1.544E+5
BANANX01        .         .        +INF  -1.392E+5
BANANX02        .         .        +INF  -2.064E+5
BANANX03        .         .        +INF  -1.643E+5
BANANX04        .         .        +INF  -1.836E+5
BANANX05        .         .        +INF  -2.231E+5
BANANN11        .         .        +INF  -2.742E+5
BANANN12        .         .        +INF  -2.141E+5
BANANN01        .         .        +INF  -1.951E+5
BANANN02        .         .        +INF  -1.938E+5
BANANN03        .         .        +INF  -1.343E+5
BANANN04        .         .        +INF  -1.255E+5
BANANN05        .         .        +INF  -1.212E+5
DRYCRNBNS       .       10.568     +INF        .

---- VAR Y            WATER ACTIVITIES MEASURED IN HOURS

        LOWER     LEVEL     UPPER    MARGINAL

NOV1      .       0.942     +INF        .
NOV2      .       0.466     +INF        .
NOV3      .       1.146     +INF        .
NOV4      .       0.445     +INF        .
DEC1      .       0.741     +INF        .
DEC2      .       0.872     +INF        .
DEC3      .       0.720     +INF        .
DEC4      .       0.668     +INF        .
JAN1      .       0.701     +INF        .
JAN2      .       0.668     +INF        .
JAN3      .         .       +INF       EPS
JAN4      .       0.668     +INF        .
FEB1      .       0.639     +INF        .
FEB2      .       0.861     +INF        .
FEB3      .       0.639     +INF        .
FEB4      .       0.861     +INF        .
MAR1      .       0.818     +INF        .
MAR2      .       0.832     +INF        .
MAR3      .       0.497     +INF        .
MAR4      .       0.853     +INF        .
APR1      .       0.507     +INF        .
APR2      .       0.832     +INF        .
APR3      .       0.625     +INF        .
APR4      .       1.036     +INF        .
MAY1      .       1.346     +INF        .
MAY2      .       0.214     +INF        .
```

```
MAY3      .        1.246     +INF       .
MAY4      .        0.193     +INF       .
JUN1      .        1.363     +INF       .
JUN2      .        0.204     +INF       .
JUN3      .        1.042     +INF       .
JUN4      .         .        +INF      EPS
JUL1      .        1.267     +INF       .
JUL2      .         .        +INF      EPS
JUL3      .        0.971     +INF       .
JUL4      .        0.021     +INF       .
AUG1      .        0.875     +INF       .
AUG2      .        0.021     +INF       .
AUG3      .        0.671     +INF       .
AUG4      .        0.204     +INF       .
SEP1      .        0.993     +INF       .
SEP2      .        0.204     +INF       .
SEP3      .        0.671     +INF       .
SEP4      .        0.021     +INF       .
OCT1      .        0.875     +INF       .
OCT2      .         .        +INF      EPS
OCT3      .        0.993     +INF       .
OCT4      .        0.204     +INF       .

                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR Z              -INF  2.5301E+5     +INF          .

  Z           TOTAL REVENUE IN ESCUDOS

**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED

----   1229 VARIABLE  X.L           CROP ACTIVITIES MEASURED IN LITERS
                                    (ONE-TENTH HECTARE)

MANOCN05   0.224,    SWTMAN03   0.007,    SWTMAN04   0.068,    CANEX03    0.100
TOMATN11   0.148,    TOMATN12   0.074,    TOMATN02   0.213,    TOMATN03   0.064
ONION11    0.166,    ONION03    0.101,    ONION05    0.124,    DRYCRNBNS 10.568

----   1229 VARIABLE  X.M           CROP ACTIVITIES MEASURED IN LITERS
                                    (ONE-TENTH HECTARE)

MANOCN11  -74752.157,    MANOCN12 -105575.983,    MANOCN01  -88532.296
MANOCN02 -116841.346,    MANOCN03  -25775.724,    MANOCN04  -16970.966
MANOCX11 -120630.179,    MANOCX12  -88285.551,    MANOCX01  -81040.808
MANOCX02 -109669.133,    MANOCX03  -48385.422,    MANOCX04  -73773.470
MANOCX05  -75086.931,    SWTMAN11 -106371.053,    SWTMAN12  -16236.166
```

```
SWTMAN01  -35717.771,    SWTMAN02  -69286.840,    SWTMAN05  -89080.813
SWTPOT11 -142343.877,    SWTPOT12 -116024.509,    SWTPOT01  -99509.331
SWTPOT02 -189847.299,    SWTPOT03  -63962.801,    SWTPOT04  -18677.242
SWTPOT05  -24300.880,    CANEN11  -109909.997,    CANEN12   -82035.219
CANEN01   -72874.826,    CANEN02   -70001.351,    CANEN03   -40219.440
CANEN04   -65607.488,    CANEN05   -66920.949,    CANEX11  -107365.239
CANEX12   -12033.868,    CANEX01   -74732.447,    CANEX02   -67775.868
CANEX04   -71867.488,    CANEX05   -73180.949,    TOMATX11  -95102.876
TOMATX12  -98987.712,    TOMATX01  -90998.434,    TOMATX02 -133706.750
TOMATX03  -90771.000,    TOMATX04  -88247.614,    TOMATX05 -174264.562
TOMATN01   -9865.984,    TOMATN04  -19476.614,    TOMATN05 -132493.562
ONION12    -7756.568,    ONION01   -35152.591,    ONION02   -66154.383
ONION04    -9539.846,    CABBAG11  -95142.129,    CABBAG12 -100084.066
CABBAG01  -90460.100,    CABBAG02 -166240.205,    CABBAG03 -102556.198
CABBAG04  -65032.811,    CABBAG05 -147049.760,    POTATO11  -65711.702
POTATO12  -84270.722,    POTATO01  -67869.425,    POTATO02 -143723.777
POTATO03  -87533.819,    POTATO04  -65127.329,    POTATO05  -93150.320
BANANX11 -276062.757,    BANANX12 -154421.874,    BANANX01 -139226.366
BANANX02 -206363.684,    BANANX03 -164303.655,    BANANX04 -183582.267
BANANX05 -223137.261,    BANANN11 -274239.817,    BANANN12 -214062.983
BANANN01 -195061.076,    BANANN02 -193826.546,    BANANN03 -134262.724
BANANN04 -125457.966,    BANANN05 -121172.860

----   1230 VARIABLE  Y.L           WATER ACTIVITIES MEASURED IN HOURS

NOV1 0.942,    NOV2 0.466,    NOV3 1.146,    NOV4 0.445,    DEC1 0.741
DEC2 0.872,    DEC3 0.720,    DEC4 0.668,    JAN1 0.701,    JAN2 0.668
JAN4 0.668,    FEB1 0.639,    FEB2 0.861,    FEB3 0.639,    FEB4 0.861
MAR1 0.818,    MAR2 0.832,    MAR3 0.497,    MAR4 0.853,    APR1 0.507
APR2 0.832,    APR3 0.625,    APR4 1.036,    MAY1 1.346,    MAY2 0.214
MAY3 1.246,    MAY4 0.193,    JUN1 1.363,    JUN2 0.204,    JUN3 1.042
JUL1 1.267,    JUL3 0.971,    JUL4 0.021,    AUG1 0.875,    AUG2 0.021
AUG3 0.671,    AUG4 0.204,    SEP1 0.993,    SEP2 0.204,    SEP3 0.671
SEP4 0.021,    OCT1 0.875,    OCT3 0.993,    OCT4 0.204

----   1234 PARAMETER OPTLND        MONTHLY BREAKDOWN OF LAND USE BY CROP J

          MANOCN05    SWTMAN03    SWTMAN04     CANEX03    TOMATN11    TOMATN12

LNDNOV       0.224       0.007       0.068       0.100       0.148
LNDDEC       0.224       0.007       0.068       0.100       0.148       0.074
LNDJAN       0.224       0.007       0.068       0.100       0.148       0.074
LNDFEB       0.224       0.007       0.068       0.100       0.148       0.074
LNDMAR       0.224       0.007       0.068       0.100       0.148       0.074
LNDAPR       0.224       0.007       0.068       0.100                   0.074
LNDMAY       0.224       0.007       0.068       0.100
LNDJUN       0.224       0.007       0.068       0.100
LNDJUL       0.224       0.007       0.068       0.100
```

```
LNDAUG       0.224       0.007       0.068       0.100
LNDSEP       0.224       0.007       0.068       0.100
LNDOCT       0.224       0.007       0.068       0.100

     +    TOMATN02    TOMATN03     ONION11     ONION03     ONION05

LNDNOV                               0.166
LNDDEC                               0.166
LNDJAN                               0.166
LNDFEB       0.213                   0.166
LNDMAR       0.213       0.064                   0.101
LNDAPR       0.213       0.064                   0.101
LNDMAY       0.213       0.064                   0.101       0.124
LNDJUN       0.213       0.064                   0.101       0.124
LNDJUL                   0.064                   0.101       0.124
LNDAUG                                                       0.124
LNDSEP                                                       0.124
LNDOCT                               0.166


----   1238 PARAMETER OPTLAB        MONTHLY BREAKDOWN OF LABOUR USE BY CROP J

          MANOCN05    SWTMAN03    SWTMAN04     CANEX03    TOMATN11    TOMATN12

LABNOV                   0.003       0.025                   1.058       2.238
LABDEC                   0.003       0.025                   0.316       0.529
LABJAN                               0.025                   0.316       0.158
LABFEB                   0.198                               0.279       0.158
LABMAR                   0.028       1.910       0.337                   0.140
LABAPR       8.282       0.020       0.275       0.262
LABMAY       0.839       0.003       0.189
LABJUN       0.168       0.011       0.025       0.037
LABJUL       0.839       0.005       0.107       0.262
LABAUG       0.168       0.003       0.051
LABSEP       0.168       0.020       0.025       1.062
LABOCT       0.168       0.003       0.194       0.037       4.475

     +    TOMATN02    TOMATN03     ONION11     ONION03     ONION05   DRYCRNBNS

LABNOV                               0.919       0.081
LABDEC                               0.373
LABJAN       6.419                   0.145                   0.099      52.838
LABFEB       1.518       1.943       0.828       2.833
LABMAR       0.453       0.460                   0.562
LABAPR       0.453       0.137                   0.228       3.462       5.284
LABMAY       0.400       0.137                   0.089       0.686      10.568
LABJUN                   0.121                   0.506       0.278      15.851
LABJUL                               0.132                   0.108      21.135
```

```
LABAUG                                                       0.618      10.568
LABSEP                                                                  10.568
LABOCT                               4.637                              10.568


----   1242 PARAMETER OPTWAT        WEEKLY BREAKDOWN OF WATER USE BY CROP J

           MANOCN05    SWTMAN03    SWTMAN04     CANEX03    TOMATN11    TOMATN12

WATNOV1                                                       0.445
WATNOV2                   0.021                               0.445
WATNOV3                               0.204                   0.445
WATNOV4                                                       0.445
WATDEC1                   0.021                                           0.223
WATDEC2                               0.204                   0.445       0.223
WATDEC3                                                                   0.223
WATDEC4                                                       0.445       0.223
WATJAN1                               0.204
WATJAN2                                                       0.445       0.223
WATJAN4                                                       0.445       0.223
WATFEB2                                                                   0.223
WATFEB4                                                                   0.223
WATMAR1                   0.021                   0.300
WATMAR4                   0.021
WATAPR1                               0.204
WATAPR3                   0.021                   0.300
WATAPR4                               0.204
WATMAY1       0.671
WATMAY2                   0.021
WATMAY3       0.671                   0.204
WATJUN1       0.671       0.021                   0.300
WATJUN2                               0.204
WATJUN3       0.671
WATJUL1       0.671       0.021       0.204
WATJUL3       0.671                               0.300
WATJUL4                   0.021
WATAUG1       0.671                   0.204
WATAUG2                   0.021
WATAUG3       0.671
WATAUG4                               0.204
WATSEP1       0.671       0.021                   0.300
WATSEP2                               0.204
WATSEP3       0.671
WATSEP4                   0.021
WATOCT1       0.671                   0.204
WATOCT3       0.671       0.021                   0.300
WATOCT4                               0.204
```

```
      +    TOMATN02    TOMATN03     ONION11     ONION03     ONION05

WATNOV1                               0.497
WATNOV3                               0.497
WATDEC1                               0.497
WATDEC3                               0.497
WATJAN1                               0.497
WATFEB1       0.639
WATFEB2       0.639
WATFEB3       0.639
WATFEB4       0.639
WATMAR1                   0.193                   0.304
WATMAR2       0.639       0.193
WATMAR3                   0.193                   0.304
WATMAR4       0.639       0.193
WATAPR1                                           0.304
WATAPR2       0.639       0.193
WATAPR3                                           0.304
WATAPR4       0.639       0.193
WATMAY1                                           0.304       0.371
WATMAY2                   0.193
WATMAY3                                                       0.371
WATMAY4                   0.193
WATJUN1                                                       0.371
WATJUN3                                                       0.371
WATJUL1                                                       0.371


----   1246 PARAMETER OPTREV        BREAKDOWN OF TOTAL REVENUE

MANOCN05  36217.629,    SWTMAN03    833.604,    SWTMAN04   8058.171
CANEX03    1484.800,    TOMATN11  35555.383,    TOMATN12  14808.941
TOMATN02  57380.623,    TOMATN03  11700.240,    ONION11   20684.906
ONION03    9726.664,    ONION05   11576.977,    DRYCRNBNS 44986.080
```

SELECTED BIBLIOGRAPHY

Bromley, David W., Donald Taylor, and Donald Parker. "Water Reform and Economic Development: Institutional Aspects of Water Management in the Developing Countries." *Economic Development and Cultural Change.* 28(1980):365-387.

Carreira, Antonio. *The People of the Cape Verde Islands.* Hamden, CT: Archon Books, 1979.

Courier, The. *Cape Verde: A very poor country strives to improve its lot.* No.107, Jan-Feb 1988, pp.15-31.

Diaz-Briquets, Sergio. *Cape Verde: Social and Demographic Situation and Prospects.* Report prepared as part of Cape Verde Economic Mission, July, 1983.

Duloy, J.H., and Gerald T. O'Mara. *Issues of Efficiency and Interdependence in Water Resource Investments: Lessons for the Indus Basin of Pakistan.* World Bank Staff Working Papers, no. 665. 1984.

The Economist. *The World in Figures.* The Economist: London, 1988.

Finan, T. J. "The Farming System under Duress: Agricultural Adaptations on the Cape Verde Islands". *Human Organization,* 47(1988): 109-118.

Finan, T.J., and J. Belknap. *Characteristics of Santiago Agriculture.* Report submitted to USAID Food Crops Research Project. USAID: Praia, Cape Verde, 1985.

Finan, T.J. and H. K. Henderson. "The Logic of Cape Verdean Female-Headed Households: Social Response to Economic Scarcity." *Urban Anthropology* 17(1988): 87-103.

Food Crops Research Project. *Project Paper, Food Crop Research.* Proposal submitted to U.S. AID. 1982.

Food Crops Research Project, and Department of Social Sciences, INIA. *Crop Budgets for Selected Irrigated Crops on Santiago and Santo Antao Islands.* 1987.

Freeman, Peter H. et al. *Cape Verde Assessment of the Agricultural Sector.* Report present to U.S.AID, Santiago, Cape Verde, 1978.

Gotsch, Carl H. et. al., *Linear Programming and Agricultural Policy: Micro Studies of the the Pakistan Punjab.* Food Research Institute Studies, volume XIV, No. 1, 1975.

Hammer, Jeffrey S. "'Subsistence First': Farm Allocation Decisions in Senegal"." *Journal of Development Economics,* 23(1986) October: 355-369.

Hillman, Jimmye S., Timothy J. Finan, and Mark W. Langworthy. *A Study on Food and Agricultural Statistics in the Context of a National Information System: the Case of Cape Verde.* 1986.

Howe, Charles. "The Effects of Water Resource Development on Economic Growth: The Conditions for Success". *Water in a Developing World: The Management of a Critical Resource.* A. Utton and L. Teclaffseds, eds. Boulder: Westview Press, 1978.

Langworthy, Mark, Timothy J. Finan, Raul Varela, and Elisio Rodrigues. *Characteristics of Santo Antao Agriculture*, and *Characteristics of Sao Nicolao Agriculture.* Report on 1985 Survey. University of Arizona and National Agricultural Institute of Cape Verde (INIA), 1986.

Langworthy, Mark, and Jimmye S. Hillman. *The Role of Food Policy and Agricultural Production in the Economic Development of Cape Verde.* Unpublished paper to be presented for the 19th EAAE Seminar, Montpelier, France, 1989.

Multinational Agribusiness Systems Incorporated. *1985 Update: Agricultural Sector Assessment, Cape Verde.* Report submitted to U.S.AID, 1986.

Ministerio do Desenvolvimento Rural. *Estatisticas Agricolas.* Gabinete de Estudos de Planeamento: Praia, Cape Verde, 1984.

Estudo da Evolucao Absoluta dos Precos de Produtos Agricolas: Junho-Agosto/1988. Praia, Cape Verde,1988.

Moran, Emilio F. "*The Evolution of Cape Verde's Agriculture.*" African Economic History 11(1982):63-86.

Musser, Wesley N., Bruce A. McCarl, and G. Scott Smith. "*An Investigation of the Relationship Between Constraint Omission and Risk Aversion in Firm Risk Programming Models.*" Southern Journal of Agricultural Economics. December (1986): 147-154.

The Netherlands, State Secretariat of Development Cooperation and Planning. *Food Strategy Study, The Republic of Cape Verde: Preliminary Report.* Vol.1: General Outline of the Strategy. Vol 2: Water Resources and Irrigation., 1982.

Seagraves, James A. and K.William Easter. *Pricing Irrigation Water in Developing Countries.* Water Resources Bulletin, vol.19 (4), 1983.

United States Agency for International Development. *Cape Verde: Country Development Strategy Statementt.* Small Program statement FY 82. U.S.AID, Washington, D.C., 1980.

Cape Verde Watershed Development. Project Paper 655-0013. U.S.AID, Washington, D.C. 1984.

United States Department of Agriculture. *World Food Needs and Availabilities, 1987-88.* Washington, D.C., 1987.

World Bank. *The Republic of Cape Verde: Economic Development of a Small Island Archipelago*. Volumes I and II. Report no. 2730 - CV, West African Regional Office, (BRD), Washington, D.C. 1980.

Cape Verde: Economic Situation and Prospects. Volumes I to III. Report No. 5446-CV, West African Regional Office, (BRD), Washington, D.C. 1985.