Economic Impacts of Irrigating
The Grenadian Paradise Model Farms:
A Representative Farm Study

By

MICHAEL ALEXANDER CHURCH

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ECONOMIC IMPACTS OF IRRIGATING THE GRENADIAN PARADISE MODEL FARMS: A REPRESENTATIVE FARM STUDY

BY

MICHAEL ALEXANDER CHURCH

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Dedication

This pioneering work is dedicated to the grandmother who fathered me, Camaila Cadore, who died on June 20th, 1993.

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Abstract

Irrigation adoption in agriculture has the potential to increase farm profitability and to improve farm performance. The critical economic questions of this study are—is it optimal to irrigate a representative farm of the Grenada Paradise Model Farms? and, to what extent would irrigation adoption affect production decisions of the farm?

Linear programming analytical tools are applied to a prescriptive multi-input, multi-output, multi-period farm model for a representative farm of the Grenada Paradise Model Farms. Special emphasis is directed to the Government minimum banana acreage policy and its effects on the individual farm, from a profitability and a farm performance perspective.

The model results suggest that total discounted net revenue (a proxy for discounted profits) is relatively higher for the irrigated farm model and not the unirrigated model. There is also increased farm performance when the representative farm is irrigated. From inspired minimum banana acreage policy is in conflict with the micro-based profit maximization objective of the individual farm.

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1.1 An Overview of the Performance of the Agricultural-Sector

Agriculture is the most important sector of the Grenadian economy as an earner of foreign exchange and a source of employment. However, there has been a steady decline in its capacity to fulfil those roles. Between 1979 and 1984 export earnings from its major crops (bananas, cocoa, nutmegs and mace) fell from U.S. $18.4 million (E.C. $49.6 million) to U.S. $10.8 million (E.C. $29.1 million). However, exports of fresh vegetables and fruits increased from U.S. $0.36 million (E.C. $972,000) to U.S. $5.08 million (E.C. $13,716,000) for the same period. Production of the traditional export crops fell during that same period—banana production declined by 13%, cocoa by 17%, nutmeg by 8% and mace by 44%. The decline in production between 1985 and 1990 was even more dramatic. In the case of bananas, there was a 33% decrease while cocoa showed a 32% decline. Although nutmeg production increased by 24%, mace production dropped by 34% (Agricultural Statistics, 1991). The sector's contribution to Gross Domestic Product declined from 25% in 1985 to 20.5% in 1988 (Noel, 1991).

The agricultural sector's troubles began in the early years of the 1970s. A series of factors, both domestic and external, combined to have a negative impact on the Grenadian agricultural economy. During the early 1970s, Grenadian farmers perceived that the U.K.'s entry into the European Economic Market meant the end of preferential treatment for the island's agricultural exports to the U.K. market. That perception was further strengthened by the decreasing infusion of agricultural subsidization—the main source being British grants-in-aid.

On the domestic scene, the Government's move towards constitutional independence from the U.K. was interpreted by many as the green light to Britain to abandon Grenada and, by extension, the Grenadian farmer. Those fears were harnessed and manipulated by the political anti-independence movement. As the large landowners attempted to use their economic power to dethrone the Government the latter retaliated with massive land acquisitions. By 1979, 19 of the best plantations had been acquired and subsequently left abandoned while many of the remaining large plantations drastically curtailed agricultural production. During that period no attempts were made to restructure the agricultural sector and to diversify production. It was not until 1985 that Government finally decided to provide a boost to the sector by supporting the development of the non-traditional small farm sub-sector.[1] This support came with the formulation of the Grenada Model Farms Project.

Four very important objectives have been established for the Model Farms Project. The first objective is the divestment of approximately 3,400 acres (1377 hectares) of state-owned farm lands. The strategic importance of that divestment is to create economically viable and efficient small farms. The second objective is to settle those farms with young farmers who would undergo on-farm training in proper agronomic and farm management practices. The third objective is to ensure that those farms produce at least 2 acres (0.81 hectares) of bananas in each production year. This objective is intended to help meet the

[1] The non-traditional small farm sub-sector refers to farms of up to 5 acres in size that predominantly produce crops other than the traditional export crops of bananas, cocoa, nutmegs and mace.

Government's goal of increasing banana production and export. The fourth objective is to facilitate the land transfer to the small-holder through a lease-purchase agreement. This instrument of transfer allows the small-holder to pay for the farm over a fifteen year period. More importantly, it permits the small farmer to gain access to farm loans from the Grenada Development Bank with the Model Farms Corporation acting as a guarantor.

1.2 The Economic Problem

The problem of the non-traditional small farm sub-sector has a complexity that rests on both technical and institutional shortcomings. The main problem from a technical perspective can be summarized in the following words:

> When growth is based on a more intensive use of traditional inputs little extra becomes available to improve the well-being of rural people...Little surplus has been generated by simple resource allocation within farms...in the absence of technical change embodied in...more productive inputs (Ruttan, 1977, p. 197).

Among the production shortcomings is the sub-sector's inability to better exploit available lands, due to prolonged dry seasons. One of the proposed strategies for the alleviation of that problem is the use of irrigation. In fact, the infrastructural development designed for some of the member farms within the Model Farms Project is explicitly aimed at prolonging the growing season.

Also, adoption of irrigation may cause changes in the crop mix, from the production of low-priced crops to high-priced, high-profit ones. Irrigation adoption may even influence a transformation in farm management from current practice to a more organised multi-cropping regime. That new multi-cropping system would be dictated by the need to be more efficient in water use. While irrigation offers the potential to help improve farm performance and profitability, it is not clear whether or not adoption of irrigation technology is optimal and to what extent the use of irrigation will affect production decisions of the farms.

1.3 Purpose and Objectives of the Study

The economic question provides the focus for the research plan of this study. The overall research goal of this study is to investigate the potential profitability of irrigation adoption by a sub-set of Model Farms Project farms, given constant input and output prices. Emerging from this general goal are several specific research objectives, as follows:

i) To identify a farm operation representative of the Paradise Model Farms Project farms defined in terms of physical and financial characteristics;

ii) To develop an economic model capable of simulating the representative farm;

iii) To incorporate irrigation, from a technical and economic perspective, into the model;

iv) To assess the effects of irrigation on production decisions;

v) To assess the effects of irrigation on farm profitability; and

vi) To draw some policy implications.

1.4 Hypotheses

Given the specific objectives, several hypotheses are tested in this study, as follows:

i) It is hypothesized that if adopted, irrigation would increase the profitability of the representative farm.

ii) It is hypothesized that if adopted, irrigation would make the banana enterprise more profitable.

iii) It is hypothesized that if irrigation is adopted and the institutional constraint on the banana enterprise is relaxed, the farm profitability would increase.

iv) It is hypothesized that if irrigation is adopted and the institutional constraint on the banana enterprise is relaxed, farm production patterns would shift in favour of the vegetable enterprises.

1.5 Outline of the Study

In addition to this chapter, there are five other chapters, that is Chapter Two through Chapter Six. Chapter Two presents a background of the agricultural sector of Grenada. Also, a general discussion on the role of irrigation in agricultural development and its historical role in Grenada agriculture is discussed. In addition, vital information relevant to the modelling of irrigation in the model is provided. Chapter Three discusses the conceptual framework which provides the foundation for the empirical model and the methodology. Chapter Four provides a discussion of the representative farm and model data and specifications. The model results are presented in Chapter Five. The thesis concludes with Chapter Six which provides a summary of the study, its limitations and recommendations.

Chapter 2. Background

2.0 Introduction

This chapter is both general and diverse in its outlook. It begins with a discussion on climate, topography and soils of Grenada. The major emphasis in that section is on the tremendous influence that topography has on agricultural development in Grenada. A discussion then follows on the farmer population and farm size distribution. Here, two critical points are brought into focus. First, a small minority of farmers owns an inordinately huge percentage of total farmlands while the greater farmer population owns very small farms that comprise a small percentage of the farmland collectively. Secondly, although the average farmer can be considered old, there is a slow reversal of that phenomenon, especially among the small farm operations.

The agricultural sector is also discussed from a historical and economic perspective. The reasons for the demise of the traditional (plantation) sub-sector and the rise of the small farm sub-sector are discussed. The major thrust of Government agricultural policy is highlighted in the context of the Grenada Model Farms Project. Also, the problems confronted by the small farm sub-sector are discussed at some length.

A brief but relevant discussion on the role of irrigation in agricultural development is presented. This is followed by a discourse of irrigation practice in Grenada. These two sections aid in contrasting what can be accomplished versus actual practices with respect to irrigation in Grenada. The discussion also identifies the potential problems that may arise as one attempts to incorporate irrigation in this study. Finally, some useful and relevant background and data are presented for the crops used in this study which will be useful when incorporating moisture and irrigation considerations into the model.

2.1 Climate, Topography and Soils

The 76,800 acre (31,093 hectare) island of Grenada experiences a tropical humid climate. There are two marked seasons—a dry season and a wet season that roughly correspond to the first and second halves of the calendar year respectively. The average daily temperature is around 85 F (27 C). The annual average rainfall ranges from 50 inches (1,250 mm) in the flat coastal regions to 160 inches (4,000 mm) in the mountainous areas.

The island is volcanic in origin and is extremely rugged and mountainous. The soil types range from sandy-loams to heavy clays. Although Grenada is endowed with fertile soils, in the main, they are not often located in the most topographically favourable regions. Topography, in combination with climate, dictates the nature of agricultural practices on the island. Tree crops predominate the agricultural landscape with vegetable production occurring in the limited areas of flat lands.

In the *Grenada Agricultural Extension Atlas* (1991), seven slope categories are identified with their corresponding acreage distributions. Table (2.1) shows the slope categories, the slope description and the corresponding acreage distributions. The information in this table indicates the mountainous nature of the island.

Francis (1982), in his classification of soils, defines five soil categories based on criteria such as texture, structure, nutrient status, pH and stoniness, and places these soil categories in the context of topography. Once again the feature of topography as a major influencing factor on agriculture is evident. Table (2.2) presents his findings.

Table 2.1 Slope Categories, Description of Slopes and Acreage Distribution According to Slope for Grenada

Slope Category	Description in Degrees	Acreage Distribution
A	0-2	1,175 (476)
B	2-5	2,500 (1,012)
C	5-10	3,600 (1,457)
D1	10-15	8,000 (3,239)
D2	15-20	8,100 (3,279)
E	20-30	35,000 (14,170)
F	>30	17,100 (6,923)
Total		75,475 (30,556)

Source: Ministry of Agriculture, Grenada, 1982

Table 2.2 Soils Classes and Their Distribution According to Topography

Soil Classes	Slope Categories	Acreage Distribution
1	A & B	3,675 (1,488)
2	C	3,600 (1,457)
3	Mainly D1	8,000 (3,239)
4	D2 & E	43,100 (17,449)
5	F	17,100 (6,923)
Total		75,475 (30,556)

Source: Francis, 1982

From the data presented, only 20 percent of Grenada's area is located in the 10 degree, or less, slope categories. One also has to consider the encroachment made on these areas by housing developments. This encroachment is progressing at an amazing pace, partly due to the lack of enforceable and effective agricultural zoning laws. In this context it can be appreciated that there is a declining land base available for agricultural development. One relevant question, therefore, is—*is irrigation adoption a profitable and viable option in those regions?* This issue shall be addressed in greater detail later.

2.2 Farmer Population and Farm Size Distribution

According to the last agricultural census, taken in 1981, there were 8,202 farmers in Grenada. The gender distribution of the farmer population was 62% male and 38% female. Fifty-one percent of farmers were described as part-time farmers while 49% were categorised as full-time. The average age of the farmer was 56 years. Today the average age of the farmer deployed within the Model Farms Project is about 36 years, according to the General-Manager of the Grenada Model Farms Corporation.

The 1981 census established that the total farm acreage was 34,243 acres (13,864 hectares). Between 1961-1975, the farm acreage fell from 47,173 acres (19,098 hectares) to 38,352 acres (15,527 hectares). Between 1975-1981 there was a further decrease to 34,243 acres (13,864 hectares). The average annual percentage decline in farm acreage was 1.5% between 1961-1975 and 1.7% between 1975-1981 (Agricultural Census, 1981). Thus, the decline in available farm land has contributed to some extent to the downward trend in agricultural production.

The 1981 census was very revealing with regards to farm size and land distribution per farmer. In 1981, farm land distribution was markedly skewed in favour of the large farm owner. Farmers owning farms of 20 acres (8.09 hectares) or more comprised only 2% of the farm population but controlled 47% of total farm acreage. This numerically small group of big landowners owning an inordinately large percentage of the farm lands emphasizes why they were able to affect total agricultural production as they did. Eighty-eight percent of the farmer population owned farms of 5 acres (2.02 hectares) or less but occupied only 31% of total farm area. Individually, these small farmers lacked the land base that would have allowed them to assume the role of the traditional sub-sector. The Government owned 3,696 acres (1,496.4 hectares) of farm land making it the biggest single land owner. In fact 23% of the farms 20 acres (8.09 hectares) or more and 26% of farms of 100 acres (40.5 hectares) or more was owned by Government. Table (2.3) gives a picture of relative and cumulative distributions of farm acreages and farmer holdings and shows the dominant role of the big land owners.

2.3 The Agricultural Sector

The agricultural sector is divided into two sub-sectors—the traditional sub-sector and the non-traditional sub-sector. This classification is based on differences in farm size, crop choices and market destinations.

2.3.1 The Traditional Agricultural Sub-Sector

This sub-sector is characterised by four important features. First, the farms are medium to large in size. A medium farm size covers an area of between 10-20 acres (4.05-8.09 hectares) while a large farm is one in excess of 20 acres (8.09 hectares). There are a few

Table 2.3 Relative and Cumulative Distribution of Farm Acreages and Farmers According to Farm Sizes in Grenada

	Relative		Cumulative	
Farm Size Ac (Ha)	% Acreage	% Farmers	% Acreage	% Farmers
0-1 (0-0.40)	6.49	49.43	6.49	49.43
1-2 (0.40-0.80)	7.63	18.59	14.12	68.02
2-5 (0.80-2.02)	16.93	20.28	31.05	88.30
5-10 (2.02-4.05)	12.97	6.90	43.06	95.20
10-20 (4.05-8.09)	9.97	2.89	53.03	98.09
>20 (8.09)	46.97	1.91	100.00	100.00

Source: Ministry of Agriculture, St. George's, Grenada, 1981

super-size farms (e.g. Dougaldston and River Antione) that are 500 acres (202.4 hectares) or more in size. The second feature is that these farms are located more to the interior of the island and receive adequate rainfall throughout the year to sustain the crops that are grown. They also exhibit great topographical diversity, generally tending towards steeper slopes. The third distinguishing factor relates to the crops grown. Crops are predominantly plantation crops of bananas, cocoa, nutmegs and mace destined for the United Kingdom. Some vegetables and root crops are grown but on a very small scale by plantation workers who have been given permission to have small gardens, albeit, to supplement their labour incomes and also to ensure the continued availability of their services to the plantation farm. Lastly, since the decade of the 1970s the sub-sector has been handcuffed in the throes of rapidly declining buoyancy and profitability.

Since the advent of the 70s, the traditional sub-sector has been experiencing tremendous negative shocks to its production and profitability performance. On the one hand, there was decreased direct subsidization of the traditional export crops. This development coupled with the serious political instability and, sometimes unrest throughout the 1970s, caused further aggravation to the sub-sector's performance. There was almost a steady and dramatic decline in the production of the traditional crops for the next two decades. Between 1970-1990, banana production fell from an annual output of 16,000 tonnes to 8,730 tonnes. Production in 1990 was only 55% of that in 1970. Production of cocoa, for the same period, declined from 2,131 tonnes to 1,475 tonnes. Output in 1990 was 69% of that in 1970. Although nutmeg production rose from 2,704 tonnes to 2,905 tonnes mace production fell from 324 to 269 tonnes. That represented a 7% increase in nutmeg production but a 17% decrease in mace production.[2] Appendix A provides a more detailed picture of the annual production trends for those crops from 1970-1990 which reflect the general decline alluded to earlier.

As discussed in the first chapter, internal political instability was a significant contributing factor in the decline of the sub-sector. However, in order, to appreciate its effect one has to factor in the average farmer's perception of political events in terms of their impact on him or her.

There were two significant events in the 1970s that contributed to the downslide in agricultural production of the traditional crops. The first was the United Kingdom's preparation for and its eventual entry into the European Common Market. The Grenadian farmer perceived that movement as the first step that would eventually lead to Grenada losing the preferential treatment that the United Kingdom accorded to bananas, cocoa, and nutmegs and mace. Simply put, the United Kingdom provided those crops from Grenada

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[2] Nutmeg and mace are parts of the same product. Nutmeg is the nut and mace is the outer petal-like covering of the nut.

with a secured market and there was fear of losing it. On the domestic scene, the movement towards independence by the ruling Grenada United Labour Party further hardened the perception of the farmer that the competitiveness protected by preferential treatment, was about to disappear (Jacobs, 1974). That fear forced already conservative farmers to join the anti-independence movement. Self-interest and manipulation by the anti-independence political forces propelled the big landowners into voluntarily curtailing production as a means of pressuring the Government to give up its independence route and even to drive it out of power.

Between 1970-1979 Government retaliated against the big landowners by acquiring numerous large farms belonging to its most vocal opponents. The acquired farms fell out of production while a few were fragmented to provide housing for farm labour hands who previously had worked on some of those farms. Production on the farms that were not acquired continued its downward trend. Possible reasons for that trend were the continued adamant stand of some large farmers and, also, their morbid anticipation that it was only a matter of time before the remaining farms would be taken over by Government. Between 1970-1979, 19 of the best large farms were acquired by Government. From 1979-1981 the People's Revolutionary Government acquired another 5 large farms. The effects of those acquisitions and related factors were so devastating that by 1981 50% of traditional crop exports came from farms averaging in size of 10 acres (4.05 hectares) or less (Thompson, 1988).

2.3.2 The Non-Traditional Agricultural Sub-Sector

The rudiments of the small farm non-traditional sub-sector began its emergence in Grenada in the immediate post-emancipation period. However, an overwhelming majority of those farmers were part-timers and landless—a characteristic that is still very evident today. Only in Grenada's recent history has this feature begun to change and give way to a more definitive structure. At least two reasons can be cited to explain the changing phenomenon. The first reason is found in the demise of the plantation economy which began in the 1970s. With the growth of bankruptcy among large farmers, there grew a willingness by some of these farmers to sell out in small holdings to their former employees and other interested parties. This occurred on a relatively small scale during the latter half of the 1970s but accelerated in the 1980s.

The other factor was the growing stock of younger and more sophisticated farmers willing to respond to perceived new opportunities for marketing vegetables and non-traditional exotic fruits in the newly found domestic and extra-regional markets. This movement accelerated in the 1980s and was encouraged and supported by the Government's intention in 1984 to privatize its agricultural lands with a distinct bias in favour of small holdings by young farmers. This added an extra fillip to the future of that sub-sector. As was discussed in chapter one, The Model Farms Project, an agrarian reform programme initiated in 1986, became the embodiment of this privatization policy.

There is a rapidly growing notion among Ministry of Agriculture officials that the small farm sub-sector will replace the traditional sub-sector. The evidence arises from the fact that in the early 1970s Grenada was the largest banana producer in the Windward

Islands but by 1986, it had become the smallest producer. The large farms that initially were producers had ceased to perform their traditional role effectively. Also, the fact that little was done during that period to reorganise the sector encouraged Government into believing that the non-traditional sector was the answer to all the ills of the entire sector.

This study maintains that the two sub-sectors must be seen as essential and complementary. The small farm sub-sector should be seen as a strategic option aimed at improving crop production diversity and increasing farm profitability. In fact, Adams and Pringle, members of the project design team,merely reflected Government's position and hopes by recommending the following:

> Irrigated bananas and vegetable cropping systems for thirty-six 4.5-5 acre farms on six estates [plantations]. Areas proposed for irrigation have all been irrigated in the past, but equipment, structure and canals are in need of replacement or repair. Irrigation will be supplied by sprinkler or gravity systems. The Paradise, Grand Bras, Pointzfield, Requin, Black Bay and La Sagesse estates [plantations] are involved. (Adams and Pringle, 1986; p. 18)

The idea of irrigation use on some model farms is the most critical element of the present study. However, a more detailed discussion of irrigation shall be pursued later in this chapter. In the interim, an effort shall be made to assess the sub-sector's recent performance and to also highlight some of the more serious problems confronting it.

Since the 1980s, the non-traditional sub-sector has shown significant positive financial performance. Adams and Pringle (1986) observed that the value of exports of fresh vegetables and fruits mainly from that sub-sector increased from U.S. $0.36 million (E.C. $972,000) in 1979 to U.S. $5.08 millions (E.C. $13,716,000) in 1984. The destinations of these exports have been Trinidad and Tobago and Europe, especially the U.K. and Holland.

Small farmers are also gradually accessing the local hotel market for fresh produce. According to the Agricultural Rehabilitation and Crop Diversification Unit (ARCDU) of the Ministry of Agriculture, in 1990, hotels operating on Grenada purchased 608 tonnes of assorted fruits and vegetables in 1970 mainly from small farmers. The sub-sector's participation in banana production and export has been commended highly by the Grenada Banana Cooperative Society (GBCS). The Windward Islands' Crop Insurance (WINCROP) claimed that in 1990, 90% of total banana exports came from holdings of 5 acres (2.02 hectares) or less in area (Noel, 1991).

Unquestionably, many of the improvements in the performance of the small farm non-traditional sub-sector have been due to chemical, biological and other non-institutional innovations. However, the performance frontier is rigidly constrained by several institutional problems. It is very true that,

> ...the need for viable institutions capable of supporting more rapid agricultural growth and rural development is even more compelling today...As the technical constraints on growth of agricultural productivity have become less binding there is an increasing need for institutional innovation that will result in a more effective realization of the new technical potentials (Ruttan, 1977; P.216).

Some of the manifestations of the more serious institutional constraints are visible in the following: (i) the uncoordinated policies of a multiplicity of extension services units; (ii) the irrational marketing policy and strategies of the Marketing National Importing Board; (iii) the extreme difficulty by farmers to access credit even when it is available in relative abundance; and (iv) high customs duties on agricultural implements.

There are four different extension service units officially involved in agriculture: the Banana Extension Unit, the Nutmeg Extension Unit, the Cocoa Extension Unit and the Agricultural Extension Unit of the Ministry of Agriculture. The first three are involved in the promotion of specific agricultural commodities as indicated by their names. The Ministry's Extension unit is intended to complement the activities of the other three agencies while at the same time responding to farmers' needs not specifically addressed by those crop-specific units. It is the lack of coordination and focus that oftentimes infiltrate such a top-heavy system and creates problems for the average farmer.

The Ministry, by itself, maintains an officer corp of 40 agents (Agricultural Policy Document, 1991). The further inclusion of the extension officers of the other agencies not only complicates the competition among them for the farmer clientele but more fundamentally confuses the farmer and leaves unanswered many of the farmer's farming-related concerns. The lack of coordination among the units has been so problematic that the Marketing National Importing Board (MNIB) has become involved in the canvassing of farmers to promote the crops in which it has interest. Also, the Caribbean Agricultural Research Development Institute (CARDI), the regional institution responsible for technology and its dissemination, has over the years carved out its own enclave. The result has been a further segmentation of the farmer population with a certain disregard for existing Ministry policy. That feature, coupled with the lethargy suffered by the Ministry's Extension Unit, completes the prescription for ensuring farmer frustration.

The accessing of loans is still very problematic for many of the small non-traditional sub-sector farmers. That problem arises and is better understood in the context of property rights viewed as a legal institution. As Cooter explains,

> ...that by allocating a bundle of rights gives people liberty over resources,...these rights describe what people may, or may not do with the resources: the extent to which he may possess, use, transform, bequeath, transfer or exclude others from his property (Cooter, 1988, p. 90).

Historically, the small farm sub-sector grew out of the practice of large land owners allowing their workers to farm small patches of land on the estates without giving them the rights to ownership. Where ownership rights were eventually obtained, parcelization of the land within the family or internal family conflict over clear ownership often occurred. In this type of environment it became difficult and sometimes impossible for the individuals interested in farming to obtain bank loans because tenureship was either unclear or non-existent.

One goal of the Grenada Model Farms Project was to eliminate the problem of loan access by the small farmer through an instrument called a lease-purchase agreement. The strategy was that the model farmer would pay the Model Farms Corporation a sum of money in exchange for ownership rights. That sum had to be paid over a fifteen year period or at the end of the fifth year of settlement given satisfactory performance and paying ability of the farmer. During the period in which the farmer was obligated to the Corporation the latter would act as a guarantor for loans obtained by the farmer from the Grenada Development Bank (Beddoe, 1989).

The Grenada Development Bank (GDB), a quasi-statal institution, agreed to the principle as it had funds earmarked for agricultural development at 7% per annum that were not being accessed by farmers. Implementation of the plan was stalled because of the uncertainty surrounding the role and longevity of the Corporation as outlined by the then General-Manager. Briefly, the General-Manager, in 1989, clearly established that the Corporation would cease to exist once land divestment had been completed—a process that was supposed to end around 1991. Naturally, this raised the question of debt responsibility to the GDB of loans that might have had a life beyond the time of divestment completion. Consequently, the model farm farmers were rigidly restricted in accessing adequate loans from GDB via the instrument of the lease-purchase arrangement. This problem is being addressed and will be resolved, according to the Permanent-Secretary of the Ministry of Agriculture and the present General-Manager of the Model Farms Corporation.

The other serious bottleneck has to do with marketing and marketing infrastructure. Here is a classical case in which tradition fails to comprehend the new realities of potentially profitable markets. Historically, Grenada has always looked outwards, especially extra-regionally, for markets for its agricultural produce—no doubt that attitude is a reflection of its colonial legacy. The three major export crops which are marketed by the various commodity boards are destined for Europe and specifically the U.K. In 1980, the Marketing National Import Board (MNIB) was founded to promote the marketing of fresh fruits and vegetables. Again, the destination targeted was Europe especially the U.K. and Holland. At the same time, there was a growing domestic market concentrated in the hotel belt and the supermarkets that were expanding to meet the demands of the growing urban population. These markets continued to meet much of their demands for fresh vegetables through imports. It is important to note that while the island has a very good road network, farmers are typically unable to afford the right type of vehicles for transporting consistently high quality produce. This undoubtedly influences hoteliers and the supermarket owners to continue their reliance on imports.

Table (2.4) clearly indicates the existence of a genuine demand by the hotels for the fruit and vegetables presented in the table, given the substantially higher prices paid to farmers by the hotel in comparison to prices paid by MNIB. The point being emphasized is that if there were a greater supply, the prices paid by hotels and, by extension, the supermarkets, should eventually gravitate to those paid by MNIB. It also means that if access to the hotels and supermarkets by farmers were greater there would have been a greater supply to drive the prices closer to those of the MNIB. The problem being confronted here is, therefore, one in which the farmer is incapable of bringing the produce to those markets on a consistent basis due to the absence of an infra-structure that allows for that to happen.

This problem extends into intra-regional trade especially with respect to Trinidad and Tobago and Barbados. While it is true that high volumes of fresh vegetables and fruits arrive at the Trinidad and Tobago market on an annual basis, more ought to be done to improve the marketing of those products. The vast proportion of those products is moved in wooden unrefrigerated ships. Those crops on arrival at their destinations are at a significantly decreased quality level. This in turn has a negative effect on the prices obtainable and these products do not reach the premium markets of the hotel industry. This is a significant problem that Grenadian exports of fruits and vegetables also face in

Table 2.4 Prices in Eastern Caribbean (EC) Currency Paid to Farmers by MNIB and the Hotels for a Selected Set of Fruits and Vegetables

Produce	Price per Pound in $ Paid by MNIB				Price per Pound in $ Paid by Hotel
	1989	1990	1991	Three Year Average	1991
Papaya	0.42	0.45	0.45	0.45	0.80
Passion Fruit	1.00	1.00	0.95	0.98	NA
Beets	1.78	2.00	2.30	2.03	3.00
Carrots	1.82	1.50	1.56	1.63	3.00
Cucumbers	0.64	0.30	0.44	0.46	1.00
Sweet Potatoes	0.90	1.00	1.01	0.97	1.50
Ripe Bananas	0.10	0.10	0.10	0.10	0.30

Barbados. The importance of that marketing shortcoming is better appreciated when one considers the influence of North American television on shaping the tastes and preferences of the Caribbean native. Thus, consumers are making more and more demands for better quality and more attractively presented products. The failure to address these marketing problems continue to ensure that the farmer is excluded from benefitting from a market demand that exists in those more affluent societies.

The last institutional constraint refers to the importation of irrigation systems and the effects of high customs duties. It is almost prohibitive for a farmer, outside the Model Farms Project, to obtain an irrigation system. Pumps and water lines are considered by the Custom's Division of Grenada as dual purpose. As a result, those parts imported from Barbados, for example, by a farmer could cost him approximately two to three times the landed cost. Even in instances where a farmer might be granted a concession on import duties, because the farmer is required to post bond, oftentimes, that renders the concession unusable. Due to that institutional constraint the small farmer is unable to improve the production system through the innovation of irrigation. In the end, the farmer who is endowed with irrigation most likely would be one of the few model-farm farmers.

2.4 Irrigation Considerations

2.4.1 Irrigation and Agricultural Development

Irrigation is the application of water, by human beings, to assist the growth of crops (Clark, 1970). Irrigation water might be used to supplement rainfall deficits and to effectively prolong the growing season, while in still other cases it may be used as a yield assurance device. Whatever the objective there are basically four methods of applying water to crops. Briefly, the methods of application are flooding, furrowing, sprinkling and sub-irrigating.

Flooding involves the covering of the surface with water. The water is led from supply canals into ditches with gaps through which the water reaches the soil surface. Once the soil surface is saturated, the flow is cut off. This method is most effective on lands that are sloping in topography. Furrowing is the practice of channelling water into furrows normally constructed between crop rows. Furrowing is very adaptable to a wide range of land slopes and soil textures. However, where the slopes are too steep furrowing could be destructively erosive. Also, furrowing on pervious soils is wasteful in that the water does not reach the crop but sinks downwards. Sprinkling applies water to the soil in the form of a spray and is suitable for almost any slope type. Sub-irrigation is the application of water beneath the surface through the use of lateral ditches. The effectiveness of this system is contingent on the maintenance of the water table (Cantor, 1970).

Since the sprinkler system is the main method under consideration, attention shall now be devoted to discussing the system in more detail. The choice to adopt sprinkler irrigation has many advantages. Land that is irregular in topography can be irrigated without disturbing the topsoil through levelling. Field ditches are unnecessary thus increasing the area available for crop production and obviously eliminating the cost involved in ditch maintenance. More efficient use of both water and labour results where the available water source might be a small continuous stream. It is also well adapted to seed bed preparation and the thinning of seedlings because of its capability to provide light water applications.

There are also disadvantages. To a small farmer the initial costs and operating costs could be high. Unless the system can be operated almost continuously the investment in equipment might be too high. Depending on the regularity with which lines have to be moved and the softness of the soil, compaction can result. If not properly designed, great losses of water can result due to wind.

In spite of these shortcomings the sprinkler system still remains a highly adaptable method especially under conditions where supplemental moisture in periods of insufficient rainfall proves to be a profitable practice. This is not a claim of superiority for the sprinkler system above others. Once the system is well-designed and effectively replenishes the moisture utilized by the growing crop, it can be described as efficient (F.A.O., 1960).

Climatological factors influence when and how much water is available for irrigation. They also determine, to a great extent, the amount of water available to crops and therefore partially would influence which crops are chosen for cultivation in a given area. From the perspective of rate of water use by a crop, radiation intensity is the most major factor (Carruthers and Clark, 1981). The measurement of solar radiation is an informant with respect to approximating evapotranspiration rates of crops. However, due to the limited data on this measure, temperature is usually substituted in its place. Doorenboos et al, 1979; and F.A.O., 1962 have provided rates at which crops might be expected to remove readily available soil moisture, based on broadly defined climatic conditions. It is important to note that evapotranspiration rate is a very good proxy for consumptive water use by plants considering that 99% of water uptake is lost through transpiration and only 1% is used in photosynthetic and respiratory processes in the plant (Hillel, 1990). Knowledge of the evapotranspiration rate of crops helps the irrigator to reasonably determine the optimal irrigation schedule. Table (2.5) gives a general guide for the determination of crop evapotranspiration rates on the basis of climatic factors.

The other important determinant of irrigation scheduling is knowledge of the physical properties of the soil. Data in this domain permit one to approximate both the water intake rate of the soil and its moisture-holding capacity. The application of such information would avert the problems of waterlogging and leaching in the practice of irrigation use. Knowledge of soil texture is used to determine rate of water intake and

Table 2.5 Maximum Rates of Soil Moisture Used by Crops Under Different Climatic Conditions

Climatic Condition	Peak Rate of Soil Moisture Removal	
	in/day	mm/day
Cool, humid	0.10	2.5
Cool, dry	0.15	3.8
Moderate, humid	0.15	3.8
Moderate, dry	0.20	5.1
Hot, humid	0.20	5.1
Hot, dry	0.30	7.6

Source: F.A.O., 1962

holding-capacity of the soil.[3] Soil structure or clusters of particles of different sizes does influence the behaviour of the soil in reaction to water (F.A.O., 1962). Tables (2.6) and (2.7) give approximations of water intake rates and holding capacities respectively, for various soil types.

Table 2.6 Approximate Water Intake Rates of Soil

Textural Classification of Soil	Basic Rate of Water Intake	
	in/hr	mm/hr
Coarse Sands	0.75-1.00	19.0-25.5
Fine Sands	0.50-0.75	12.5-19.0
Fine Sandy Loams	0.50	12.5
Silt Loams	0.40	10.0
Clay Loams	0.30	7.5

Source: F.A.O., 1961

[3] Soil texture is the soil characteristic that deals with the relative proportion of sand, silt and clay particles in the soil mass and forms the basis of soil classification into sands, loams and clays.

Table 2.7 Available Moisture-Holding Capacity of Soils per Unit of Depth

Soil Type	Available Moisture	
	in/ft	mm/cm
Very coarse-textured sands	0.40-0.75	0.33-0.62
Coarse-textured sands, fine sands and loamy sands	0.75-1.00	0.60-0.50
Moderately coarse-textured sandy loams and fine sandy loams	1.00-1.50	0.85-1.25
Medium-textured fine sandy-loams, loams, sandy-clay-loams, silt-loams	1.50-2.30	1.25-1.90
Moderately-fine textured clay-loams and silty-clay-loams	1.75-2.50	1.45-2.10
Fine-textured sandy-clays, silty-clays and clay	1.60-2.50	1.35-21.0

Source: F.A.O., 1962

Because the chief objective of irrigation is to provide the crop with its required amounts of water for healthy growth, the importance of soil moisture-holding capacity assumes relevance in the context of the crop's root depth zone. To illustrate, a shallow water-feeder like bananas would require more frequent irrigating than a deep-feeder like passion fruit. This has important implications about the level and quality of yields the farmer would eventually obtain and by extension influence the style of irrigation management. The other implication is that based on irrigating water capacity and soil moisture-holding capacity, the irrigator would determine the crop mix that would provide the highest profits. Therefore, the most efficient use of irrigation, in regions of variable and unevenly distributed rainfall should be the prolongation of the growing season to accommodate three or four crops (Hillel, 1990; and Jensen, 1990)). In the end,

> ...a well-managed irrigation system [would be] one that optimizes the spatial and temporal distribution of water so as to promote crop growth and yield, and to enhance the economic efficiency of crop production. The aim is not necessarily to obtain the highest yields per unit area of land or even per unit of water, but to maximize the net returns (Hillel, 1990; p. 6).

A general rule of thumb in irrigation practice is to replenish the soil moisture when about two-thirds of the moisture in the root zone has been exhausted (F.A.O., 1962). A more practical rule is to obtain a soil sample at a depth of 6 to 18 inches by taking a handful of soil and forming it into a ball. The ball is tossed about a foot into the air and allowed to drop into the palm. After five tosses, if there is no crumbling, irrigation is not required. However, if the ball crumbles on tossing only 1/4 to 1/2 of the available water is left in the soil. If a ball cannot be formed then the soil is too dry and extensive and immediate irrigation is required. Such a procedure can assist the unsophisticated farmer in deciding when to irrigate (Dubetz and Lethbridge, 1974).

2.4.2 Irrigation Use in Grenada

Irrigation use in Grenada has not been widespread. During the more buoyant period of the plantation economy, there was extensive use of irrigation in bananas and cocoa production. However, with the demise of the plantation economy also came the disrepair of the irrigation systems on many of the plantations (Adams and Pringle, 1986). During that era, like today, irrigation water was a free good to the user. Today, the only significant areas of irrigated agriculture are the Government-owned Mardi Gras Agricultural Station and the Paradise Model Farms. In both cases, the sprinkler system has been adopted. Pumps are used to lift water from the nearby rivers and water is transported throughout the farming areas via moveable plastic lines.

Specifically in the case of Paradise, the European Development fund (EDF) was responsible financially for the implementation of the system (EDF, 1988). It is hoped that the La Sagesse and Pointzfield clusters would be equipped with similar irrigation systems through the assistance from the French Technical Mission (FTM).

2.5 Background Information for Crops Considered in this Study

2.5.1 Bananas (Musa spp.)

Banana is one of the most important tropical fruits and is grown most successfully between latitudes 30 N and 30 S of the equator. It thrives best in areas with an average annual temperature of 27 C but will grow successfully within a temperature range of 16 C-38 C. Humidity should be at least 60%. Windy conditions are not desirable.

Although the crop grows on a wide range of soils, soil fertility and good drainage are prerequisites for good growth. Growing bananas in waterlogged soils is a prescription for Panama disease. The crop has a huge demand for nitrogenous and potash fertilizers. Regular fertilizer applications are recommended for optimal growth.

The first crop matures anywhere between 10-18 months after planting. For example, the Lacatan variety takes approximately 12 months while the Cavendish variety can take about 10 months. The ratoon crops mature within 9 months. The average life of a commercial plantation can be from 3-20 years (Doorenboos et al, 1979). The Panama Disease resistant Cavendish is often grown most successfully in a one-period cycle (Samson, 1980).

Banana is a very big consumer of water and requires between 80-100 inches (2,000-2,500 mm) of rain annually for optimal growth (Doorenboos et al, 1979). Summerville (1994), Simmonds (1967), Salter (1967), and Grumbs and Holder (1980) have established that adequate water is critical at every stage of the development of the banana. Water deficits at the vegetative stage seriously and permanently warp the potential for growth and fruiting. Growth of the apical meristem at that early stage would be stunted, having a negative effect on potential growth (Summerville, 1944). Water deficits during the flowering stage would limit leaf growth and the number of fruits. During the yield formation period, water shortages would impact on the plant by further impeding leaf area development which in turn causes a reduction in the rate of fruit filling, and at harvest, bunches would be older than they appear to be and fruits would be more liable to premature ripening in storage (Doorenboos et al, 1979). Under water stress conditions the ratoons or suckers would suffer irreversible damage to their development which would be reflected ultimately in poor yields (Slater, 1967).

The shallow root system of the plant, with most roots spreading laterally near the surface, has implications for irrigating. Although the maximum rooting depth is about 0.75 m, 60% of water uptake occurs at the first 0.3 m depth. Thus, given a high daily evapotranspiration rate of 7.5 mm, a 35% depletion of the total available soil water should not be exceeded. Consequently, regular irrigation is important (Doorenboos et al, 1979). At present, on the Paradise farms, bananas would be irrigated every 3 days on average.

2.5.2 *Vegetables*

The major goal of irrigation in vegetable production is to avoid water stress and facilitate efficient nutrient uptake (Stanley and Maynard, 1990). Water stress caused by soil moisture deficits and moisture excesses affect the physiological functions and the overall development of the crops (Craft, 1968). The prevention of water stress is dependent on the proper use of irrigation. The efficient use of irrigation considers not just the total water requirements of those crops but their water needs related to their critical growth stages, rooting characteristics and the soil water-holding capacity (Hiler and Howell, 1983).

The use of raised beds for vegetable production is the common cultural practice in Grenada. While this method positively contributes to effective weed control, it requires an irrigation schedule characterised by high frequency since most vegetables are shallow feeders. The use of raised beds increases the possibility of nutrient leaching under rainy conditions, thus causing an increase in fertilizer applications to offset the effects of leaching.

The irrigation of cucumber (Cucumis sativus L) throughout its growing season ensures proper development. However, the most critical growth stage when water stress can adversely affect yield and quality is from the onset of flowering and fruiting (Robson and Johnson, 1985). Total water use throughout the growing season ranges from 1-2 inches (30 mm) to 16 inches (400 mm). Under Grenada conditions with a crop evapotranspiration rate of 0.3 inch (7.6 mm) daily and a 56 day season, the water requirements for the season would be about 17.0 inches (425 mm).

Carrots (Daucus carota L) and beets (Beta vulgaris L) are the two most important root vegetables being considered. These two vegetables are very water sensitive. They perform best on well-tilled soil with adequate irrigation (Orzolek and Carol, 1978). Carrots which have a 98 day growing season and experience a daily crop evapotranspiration rate of 0.3 inch (7.6 mm) have a water requirement of 34 inches (851 mm). Beets have a growing period of 70 days and a water requirement of 21 inches (525 mm).

Sweet potatoes (Ipomoea batatas) are relatively drought resistant but is extremely sensitive to water deficits during the root-enlargement growth phase (Stanley and Maynard, 1990). The gestation period of variety grown in Grenada is between 84 and 98 days. Its water requirement is about 25 inches (638 mm) per season.

The other two crops, papaya (Carica papaya L) and passion fruit (Passiflora mollissima L), are fruit trees grown in orchards. They, like other tree crops, respond more to soil water levels and irrigation scheduling rather than the irrigation method (Fereres and Goldhammer, 1990). They consume substantial amounts of water especially during their establishment periods (Salter, 1967). According to Cecil Winsborrow, agronomist in the Ministry of Agriculture, Grenada, papaya and passion fruit have a gestation period of about 9 months. Again with the same daily evapotranspiration rate of 0.3 inch (7.6 mm) each crop would require about 90 inches (2,250 mm).

2.6 Summary

Briefly, the most salient points need to be re-emphasized. First, the crucial importance of agriculture to the Grenadian economy has been established. However, agricultural development is seriously constrained by topographical factors in an already small land mass. The small agricultural land base continues to be threatened by the encroachments of non-agricultural development. This process has been catalyzed by the long and progressive demise of the traditional sub-sector. However, that same demise has also given rise to a growing commercially-oriented small farm sub-sector, which the Grenada Model Farms Project is designed to enhance. This complex of factors serve to demonstrate the need and urgency with which agricultural development has to be approached. This is especially so if the Grenadian farmer is to exploit the emerging demand potential for special tropical crops regionally and extra-regionally. Second, many of the serious constraints, institutional and technical, have been discussed. Irrigation adoption by model farm—farms in some moisture deficit regions has been identified as a viable option for improving farm profitability and farm performance. It is that prospect chapter two establishes as central to the rationale for the conduct of the present study.

Chapter 3. Theoretical and Conceptual Framework

3.1 Introduction

This chapter provides a discussion of the relevant theoretical and conceptual considerations for the study. In particular, linear programming is given special attention as an appropriate tool for modelling the multi-input, multi-output, multi-period competitive farm-firm.

The chapter shall proceed with a presentation of a set of basic assumptions governing the behaviour of the farm-firm. Next the profit-maximization conditions for the firm, as static and dynamic models, are established. In the case of the static model, Beattie and Taylor (1985) is the reference source. The dynamic model is patterned and discussed following the exposition of Naylor (1965, 1966). Finally, the conceptual linear programming model is presented. Special focus is given to the underlying assumptions of linear programming and its appropriateness for addressing the economic problem, as defined in chapter one. Hazell and Norton (1986) is the main reference source. The underlying rationale for the outlined approach is to generate a set of analogs among the different models which would prove the suitability of the linear programming (L.P.) approach to profit-maximization.

3.2 Theoretical Assumptions

In developing and discussing a theoretical model for this study, the following assumptions are made:

i) The firm exists as a multi-input, multi-output entity. Generally, the assumption of the double-input, single-output firm is imposed on the conceptual model for simplicity of analysis. However, the firm in this study is characterized by multi-input use and multi-output production. This is characteristic of most, if not all agricultural firms (Hazell and Norton, 1986). Multi-product production of the firm can appropriately be viewed as the production of a set of single-outputs linked by resource constraints (Beattie and Taylor, 1985).

ii) All factors of production are assumed to be allocable. Factor allocability infers that, given multi-product production, the amount of nitrates (x_1), for example, used to produce an acre of bananas (y_j) is distinguishable from the amount used to produce an acre of papaya (y_k). Thus, the total amount of x_1 used to produce y_j and y_k can be expressed as $x_1 = x_{1j} + x_{1k}$.

iii) The firm operates in a perfectly competitive environment. In other words, the prices for all relevant outputs and inputs are determined outside of the firm.

iv) The firm behaves as if it knows input and output prices with certainty.

v) Profit is symbolically defined as $\pi = TR - TC$. According to the meaning attached to total cost (TC), one could be referring to accounting, normal or economic profit (Thompson, 1981). However, the definition of profit used in this study is that of gross margin or net revenue. Therefore, attention shall be focused on the validity of the profit-maximization assumption as the maximization of that discounted net revenue.

The opponents of the profit-maximization assumption have put forward a plethora of arguments. One argument is that uncertainty and imperfect information make it impossible to say which course of action would achieve profit maximization. Hence, the assumption becomes meaningless (Anthony, 1960). Another argument is that as separation of control from ownership develops, managers are endowed with discretionary authority to pursue goals other than profit-maximization (Galbraith, 1969). Some economists (e.g. Niel Chamberlain and Melvin Reder) claim that the maximization of profit is not only difficult and unrealistic but immoral (Thompson, 1981).

Proponents of the validity of the profit-maximization assumption have championed very compelling arguments. They argue, for example, that a firm may pursue other goals in conjunction with that of profit-maximization. However, the impact of those other goals on the firms's behaviour might be less significant. Thus, the imputation of the so called 'more realistic goals' only increases the complexity of the analysis.

Friedman debates that,

> ...the body of evidence for the maximization-of-returns hypothesis is experience from countless applications of the hypothesis to specific problems and the repeated failure of its implications to be contradicted (Friedman, 1962. pp. 21-23).

Despite the disagreement surrounding of the received theory, given the major purposes of the firm, the conclusion on the validity of the hypothesis is that,

> ...the theory describes how individual firms make decisions in a market system...The theory prescribes how individual business firms should make decisions in a market system...The theory is a tool for deciding among some alternative economic policies...We will conclude that the theory is most obviously relevant to a description of how individual firms (including the firm in this study) behave (Cyert and March, 1992. pp. 177-178).

Thus, the assumption that the farm-firm behaves as if it were maximizing profit is upheld for this study.

3.3 Requirements for Profit Maximization of the Static Multi-Output, Multi-Input, Competitive Firm

The derivation of the first-order profit maximizing conditions can be obtained from either an unconstrained or a constrained formulation (Henderson and Quandt, 1985; Beattie and Taylor, 1985; and Debertin, 1987). The results of both approaches shall be presented following the treatment developed by Beattie and Taylor (1985).

In the unconstrained formulation, the second-order conditions are assumed to hold. These conditions imply that the variable and total costs equations are strictly convex in the neighbourhood of output values that satisfy the first-order conditions. They also imply that as output or production increases, the marginal cost increases at an increasing rate.

Consider the static model of the competitive firm as producing m-outputs using n-inputs, where

π	=	the profit generated by the firm
p_j	=	the price per unit of the *jth* output (j = 1, ..., m)
r_i	=	the cost per unit of the *ith* input (i = 1, ..., n)
y_j	=	the quantity of the *jth* output produced by the firm (j = 1, ..., m)

MR_j	=	the marginal revenue of the *jth* output produced (j = 1, ..., m)
MC_j	=	the marginal cost of the *jth* output (j = 1, ..., m)
MFC_i	=	the marginal factor cost of the *ith* input (i = 1, ..., n)
MVP_{ij}	=	the marginal value product of the *ith* input in production of the *jth* output
$\tilde{c}(r_1, \ldots, r_i; y_1, \ldots, y_m)$	=	the variable cost function from the output side which assumes that the cost minimization problem is solved
$f(x_1, \ldots, x_i; y_1, \ldots, y_m)$	=	the implicit production function.

The unconstrained profit function which provides the output perspective is given by

$$\pi = \sum_{j=1}^{m} p_j y_j - \tilde{c} \quad (r_1, \ldots, r_i, y_1, \ldots, y_m) \tag{3.1}$$

$$\frac{\partial \pi}{\partial y_j} = p_j - \frac{\partial \tilde{c}}{\partial y_j} = 0 \ \ for\ j = 1, \ldots, m \tag{3.2}$$

which implies

$$p_j = \frac{\partial \tilde{c}}{\partial y_j} \qquad for \;\; j = 1,\ldots,m \tag{3.3}$$

or the well-known profit-maximizing requirement that

$$MR_j = MC_j \qquad for \;\; j = 1,\ldots,m \tag{3.4}$$

The economic significance of Equation (3.4) is that at the level of profit-maximization the marginal revenue or price of the *jth* output is equal to the marginal cost of producing that unit of output. The satisfaction of the first and second-order conditions guarantee profit-maximization.

The alternative approach, constrained profit-maximization, provides the first-order conditions from which the output-expansion path, the factor-expansion path and the profit-maximizing factor usage conditions are generated. Again, the second-order condition is assumed to hold.

The constrained profit function is given by

$$L = \sum_{j=1}^{m} p_j y_j - \sum_{i=1}^{n} r_i x_i + \lambda f \;\; (x_1,\ldots,x_n,y_1,\ldots,y_m) \tag{3.5}$$

The output expansion path condition is represented in the mathematical form as,

$$\frac{p_j}{p_k} = -\frac{\partial y_k}{\partial y_j} \qquad for \; j, k = 1,\ldots,m \tag{3.6}$$

which by implication means that the

$$\frac{MR_j}{MR_k} = RPT_{jk} \geq 0 \tag{3.7}$$

Equation (3.7) requires that the ratio of the marginal revenues of y_j and y_k must be equal to the rate of their product transformation (RPT_{jk}).[4] Rational production requires that the RPT_{jk} must be non-negative, as shown in Equation (3.7). Also, the product transformation curve must be negatively sloped (Debertin, 1986). The expression $-\frac{\partial y_k}{\partial y_j}$ in

Equation (3.6) indicates that the negative slope of the product transformation curve is met.

The factor-expansion path condition is mathematically represented as,

$$\frac{r_i}{r_l} = -\frac{\partial x_i}{\partial x_l} \qquad for\ i, l = 1, \ldots, n \tag{3.8}$$

which implies

$$\frac{MFC_i}{MFC_l} = RTS_{il} \qquad for \quad i, l = 1, \ldots, n \tag{3.9}$$

Equation (3.9) states that whenever profit-maximization is achieved the ratio of the marginal factor costs of inputs, *i* and *l* used to produce the given output would be equal

[4] The RPT_{jk} is defined as the quantity ratio of outputs, *j* and *k*, that can be secured from a given input.

to their rate of technical substitution.[5] In economic behavioural terms, Equation (3.9) implies that the firm chooses the least cost bundle of inputs to produce the most profitable level of output.

Finally, the profit maximizing factor-usage condition is expressed mathematically as,

$$-p_j\left(-\frac{\partial y_j}{\partial x_i}\right) = r_i \qquad for \;\; i = 1,\dots,n; \;\; j = 1,\dots,m \qquad \textbf{(3.10)}$$

which implies that

$$MVP_{ij} = MFC_i \qquad for \;\; i = 1,\dots,n_j; \;\; j = 1,\dots,m \qquad \textbf{(3.11)}$$

Equation (3.11) means that, at profit maximization, the marginal value product of input i in the *jth* product is equal to its marginal factor cost.

The satisfaction of these three conditions guarantee profit-maximization of firm once the second-order condition holds, from the input perspective.

3.4 Requirements for Profit-Maximization of the Dynamic Multi-Input, Multi-Output, Competitive Firm

The farm-firm uses a multiple of inputs to produce a set of outputs over more than one time period. Consequently, the element of time must be incorporated in the model. To achieve that, a discount factor is utilized. The discount factor serves two purposes. First,

[5] The RTS_{il} is defined as the rate at which input l would have to be substituted for input i in order to maintain the corresponding output level.

it allows for the calculation of the present value of future net income (profit) streams (Conrad and Clarke, 1989). Second, it provides a dynamic link in the model by linking the annual net revenues in the objective function. The model assumes concavity and differentiability of the profit and implicit production functions. These assumptions coupled with the constraint inequalities, to be introduced, qualify the model for the application of the Kuhn-Tucker theorem. The Kuhn-Tucker theorem would be used for the derivation of the first-order conditions.

The firm produces m-outputs by using n-variable inputs and k-fixed inputs through time, t. Its production in each time period, and inter-temporally, is constrained by the amount of fixed inputs available. In the model

π = the discounted profit generated by the firm through time.

$y_{j,t}$ = the quantity of the *jth* output produced in time, t (j = 1, ..., m; t = 1, ..., t +1, v).

$x_{i,j,t}$ = the quantity of the *ith* variable used to produce the *jth* output in time, t (i = 1, ...n; j = 1, ..., m; t = 1, ..., t+1, V).

$z_{d,j,t}$ = the quantity of the *dth* fixed input used in the production of the *jth* output in time, t (d = 1, ..., k; j = 1, ..., m; t = 1, ..., t+1, V).

$Z_{d,t}$ = the fixed endowment of the *dth* fixed input in time, t (d = 1, ..., k; t = 1, ..., t+1, V).

$\left(\frac{1}{1 + r}\right)^t$ = the discount factor (t = 1, ..., t+1, V).

$f(z_{111}, z_{djt}; x_{111}, \ldots, x_{ijt}; y_{111}, \ldots, y_{jt})$ = the implicit production function (d = 1, ..., k; i = 1, ..., n; j = 1, ..., m; t = 1, 111, t + 1, V).

The theoretical dynamic model is represented, thus

Maximize

$$\pi = \left[\sum_{t=1}^{v}\left(\frac{1}{1+R}\right)^t\left(\sum_{j=1}^{m} p_j y_{j,t} - \sum_{i=1}^{n}\sum_{j=1}^{m} r_i x_{i,j,t}\right)\right] \tag{3.12}$$

Subject to

$$f(z_{1,1,1}, \ldots, z_{d,j,t}; x_{1,1,1}, \ldots, x_{i,j,t}; y_{1,1}, \ldots, y_{j,t}) = 0 \tag{3.13}$$

$$\sum_{j=1}^{m}\sum_{t=1}^{v} z_{d,j,t} - Z_{d,t} \le 0 \tag{3.14}$$

$$Z_{d,t+1} - Z_{d,t} \leq 0 \quad \forall d, t \tag{3.15}$$

Equation (3.12) defines discounted profit as the difference between total revenue and total costs, discounted by $\left(\frac{1}{1 + R}\right)^t$. Equation (3.13) is the implicit production function.

Equation (3.14) defines the requirement of the *dth* fixed input by the *jth* output in time, t is constrained by the fixed endowment Z_{dt}. Equation (3.15) defines the inter-temporal constraint associated with the availability of the fixed input.

The constrained dynamic formulation is

$$\begin{aligned} L = & \left[\sum_{t=1}^{v}\left(\frac{1}{1+R}\right)^t\left(\sum_{j=1}^{m} p_j y_j - r_i x_{i,j,t}\right)\right] + \lambda_{j,t} f(\cdot) \\ & + M_{d,j,t}\left(Z_{d,t} - \sum_{j=1}^{m}\sum_{j=1}^{v} z_{d,j,t}\right) + \alpha_{dt}\left(Z_{d,t} - Z_{d,t+1}\right) \end{aligned} \tag{3.16}$$

For a constrained profit maximum, the first-order Kuhn-Tucker conditions must be satisfied at y_{jt}^0, x_{ijt}^0, z_{djt}^0, λ^0, M^0 and α^0. The mathematical representation of the Kuhn-Tucker conditions are:

$$\frac{\partial L^0}{\partial y_{j,t}} = \left[\left(\frac{1}{1 + R}\right)^t p_j\right] + \lambda_{jt}\frac{\partial f(\cdot)}{\partial y_{j,t}} \leq 0 \quad \forall j, t \tag{3.17}$$

$$\left(\frac{\partial L^0}{\partial y_{j,t}}\right)y_{j,t}^0 = \left(\left[\left(\frac{1}{1+R}\right)^t p_j\right] + \lambda_{j,t}\frac{\partial f(\cdot)}{\partial y_{j,t}}\right)y_{j,t}^0 = 0 \quad \forall j,t \tag{3.18}$$

$$\frac{\partial L^0}{\partial x_{i,j,t}} = \left[-\left(\frac{1}{1+R}\right)^t r_i\right] + \lambda_{i,j,t}\frac{\partial f(\cdot)}{\partial x_{i,j,t}} \le 0 \quad \forall i,j,t \tag{3.19}$$

$$\left(\frac{\partial L}{\partial x_{i,j,t}}\right)x_{i,j,t}^0 = \left(\left[-\left(\frac{1}{1+r}\right)^t r_i\right] + \lambda_{i,j,t}\frac{\partial f(\cdot)}{\partial x_{i,j,t}}\right)x_{ijt}^0 = 0 \quad \forall i,j,t \tag{3.20}$$

$$\frac{\partial L^0}{\partial z_{d,j,t}} = \lambda_{d,j,t}\frac{\partial f(\cdot)}{\partial z_{d,j,t}} - M_{d,j,t} \le 0 \quad \forall d,j,t \tag{3.21}$$

$$\left(\frac{\partial L}{\partial z_{d,j,t}}\right)z_{d,j,t}^0 = \left(\lambda_{d,j,t}\frac{\partial f(\cdot)}{\partial z_{d,j,t}} - M_{d,j,t}\right)z_{d,j,t}^0 = 0 \quad \forall d,j,t \tag{3.22}$$

$$\frac{\partial L^0}{\partial \lambda} = f(\cdot) \ge 0 \tag{3.23}$$

$$\left(\frac{\partial L}{\partial \lambda}\right)\lambda^0 = [f(\cdot)]\lambda^0 = 0 \tag{3.24}$$

$$\frac{\partial L^0}{\partial M} = \left(Z_{d,t} - \sum_{j=1}^{m}\sum_{t=1}^{v} z_{d,j,t}\right) \geq 0 \quad \forall d,t \tag{3.25}$$

$$\left(\frac{\partial L}{\partial M}\right)M^0 = \left(Z_{d,t} - \sum_{j=1}^{m}\sum_{t=1} z_{d,j,t}\right)M^0 = 0 \quad \forall d,t \tag{3.26}$$

$$\left(\frac{\partial L^0}{\partial \alpha}\right) = \left(Z_{d,t} - Z_{d,t+1}\right) \geq 0 \quad \forall t \tag{3.27}$$

$$\left(\frac{\partial L}{\partial \alpha}\right)\alpha^0 = \left(Z_{d,t} - Z_{d,t+1}\right)\alpha^0 = 0 \quad \forall t \tag{3.28}$$

$$y^0_{j,t},\ x^0_{i,j,t},\ z^0_{d,j,t} \geq 0 \quad \forall i,j,d,t \tag{3.29}$$

$$\lambda^0,\ M^0,\ \alpha^0 \geq 0 \quad \forall d,t \tag{3.30}$$

3.4.1 Implications for Profit-Maximization from Results

The exposition presented in the following discussion is based on Naylor (1965). The lagrangian multipliers, λ^0, M^0 and α^0, determined internally by the model are interpreted as imputed values or shadow prices. The appearance of the discount factor in some of the equations does not change the essence of the optimal condition requirements

(Harowitz, 1985). However, because the time element affects the values in degree, the term "discounted" shall be used when necessary.

Equation (3.17) rewritten in the form

$$\left(\frac{1}{1+R}\right)^t p_j \leq -\lambda_{j,t}\frac{\partial f(\cdot)}{\partial y_{j,t}} \tag{3.31}$$

means that the discounted marginal price of the *jth* output is equal to or less than the discounted marginal imputed cost of producing that *jth* output in the t^{th} time period. If the inequality holds, it shows that the discounted price or marginal revenue is not sufficient to defray the discounted marginal imputed cost of producing that *jth* output in the t^{th} time period. This implies that when the equality in Equation (3.31) holds, it implies that discounted price or marginal revenue for the *jth* output is equal to the discounted imputed cost of producing that output in the t^{th} period. Under the latter condition y_{jt} maximizes profits. The satisfied condition of $\left(\frac{1}{1+R}\right)^t p_j = \lambda_{jt}\frac{\partial f(\cdot)}{\partial y_{jt}}$ can be considered somewhat analogous to Equation (3.4).[6]

Assuming that the equality holds over all m, then for any two outputs *j* and *k* the output-expansion path condition can be expressed thus,

[6] See Appendix B for a tabulated presentation of analogs from among the different model results.

$$\frac{p_j}{p_k} = -\frac{\partial y_{k,t}}{\partial y_{j,t}} \tag{3.32}$$

$$\frac{MR_j}{MR_k} = RPT_{j,k,t} \tag{3.33}$$

Equation (3.33) is the output expansion path condition and is analogous to Equation (3.7).

Equation (3.19) can be rewritten as

$$\left(\frac{1}{1 + r}\right)^t r_i \geq \lambda_{i,j,t} \frac{\partial f(\cdot)}{\partial x_{i,j,t}} \tag{3.34}$$

Equation (3.34) implies that the discounted marginal cost of the *ith* variable input is equal to or greater than its discounted imputed value in the production of the *jth* output in the t^{th} time period. If the inequality holds, the discounted marginal cost of the *ith* input exceeds the discounted value added by that input in the production of the *jth* output and its use is, therefore, not being maximized. When the equality holds, the input *i* is being used optimally. That is, the discounted marginal cost is equal to the discounted imputed value of the *ith* input in producing the *jth* output in time *t*. Rational production occurs which is suggestive of profit-maximization. Thus, in the context of multi-inputs, the firm chooses the least cost bundle of inputs to produce the most profitable outputs in the t^{th} period. This gives rise to the factor-expansion path which can be expressed mathematically as,

$$\frac{MFC_i}{MFC_l} = RTS_{i,l,t} \qquad for\ i, l = 1, \ldots, n \tag{3.35}$$

Again, it is found that, in essence, Equation (3.35) is analogous to Equation (3.9).

By choosing any optimum level of output, say of *j* and any optimum level of input, *i*, and by manipulating Equations (3.32) and (3.34) the maximizing profit factor-usage condition is found. It is expressed mathematically as,

$$p_j\left(-\frac{\partial y_{j,t}}{\partial x_{i,j,t}}\right) = r_i \qquad for\ i = 1, \ldots, n; j = 1, \ldots, m; \quad t = 1, \ldots, t+1, v \tag{3.36}$$

which implies that

$$MVP_{i,j} = MFC_{i,t} \tag{3.37}$$

Equation (3.37) implies that, at profit-maximization, the marginal value product of the *ith* input in the production of the *jth* output is equal to the marginal factor cost of the *ith* input in the t^{th} period. Again, Equation (3.37) is, essentially, analogous to Equation (3.11).

The analogs between the static and dynamic models of the competitive firm proves that, in both cases, the conditions for profit-maximization are essentially the same.

However, the application of the Kuhn-Tucker theorem to the dynamic model brings out some other interesting conditions. The more important ones shall now be discussed.

Equation (3.21) may be rewritten as follows:

$$\lambda_{d,j,t}\frac{\partial f(\cdot)}{\partial z_{d,j,t}} \leq M_{d,t} \tag{3.38}$$

Equation (3.38) would imply that the value added by the *dth* fixed input in the production of the *jth* output in the t^{th} period is equal to or less than the opportunity cost of using that input in the same period. For profit-maximization to occur, the equality must hold. The economic implication of Equation (3.38), given profit-maximization, is that fixed input is employed in its most profitable use.

If the assumption that all inputs represented in the model are essential to production is made, then rational production would be positive. Consequently, the levels of y_{jt}^{0}, x_{ijt}^{0} and z_{djt}^{0} would be positive. Thus, Equations (3.18), (3.20) and (3.22) would be satisfied and be consistent with profit-maximization.

Equation (3.25) shows that whatever level of the *dth* fixed input in the t^{th} period must be less than the fixed endowment, in order, for profit-maximization to be attained. Assuming that there is no usage slack, $M_{djt}^{0} > 0$ then Equation (3.26) would be satisfied. Even if, a slack exists in Equation (3.25), $M_{djt} = 0$ would still satisfy Equation (3.26).

Equation (3.27) implies that the endowment of the fixed input, d, available in a future period $t + 1$ cannot be greater than its current endowment. The satisfaction of Equation (3.27) guarantees Equation (3.28).

The satisfaction of those resource use constraints provide boundedness to the model. In addition y_{jt}^{0}, x_{ijt}^{0}, z_{djt}^{0} and the implicit production are well-defined. The result is that the profit-maximization solution is a bounded and global one.

3.5 Linear Programming and Its Basic Assumptions

Before 1947, the marginal analysis approach to modelling firm behaviour was most widely used by economists. The development of the simplex algorithm for solving linear programming models by George Dantzig provided the basis for an alternative approach. Robert Dorfman's publication of "Application of Linear Programming to the Theory of the Firm" in 1951 was among the first important contributions to the development of that alternative approach (Naylor, 1966). In the last 15 years the world has witnessed tremendous improvements in that area which permit a greater link between economic theory and linear modelling of the firm. The mathematical programming format is suitable to agriculture because the agricultural specialists and farmers often think about agricultural inputs and outputs in terms of annual crop cycles, input-output ratios per land area, and the whole disaggregation of farm level input costs. The practical application of the principle of resource slackness and lower and upper bounds on resources, often because of seasonal realities, also reflect the nature of that thinking. This kind of mind set is accommodated by linear programming analysis (Hazell and Norton, 1986).

The applicability of linear programming allows for the circumvention of models that might not exhibit the properties of concavity and continuity of the production function and the first and second order non-zero partial derivatives required by marginal analysis. It follows, therefore, that the application of linear programming to problems of the firm invariably would impose certain restrictions on the firm's behaviour. It is that concern that shall now be addressed as the basic linear programming assumptions are presented and discussed.

The following assumptions are based on the presentation by Hazell and Norton (1986):

i) Optimization assumes that an objective function, for example in this study, the profit function is being maximized.

ii) The assumption of fixedness insists that one or more of the constraints must have a non-zero right hand coefficient.

iii) Finiteness demands that there must be a finite number of activities and constraints in order for a solution to be obtained.

iv) Determinism assumes that all the coefficients in the objective function and constraint equations are known with certainty. Perfect competition is imposed on the profit maximizing model.

v) The assumption of continuity means that resources and activities are divisible.

vi) The link established between the objective profit function (π) and the fixed resources (z) can be expressed as $\pi = f(z)$. If z is changed by any constant, k then the value of the relationship changes to $k\pi = kf(z)$. This implies constant returns to scale—a condition that always holds for linear programming application to the firm.

3.6 The Conceptual Linear Programming Model: Formulation, Notation and Interpretation

The conceptual linear programming model assumes a multi-input, multi-output firm operating in a perfectly competitive environment. The firm's objective is to maximize profits by producing *j*-outputs using *i*-variable inputs and *d*-fixed inputs over a multi-period time horizon. The L.P. model formulation of the firm is,

Maximize

$$Maximize \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{t=1}^{v} \left(\frac{1}{1+r}\right)^{t} \left[\sum_{j=1}^{m} \left(p_j y_{jt} - \sum_{i=1}^{n} r_i \, x_{ijt}\right)\right] \tag{3.39}$$

Subject to

$$a_{i1t} y_{1t} - x_{i1t} \leq 0 \quad for \quad i = 1, \ldots, n; \; j = 1; \; t = 1, \ldots, t+1, v \tag{3.40}$$

$$a_{ijt} y_{jt} - x_{ijt} \leq 0 \quad for \; l = 1, \ldots, n; \;\; j = 2, \ldots, m; \;\; t = 1, \ldots, t+1, v \tag{3.41}$$

$$l_{d1t} y_{1t} \geq z_t \qquad for \quad d = 1, \ldots, k; \; j = 1; \; t = 1, \ldots, t+1, v \tag{3.42}$$

$$\sum_{d=1}^{k}\sum_{j=1}^{m} l_{djt}\, y_{jt} \le Z_t \qquad for \quad d = 1, \ldots, k; j = 1, \ldots, m; \qquad (3.43)$$

$$t = 1, \ldots, t+1, v$$

$$Z_{t+1} - Z_t \le 0 \qquad for \quad t = 1, \ldots, t+1, v \qquad (3.44)$$

$$y_{1t}, y_{jt}, x_{i1t}, x_{ijt} \ge 0 \qquad (3.45)$$

Where

y_{1t} = output of y_l in time, t

y_{jt} = the *jth* output in time, t

x_{i1t} = the purchases of the *ith* variable input to the requirements for the y_l output in time, t

x_{ijt} = the purchases of the *ith* variable input to satisfy the requirements of the *jth* output in time, t

z_t = the minimum endowment of the fixed input to the y_l output in time, t

Z_t = the total endowment of fixed input available to the firm in time, t

Z_{t+1} = the total endowment of fixed input available to the firm in time, $t + 1$

p_1 = the unit price of the y_l output

p_j = the unit price of the *jth* output

r_1 = the price of the variable input used to produce the y_l output

r_j = the price of the variable input used to produce the *jth* output

a_{i1t} = the amount of the *ith* variable input required to produce the y_l output in time, t

a_{ijt} = the amount of the *ith* variable input required to produce the *jth* output in time, t

l_{djt} = the amount of the *dth* fixed input required to produce the *jth* output in time, t

l_{d1t} = the amount of the *dth* fixed input required to produce the y_l output in time, t

Equation (3.39) is the linear objective function which defines profit as the difference between total revenue and total variable costs discounted over time. Equation (3.40) implies that the amount of the *ith* variable input required by the y_l output in time t (a_{i1t}) is satisfied by exact purchases of that input in time, t (x_{i1t}). Equation (3.41) shows that the amount of the *ith* variable required to produce the *jth* output in t (a_{i1t}) is met by purchases in that period (x_{i1t}). Equation (3.42) expresses a minimum constraint on the use of the *dth* fixed input in the production of y_l in t, if y_1 is taken to represent the banana enterprise.

Equation (3.43) states that the amount of the *dth* fixed input to be utilized by the *jth* output in time, t, cannot exceed the available endowment (Z_t). The penultimate constraint, Equation (3.44) states that the total endowment of the fixed input in the immediately future period ($t + 1$) cannot be greater than what it was in the previous period (t). The last statement, Equation (3.45), emphasizes the non-negativity requirement placed on the variables. This condition is important in assisting rational production to occur.

3.6.1 Presentation of Kuhn-Tucker Conditions for the Conceptual L.P. Model

The decision to apply the Kuhn-Tucker theorem to the L.P. model is based on two considerations. First, the inequality constraints in the model do not qualify it for the application of the marginalist approach. Instead, the structure supports the application of the Kuhn-Tucker theorem for determining optimal conditions for a maximum. The second consideration is that the linearity of the objective function and the linear constraints impose quasi-concavity and therefore satisfies the concavity requirements for the Kuhn-Tucker approach (Naylor, 1966).

The formulation for the Kuhn-Tucker application is,

$$\begin{aligned} L = & \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{v}\left(\frac{1}{1+R}\right)^{t}\left[p_1 y_{1t}\ldots, p_j y_{jt} - r_1 x_{i1t}, \ldots, - r_j x_{ijt}\right] \\ & + \lambda_{i1t}\left(x_{i1t} - a_{i1t}y_{1t}\right) + \lambda_{ijt}\left(x_{ijt} - a_{ijt}y_{jt}\right) \\ & + M_{d1t}\left(z_t - l_{d1t}y_{1t}\right) + \alpha_{djt}\left(Z_t - \sum_{d=1}^{k}\sum_{j=1}^{m} l_{djt}y_{jt}\right) \\ & + w\left(Z_t - Z_{t+1}\right) \end{aligned} \qquad (3.46)$$

The Kuhn-Tucker conditions for maximization are satisfied at y_{1t}^0, y_{jt}^0, x_{i1t}^0, x_{ijt}^0, λ_{i1t}^0, λ_{ijt}^0, M_{d1t}^0, α_{djt}^0 and w^0.

$$\frac{\partial L^0}{\partial y_{1t}} = \left[\left(\frac{1}{1 + r}\right)^t p_1\right] - \lambda_{i1t}a_{i1t} - M_{d1t}l_{d1t} \leq 0 \tag{3.47}$$

$$\left(\frac{\partial L}{\partial y_{1t}}\right)y_{1t}^0 = \left(\left[\left(\frac{1}{1 + r}\right)^t p_1\right] - \lambda_{i1t}a_{i1t} - M_{d1t}l_{d1t}\right)y_{1t}^0 = 0 \tag{3.48}$$

$$\frac{\partial L^0}{\partial y_{jt}} = \left[\left(\frac{1}{1 + r}\right)^t p_j\right] - \lambda_{ijt}a_{ijt} - \alpha_{djt}l_{djt} \leq 0 \tag{3.49}$$

$$\left(\frac{\partial L}{\partial y_{jt}}\right)y_{jt}^0 = \left(\left[\left(\frac{1}{1 + r}\right)^t p_j\right] - \lambda_{ijt}a_{ijt} - \alpha_{djt}l_{djt}\right)y_{jt}^0 = 0 \tag{3.50}$$

$$\frac{\partial L^0}{\partial x_{i1t}} = \left[-\left(\frac{1}{1 + r}\right)^t r_1\right] + \lambda_{i1t} \leq 0 \tag{3.51}$$

$$\left(\frac{\partial L}{\partial x_{i1t}}\right)x_{i1t}^{0} = \left(\left[-\left(\frac{1}{1+r}\right)^{t} r_1\right] + \lambda_{i1t}\right)x_{i1t}^{0} = 0 \tag{3.52}$$

$$\frac{\partial L^{0}}{\partial x_{ijt}} = \left[-\left(\frac{1}{1+r}\right)^{t} r_j\right] + \lambda_{ijt} \leq 0 \tag{3.53}$$

$$\left(\frac{\partial L}{\partial x_{ijt}}\right)x_{ijt}^{0} = \left(\left[-\left(\frac{1}{1+r}\right)^{t} r_j\right] + \lambda_{ijt}\right)x_{ijt}^{0} = 0 \tag{3.54}$$

$$\frac{\partial L^{0}}{\partial \lambda_{i1t}} = \left(x_{i1t} - a_{i1t}y_{1t}\right) \geq 0 \tag{3.55}$$

$$\left(\frac{\partial L}{\partial \lambda_{i1t}}\right)\lambda_{i1t}^{0} = \left(x_{i1t} - a_{i1t}y_{1t}\right)\lambda_{i1t}^{0} = 0 \tag{3.56}$$

$$\frac{\partial L^{0}}{\partial \lambda_{ijt}} = \left(x_{ijt} - a_{ijt}y_{jt}\right) \geq 0 \tag{3.57}$$

$$\left(\frac{\partial L}{\partial \lambda_{ijt}}\right)\lambda_{ijt}^{0} = \left(x_{ijt} - a_{ijt}y_{jt}\right)\lambda_{ijt}^{0} = 0 \tag{3.58}$$

$$\frac{\partial L^0}{\partial M_{djt}} = \left(z_t - l_{d1t}y_{1t}\right) \le 0 \tag{3.59}$$

$$\left(\frac{\partial L}{\partial M_{d1t}}\right) M_{d1t}^0 = \left(z_t - l_{d1t}y_{1t}\right) M_{d1t}^0 = 0 \tag{3.60}$$

$$\left(\frac{\partial L^0}{\partial \alpha_{d1t}}\right) = \left(z_1 - \sum_{d=1}^{k}\sum_{j=1}^{m} l_{djt}y_{jt}\right) \ge 0 \tag{3.61}$$

$$\left(\frac{\partial L}{\partial \alpha_{djt}}\right) \alpha_{djt}^0 = \left(z_t - \sum_{d=1}^{k}\sum_{j=1}^{m} l_{djt}y_{jt}\right) \alpha_{djt}^0 = 0 \tag{3.62}$$

$$\frac{\partial L^0}{\partial w} = \left(Z_t - Z_{t+1}\right) \ge 0 \tag{3.63}$$

$$\left(\frac{\partial L}{\partial w}\right) w^0 = \left(Z_t - Z_{t+l}\right) w^0 = 0 \tag{3.64}$$

$$y_{1t}^0,\ y_{jt}^0,\ x_{i1t}^0,\ x_{ijt}^0 \ge 0 \tag{3.65}$$

$$\lambda^0_{i1t},\ \lambda^0_{ijt},\ M^0_{d1t},\ \alpha^0_{djt},\ w^0 \geq 0 \qquad (3.66)$$

3.6.2 Interpretation of Profit-Maximization Conditions

In this section, economic significance shall be interpreted using the mathematically derived Kuhn-Tucker conditions. Those interpretations shall be made in the context of profit maximization. Also, essential analogs among the L.P. model results and previously discussed models shall be presented. This latter approach would justify the appropriateness of L.P. for addressing the problem of profit-maximization. Throughout this discussion, the lagrangian multipliers in Equation (3.66) are interpreted as shadow prices and are assumed to be non-negative and positive. Also, the decision variables in Equation (3.65) are non-negative. Lastly, an orderly tabulation of analogs is presented in Appendix 3.1.

Equation (3.47) can be rewritten as

$$\left(\frac{1}{1+R}\right)^t p_j \leq \lambda_{i1t} a_{i1t} + M_{d1t} l_{d1t} \qquad (3.67)$$

Equation (3.67) says that the discounted price of a unit of output, y_l is equal to or less than the sum of the discounted imputed cost of a unit of variable input, i and a unit of fixed input, d that go into the production of that unit of output, y_l in the t^{th} time period. At profit-maximization and $y_1 > 0$, the discounted price received for a unit of y_l exactly covers the discounted imputed cost of producing that same unit in the t^{th} time period. Equation (3.67), given the equality, is analogous to Equation (3.4) and Equation (3.31) when the equality holds in the case of the latter. At the same time, with $y_{1t} > 0$ and the equality holding in Equation (3.67), the satisfaction of Equation (3.48) is guaranteed.

Equation (3.49) can be rewritten similarly as

$$\left(\frac{1}{1+R}\right)^t p_j \leq \lambda_{ijt} a_{ijt} + \alpha_{djt} l_{djt} \tag{3.68}$$

Again, Equation (3.68) states that the discounted price received for a unit of the *jth* output is equal to or less than the discounted imputed cost of a unit of the *i*-variable input plus the cost of a unit of the *dth* fixed input used to produce that same unit of output in time, *t*. By implication, profit-maximization is achieved because the discounted price received for a unit of the *jth* output exactly satisfies the discounted imputed variable cost plus the discounted imputed fixed factor cost of producing that same unit of the *jth* output in time, *t*. Thus, Equation (3.68), with the equality holding is analogous to Equations (3.4) and (3.31). Also, with $y_{jt} > 0$, Equation (3.50) is satisfied.

Equation (3.51) can be expressed as

$$\left(\frac{1}{1+R}\right)^t r_1 \geq \lambda_{i1t} \tag{3.69}$$

The economic implication of Equation (3.69) is that the discounted price of input i used to produce a unit of y_l is equal to, or greater than, its discounted imputed cost in time, t.

Under profit-maximization, Equation (3.69) is transformed into a strict equality. Its significance now is that the discounted cost of a unit of input i used in the production of y_l is equal to its discounted imputed cost in time, t. This requirement of profit-maximization is essentially analogous to Equation (3.34) when the equality holds in the latter. Also, with $x_{i1t} > 0$, the Equation (3.52) holds.

Equation (3.53) treated similarly takes the form of

$$\left(\frac{1}{1 + r}\right)^t r_j \geq \lambda_{ijt} \qquad (3.70)$$

Its economic implication is that the discounted factor cost of a unit of i-variable used to produce a unit of the *jth* output is equivalent to the discounted imputed cost of the exact unit of i-variable input in the *jth* output in time, t. Similarly, this profit-maximizing condition is analogous, in essence, to Equation (3.34). Assuming that $x_{i1t} > 0$, then Equation (3.54) is satisfied.

As an aside, it should be noted that the attempt to develop analogs to Equations (3.7), (3.9), (3.10), (3.33), (3.35) and (3.37) has not been made. This is because

> The difficulty stems from the fact that the main emphasis of linear programming is placed on the activity...Unless we specify which activities are associated with which products, the rate of product transformation between any two products will not be defined...If we had assigned each activity to the production of one of the firm's products and if there were

several activities capable of turning out the same product each with its own input proportions, then there would be...exist...piecewise linear iso-product curves connecting corresponding points on the different activity rays and the slopes of these segments would be the marginal rates of substitution...[Equation (3.10) does not find its analog because] marginal product is not defined under the assumptions of linear programming...attributed to the fact that we have not specified which products are produced by the firm's different activities (Naylor, 1966. pp.270-272).

Equations (3.55) to (3.64) provide some intuitively interesting insights into profit-maximization. Consider Equation (3.57) which is more general but identically structured as Equation (3.55). The term, x_{ijt}, was previously defined as the purchases of the *ith* variable input necessary to satisfy the requirements of the *jth* output for that input in the t^{th} time period. The term, $a_{ijt}y_{jt}$, defines the amount of the *ith* variable input required to produce a unit of the *jth* output in time, *t*. given those definitions, at profit-maximization the equality in Equation (3.57) would hold. Or put differently, that constraint on the use of i would be binding on the firm thus helping to give a bounded solution to profit-maximization. Also, because of the satisfaction of boundedness, the imputed cost, λ_{ijt}, of the use of an additional unit of i would be positive; thus satisfying Equation (3.58). The identical argument can be made with reference to Equations (3.55) and (3.56) but keeping in mind the specific output, y_1, in time t.

Equation (3.59) reflects the minimum constraint placed on the production of y_1 in time, t. Suppose z_t represents the minimum number of acres to be devoted to producing bananas (y_1) in each time period, t. Then z_t gets determined within the model finally. But, whatever the final determination of z_t, that amount of land would not be greater than the total land acreage available to the farm in each t. Consequently, at profit-maximization, Equation (3.59) would be an exact equality which would be binding on the solution. Because Equation (3.59) reflects a minimum constraint on the use of a fixed input, land (z_t), the imputed cost of converting another unit of z_t into banana production (y_1) in any time, t must necessarily be positive. Thus $M_{d1t} > 0$ would satisfy the optimizing condition of Equation (3.60).

Equation (3.61) provides the condition for maximum use of the entire endowment of the fixed input, land (Z_t) in time t, given the existence of an equality. In other words, by the various outputs totally exhausting the fixed endowment of land (Z_t), the profit-maximization solution would be bounded by that constraint. Once the constraint is binding, the imputed cost to obtain an extra unit of Z_t would be positive. Thus, $\alpha_{djt} > 0$ implies that Equation (3.62) would be satisfied under the bounded solution.

Equation (3.63) restates the inter-temporal constraint governing the use of fixed input by the model through time. Equation (3.63) is binding when the equality holds. This implies that the constraint is binding on the model and contributes to guaranteeing a bounded profit-maximization solution. Any relaxation of that binding constraint involves an imputed cost (W^0) that is greater than zero. $W^0 > 0$ guarantees the satisfaction of Equation (3.64).

The satisfaction of the constraints, Equation (3.55) to (3.64) guarantees a global profit maximum. In the case of the inequality holding in Equation (3.59), the model solution would be infeasible. The focus of this exposition remains the discussion of conditions that support a global profit maximum.

Chapter three has fulfilled the general aim of presenting and discussing the theoretical and conceptual considerations for modelling the competitive multi-input, multi-output farm-firm. By positing the farm-firm in static, dynamic and linear programming models, interesting profit-maximizing analogs have been drawn among the various models (Appendix B). Those first-order profit-maximizing analogs coupled with the highlighting of the uniqueness of linear programming form the basis for proving the appropriateness of L.P. for modelling the profit-maximization problem of the farm-firm.

Chapter 4. The Representative Farm, Empirical Model and Model Data

4.0 Introduction

The chapter begins with a brief discussion of the criteria used for selecting the representative farm. The major thrust of that discussion is to establish the rationale behind the choice of those criteria. Each criterion is then discussed with a view of explaining and providing specific information as each relates to the actual environment.

Additional assumptions affecting the conduct of the study are noted. This is followed by the presentation of the empirical model and an explanation of each of the empirical model equations. Also, major modifications required for the modelling of irrigation are then presented.

Finally, the model data are presented. The model data are presented at two levels: the farm level data and the exogenous farm data. Throughout that presentation, some of the potential problems are noted and relevant assumptions are emphasized.

4.1 The Representative Farm

In Chapter Two, reference was made to the recommendation by the Model Farms Project Team to the Grenada Government to irrigate 6 of the 24 Government-owned estates. The identified estates are Paradise, Grand Bras, Pointzfield, Requin, Black Bay and La Sagesse. The stated criterion used to determine their suitability for irrigation was their past history of irrigation use (Adams and Pringle, 1986).

The Paradise Model Farms have been selected as the focus in this study for a variety of reasons. First, the Paradise Model Farms are among the few farms actually divested and handed over to the farmers. In addition, the Paradise Model Farms are the best example in which the criteria for selection of model farm beneficiaries have been followed (Appendix C). The second reason is that the Paradise Model Farms are the only ones in which irrigation systems have now been installed. Finally, there is a strong desire and participation of the Government, Grenada Development Bank, the Marketing National Import Board and the Caribbean Agricultural Research Development Institute in the development of the Paradise Model Farms.

The criteria used to determine the farm that best reflects the average farm in the Paradise cluster for this study are: (i) Location, Elevation and Rainfall; (ii) Soil Type; (iii) Vegetation; (iv) Farm Size; (v) Farmer Characteristics; (vi) Farm Labour Supply; (vii) Irrigation and Related Conditions; and (viii) Crop Choices. The rationale underlying the choice of those criteria is to show how homogenous the vast majority of the individual farms are. The natural and geographical criteria, specifically (i) and (ii), are used to emphasize the great influence location, elevation and rainfall exert on agriculture in a uniform manner for that area. When viewed in the micro-environment of the Paradise Model Farms, it helps to differentiate the nature of agriculture there from that found in some other regions of the island. The type of crops and the yields obtainable depend on those factors. Even the type of technology for yield enhancement would be influenced by these two criteria, (i) and (ii).

Vegetation is selected as a criterion for determining the characteristics of the representative farm for two reasons. The first is that the type of vegetation and its persistence on the farm would influence the type of weed control practised. This in turn would affect the production costs to the farm. The second reason is that the degree of homogeneity of the natural vegetation among farms would determine the extent to which a common cost of initial clearing can be applied to the farms in the Paradise cluster.

Farm size and farmer characteristics are two more important criteria. The farm size criterion has the potential for making it possible to consider farm activities of the individual farms at basically the same scale of production. The rationale in support of the farmer characteristics criterion is in recognition of the degree of influence educational level and age, for example, could have on the efficiency of the farmers.

The farm labour supply criterion is extremely important in that the farm operations are very labour intensive. As a consequence, it is essential to identify the major sources of labour supply to those farms. By so doing, variations, or the lack thereof, in labour costs among farms could be explained or justified.

The need to consider the "irrigation and related conditions" criterion is obvious from the perspective of the emphasis placed on irrigation in the study. It is important to determine the degree of commonness, related to the natural and institutional aspects that would support homogeneity among the farms vis a vis irrigation.

Finally, the "crop choices criterion" helps to establish how alike the various farms are, not just in terms of what is produced, but how they are produced. Such a consideration permits the study to establish more accurately the homogeneity in production costs across the different farms.

Thus, the overall rationale for the selection of those criteria is to establish the homogeneity of the farms under consideration, or more pointedly, to rationally present a basis for the selection of a representative farm reflective of the group. Throughout this discussion one must keep in mind that the acreage of the Paradise cluster is approximately 70 acres (28 hectares). This smallness in area helps to support the assumption of homogeneity among the individual farm units.

4.1.1 Location, Elevation and Rainfall

The Paradise model farms are located on the eastern coastal plain at an elevation of approximately 25 feet above sea level. This location exposes the farms to the north-east trade winds for the greater part of the year. The low altitude at which those farms are located place them in a rain-starved location. The annual average rainfall is between 50-60 inches (1250-1500 mm) with November being the wettest month, averaging 10-12 inches (250-300 mm) of rain. Rainfall tends to be light rather than torrential (Agricultural Extension Atlas of Grenada, 1990).

4.1.2 Soil Type

Throughout the Paradise region, the soil type is a deep loam. This soil type, called the Plains Loam, has a water holding capacity of 1.44 inches/foot (120 mm/metre) and has a readily available soil water status of 48% (Paradise Model Farms Development Sub-Project, Undated).

4.1.3 Vegetation

The vegetation is mostly of a secondary and scrub-like nature. The littoral location of the farms and the low rainfall do not support the growth of massive forest. In the areas closest to the coast are found bands of coconut palms which are to be conserved as a traditional crop consistent with Government's policy of supporting traditional crop production. However, those palms do not present serious constraints to the development of the individual farms. Due to the vegetation, initial land clearing costs should be nearly the same among the individual farms.

4.1.4 Farm Size

The Model Farms Corporation policy was to provide every farmer chosen with approximately 5 acres (2.02 hectares) of cultivable land. See Table (D.1) for data on number of farms, farm acreages and irrigation status.

The average size for the 10 farms outfitted with irrigation is approximately 5.5 acres (2.23 hectares) and the mode is 5.17 acres (2.09 hectares). Considering the farm size distribution, 80% of the individual farms satisfy the 5-acre requirement policy. Consequently, it is reasonable to assume that the representative farm would cultivate an area of 5 acres (2.02 hectares).

4.1.5 Farmer Characteristics

The farmer is assumed to be full-time and heads a family which is consistent with criterion 4 of the criteria for farmer selection. (Appendix D).

The average farmer has a minimum academic background of primary level education. That is, the farmer has successfully completed seven years of education at the primary school level. The farmer receives on-farm training in farm management and husbandry practices conducted by the Ministry of Agriculture, the Grenada Development Bank and the Caribbean Agricultural Research Development Institute.

Also, by virtue of being a "model farmer", the farmer has access to farm credit at 7% per annum at the Grenada Development Bank. This last point is consistent with the privilege of the lease-purchase agreement discussed in Chapter Two.

4.1.6 Farm Labour Supply

Farm labour is not a serious constraint on the farm. Farm labour comes from three sources—family labour, maroon labour[7] and rural wage labour. Noel (1991) claimed that the national unemployment rate was in the vicinity of 25-30%. Thompson (1988) estimated rural unemployment to be as high as 40%. Basically, the Paradise Model Farms face the same labour conditions making labour cost uniform throughout the farms.

4.1.7 Crop Choices

Each farm is constrained by an institutional minimum requirement on banana production. At least two acres of each farm must be devoted to banana cultivation in every year of the life of the farm. The other crops in which the farmer has shown interest are papaya, passion fruit, carrots, beets, cucumbers and sweet potatoes.[8]

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[7] The maroon is a traditional practice of soliciting self-help. The farmer organizes friends and relatives on weekends who provide farm labour in exchange for food and drinks.

[8] Although there are other crops capable of being grown, the farmers showed interest in those crops for a variety of reasons e.g., their relatively high output prices and the influence of MNIB and GDB.

4.1.8 Irrigation and Water Availability

According to the data in Table (D.1), 10 of the 12 Paradise farms are outfitted with sprinkler irrigation systems. The entire system was funded by the European Development Fund. The farmer's financial obligation for receipt of the irrigation system is zero (Financial Proposal, EDF, 1988).

The largest river, the Great River, which forms part of the Paradise cluster's boundary is the source of the irrigation water to the various farms. There is no charge for water use. It would be assumed, in this study, that each farm would have an adequate water supply for use as required.

4.2 The Empirical Model

As discussed in Chapter 3, the production activities of the representative farm are modelled using linear programming. Specifically, a multi-period linear programming model is developed and used to replicate the behaviour of the farm in order to provide answers to the hypotheses outlined in Chapter One. The empirical model comprises an objective function which is optimized, and a set of activity constraints.

4.2.1 Additional Assumptions

There are additional assumptions imposed on the empirical model. These assumptions are:

(i) the farm has a 5-acre (2.02 hectares) fixed endowment of cultivable land in each period;

(ii) there is a minimum institutional constraint requiring 2 acres (0.81 hectare)of the farm acreage to be devoted to bananas in each period;

(iii) all variable costs in each period are covered by loans obtained at 7% from the Grenada Development Bank and are repaid at the end of each harvesting year;

(iv) available family labour is 330 man-days in each year; and

(v) banana has a maximum five-year cycle, papaya, a maximum four-year cycle, each passion fruit stand has a maximum five-year cycle while each vegetable enterprise is restricted to one-year cycles.

4.2.2 Explanation of Model Equations

The multi-period linear programming model is defined to maximize discounted net revenues subject to a set of activity constraints. Discounted net revenues are defined as the difference between total discounted revenues and discounted variable costs. The general model is stated as follows:

Maximize:[9]

$$\sum_{t=1}^{5} \left(\frac{1}{1 + R} \right)^{t} \left[NR_{t} \right] \qquad \forall\, t \tag{4.1}$$

Subject to:

$$\sum_{k} \sum_{g} X_{g,t}^{k} \leq b_{1} \qquad \forall\, t \tag{4.2}$$

[9] R in $\left(\frac{1}{1 + R} \right)^{t}$ represents the farmer's subjective discount rate.

$$\sum_{g} X_{g,t}^{BA} \geq b_2 \qquad \forall\, t \tag{4.3}$$

$$\sum_{g} X_{g,t}^{PP} \leq b_3 \qquad \forall\, t \tag{4.4}$$

$$\sum_{g} X_{g,t}^{PF} \leq b_4 \qquad \forall\, t \tag{4.5}$$

$$X_{g,t}^{k} \leq b_5 \qquad \forall t \quad \textit{for } k = BBE, BBS, CCE, CCS, BCE, BCS \tag{4.6}$$

$$\sum_{k} \sum_{g} a_{k,t} X_{g,t}^{k} - FEA_t \leq 0 \qquad \forall\, t \tag{4.7}$$

$$\sum_{k} \sum_{g} c_{k,t} X_{g,t}^{k} - FEB_t \leq 0 \qquad \forall\, t \tag{4.8}$$

$$\sum_{k} \sum_{g} d_{k,t} X_{g,t}^{k} - FEC_t \leq 0 \qquad \forall\, t \tag{4.9}$$

$$\sum_{k} \sum_{g} e_{k,t} X_{g,t}^{k} - FED_t \leq 0 \qquad \forall\, t \tag{4.10}$$

$$\sum_{k}\sum_{g} f_{k,t}X_{g,t}^{k} - CHA_t \leq 0 \qquad \forall\, t \tag{4.11}$$

$$\sum_{k}\sum_{g} g_{k,t}X_{g,t}^{k} - CHB_t \leq 0 \qquad \forall\, t \tag{4.12}$$

$$\sum_{k}\sum_{g} i_{k,t}X_{g,t}^{k} - CHC_t \leq 0 \qquad \forall\, t \tag{4.13}$$

$$\sum_{k}\sum_{g} j_{k,t}X_{g,t}^{k} - CHD_t \leq 0 \qquad \forall\, t \tag{4.14}$$

$$\sum_{k}\sum_{g} l_{k,t}X_{g,t}^{k} - CHE_t \leq 0 \qquad \forall t \tag{4.15}$$

$$m_{k,t}X_{g,t}^{k} - PL_t \leq 0 \qquad \forall\, k, \;\; \forall\, t \tag{4.16}$$

$$\sum_{g} s_{BA,t}X_{g,t}^{BA} - SL_t \leq 0 \qquad \forall\, t \tag{4.17}$$

$$\sum_{g} u_{BA,t}X_{g,t}^{BA} - TW_t \leq 0 \qquad \forall\, t \tag{4.18}$$

$$\sum_{g} w_{BA,t} X_{g,t}^{BA} - CPD_t \leq 0 \qquad \forall\, t \tag{4.19}$$

$$\sum_{g} v_{PF,t} X_{g,t}^{PF} - WR_t \leq 0 \qquad \forall\, t \tag{4.20}$$

$$\sum_{k} \sum_{g} n_{k,t} X_{g,t}^{k} - HL_t \leq OWNWORK_t \qquad \forall\, t \tag{4.21}$$

$$\sum_{n} \left(r_n \times INP_{n,t} \right) - OPCOST_t \leq 0 \qquad \forall\, t \tag{4.22}$$

$$OPCOST_t - LN_t \leq 0 \qquad \forall\, t \tag{4.23}$$

$$\left(\sum_{k} \sum_{g} P_k \times YLD_{g,t}^{k} \times X_{g,t}^{k} \right) - (1 + i)\, OPCOST - NR_t \geq 0 \tag{4.24}$$

$$\sum_{g} X_{g,t}^{k} - \sum_{g} X_{g,t-1}^{k} \leq 0 \qquad \textit{for } k = BA, PP, PF \tag{4.25}$$

$$\textit{non-negativity of all activities} \tag{4.26}$$

where

X_{gt}^{k} = The *g*th stand of the *k*th enterprise in time t where k = the alternative crop enterprises, g = 1, 2, 3, 4, 5 and t = 1, 2, 3, 4, 5;

BA = the banana enterprise;

PP = the papaya enterprise;

PF = the passion fruit enterprise;

BBE = the beets, beets and cucumber enterprise in rotation;

BBS = the beets, beets and sweet potatoes enterprise in rotation;

CCE = the carrots, carrots and cucumbers enterprise in rotation;

CCS = the carrots, carrots and sweet potatoes enterprise in rotation;

BCE = the beets, carrots and cucumbers enterprise in rotation;

BCS = the beets, carrots and sweet potatoes enterprise in rotation;

FEA_t = Pounds of 15-7-21+2 fertilizer purchased and used by the farm in each time, t = 1, ..., 5;

FEB_t = Pounds of tri-phosphate fertilizer purchased and used by the farm in each time, t = 1, ..., 5;

FEC_t = Pounds of sulphate of ammonia purchased and used by the farm in each time, t = 1, ..., 5;

FED_t = Pounds of 16-16-16 fertilizer purchased and used by the farm in each time, t = 1, ..., 5;

CHA_t = Gallons (litres) of gramoxone and vydate purchased and used by the farm in each time, t = 1, ..., 5;

CHB_t = Number of packages of racumen purchased and used by the farm in time, t = 1, ..., 5;

CHC_t = Number of litres of malathion purchased and used by the farm in time, t = 1, ..., 5;

CHD_t = Pounds of Champion WP purchased and used by the farm in time, t = 1, ..., 5;

CHE_t = C.C. of ambush purchased and used by the farm in time, t = 1, ..., 5;

PL_{kt} = Number of plants per acre of *k*th enterprise in time t= 1, ..., 5 and k = the alternative crop enterprises;

SL_t = Rolls of sleeving material per acre of k = BA enterprise in time, t = 1, ..., 5;

TW_t = Rolls of twine per acre of k = BA enterprise in time, t = 1, ..., 5;

CPD_t = Rolls of crown pads per acre of k = BA enterprise in time, t = 1, ..., 5;

WR_t = Rolls of wire per acre of k = PF enterprise in time, t = 1, ..., 5;

HL_t = Total number of man-days hired in time, t = 1, ..., 5;

$OWNWORK_t$ = Total number of available man-days of family labour in time, t = 1, ..., 5;

$INP_{i,t}$ = The n-variable inputs used by the model in time, t = 1, ..., 5, i = 1, ..., n.

$OPCOST_t$ = Total operating costs in time, t = 1, ..., 5;

NR_t = Net revenue generated by the model in time, t = 1, ..., 5;

$\left(\frac{1}{1+R}\right)^t$ = The discount factor in time, t = 1, ..., 5;

b_1 = Total fixed endowment of land in acres in time, t = 1, ..., 5;

b_2 = Minimum endowment of acres of land devoted to BA enterprise in time, t = 1, ..., 5;

b_3 = Maximum endowment of acres of land devoted to PP enterprise in time, t = 1, ..., 5;

b_4 = Maximum endowment of acres of land devoted to PF enterprise in time, t = 1, ..., 5;

b_5 = Maximum endowment of land devoted to each vegetable enterprise, k = the alternative vegetable enterprises in time t = 1, ..., 5;

a_{kt} = The requirement of pounds of 15-7-21+2 fertilizer to produce an acre of the *k*th enterprise in time, t = 1, ..., 5;

c_{kt} = The requirement of pounds of tri-phosphate to produce an acre of the *k*th enterprise in time, t = 1, ..., 5;

d_{kt} = The requirement of pounds of sulphate of ammonia to produce an acre of the *k*th enterprise in time, t = 1, ..., 5;

e_{kt} = The requirement of pounds of 16-16-16 fertilizer to produce an acre of the *k*th enterprise in time, t = 1, ..., 5;

f_{kt} = The requirement of gallons of gramoxone and vydate to produce an acre of k = BA enterprise in time, t = 1, ..., 5;

g_{kt} = The requirement of packs of racumen to produce an acre of PF in time, t = 1, ..., 5;

i_{kt} = The requirement of litres of malathion to produce an acre of PP enterprise in time, t = 1, ..., 5;

j_{kt} = The requirement of pounds of Champion WP to produce an acre of k = the alternative vegetable enterprises in time, t = 1, ..., 5;

l_{kt} = The requirement of C.C. of ambush to produce an acre of k = BCS, BCE, CCS, CCE, BBS in time, t = 1, ..., 5;

m_{kt} = The requirement of number of plants to produce an acre of each k enterprise in time, t = 1, ..., 5;

s_{kt} = The requirement of rolls of sleeves to produce an acre of BA in time, t = 1, ..., 5;

u_{kt} = The requirement of rolls of twine to produce an acre of BA in time, t = 1, ..., 5;

w_{kt} = The rolls of twine required in the production of an acre of BA in time, t = 1, ..., 5;

v_{kt} = Rolls of wire required in the production of an acre of PF in time, t = 1, ..., 5;

n_{kt} = Man/days required in the production of each k enterprise in time, t = 1, ..., 5;

r_n = The unit cost in dollars for each n-input used by the model in time, t = 1, ..., 5;

P_k = The output unit price of each k-enterprise in time, t = 1, ..., 5;

YLD_{gt}^{k} = The expected yield in pounds of each *g*th stand of the *k*th enterprise in time, t = 1, ..., 5;

q_{kt} = Inches of moisture required by an acre of each k-enterprise in time, t = 1, ..., 5; and

Rn_t = The fixed endowment of inches of moisture available from average annual rainfall in time, t = 1, ..., 5.

Equation (4.1) is the objective function which defines the maximization of the discounted net revenue generated by the farm over the planning horizon in this study. Net revenue is defined as the residual of total revenues over total variable costs which is maximized, as shown in Equation (4.24).[10] The individual annual net revenue, discounted by its appropriate discount factor and then summed, provides the total discounted net revenue.

Equation (4.2) states that the sum of the various stands of crops in any harvesting year cannot exceed the fixed land endowment of b_1 acres. Equation (4.3) states that the

[10] Total variable costs are made up of the costs for fertilisers, chemicals, other material inputs, labour and the cost of the annual operating loans.

acres of stands of bananas, in each of the harvesting years, must be at least equal to b_2 acres. This equation is a reflection of the minimum institutional constraint placed on the banana acreage of the representative farm. Equations (4.4) to (4.6) are maximum constraints placed on the amount of land that could be devoted to each of the other enterprises in each of the harvesting years. Those constraints are aimed at forcing the farm to be as diverse as possible in its production. Equation (4.4) addresses the papaya enterprise. Equation (4.5) addresses the passion fruit enterprise while Equation (4.6) addresses the vegetable enterprises individually.

Equations (4.7) through (4.20) model the requirements per various crop inputs that are satisfied under perfectly competitive market conditions. Equations (4.7) to (4.10) address the requirement-purchase relationship for various types of fertilizer in each of the harvesting years. Equations (4.11) to (4.15) show the requirement and purchase relationship for the different types of chemicals in each harvesting year. Equation (4.16) reflects the requirement for plants and their purchase for each enterprise in each harvesting year. Equations (4.17) to (4.19) show the requirement and purchase relationship for the inputs of sleeving material, twine and crownpads respectively, for the banana enterprise, in each harvesting year. Equation (4.20) reflects the requirement and purchase relationship for wire by the passion fruit enterprise.

Equation (4.21) states that the total labour requirement for the production of stands of the various crops, in any harvesting year, is satisfied by the sum of available family labour and hired labour in the given harvesting year.

Equation (4.22) defines operating cost in each harvesting year as the sum of the costs of all variable inputs.[11] Equation (4.23) states that all operating costs, in each harvesting year, would be covered by loans in those years.

Equation (4.24) defines net revenue in each harvesting year. Net revenue is defined as the difference between total revenue and the sum of operating costs and interest payments on the loan in the given year.

Equation (4.25) is a general representation of the inter-period link for each of the perennial crops (bananas, papaya and passion fruit). Using banana, as an example, Equation (4.25) states that the *g*th stand of banana planted in the previous year and moved into the present year must be less than or equal to each other in area.

Equation (4.26) states that the moisture requirements by a stand of the *kth* crop in any harvesting year is constrained by the available moisture from rainfall in that harvesting year.

4.2.3 Modifications Required for Modelling Irrigation

From the discussion in both Chapter Two and Section 4.1, it has been established that irrigation water to the Paradise farmer is a free good. Consistent with that assumption, the study assumes that the farmer has sufficient water at his disposal to satisfy the moisture deficits due to inadequate rainfall. The second assumption is that the farmer applies water in adequate amounts and at the right times. Thirdly, extra labour is required

[11] Variable inputs include hired labour, fertiliser, chemicals, plants, boxes, wire, twine, sleeves and crown pads.

to move the irrigation lines around the farm. However, due to the small farm size, the amount of labour required is not extraordinarily high.[12]

Given those simplifying assumptions, Equations (4.24) and (4.25) would have to be modified. The modification with regards to the labour constraint would be effected in the inclusion of an annual cost in Equation (4.24) to reflect the increased labour requirement under the irrigation regime while for the unirrigated farm a linear yield-moisture relationship is used to approximate crop yields under rain-fed conditions, the Equation (4.27) represents the irrigation constraint for the irrigated farm.

$$q_{k,t}x_{g,t}^{k} - \boldsymbol{Rig_t} \leq \boldsymbol{Rn_t} \tag{4.27}$$

Thus, Equation (4.27) now states that the moisture requirements by a stand of the *kth* crop in any harvesting year would be totally satisfied from a combination of sources—irrigation ($\boldsymbol{Rig_t}$) and rainfall ($\boldsymbol{Rn_t}$). Other modifications are reflected in the expected yield coefficients, banana boxes requirements and labour requirement coefficients.

4.3 Model Data

4.3.1 Farm Level Data

The farm level data used in this study is taken from the production costs and returns study done by Marks and Murillo-Yepes (1989). The input requirements for the perennial

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[12] The annual labour requirements for moving irrigation lines is estimated to be 80 man/days. This estimate was provided by Dr. Sri Ranjan of the Agricultural Engineering Department, University of Manitoba.

crops are similar to those estimated in the Dominica Study by Oldham (1991). Another production study prepared for the Organization of Eastern Caribbean States by Taylor, Antione and Smith (1991) reveals that the Marks and Murillo-Yepes study formed the basis for their data compilation on Grenada. Consequently, the use of the 1989 study, as the secondary farm level data source, is justified particularly in the context of it being the first serious attempt to address this issue in a Grenadian setting.

The farm operation involves nine different potential crop enterprises. From those enterprises, the farm can choose any combination in each year of its five-year life. However, the crop enterprise choices must include two acres of bananas every year, as required by the Model Farms Corporation. If required, the inputs necessary for production of the chosen enterprises would be purchased, in the required amounts, by the farmer in the particular production year. Any enterprise chosen is assumed to yield marketable outputs within the calendar year for which the selection was made. The banana and passion fruit enterprises have a five-year cropping cycle while papaya has a four-year cycle. However, the modelling does not preclude the L.P. model from suggesting a different cropping cycle from any of the perennials. The other enterprises, which are vegetable operations, each has a one-year cycle.

Fertilizer use by the various enterprises is relatively high. Tables (D.2), (D.3), (D.4) and (D.5) present the levels of different fertilizer requirements by the various crop enterprises on a per acre basis in each harvesting year.[13] Four different types of fertilizers are used by the farm. Fertilizer type, 15-7-21+2 is required by all the crop

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[13] All table references containing 'D' are found in Appendix D.

enterprises, as shown in Table (D.2). This fertilizer is extremely important to the banana enterprise. Banana production needs high levels of nitrates and potassium. Tri-phosphate fertilizer is provided only to the vegetable enterprises (Table D.3). According to the Agronomy Division, Ministry of Agriculture, Grenada, tri-phosphate speeds up the establishment of root systems in vegetables. Sulphate of ammonia requirements are presented in Table (D.4). Again, that type of fertilizer use is specific to the vegetable enterprises. Sulphate of ammonia speeds up fruit formation in cucumbers and tuber formation in sweet potatoes. The fertilizer type, 16-16-16, is applied to the vegetable enterprises with sweet potato (Table D.5).

The next two tables, (D.6) and (D.7), present data specific to the banana enterprise. Table (D.6) presents the requirements of vydate and gramoxone needed to produce an acre of bananas. Gramoxone is a weed controller. Its application to the banana mats is important for weed control and for ensuring the minimization of competition between the young banana suckers and weeds for nutrients. Vydate is applied to the banana mat to control the incidence of nematodes.

Table (D.7) presents the requirements of twine, sleeving material, crown pads and boxes[14] for the production of an acre of bananas. Banana is susceptible to high winds because of its shallow adventitious rooting system (Holder and Gumbs), 1981). As a consequence, nylon twine is used to help anchor the plant more firmly in order to withstand the potential ravages of strong winds. The twine coefficient presented in the table is according to Oldham (1991). Sleeving material is used to cover and protect the

[14] The number of boxes required is dependent on the yields generated under each specific moisture scenario.

maturing fruit from scratches that could be inflicted on them by birds, especially the humming bird. Crown pads are used during the handling of the fruit for export. The pads are applied to the crowns of the fruit hands to prevent latex flow on to the fingers. Cardboard boxes are the containers in which the bananas are shipped. Each box is designed to accommodate 28-30 pounds (12.5-13.4 kg) of fruits. The box requirement coefficient is determined by taking the expected yield of each harvesting year and dividing by the average of the recommended capacity per box.

The number of plants required to establish an acre of each of the various enterprises is presented in Table (D.8). In each case, the plant spacing which determines the required number of plants is based on acceptable husbandry practices (G.M.F.C., Important Husbandry and Management Notes, Undated). The large plant per acre requirement for the vegetable enterprises is as such because, in each case, the enterprise reflects the combination of three crops. In other words, the plant requirement coefficient, for any vegetable enterprise, is the summation of the number of plants required by the individual crops comprising the given enterprise.

The next four tables, (D.9), (D.10), (D.11) and (D.12) present the coefficients for the various chemicals required to produce the various enterprises. Table (D.9) presents the amount of racumen necessary to control rodents, mongoose and rat, in the passion fruit enterprise in each harvesting year. Malathion requirements by an acre of papaya is given in Table (D.10). Malathion is used to prevent and control the incidence of "bunchy top" in papaya. Champion WP chemical is used to control the white fly in the various vegetable enterprises. Table (D.11) presents the coefficients of Champion WP per acre of vegetable enterprise. Table (D.12) presents the requirements for ambush per acre for each vegetable enterprise. Ambush is especially effective in the control of beetles in vegetable production. On careful investigation, one notices that the vegetable enterprises containing sweet potatoes and cucumbers are the biggest users of ambush. That is due to the susceptibility of those crops to beetle attacks.

Tables (D.13) and (D.14) present the expected yields associated with the different crop enterprises on a per acre basis.[15] Specifically, the data in Table (D.13) represent expected crop enterprise yields under ideal moisture conditions in each of the harvesting years. The data in Table (D.14) is an approximation of the water-yield relationship given the moisture deficit scenario. The data in Table (D.14) would be used in the model that replicates the representative farm's behaviour under conditions of no irrigation. Although the relationship between moisture and crop yield is non-linear, a linear relationship was used due to the unavailability of more suitable data.[16]

As Tables (D.15) and (D.16) indicate, the various crop enterprises are labour intensive. In the initial year of each crop enterprise, labour required for initial land clearing is included in the labour requirement coefficient. The other activities requiring labour are well documented in the Marks and Murillo-Yepes study and form the basis of each of the coefficients in Table (D.15) for the farm under adequate moisture. Table (D.16) presents labour requirements under deficit moisture conditions. In the case of the perennial crops, bananas, papaya and passion fruit, the declining labour requirement is

[15] Table (4.22) provides the base yields for each vegetable crop in the vegetable rotations.

[16] Attempts were made to obtain more accurate data from Florida and Israel but were unsuccessful.

consistent with lower labour needs given the reduced harvesting activities throughout their lifetimes. In the case of the vegetable enterprises, land preparation like bed-formation occurs once in every year and partial clearing during harvesting explain the lower labour requirement coefficients after the first year. Available labour is obtained from family labour, maroon labour and the substantial rural labour force. It is assumed that the farm has no problems in obtaining outside labour to satisfy any deficit that otherwise would have arisen after family labour would have been exhausted.

Family labour is defined as man-days available to the farm from family members. The quantification of family labour available on a consistent basis to the farm is extremely difficult. The difficulty arises due to the irregularity with which minors contribute of their labour power to the farm. Also, the daily domestic demands that have to be met by the adult female (wife) in the family contributes to that difficulty. Although the farmers obtain amounts of "free" labour from friends and relatives through the maroon system that too cannot be estimated. Consequently a conservative estimate of available family labour is made based on the following assumptions. First, the assumption is that family labour is provided by the man and woman in the family. Secondly, the major family member provides 44 five-day weeks of labour per year. The other member, the female, contributes half the amount of labour time of the former. Cumulatively, they provide 330 man/days of labour to the farm annually.

4.3.2 Exogenous Data

Table (D.17) presents the 1991 prices of the inputs needed by the various crop enterprises. The first 14 input prices, in Table (D.17), are taken from the price list compiled by the Model Farms Corporation. The study assumes equality in farm wages and therefore male and female receive $20.00 per man-day. All planting material are bought by the farm from plant propagators. The farmer purchases papaya, passion fruit and banana plants from the Government propagation station at Mirabeau. The vegetable seedlings are obtained, at the prices indicated, from private seedling propagators.

All output prices are those received by the farmer (Table D.18). The output prices per pound of banana, papaya and passion fruit is an arithmetic three-year average for the period 1989-1991. In the case of the vegetable enterprises, weighted average prices computed for the same period, 1989-1991 are used. All those prices are assumed to be constant throughout the planning horizon used in the study.[17]

The computation of input and output prices are averages based on past actual data. This procedure is a replication intended to project the end result of the farmer's attempt to actually formulate his expectations of prices. Such a procedural approach implies that the prices should be interpreted as expected prices and not actual prices. Also, by considering the model coefficients as expected, and not actual, would suggest that the representative farmer is risk-neutral and thus, the expected discounted profit maximum should be optimal for the farmer (Debertin, 1986).

The model assumes that the farmer would take loans annually to defray his operating costs. Loans shall be taken during the harvesting year and paid off at the end of that same year. Farmers can get loans from the commercial banks at an annual rate

[17] See Table (D.21) for a listing of the output prices for the individual crops used in the study.

of 10% or from the Grenada Development Bank (G.D.B.) at 7%. It is assumed that the farmer takes advantage of the G.D.B. terms.

Since the farmer is assumed to be operating the farm over a multi-period horizon the necessity of the use of a discount factor arises. Two basic justifications exist in support of this innovation. First, the goal of multi-period profit-maximization must consider the time value of money. This consideration is based on the principle that a current dollar is more valuable than a future dollar. Interest could begin accruing on that current dollar if invested today. Also, generally inflation has the negative effect of eroding the value of the dollar over time thus making the future dollar less valuable than the current one (Baker, 1983; Lee et al, 1988). The discount is therefore a reflection of the lost earnings of the investor (farmer) due to his inability to immediately invest the future gains in the alternative opportunity yielding the interest rate of return sought by him, the investor (farmer) (Baker, 1983). The second reason is the acknowledgment of uncertainty with respect to prices of inputs and outputs since the farmer lacks that magical power to foretell the future accurately. The discount factor acts, therefore, as a subjective measure of the farmers expectations of the behaviour of those prices as they are influenced by time. The farmer, unlike other investors, seem either to be maximizing something other than profits or has a subjective lower discount rate than, for example, the bank rate (Hazell and Norton). Since the study has assumed profit-maximization, it is reasonable, along the lines of Hazell and Norton, to assume that the farmer's discount rate is subjective and generally low. However, the representative farmer is characterised as one having a discount rate of 7%, equivalent to the interest rate on loans accessed, and remains constant throughout the life of the farm operation. Table (D.19) provides the discount factor for each of the five years.

Irrigation is modelled as a moisture constraint in the study. This approach is adopted because of the lack of relevant data that would allow for a more explicit modelling approach. However, because of the adjustments made in the yield and input coefficients, the effects of irrigation on the farm's performance are reasonably well-represented. As discussed in Chapter Two, water available for irrigation is not a problem. In fact, water abundance in the area allows for the free use of that resource by the farmer. From that perspective three simplifying assumptions shall be made.

First, water is available in sufficient quantities, and at all times, to satisfy the consumptive needs of the enterprises chosen in the model.

> Consumptive use is the total water a crop uses in a season to build plant tissue and in transpiration plus the water that evaporates from the soil surface and from the leaves and stems of the plants. It does not include water that drains down through the soil beyond the reach of plant roots (Dubetz and Hobbs, 1974).

In this study, consumptive water need is calculated and represented by the product of the average crop evapotranspiration rate and the length of the crop season. The values in the column, captioned "Crop Water Requirements" in Table (D.20) are proxies of the consumptive needs of the enterprises. The second assumption is that the farmer applies water in the right amounts and at the right times to meet the water deficits created by insufficient moisture from rainfall. The moisture available from rainfall is computed using the five-year (1986-1990) annual average rainfall for the Paradise area.

4.4 Summary

In this chapter, very basic and essential criteria have been used to establish the homogeneity of the farms under consideration. The consequential result has been the creation of one representative farm to be modelled under two moisture scenarios—the adequate moisture scenario and inadequate (deficit) moisture scenario. Also, the relevant on-farm and exogenous data with accompanying assumptions have been presented. The stage has, therefore, been set for the consideration, presentation and analysis of the various model results against the background of the research goal and hypotheses enunciated in Chapter One. The following chapter, Chapter Five, is intended to satisfy that requirement.

Chapter 5. Linear Programming Models

5.1 Introduction

This chapter begins with a brief overview of model verification and the method used to determine the optimal solutions for the representative farm. The representative farm model is analyzed alternatively under conditions of adequate moisture (with irrigation) and conditions of inadequate moisture (without irrigation). Each of the two farm models is further manipulated by changing the institutional minimum banana acreage constraint. This has been done to allow the analysis to focus sharper on the goal, objectives and hypotheses outlined for the study. A discussion of the model results is then pursued. In addition, a related section on the analysis of the four hypotheses follows. The chapter concludes with a brief summary of the important model results.

5.2 Model Verification

By examination, the linear programming farm models have shown a capability to replicate the activities of the farm under the two different moisture conditions with varying constraints on the banana enterprise. More importantly, the models have exhibited the ability to forecast the consequences of adequate moisture on the profitability and performance of the representative farms. There is a further implicit and useful prescriptive element gained from the use of those models. That is, from the results provided, there are implicit suggestions regarding best policy directions, for example, farm acreage that should be devoted to the banana enterprise subject to the goal of profit-maximization. Also, the model results clearly indicate that all the assumptions imposed on the farm models have been satisfied consistently. Consequently, it can be concluded that the linear programming farm models have performed as expected.

5.3 Method of Determining the Optimal Solutions for the Representative Farm

The linear programming models of the representative farm are solved using MINOS5, which is part of the General Algebraic Modelling System (GAMS) programme (Brooke, Kendrick and Mecraus, 1988; Jefferson and Boisvert, 1989). MINOS5, the linear programming algorithm, is particularly applicable since none of the activities is required to take on integer values. Although many of the solution values are mixed integers, they are, in general, presented in rounded off values. In spite of the resulting minute inaccuracies, the presented results are assumed to be feasible and approximate the true global solutions.

5.4 Discussion of Model Results

In this section, the discussion shall proceed by considering the behaviour of discounted net revenues, crop choices and the marginal values of the activities and land.[18] Those aspects of the farm behaviour shall be discussed under three sub-headings:

i) The base scenario involving the institutional minimum banana acreage constraint ($BA \geq 2$),

ii) An off-base scenario involving two relaxations of the institutional banana constraint ($BA \geq 1$ and $BA \geq 0$), and

iii) The final scenario involving one maximum constraint on banana ($BA \leq 1$).

[18] Appendix E provides a general discussion of the significance and interpretation of marginal or shadow values.

Finally, the total discounted net revenue measures the difference between annual total revenue and total variable costs, discounted by an annual factor of 7%, summed over a five-year period for each irrigated and non-irrigated farm model.

5.4.1 *Results for the Base Model ($BA \geq 2$)*

The base model is defined by the imposition of the institutional minimum banana acreage on the representative farm. The farm is required by Government to devote, at least, 2 acres to banana production annually. The total discounted net revenue generated over the five-year period by the irrigated farm model and the non-irrigated model is $180,095 and $56,469 respectively. At the same time, the irrigated model consumes 4,465 man-days while the non-irrigated model uses 2,618 man-days over the five-year period.

The crop choices of the farm model significantly influence both the discounted net revenue and labour use. Due to the yield-enhancing effect of irrigation on the crops, higher levels of farm activities induce increased need for labour. Thus, 410 man-days of the 4,465 man-days are irrigation-related for the time horizon being considered. The crop selection of the irrigated farm model proves to be more profitable than that of the non-irrigated farm model. Two factors are responsible. First, the increased crop yields enjoyed by the irrigated farm lead to increased additional revenue. The second factor is that the profitable crop enterprise of beets, beets, sweet potatoes (BBS) is produced only by the irrigated model. Table (5.1) presents the crop choices of the irrigated and non-irrigated farm models over the five-year period.

According to the results in Table (5.1), the passion fruit enterprise (PF) does not form part of the solution in the irrigated model. The vegetable enterprise, the rotation of beets, beets, sweet potatoes (BBS), is in the irrigated model but not in the non-irrigated model. The insufficiency of moisture excludes that vegetable enterprise but includes the relatively more drought-resistant crop of passion fruit (PF). One other reason for the exclusion of passion fruit from the irrigated model might be attributed to the effect of the institutional minimum banana acreage constraint. The marginal or shadow values on the enterprise constraints when $BA \geq 2$ demonstrate that the perennial crops are generally more valuable to produce in the non-irrigated model. However, for the irrigated model, the two vegetable enterprises (BBE and BBS) are most valuable to the farmer. (Tables F.7 and F.8 in Appendix F).

Table 5.1 Annual Crop Choices in Acres Harvested for the Irrigated and Non-Irrigated Farm Models, Given BA ≥ 2

Enterprises	Irrigated Model					Non-Irrigated Model				
	Year					Year				
	1	2	3	4	5	1	2	3	4	5
BA	2	2	2	2	2	2	2	2	2	2
PP	1	1	1	1	1	1	1	1	1	1
PF	0	0	0	0	0	1	1	1	1	1
BBE	1	1	1	1	1	1	1	1	1	1
BBS	1	1	1	1	1	0	0	0	0	0
Total	5	5	5	5	5	5	5	5	5	5

5.4.2 *Results for the Non-Base Models (BA ≥ 1 and BA ≥ 0)*

The rationale for the relaxation of the institutional minimum banana acreage from 2 acres to 1 acre (*BA*≥ 1) and 0 acres (*BA* ≥ 0) is to demonstrate that, with less restriction placed on the farm, profitability would improve. Thus, in this section, the investigation of the results is to determine how crop choices, farm performance, and profitability for the irrigated and the non-irrigated models would change from the base model.

The levels of total discounted net revenue and labour use are presented in Table (5.2) for the irrigated and non-irrigated models when *BA*≥ 1 and *BA*≥ 0.

From the model results in Table (5.2), it is clear that by relaxing the constraint on the banana acreage, farm profitability has increased for both the irrigated and non-irrigated models compared to that for the base model. Total discounted net revenue for

Table 5.9 Total Discounted Net Revenue and Total Man-Days for the Irrigated and Non-Irrigated Models when BA ≥ 1 and BA ≥ 0

	Irrigated Farm Model	Non-Irrigated Farm Model
For BA ≥ 1		
Total Discounted Net Revenue	$196,599	$60,060
Labour in Man-Days	4,420	2,362
For BA ≥ 0		
Total Discounted Net Revenue	$197,578	$62,612
Labour in Man-Days	4,298	2,042

the irrigated model increased from \$196,599 to \$197,578 when the minimum banana constraint is relaxed from $BA \geq 1$ to $BA \geq 0$. The same positive shift in discounted net revenue occurs in the non-irrigated model but with a greater relative change. The relaxation of the banana constraint from $BA \geq 1$ to $BA \geq 0$ has also resulted in a reduction in the amount of labour used for the five year period.

The most interesting results are to be found in the crop choices. Table (5.3) provides the crop choices of the irrigated and non-irrigated models for the five-year period when $BA \geq 1$.

With the relaxation of the institutional minimum banana constraint from 2 acres to 1 acre, the passion fruit enterprise (PF) enters the solution base of the irrigated model. Thus, in all likelihood, the institutional minimum banana constraint of at least 2 acres was

Table 5.10 Annual Crop Choices in Acres Harvested for the Irrigated and Non-Irrigated Models, Given BA ≥ 1

	Irrigated Condition					Non-Irrigated Condition				
	Year					Year				
Enterprise	1	2	3	4	5	1	2	3	4	5
BA	1	1	1	1	1	1	2	2	1	1
PP	1	1	1	1	1	1	1	1	1	1
PF	1	1	1	1	1	1	1	1	1	1
BBE	1	1	1	1	1	1	1	1	1	1
BBS	1	1	1	1	1	0	0	0	0	0
Total	5	5	5	5	5	4	5	5	4	4

restricting the entry of the passion fruit enterprise. In the case of the non-irrigated model, the crop enterprise choices remain the same. However, in the second and third years, the model is requiring the harvesting of 2 acres of bananas for each period. This is a reflection of the combined effects of the banana constraint and the profitability of banana.

Table (5.4) presents the crop choices of the irrigated models for the five-year period when $BA \geq 0$. The further relaxation of the banana minimum constraint to $BA \geq 0$ results in no change in the enterprises chosen from those of the previous model. However, the annual banana acreages exhibit some changes in the irrigated and non-irrigated models. For the irrigated model, no banana is produced in the first year. For the unirrigated model. Banana harvesting occurs in the second and third years. Two acres are produced in each of those two years.

Table 5.11 Annual Crop Choices in Acres Harvested for the Irrigated and Non-Irrigated Models, Given BA ≥ 0

	Irrigated Condition Year					Non-Irrigated Condition Year				
Enterprise	1	2	3	4	5	1	2	3	4	5
BA	0	1	1	1	1	0	2	2	0	0
PP	1	1	1	1	1	1	1	1	1	1
PF	1	1	1	1	1	1	1	1	1	1
BBE	1	1	1	1	1	1	1	1	1	1
BBS	1	1	1	1	1	0	0	0	0	0
Total	4	5	5	5	5	3	5	5	3	3

The relaxation of the institutional minimum banana acreage from 2 acres ($BA \geq 2$) to 1 acre ($BA \geq 1$) and 0 acre ($BA \geq 0$) alternatively results in changes in farm land utilization. Under the relaxed condition ($BA \geq 1$), the non-irrigated farm consume only 4 of the available 5 acres of land in the first, fourth and fifth years. When the relaxed condition ($BA \geq 0$) is imposed both the irrigated and non-irrigated farm models are affected. The irrigated farm model uses 4 of its 5 acres in the first year. In the case of the non-irrigated farm model, 1 acre of land remains fallow in the first, fourth and fifth years. Again, the effects of the constraints have manifested themselves. The marginal value on land in the fallow year is $0 (Appendix A.10).

5.4.3 Results for the Non-Base Models ($BA \leq 1$ and $BA \leq 0$)

The maximum banana acreage constraint ($BA \leq 1$) is imposed for two related reasons. First, to determine how total discounted net revenue and crop selection would behave. Secondly, to assess whether, or not, there is any sign of convergence in model results among the minimum and maximum banana acreage constrained models. Table (5.5) presents the total discounted net revenues for the irrigated and non-irrigated models.

Both the irrigated and non-irrigated farm models are more profitable when the maximum banana acreage constraint is $BA \leq 1$ rather than when $BA \geq 2$. It is also significant to note that the irrigated farm model ($BA \leq 1$) generates $197,578 of total discounted net revenue which is the same when the banana minimum condition of $BA \geq 0$ is imposed on it.

Table 5.12 **Total Discounted Net Revenue for the Irrigated and Non-Irrigated Farm Models when BA ≤ 1**

Model	Irrigated Farm Model	Non-Irrigated Farm Model
BA ≤ 1	$197,578	$62,094

The crop choices for the irrigated farm model when $BA \leq 1$ are exactly the same as those when $BA \geq 0$ (Table 5.4). However, the non-irrigated farm model ($BA \leq 1$) shows a difference in land allocation to annual banana production. Table (5.6) shows the change in land-crop allocation for the non-irrigated farm model when $BA \leq 1$.

5.5 Analysis of Hypothesis

5.5.1 Irrigation Increases the Profitability of the Representative Farm

It is hypothesized that irrigation would increase the profitability of the representative farm. Five indicators are used to compare the relative profitability of the representative farm, with and without supplemental irrigation (Table 5.7).

The total discounted net revenue, which is a proxy for discounted profits, is higher for the representative farm with irrigation rather than without irrigation. In fact, the ratio of discounted net revenue with and without irrigation emphasizes the superiority of the representative farm when irrigated. The irrigated farm model generates three times more total discounted net revenue than the unirrigated farm model.

The ratio of total net revenue to total variable cost (discounted) measures the dollar return to a dollar of variable cost generated by the representative farm, with and without irrigation. For the five difference scenarios presented in the table, the returns to

Table 5.13 Annual Crop Choices in Acres for the Non-Irrigated Model, Given BA ≤ 1

	Non-Irrigated Condition				
	Year				
Enterprise	1	2	3	4	5
BA	0	1	1	0	0
PP	1	1	1	1	1
PF	1	1	1	1	1
BBE	1	1	1	1	1
Total	3	4	4	3	3

discounted variable cost for the irrigated farm range from \$0.71 to \$0.91 while the range for the unirrigated farm is \$0.44 to \$0.73.

The return of daily labour shows how the discounted net revenue is shared between labour that is utilized by the farm. This measure also gives an idea of labour efficiency. Labour used by the represented farm, when irrigated, is much higher than that of the farm when not irrigated. Labour used by the irrigated representative farm is at least 71% more than that used by the farm when not irrigated. In fact, under the most profitable scenario, ($BA \geq 0$), the representative farm with irrigation consumes 96% more labour than when it is not irrigated. However, the return to daily labour for that representative farm model with irrigation is \$45.97 (discounted) compared to \$28.56 (discounted) when not irrigated.

The superior profitability status of the farm with irrigation is due to two main irrigation-related reasons. First, irrigation has made it possible for the farmer to obtain

Table 5.14 Profitability Measures for the Representative Farm With and Without Irrigation

Indicators	BA ≥ 2		BA ≥ 1		BA ≥ 0		BA ≤ 1	
	AM[a]	DM[b]	AM	DM	AM	DM	AM	DM
Total Discounted Net Revenue	\$180,095	\$56,469	\$196,599	\$60,060	\$197,578	\$62,612	\$197,578	\$62,094
Ratio of DNR_{AM} to DNR_{DM}*	3.2	1	3.3	1	3.2	1	3.2	1
Ratio of DNR to DVC**	0.71:1	0.43:1	0.84:1	0.51:1	0.87:1	0.61:1	0.87:1	0.67:1
Return to Labour per Man/Day	\$40.33	\$21.57	\$44.48	\$25.43	\$45.97	\$28.56	\$45.97	\$30.41

[a] AM is the farm when irrigated.
[b] DM is the farm when not irrigated.

* $\frac{DNR_{AM}}{DNR_{DM}}$ is the ratio of discounted net revenue from the irrigated farm to the discounted net revenue from the unirrigated farm.

** $\frac{DNR}{DVC}$ is the ratio of the total discounted net revenue to the total discounted variable costs.

significantly higher yields from the crop enterprises. Secondly, irrigation has induced the production of an additional vegetable enterprise. The combined effect of these two factors translates into higher profitability for the represented farm, under irrigation.

5.5.2 The Relaxation of the Institutional Minimum Constraint and Farm Profitability

The hypothesis states that if irrigation is adopted and the institutional minimum banana acreage is relaxed, farm profitability could increase. This hypothesis investigated the potential conflict between the macro-inspired institutional minimum banana acreage policy and the micro-based profit-maximization interest of the farmer. Secondly, should such a conflict exist, to what extent is the linear programming model capable of providing a compromise solution to that problem?

The imposition of the Government's minimum banana acreage forces the irrigated farm to produce at least two acres of bananas in each of the five years of the life of the representative farm. That particular regime allows the farmer to obtain an expected total discounted net revenue of $180,095 for the five year period. By relaxing the minimum constraint from $BA \geq 2$ to $BA \geq 1$, the expected total discounted net revenue improves to $196,599. When the minimum constraint is $BA \geq 0$ (that is, the farm chooses freely the most optimal level of banana acreage), the expected total discounted net revenue attains its highest level of $197,578 (Table 5.7).

The evidence does in fact support that the relaxation of the institutional minimum banana acreage results in higher levels of profitability. It is also suggested that, given the annual banana yields, the best policy would be for the farm to produce one acre of bananas in each of the last four years of the life of the representative farm.

5.5.3 Irrigation Increases the Profitability of the Banana Enterprise

The hypothesis states that if irrigation is adapted, the banana enterprise would become more profitable. The relevant data for analyzing this hypothesis is capsulized in Table (5.8).

Table 5.15 Presents the Data on the Profitability of the Banana Enterprise when BA ≥ 0 for the Representative Farm, With and Without Irrigation

Indicators	With Irrigation	Without Irrigation
Contribution to total discounted net revenue	$6,920	$1,036
% Contribution to total discounted net revenue	3.5%	1.7%
Number of harvesting years	4	2
Total acreage harvested	4	4
Average annual net revenue (discounted)	$1,730	$259

The banana enterprise is profitable for the farm model, with and without irrigation. Table (5.8) shows that the banana enterprise, when irrigated, generates more than six times the discounted net revenue generated by the unirrigated farm model. In the case of irrigation use, a total of 4 acres of bananas are produced over a four year period. During that time, the banana enterprise increases the total discounted net revenue by 3.5%. Without irrigation, the banana enterprise proves to be less profitable. The banana enterprise, without irrigation, makes an annual expected discounted net return of $259 whereas the banana enterprise, with irrigation, generates $1,730 annually. The use of irrigation in the banana enterprise does increase its profitability.

5.5.4 Relaxation of the Institutional Minimum Banana Acreage on the Representative Farm, With Irrigation, Would Favour Vegetable Enterprise Choices

The imposition of the institutional minimum banana acreage constraint on the irrigated representative farm results in the choice of four crop enterprises. They are BA, PP, BBE and BBS. Of the four enterprises, BBE and BBS are vegetable enterprises. When the minimum constraint $BA \geq 2$ is relaxed to $BA \geq 1$, the PF enterprise enters the solution but the number of vegetable enterprises in the solution remains unchanged. The relaxation to ($BA \geq 0$) does not result in the entry of any of the remaining six vegetable enterprises into the solution. Table F.5 of Appendix F provides the supporting data for the above analysis.

The conclusion is that although those other six vegetable enterprises are high-priced, they are also high-cost operations. Their high production costs render them the least profitable. On this basis, the results fail to support the stated hypothesis.

5.6 Summary of Model Results

The results have demonstrated that farm profitability and performance are superior for the irrigated farm model. Table (5.9) gives a comparison of total discounted net revenue for the irrigated and the unirrigated farm models, subject to the four different banana constraints.

The irrigated farm model, under the imposition of the institutional minimum banana acreage constraint, generates a total discounted net revenue of $180,095. As that constraint ($BA \geq 2$) is relaxed, the total discounted net revenue improves to $196,599 (when $BA \geq 1$) and attains a maximum of $197,578 (when $BA \geq 0$). The unirrigated farm model exhibits the same trend with regards to total discounted net revenue generation.

The crop enterprise choices for the irrigated farm model change when the banana constraint ($BA \geq 2$) is relaxed. Under the conditions ($BA \geq 1$, $BA \geq 0$, and $BA \leq 1$), the crop choices for the irrigated farm model differs from the base model by the inclusion of the passion fruit enterprise (PF). This result demonstrates that the institutional minimum banana acreage requirement ($BA \geq 2$) was crowding out an otherwise profitable crop enterprise.

In the case of the unirrigated farm model, the enterprise choices remain generally the same, irrespective of the banana constraint. The change related to the crop enterprises is seen in the acreages allocated to the banana enterprise in some harvesting years. For example, in the first, fourth and fifth years for the unirrigated farm models ($BA \geq 0$) no

Table 5.16 Total Discounted Net Revenue Per Model Per Moisture Conditions

Model	Irrigated Model	Unirrigated Model
BA ≥ 2	$180,095	$56,469
BA ≥ 1	196,599	60,060
BA ≥ 0	197,578	62,612
BA ≤ 1	197,578	62,094

banana is produced but 2 acres in each of the second and third years are harvested. For the unirrigated farm model ($BA \leq 1$), no harvesting occurs in the first, fourth and fifth years but 1 acre is produced in each of the second and third years. The reason for this might be attributed to the combined effects of the nature of the constraints, production costs and annual yields.

The crop enterprise choices, in terms of most valuable to least valuable for the irrigated model are the rotation of beets, beets and cucumber (BBE), the rotation of beets, beets and sweet potatoes (BBS), papaya (PP), passion fruit (PF) and bananas. For the unirrigated farm model, the enterprises are papaya (PP), passion fruit (PF), the rotation of beets, beets and cucumber (BBE) and bananas. The significant observation, given those results, is that the chosen vegetable enterprises are most valuable to the irrigated farm model whereas the more drought-resistant perennials are most valuable to the unirrigated farm model. Banana is important to both the irrigated and the unirrigated farm models. However, its production is more profitable under irrigated conditions. Also, the production of one acre of bananas instead of two acres, under irrigated conditions makes the farm more profitable. The other six crop enterprises (all vegetable enterprises) were not profitable and did not enter the solution base of either the irrigated or unirrigated farm models.

The main conclusions drawn from the results of the prescriptive farm models are:

i) total discounted net revenue (a proxy for discounted profits) is higher for the irrigated farm model,

ii) the less the restrictions on the farmer's ability to make crop choice decisions, the higher the total discounted net revenue,

iii) given irrigation adoption, the 5-acre allotment seems to be optimal (Table F.5 of Appendix F),

iv) without irrigation, the optimal farm acreage suggested is not precise, and

v) assuming that the dependence on a perennial crop as a foreign exchange earner should persist, papaya qualifies as the best candidate.

Chapter 6. Summary, Limitations and Recommendations

6.1 Summary

6.1.1 Economic Problem, Goal, Objectives and Hypotheses

In the aftermath of the 1983 U.S. invasion of Grenada, the Government of Grenada embarked on a plan to support the growth and development of the small farm sub-sector. The plan embodied the privatization of Government-owned agricultural lands through the creation of small family-size farms, each averaging 5 acres in area. In addition, infrastructural development of the farms was planned to enhance their performance and to create the opportunity for the owners to be full-time commercial farmers. Irrigation development was planned for a set of those farms which belonged to the Model Farms Project. One such group is the Paradise Model Farms.

While it has been demonstrated that irrigation can contribute to improved farm performance and profitability in many parts of the world, a critical economic question remains unanswered. —would it be optimal to irrigate the Paradise Model Farms? Also, to what extent would the use of irrigation affect production decisions of the farm? The general goal of this study is to investigate those issues with regards to the Paradise Model Farms.

Six specific research objectives have been identified in response to the study goal. They are:

i) To identify a farm operation representative of the Paradise Model Farms, defined in terms of physical and financial characteristics;

ii) To build a linear programming model that will simulate the representative farm;

iii) To incorporate irrigation, from a technical and economic perspective, into the model;

iv) To assess the effects of irrigation on production decisions;

v) To assess the effects of irrigation on farm profitability; and

vi) To draw some relevant policy implications.

Furthermore, four hypotheses which relate to the objectives are identified for analysis in order to add greater focus to the study. They are:

i) It is hypothesized that if adopted, irrigation would increase the profitability of the representative farm.

ii) It is hypothesized that if adopted, irrigation would make the banana enterprise more profitable.

iii) It is hypothesized that if irrigation is adopted and the institutional constraint on banana is relaxed, farm profitability would increase.

iv) It is hypothesized that, given irrigation use and the relaxation of the institutional banana constraint, farm production patterns would shift in favour of the vegetable enterprises.

6.1.2 The Representative Farm and Data Development

The major characteristics used to define the representative farm are the physical features of the farm, weather, water availability and use, type of irrigation system in use, and institutional and human factors. Farm inputs and outputs are homogeneous in nature and all input-output relationships are linear.

The representative farm obtains credit to cover its annual variable costs from the Grenada Development Bank. The farm repays the loan at 7% annual interest at the end of the harvesting year. The farm's discount factor is assumed to be equivalent to the cost of borrowing capital.

Input prices are taken from the 1991 price list of the Model Farms Corporation. Output prices are obtained from a variety of sources. Banana prices are taken from the Grenada Banana Cooperative Society while the other prices come from the Marketing and National Import Board. Output prices for the vegetable enterprises are weighted averages over the period, 1989-1991. All output prices are those received by the farmers.

Farm data related to input-output quantities and their relationships are based on the Marks-Murillo study (1989).

The representative farm is simulated under two contrasting moisture scenarios: the inadequate moisture (without irrigation) scenario and the adequate moisture (with irrigation) scenario. The manipulation of the institutional minimum banana acreage, under the two scenarios, provide additional variants of the linear programming farm model.

6.1.3 The Empirical Model

The empirical model used in the analysis is a multi-input, multi-output, multi-period linear programming farm model. The model comprises an objective function which measures the total discounted net revenue subject to a set of activity constraints. The model is linked dynamically by the discount factor in the objective function. The other dynamic links are found in the minimum banana constraint and the maximum constraints on papaya and passion fruit through time.

A moisture constraint is utilized to approximate the influence of irrigation use on the representative farm. The constraint is structured such that the moisture deficit created by inadequate rainfall is supplemented with irrigation moisture. When this constraint is imposed, the model represents the farm with irrigation.

The condition of perfect competition in both the input and output markets is imposed on the model. The model reflects the condition that all its coefficients are known with certainty.

The empirical model provides the basis for a comparative analysis of relative farm profitability of the representative farm, with and without irrigation. Total discounted net revenue is used as a proxy for total discounted profit.

6.1.4 Model Results

The model results demonstrate that farm profitability is higher for the irrigated representative farm model. The higher profitability of the irrigated farm model is due to two main reasons. First, the supplemental amount of irrigation moisture to the representative farm has a yield enhancing effect on crop production. Secondly, the additional profitable vegetable enterprise, a rotation of beets, beets and sweet potatoes (BBS), form part of the solution base for the irrigated farm model.

The perennial crops dominate the solution for the non-irrigated representative farm model. The most profitable to the least profitable crops in the solution for the unirrigated farm model are papaya, passion fruit, a rotation of beets, beets, cucumber (BBE), and banana. However, two vegetable enterprises dominate the solution of the irrigated farm model. In the order of most profitable to least profitable are a rotation of beets, beets, cucumbers (BBE), a rotation of beets, beets, sweet potatoes (BBS), papaya, passion fruit, and banana.

The banana enterprise is more profitable for the irrigated farm model. The optimal banana acreage is determined to be one acre and the two acre minimum constraint is non-optimal. The relaxation of the institutional minimum banana acreage does not lead to the entry of new vegetable enterprises into the solution. This is true for both the irrigated and the non-irrigated farm models.

Finally, Table (6.1) provides a succinct picture of the analysis of the four hypotheses identified.

Table 6.17 Statement on Results of Hypothesis Analysis

Hypothesis	Analysis Conclusion
Hypothesis I	Supported by results.
Hypothesis II	Supported by results.
Hypothesis III	Supported by results.
Hypothesis IV	Not supported by results.

6.2 Limitations

One of the most pervasive limitations encountered in the study is the unavailability of data. As a result of that problem, the study was restricted in its scope. For example, although the linear programming approach was capable of considering more than one production technique,[19] only the one suggested by Marks and Murillo (1989) could have been used. Also, the consideration of only the sprinkler irrigation system exclusively failed to consider the potential effects of other types of irrigation systems on the profitability and performance of the representative farm. Another area that was affected by the limited nature of the data available was the use of constant input and output prices over the multi-period horizon. The non-existence of demand data for the inputs and outputs prevented the study from making reasonable price projections for the future periods of the farm models.

Another limitation refers to the treatment of the irrigation constraint and some of the related assumptions. Again, this limitation is deeply based in the unavailability of data. At one level, the paucity of micro-climatic and soil-water data for the region under study reduced the specificity with which the crop-water requirement and crop-water availability coefficients were constructed. The assumption of free water although consistent with the current policy is not supported by any hard scientific data. Consequently, the study was unable to consider the element of water pricing or to explicitly uphold the present policy of free irrigation water with a confidence based on water resource research for the area.

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[19] Choice of production technique refers to the amount of a variable input or the combination of inputs used to produce a given unit of output.

6.3 Recommendations and Further Research

From the foregone discussion on limitations confronted by the study, a basic but essential recommendation has to do with research and data documentation at the local level. The movement towards more focused agro-based research would assist in the improvement of the present study and, also, provide the basis for similar studies in the future to be more realistic in their scope and usefulness. The immediate research areas should include investigations into various production techniques, water resource, irrigation-related studies and demand and market intelligence studies.

To complement those research undertakings, there is a need to create a structure and local capability for proper documentation. This recommendation is crucial in that, too often, it is discovered that valuable research data no longer exists because it was never well-documented for future retrieval.

Finally, it is recommended that the implementation of macro policy should be done in harmony with the micro-level objectives of the farm. The failure to use that principle as a guideline results in disharmony between Government intentions and those of the individual farmer, as is the case with the banana policy suggested by the results of the prescriptive farm models in this study. The findings suggest that Government's policy of increasing banana production as a means of increasing foreign exchange earnings is not in harmony with the profit maximization objective of the individual farmer. Studies, similar to the present one, would not only demonstrate the efficacy, or lack thereof, of certain policy decisions but would also open windows to other feasible options.

6.4 Conclusion

This chapter has provided a summary of the salient and important points of the study. A brief discussion of some of the limitations confronted by the study has been provided. From that discussion, it is clear that data availability has been a major problem. Finally, the recommendations that have been suggested are done in a broad context because of the pervasive nature of the limitations identified.

Bibliography

Adams, M. and G. Pringle. 1986. Grenada Model Farms Project Report. Ministry of Agriculture, St. George's, Grenada.

Agricultural Planning Unit, Ministry of Agriculture. 1991. Agricultural Policy Document. St. George's, Grenada.

Agricultural Rehabilitation and Crop Diversification Unit, Ministry of Agriculture. 1991. Fresh Fruit and Vegetable Demand. St. George's, Grenada.

Anthony, R.M. 1960. The Trouble with Profit Maximization. Harvard Business Review 38(6):126-134.

Barnard, C.S. and J.S. Nix. 1979. *Farm Planning and Control.* Cambridge University Press, London, New York, Melbourne.

Barry, P.J., J.A. Hopkin and C.B. Baker. 1983. *Financial Management in Agriculture.* 3rd Edition. The Interstate Printers and Publishers, Inc., Danville, Illinois.

Beattie, B.R. and R.C. Taylor. 1985. *The Economics of Production.* John Wiley & Sons, Toronto.

Beddoe, T.W. 1989. The Land Settlement Scheme/Agrarian Reform Model Farms Project—Grenada. CTA-CARDI Seminar, Barbados.

Brooke, A., D. Kendrick and A. Meeraus. 1988. *GAMS A User's Guide.* Scientific press, Redwood, California.

Charles, Francis. 1981. Classification of Soils in Grenada. Ministry of Agriculture, St. George's, Grenada.

Conrad, M. Jon and Colin W. Clarke. 1989. *Natural Resource Economics Notes and Problems.* Cambridge University Press, New York.

Cooter, R. and T. Ullen. 1988. *Law and Economics.* Scott Foresman and Company, Glenview, Illinois. pp. 88-122.

Crafts, A.S. 1968. "Water Deficits and Physiological Processes" in *Plant Water Consumption and Responses: Water Deficits and Plant Growth* by T.T. Kozlowski. Academic Press, New York. Volume II:85-134.

Cyert, M. Richard and James G. March. 1992. *A Behavioural Theory of the Firm.* Blackwell Publishers, Cambridge, Massachusetts.

Doorenboos, J., A.H. Kassam, C.I.M. Bentvelson and V. Branscheid. 1979. Yield Response to Water. Food and Agricultural Organization, Rome.

Dorfman, Robert. 1951. *Application of Linear Programming to the Theory of the Firm.* University of California Press, Berkeley, Los Angeles.

Fereres, E. and David A. Goldhammer. 1990. "Deciduous Fruit and Nut Trees" in *Irrigation of Agricultural Crops* edited by B.A. Stewart and D.R. Nielsen. Agronomy 30:987-1017.

Friedman, Milton. 1962. *Essays in Positive Economics.* University of Chicago Press, Chicago and London.

Galbraith, J.K. 1969. *The New Industrial State.* Houghton Mifflin Company, Boston.

Grenada Model Farms Corporation. Undated. Important Husbandry and Management Practices Notes.

Hazell, P.B.R. and R.N. Norton. 1986. *Mathematical Programming for Economic Analysis in Agriculture.* MacMillan Publisher, New York.

Hiler, E.A. and T.A. Howell. 1983. "Irrigation option to avoid critical stress" in *Limitations to Efficient Water Use in Crop Production* by H.M. Taylor. Madison, Wisconsin. pp. 479-498.

Holder, D. Gordon and Frank A. Gumbs. 1983. Effects of irrigation on the growth and yield of banana. Tropical Agriculture 60(1):25-30.

Holder, d. Gordon and Frank A. Gumbs. 1983. Agronomic assessment of the relative suitability of the banana cultivars 'Robusto' and 'Giant Cavendish' (Williams Hybrid) to irrigation. Tropical Agriculture 60(1):17-24.

Holder, D. Gordon and Frank A. Gumbs. 1983. Effects of nitrogen and irrigation on the growth and yield of banana. Tropical Agriculture 60(3):179-183.

Jacobs, Richard. 1974. "The Movement Towards Independence" in *Independence for Grenada—Myth or Reality by the Institute of International Relations.* University of the West Indies, St. Augustine, Trinidad. pp. 21-33.

Jefferson, Robert W. and Richard N. Boisvert. 1989. *A Guide to Using the General Algebraic Modelling System (GAMS) for Applications in Agricultural Economics.* Department of Agricultural Economics, Cornell University, Ithaca, New York.

Lee, S.M., L.J. Moore and B.W. Taylor. 1990. *Management Science.* Allyn and Bacon, Inc., Brown Publishers, Boston.

Marketing National Importing Board. 1991. Price List of Crops Bought from Farmers. St. George's, Grenada.

Marks, L.R. and J. Murillo-Yepes. 1989. Production Costs and Returns per Acre for Thirty-two Selected Crops. Grenada Development Bank, St. George's, Grenada.

Ministry of Agriculture. 1990. Agricultural Extension Atlas of Grenada. Department of Water and Soil Conservation, St. George's, Grenada.

Ministry of Planning. 1981. Grenada Agricultural Census Report—1981. St. George's, Grenada.

Molenaar, A. 1960. *Irrigation by Sprinkling.* F.A.O. Rome.

Naylor, Thomas H. 1965. A Kuhn-Tucker Model of the Multi-Product, Multi-Factor Firm. *Southern Economic Journal* 31:324-330.

Naylor, Thomas H. 1966. The Theory of the Firm: A Comparison of Marginal Analysis and Linear Programming. *Southern Economic Journal* 32(3):263-274.

Noel, Monique A. 1990. A Critique of the Policy Analysis Matrix with Particular Reference to Banana in Grenada. University of Reading, England.

Oldham, Peter. 1991. Cost of Production of Major Tree Crops in Dominica. Ministry of Agriculture, Rousseau, Dominica.

Orzolek, M.D. and R.B. Caroll. 1978. Yield and Secondary Root Growth of Carrots as Influenced by Tillage System, Cultivation and Irrigation. *Journal of American Society Horticultural Science* 103:286-239.

Robson, M.G. and W.B. Johnson. 1985. Commercial Vegetable Production Recommendations. New Jersey Cooperative Extension Service. Circular E00IA.

Ruttan, V.W. 1977. Induced innovation and agricultural development. Food Policy 2(3):196-216.

Salter, P.J. and J.E. Goods. 1967. Crop Responses at Different Stages of Growth. Commonwealth Agricultural Bureau, Farnham Royal, Bucks, England.

Samson, J.A. 1980. *Tropical Fruits*. Longman Press, London and New York.

Stanley, C.D. and D.M. Maynard. 1990. "Vegetables" in *Irrigation of Agricultural Crops* by B.A. Stewart and D.R. Nielson. Madison, Wisconsin. Agronomy (30):921-950.

Taylor, G.T., P.A. Antione and S.A. Smith. Undated. Estimated Costs of Production for Specialty Crops Produced in the O.E.C.S. Gainsville, Florida.

Thompson Jr., A.A. 1981. *Economics of the Firm-Theory and Practice*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Thompson, C.H. and W.C. Kelly. 1957. *Vegetable Crops*. McGraw and Hill Book Company, Inc., New York, Toronto and London.

Thompson, Robert. 1988. "Toward Agricultural Self-Reliance in Grenada" in *Rethinking Caribbean Development by G.W. Schwyler and Henry Veltmeyer*. International Education Centre. Issues in International Series (2):111-133.

Appendix A. Production and Export Trends in Banana, Cocoa, Nutmegs and Mace for Grenada (1970-1990)

Volume (Tonnes) and Indices of Banana Production and Export for Grenada (1970-1990)

Year	Production	Exports	% Change in Production	% Change in Exports
1970	21,794	18,779	-	-
1971	19,551	14,079	90	75
1972	18,234	12,510	84	67
1973	14,781	10,992	68	59
1974	12,291	8,738	56	47
1975	18,822	13,463	86	72
1976	18,739	15,662	90	83
1977	17,263	14,264	79	76
1978	16,000	14,051	73	75
1979	15,000	13,798	69	73
1980	16,000	11,819	73	63
1981	15,000	11,201	69	60
1982	11,000	9,835	50	52
1983	14,000	8,599	64	46
1984	14,000	8,451	64	45
1985	13,000	8,007	60	43
1986	8,000	7,814	38	42
1987	10,498	8,002	48	43
1988	10,562	8,984	48	48
1989	9,730	8,486	45	45
1990	8,730	7,559	40	40

% Changes are calculated using 1970 as the point of reference.

Volume (Tonnes) and Indices of Cocoa Production and Exports for Grenada (1970-1990)

Year	Production	Exports	% Change in Production	% Change in Exports
1970	3,113	3,020	-	-
1971	2,898	2,732	93	90
1972	2,916	3,303	94	106
1973	3,022	2,733	97	90
1974	2,686	2,584	86	86
1975	2,655	2,645	85	88
1976	3,506	2,657	113	88
1977	2,046	2,129	66	70
1978	2,441	2,365	78	78
1979	2,631	2,447	85	81
1980	2,131	1,825	68	60
1981	2,520	2,678	81	89
1982	2,283	2,270	73	75
1983	2,372	2,293	76	76
1984	2,124	2,005	68	66
1985	2,171	2,041	70	68
1986	1,734	1,640	56	54
1987	1,733	1,703	56	56
1988	1,756	1,675	56	55
1989	1,425	1,429	46	47
1990	1,475	1,489	47	49

% Changes are calculated using 1970 as the point of reference.

Volume (Tonnes) and Indices of Nutmeg Production and Export for Grenada (1970-1990)

Year	Production	Exports	% Change in Production	% Change in Exports
1970	1,391	1,614	-	-
1971	2,014	1,869	148	116
1972	2,014	2,175	145	135
1973	1,649	1,444	119	89
1974	1,183	1,508	85	93
1975	2,085	1,323	150	82
1976	3,071	2,961	221	181
1977	3,394	2,639	244	164
1978	2,590	2,787	186	173
1979	2,565	2,056	184	127
1980	2,744	1,801	197	112
1981	2,651	1,620	191	100
1982	3,080	1,910	221	118
1983	2,399	2,683	172	166
1984	2,519	2,250	181	139
1985	2,340	2,995	168	186
1986	2,575	2,977	185	184
1987	3,010	2,702	216	167
1988	3,038	2,498	218	155
1989	3,382	1,928	243	119
1990	2,905	1,956	209	121

% Changes are calculated using 1970 as the point of reference.

Volume (Tonnes) and Indices of Mace Production and Exports for Grenada (1970-1990)

Year	Production	Exports	% Change in Production	% Change in Exports
1970	199	187	-	-
1971	270	261	136	140
1972	270	358	136	191
1973	284	315	143	168
1974	160	227	80	121
1975	177	111	89	59
1976	479	346	241	185
1977	251	336	126	180
1978	284	249	143	133
1979	313	261	157	140
1980	324	302	163	161
1981	266	223	134	119
1982	252	315	127	168
1983	166	410	83	219
1984	217	1,410	109	754
1985	183	203	92	109
1986	237	317	119	170
1987	340	267	186	143
1988	371	287	186	153
1989	372	197	187	105
1990	269	223	135	119

% Changes are calculated using 1970 as the point of reference.

Appendix B. Existing Analogs Among the Various Models

Static Model	Multi-Period, Multi-Input, Multi-Product Model	L.P. Multi-Period Model
$MR_j = MC_j$ (3.4)	$\left(\frac{1}{1+r}\right)^t p_j = \lambda_{jt} \frac{\partial f(\cdot)}{\partial y_{i,t}}$	$\left(\frac{1}{1+r}\right)^t p_j = \lambda_{ijt} a_{ijt} + M_{djt} l_{djt}$ (3.67)
$\frac{MR_j}{MR_k} = RPT_{jk}$ (3.7)	$\frac{MR_j}{MR_k} = RPT_{j,k,t}$ (3.33)	*
$\frac{MFC_i}{MFC_l} = RTS_{il}$ (3.9)	$\frac{MFC_i}{MFC_l} = RTS_{i,l,t}$ (3.35)	*
$MVP_{ij} = MFC_i$ (3.11)	$MVP_{i,j} = MFC_{i,t}$ (3.37)	$\lambda_{i,j,t} = \left(\frac{1}{1+r}\right)^t r_j$ (3.70)
NA	$\sum_{j=1}^{m} \sum_{t=1}^{v} z_{djt} - z_{dt} = 0$ (3.25)	$z_t - \sum_{j=1}^{m} \sum_{t=1}^{v} l_{djt} y_{djt} = 0$ (3.59)
NA	$Z_{d,t} - Z_{d,t+1} = 0$ (3.27)	$(Z_t - Z_{t+1}) = 0$ (3.63)

* The difficulty associated with coming up with identical profit-maximizing conditions have been discussed on pages 30-31 of this chapter. However, by correctly specifying which activities are associated with which products and which activities are capable of turning out which products, the derivation of the RPT_{jkt} and RTS_{ilt} conditions respectively would be possible.

Appendix C. Criteria for Selection of Model Farm Beneficiaries

Source: Beddoe, 1989

The Selection Committee will appraise applications for model farms on a wide range of criteria. Most of the criteria to be considered will be provided by candidate upon completion of the application form. The Selection Committee may also desire to interview candidates, to obtain recommendations from knowledgeable persons in the Extension Service, or use other methods to obtain information regarding the qualifications of the persons applying for a model farm. The following criteria are presented as guidelines in evaluating applications, and are not to be construed as rules.

1. Age—it is desirable that the applicant be under 45 years of age. One goal of the model farms program is to assist young persons to obtain land suitable for agriculture. Age is also related to adoption of modern farm practices, incentive to invest in crops with a long lifetime such as cocoa, and motivation.

2. Education—completion of primary school is desirable. Modern agriculture requires an ability to read and understand instructions for applying toxic farm chemicals, to obtain and use credit effectively, to learn new skills and new ways of doing things, to solve new problems, and to be aware of alternatives. Persons who have completed the course of instruction at the Farm School will be given special consideration.

3. Health—the candidate should be in generally good health. If there is no doubt about the applicant's health, the Selection Committee may require that the candidate have a physical examination.

4. Family size—preference should be given to persons with a family. In general, a family denotes a degree of stability. The program assumes that in most cases, family labor will be available to work on the model farms.

5. House—preferably but a minor consideration. Living on the model farm may reduce theft of produce. A house may also denote stability.

6. Farm ownership—precedence will be given to landless candidates. Persons who already own farms will be considered on the basis of size of the owned farm, with preference to those with a very small and uneconomic size of holdings. The model farm program is not a project to allow persons who have an adequate amount of land to obtain more.

7. Credit experience—preferable, as it indicates an ability to handle borrowed funds responsibly. However, persons obtaining farms for the first time are unlikely to have a credit background, and should not be disqualified for this reason.

8. Experience in farming—persons who have been raised in agriculture or have an agricultural background will be given precedence.

9. Full-time farmer—a strong consideration. It is believed that farming should be a full-time occupation, and that the model farm will require full-time work of the farm recipient to be successful and to make maximum contributions to the agricultural development of Grenada.

10. Work with Grenada State Farms—workers on the GFC estates will be given high priority. This group of potential beneficiaries already possess a broad range of

skills, experience, and intimate knowledge of the fields and crops already in place on these estates. Consideration will be given to length of service.

11. Willingness to take training in agriculture—a positive consideration. Continued education is required if model farm recipients are to meet production and income levels set as goals of the program. Comments regarding education apply to special training also.

Appendix D. Extended Tables of Model Coefficients

Table D.19 Number, Acreage and Status of Farms Divested in the Paradise Area

Farm Number	Acreage (Hectares)	Status
1	8.55 acres (3.46)	Unirrigated
2	5.72 acres (2.32)	Irrigated
3	5.17 acres (2.09)	Irrigated
4	4.53 acres (1.83)	Irrigated
5	4.58 acres (1.85)	Irrigated
6	5.17 acres (2.09)	Irrigated
7	5.30 acres (2.15)	Irrigated
8	5.49 acres (2.22)	Irrigated
9	6.17 acres (2.49)	Irrigated
10	6.46 acres (2.62)	Unirrigated
11	6.20 acres (2.51)	Irrigated
12	6.28 acres (2.54)	Irrigated

Table D.20 Levels of Nitrogenous Type Fertilizer, 15-7-21+2 Required by Different Crop Enterprises for each Harvesting Year of the Farm in Pounds

Crop Enterprises[a]	Year 1	Year 2	Year 3	Year 4	Year 5
BA	1360	1360	1360	1360	1360
PP	1962	2616	2616	1962	2616
PF	475	475	475	475	475
BCS	880	880	880	880	880
BCE	1430	1430	1430	1430	1430
CCS	1100	1100	1100	1100	1100
CCE	1430	1430	1430	1430	1430
BBE	990	990	990	990	990
BBS	660	660	660	660	660

Source: Marks and Murillo-Yepes, 1989.

[a] The following is the key to the abbreviated names of the crop enterprises:

BA = An acre of the banana enterprise.
PP = An acre of the papaya enterprise.
PF = An acre of the passion fruit enterprise.
BCS = An acre of beets, carrots and sweet potatoes in an annual rotation.
BCE = An acre of beets, carrots and cucumber in an annual rotation.
CCS = An acre of carrots, carrots and sweet potatoes in an annual rotation.
CCE = An acre of carrots, carrots and cucumber in an annual potatoes.
BBE = An acre of beets, beets and cucumber in an annual rotation.
BBS = An acre of beets, beets and sweet potatoes in an annual rotation

Table D.21 Tri-Phosphate in Pounds Required to Produce One Acre of Vegetable Enterprise in each Harvesting Year of the Life of the Representative Farm

Vegetable Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BCS	220	220	220	220	220
BCE	330	330	330	330	330
CCS	220	220	220	220	220
CCE	330	330	330	330	330
BBE	330	330	330	330	330
BBS	220	220	220	220	220

Source: Marks and Murillo-Yepes, 1989.

Table D.22 Sulphate of Ammonia in Pounds Used in the Production of One Acre of Each of the Vegetable Enterprises in each Harvesting Year of the Life of the Representative Farm

Vegetable Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BCS	220	220	220	220	220
BCE	330	330	330	330	330
CCS	220	220	220	220	220
CCE	330	330	330	330	330
BBE	330	330	330	330	330
BBS	220	220	220	220	220

Source: Marks and Murillo-Yepes, 1989.

Table D.23 Crop Requirements for Fertilizer, 16-16-16 in Pounds per Acre and Constant throughout the Life of the Representative Farm

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BCS	880	880	880	880	880
BCE	000	000	000	000	000
CCS	880	880	880	880	880
CCE	000	000	000	000	000
BBE	000	000	000	000	000
BBS	880	880	880	880	880

Table D.24 Average Weighted Requirements of Gramoxone and Vydate, in Gallons, to Produce an Acre of Bananas in each Harvesting Year, Given a Five-Year Rotational Cycle for that Crop

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BA	32.16	32.16	32.16	32.16	32.16

Source: Marks and Murillo-Yepes, 1989.

Table D.25 Requirements of Twine, Sleeving and Crown Pads, in Rolls and Boxes, in Numbers, to Produce an Acre of Bananas in Harvesting Year of the Representative Farm, Given a Five-Year Rotational Cycle

Other Banana Inputs	Year 1.	Year 2	Year 3	Year 4	Year 5
Twine	1.5	1.5	1.5	1.5	1.5
Sleeves	3.5	3.5	3.5	3.5	3.5
Crown Pads	10.77	13.68	15.08	12.0	12.0
+Boxes (a)	776	1268	1372	1056	1056
+Boxes (b)	474	775	839	646	646

Source: Marks and Murillo-Yepes, 1989.

+ Boxes (a) represents the box requirements for the adequate moisture scenario while Boxes (b) represents the box requirements for the inadequate moisture scenario.

Table D.26 Number of Plants Required to Establish an Acre of the Various Crop Enterprises in each Harvesting Year of the Life of the Representative Farm

Crop Enterprises	Year 1	Year 2	Year 3	Year 4	Year 5
BA	680	680	680	680	680
PP	1,308	1,308	1,308	1,308	1,308
PF	380	380	380	380	380
BCS	312,400	312,400	312,400	312,400	312,400
BCE	295,290	295,290	295,290	295,290	295,290
CCS	370,480	370,480	370,480	370,480	370,480
CCE	353,370	353,370	353,370	353,370	353,370
BBE	237,210	237,210	237,210	237,210	237,210
BBS	254,320	254,230	254,230	254,230	254,230

Source: Marks and Murillo-Yepes, 1989.

Table D.27 Number of Packages of Racumen Required to Produce One Acre of Passion Fruits in each Harvesting Year, Given a Five-Year Rotational Cycle for that Crop

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
PF	6.0	6.0	6.0	6.0	6.0

Source: Marks and Murillo-Yepes, 1989.

Table D.28 Malathion Requirements in Litres to Produce an Acre of Papaya in each Harvesting Year

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
PP	5.0	6.0	6.0	5.0	6.0

Source: Marks and Murillo-Yepes, 1989.

Table D.29 Requirements of Champion WP, in Pounds, to Produce an Acre of each Vegetable Enterprise in each Harvesting Year

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BCS	4.0	4.0	4.0	4.0	4.0
BCE	8.0	8.0	8.0	8.0	8.0
CCS	8.0	8.0	8.0	8.0	8.0
CCE	12.0	12.0	12.0	12.0	12.0
BBE	4.0	4.0	4.0	4.0	4.0
BBS	0.0	0.0	0.0	0.0	0.0

Source: Marks and Murillo-Yepes, 1989.

Table D.30 Requirements of Ambush in cc to Produce an Acre of each Enterprise in each Harvesting Year

Crop Enterprise	Year 1	Year 2	Year 3	Year 4	Year 5
BCS	750	750	750	750	750
BCE	500	500	500	500	500
CCS	1000	1000	1000	1000	1000
CCE	500	500	500	500	500
BBE	250	250	250	250	250
BBS	500	500	500	500	500

Source: Marks and Murillo-Yepes, 1989.

Table D.31 Expected Yields for Each of the Crop Enterprises in Pounds per Acre for each Harvesting Year of the Life of the Representative Farm with Irrigation

Crop Enterprises	Year 1	Year 2	Year 3	Year 4	Year 5
BA	22500	36780	39800	30650	30650
PP	33000	23100	15000	7800	33000
PF	8500	9200	9500	8200	8200
BCS	22825	22825	22825	22825	22825
BCE	20501	20501	20501	20501	20501
CCS	18648	18648	18648	18648	18648
CCE	16576	16576	16576	16576	16576
BBE	25650	25650	25650	25650	25650
BBS	28310	28310	28310	28310	28310

Source: Marks and Murillo-Yepes, 1989.

Table D.32 Expected Yields for Each of the Crop Enterprises in Pounds per Acre for each Harvesting Year of the Life of the Representative Farm without Irrigation

Crop Enterprises	Year 1	Year 2	Year 3	Year 4	Year 5
BA	13750	22477	24322	18730	18730
PP	20163	14116	9167	4766	20163
PF	5194	5621	5808	5011	5011
BCS	12308	12308	12308	12308	12308
BCE	13265	13265	13265	13265	13265
CCS	11028	11028	11028	11028	11028
CCE	10726	10726	10726	10726	10726
BBE	16597	16597	16597	16597	16597
BBS	16742	16742	16742	16742	16742

Source: Marks and Murillo-Yepes, 1989.

Table D.33 Labour Requirements in Man/Days for Each of the Crop Enterprises in each Year of the Representative Farm, Given the Rotational Cycles of the Specific Crops, under Irrigation

Crop Enterprises	Year 1	Year 2	Year 3	Year 4	Year 5
BA	122	92	92	92	92
PP	137	95	95	95	137
PF	121	81	81	81	81
BCS	308	238	238	238	238
BCE	262	192	192	192	192
CCS	302	232	232	232	232
CCE	256	186	186	186	186
BBE	268	198	198	198	198
BBS	314	244	244	244	244

Table D.34 Labour Requirements in Man/Days for Each of the Crop Enterprises in each Year of the Representative Farm, Given the Rotational Cycles of the Specific Crops, without Irrigation

Crop Enterprises	Year 1	Year 2	Year 3	Year 4	Year 5
BA	90	66	66	66	66
PP	100	66	66	66	100
PF	115	75	75	75	75
BCS	287	217	217	217	217
BCE	236	166	166	166	166
CCS	275	208	208	208	208
CCE	227	157	157	157	157
BBE	245	175	175	175	175
BBS	296	226	226	226	226

Table D.35Prices of the Various Inputs Used in the Production of the Different Crop Enterprises in each Harvesting Year and are Assumed to be Constant for all Periods

Input Names	Price Per Unit Of Input ($E.C)
15-7-21+2 Fertilizer	0.5/lb.
Tri-Phosphate	0.58/lb.
Sulphate of Ammonia	0.39/lb.
16-16-16 Fertilizer	0.5/lb.
Gramoxone and Vydate	29.62/gal.
Racumen	48.83/pack
Malathion	29.49/litre
Champion WP	14.99/lb.
Ambush	0.356/c.c.
Sleeving	195/roll
Box	1.25/box
Twine	37/roll
Wire	240/roll
Crown Pads	7.8/roll
Hired Labour	20/man/day
Banana Plants	1.00/plant
Papaya Plants	0.25/plant
Passion Fruit Plants	1.0/plant
BCS Plants	0.05/plant
BCE	0.05/plant
CCS Plants	0.05/plant
CCE Plants	0.05/plant
BBE Plants	0.05/plant
BBS Plants	0.05/plant

Table D.36 Average Output Prices Received by the Farmer for a Pound of Each Enterprise (Prices in Eastern Caribbean Currency)

Enterprise Output	Output Price
BA	0.33
PP	0.45
PF	0.9833
BCS	1.5069
BCE	1.4026
CCS	1.3452
CCE	1.2099
BBE	1.5624
BBS	1.6437

Table D.37 Discount Factors Used in the Farm Model (Rate of Discount is 7%)

Year	Discount Factor
1	0.9346
2	0.8734
3	0.8163
4	0.7629
5	0.7129

Source: Barry, Hopkin and Baker, 1983.

Table D.38 Crop-Water Requirements and Rainfall Moisture Availability in Inches (All Values Assumed to be Constant)

Crop Enterprise	Crop Water Requirements	Moisture Available from Rainfall
BA	90	55
PP	90	55
PF	90	55
BCS	102	55
BCE	85	55
CCS	93	55
CCE	85	55
BBE	85	55
BBS	93	55

Table D.39 Actual Three-Year Average Price of the Individual Crops (Prices are in Eastern Caribbean Currency)

Crops	Average Price ($E.C.)
Banana	$0.33
Papaya	0.45
Passion Fruit	0.983
Beets	2.026
Carrots	1.626
Cucumber	0.46
Sweet Potatoes	0.97

Appendix E. Discussion on Marginal (Shadow) Values

The marginal (shadow) values have their interpretational significance grounded in the profit-maximization principle of the marginal value product equal to marginal factor cost. Thus, it would not be contradictory to interpret, in the study, a shadow price, on a given enterprise, as the additional amount to the objective function due to an additional unit of production on the margin. Similarly, the marginal or shadow value associated with a resource, for example land, would be interpreted as an additional cost associated with the use of an additional unit of land on the margin.

Following Stokey and Zeckhauser (1976), five facts about shadow prices, relevant to the present study, need to be stated. First, any resource that is being utilized below its capacity must have a $0 marginal (shadow) price. An example is the shadow values on land seen in the model variant $\boldsymbol{BA} \leq 0$ of Table J. Second, shadow prices are only valid as long as the relevant resources remain within the bounds of the model. Third, the nature of the constraint on the activity or resource would determine the character of the interpretation of the given value. For instance, because of the minimum constraint placed on the banana enterprise in the model variant $\boldsymbol{BA} \geq 2$, the relationship between an additional unit increase in the banana enterprise and the marginal value is an inverse one. However, in the case of the other enterprises, the interpretational relationship is direct because of the imposition of maximum constraints. Fourth, it can be expected of an enterprise that has a $0 shadow value in one model variant to take on a non-zero positive value in another model variant. A case in point is the passion fruit (PF) enterprise. The PF enterprise has a $0 shadow value in the model variant $\boldsymbol{BA} \geq 1$ but then takes on positive values in model $\boldsymbol{BA} \geq 0$. You are referred to Table H. Finally, shadow prices, when properly interpreted, provide valuable insights into the efficacy of certain policy decisions. This shall be demonstrated as the minimum institutional constraint on the banana enterprise is analyzed.

Appendix F. Extended Table of Results

Table F.1 Annual Non-discounted Net Revenue Per Model Under Adequate Moisture

Model	Year 1	Year 2	Year 3	Year 4	Year 5
BA ≥ 2	$36618	$46963	$48233	$44371	$44371
BA ≥ 1	$41342	$50150	$51049	$49118	$49118
BA ≥ 0	$42390	$50150	$51049	$49118	$49118
BA ≤ 1	$42390	$50150	$51049	$49118	$49118

Table F.2 Annual Non-Discounted Net Revenue Per Model Under Moisture Deficit

Model	Year 1	Year 2	Year 3	Year 4	Year 5
BA ≥ 2	$7837	$15945	$16874	$14530	$14530
BA ≥ 1	$10072	$15945	$16874	$15197	$15924
BA ≥ 0	$12307	$15945	$16874	$15864	$15864
BA ≤ 1	$12307	$15823	$16370	$15863	$16550

Table F.3 Annual Non-Discounted Variable Costs Per Model Under Adequate Moisture

Model	Year 1	Year 2	Year 3	Year 4	Year 5
BA ≥ 2	$63467	$61727	$62217	$60746	$60746
BA ≥ 1	$59813	$56123	$56368	$55633	$55633
BA ≥ 0	$52589	$56123	$56367	$55633	$55633
BA ≤ 1	$52589	$56123	$56367	$55633	$55633

Table F.4 Annual Non-Discounted Variable Costs Per Model Under Moisture Deficit

Model	Year 1	Year 2	Year 3	Year 4	Year 5
BA ≥ 2	$33999	$31619	$31929	$31013	$31013
BA ≥ 1	$28094	$31619	$31929	$25191	$24511
BA ≥ 0	$22190	$31619	$31929	$19370	$19370
BA ≤ 1	$22190	$25494	$25649	$19370	$19370

Table F.5 Acres of the Various Crop Enterprises Harvested Annually Under Adequate Moisture

For Model BA ≥ 2

Year	BA	PP	BBE	BBS	Total
	Enterprises in Solution				
1	2	1	1	1	5
2	2	1	1	1	5
3	2	1	1	1	5
4	2	1	1	1	5
5	2	1	1	1	5

For Model BA ≥ 1

Year	BA	PP	PF	BBE	BBS	Total
	Enterprises in Solution					
1	1	1	1	1	1	5
2	1	1	1	1	1	5
3	1	1	1	1	1	5
4	1	1	1	1	1	5
5	1	1	1	1	1	5

For Model BA ≥ 0

Year	BA	PP	PF	BBE	BBS	Total
	Enterprises in Solution					
1	0	1	1	1	1	4
2	1	1	1	1	1	5
3	1	1	1	1	1	5
4	1	1	1	1	1	5
5	1	1	1	1	1	5

Table F.5 (Continued)

For Model BA ≤ 1						
			Enterprises in Solution			
Year	BA	PP	PF	BBE	BBS	Total
1	0	1	1	1	1	4
2	1	1	1	1	1	5
3	1	1	1	1	1	5
4	1	1	1	1	1	5
5	1	1	1	1	1	5

Table F.6 Acres of the Various Crop Enterprises Harvested Annually Under Moisture Deficit

For Model BA ≥ 2

	Enterprises in Solution				
Year	BA	PP	PF	BBE	Total
1	2	1	1	1	5
2	2	1	1	1	5
3	2	1	1	1	5
4	2	1	1	1	5
5	2	1	1	1	5

For Model BA ≥ 1

	Enterprises in Solution				
Year	BA	PP	PF	BBE	Total
1	1	1	1	1	4
2	2	1	1	1	5
3	2	1	1	1	5
4	1	1	1	1	4
5	1	1	1	1	4

For Model BA ≥ 0

	Enterprises in Solution				
Year	BA	PP	PF	BBE	Total
1	0	1	1	1	3
2	2	1	1	1	5
3	2	1	1	1	5
4	0	1	1	1	3
5	0	1	1	1	3

Table F.6 (Continued)

For Model BA ≤ 1					
		Enterprises in Solution			
Year	BA	PP	PF	BBE	Total
1	0	1	1	1	3
2	1	1	1	1	4
3	1	1	1	1	4
4	0	1	1	1	3
5	0	1	1	1	3

Table F.7 Annual Marginal Values of the Crop Enterprises in Solution for the Various Models Under Adequate Moisture

For Model BA ≥ 2

Year	BA	PP	BBE	BBS
		Enterprises in Solution		
1	($8148)	$0	$3931	$3634
2	($2783)	$2342	$7324	$7046
3	($2299)	$1972	$6629	$6369
4	($3621)	$1843	$6195	$5953
5	($3384)	$1723	$5789	$5562

For Model BA ≥ 1

Year	BA	PP	PF	BBE	BBS
		Enterprises in Solution			
1	($4415)	$4502	$0	$8434	$8137
2	($2783)	$2342	$0	$7324	$7045
3	($2298)	$1972	$0	$6629	$6369
4	$0	$5465	$0	$9816	$9574
5	($3384)	$1723	$0	$5789	$5562

For Model BA ≥ 0

Year	BA	PP	PF	BBE	BBS
		Enterprises in Solution			
1	-	$7939	$3436	$11870	$11573
2	$0	$5125	$2783	$10107	$9829
3	$0	$4271	$2299	$8928	$8668
4	$0	$5465	$3622	$9817	$9574
5	$0	$5107	$3384	$9174	$8947

Table F.7 (Continued)

For Model BA ≤ 1					
		Enterprises in Solution			
Year	BA	PP	PF	BBE	BBS
1	-	$7939	$3436	$11870	$11573
2	$0	$5125	$2783	$10107	$9829
3	$0	$4271	$2299	$8927	$8668
4	$0	$5465	$3622	$9817	$9574
5	$0	$5107	$3384	$9174	$8947

Table F.8 Annual Marginal Values of the Crop Enterprises in the Solution for the Various Models Under Moisture Deficit

For Model BA ≥ 2

Year	BA	PP	PF	BBE
		Enterprises in Solution		
1	($2539)	$3369	$380	$0
2	$0	$3463	$2326	$1623
3	$0	$2925	$1996	$1205
4	($508)	$3118	$2249	$1511
5	($1887)	$1502	$689	$0

For Model BA ≥ 1

Year	BA	PP	PF	BBE
		Enterprises in Solution		
1	($2088)	$3820	$831	$451
2	$0	$3460	$2326	$1623
3	$0	$2925	$1996	$1205
4	($508)	$3118	$2249	$1511
5	($475)	$3432	$2101	$1412

For Model BA ≥ 0

Year	BA	PP	PF	BBE
		Enterprises in Solution		
1	-	$3820	$831	$451
2	$0	$3460	$2326	$1623
3	$0	$2925	$1996	$1205
4		$3118	$2249	$1511
5		$3432	$2101	$1412

Table F.8 (Continued)

For Model BA ≤ 1				
		Enterprises in Solution		
Year	BA	PP	PF	BBE
1		$3820	$831	$451
2	$107	$3570	$2433	$1730
3	$412	$3336	$2408	$1616
4		$3118	$2249	$1511
5		$2914	$2101	$1412

Table F.9 **Annual Marginal Values on Land Per Model Per Moisture Scenario**

For Model BA ≥ 2

Year	Adequate Moisture	Moisture Deficit
1	$7939	$451
2	$5077	$107
3	$4961	$412
4	$4637	$0
5	$4333	$1412

For Model BA ≥ 1

Year	Adequate Moisture	Moisture Deficit
1	$3436	$0
2	$5077	$107
3	$4961	$412
4	$1015	$0
5	$4333	$0

For Model BA ≥ 0

Year	Adequate Moisture	Moisture Deficit
1	$0	$0
2	$2294	$107
3	$2662	$412
4	$1015	$0
5	$948	$0

Table F.9 (Continued)

For Model BA ≤ 1		
Year	Adequate Moisture	Moisture Deficit
1	\$0	\$0
2	\$2294	\$0
3	\$2662	\$0
4	\$1015	\$0
5	\$948	\$0

Table F.10 Total Man/Days Utilized Per Model Per Moisture Condition

Model	Adequate Moisture*	Moisture Deficit**
BA ≥ 2	4465	2618
BA ≥ 1	4420	2362
BA ≥ 0	4298	2192
BA ≤ 1	4298	2042

* The total man/days per model are the sum of hired labour, family labour and labour used to operate irrigation system.

** The total man/days per model are the sum of hired labour and family labour.

Appendix G. Equation Listings of The Basic Irrigated and Unirrigated Farm Models

Equation Listings for Unirrigated Farm Model

```
VARIABLES
ACRE(CR,ST,HA)   ACRES IN HARVESTING YEAR
FERT1(HA)        15-7-21+2 FERTILISER PURCHASES
FERT2(HA)        TRIPHOSPHATE PURCHASES
FERT3(HA)        SULPHATE PURCHASES
FERT4(HA)        16-16-16 PURCHASES
CHEM1(HA)        GRAMOXONE AND VYDATE PURCHASES
CHEM2(HA)        RACUMEN PURCHASES
CHEM3(HA)        MALATHION PURCHASES
CHEM4(HA)        CHAMPION WP PURCHASES
CHEM5(HA)
PURBLO(HA)       BANANA PLANT PURCHASES
PURPA(HA)        PAPAYA PLANT PURCHASES
PURPASS(HA)      PASSIONFRUIT PLANT PURCHASES
BET(HA)          BCS PLANT PURCHASES
CAT(HA)          BCE PLANT PURCHASES
SWEET(HA)        CCSPLANT PURCHASES
EAT(HA)          CCE PLANTPURCHASES
BOW(HA)          BBE PLANT PURCHASES
ARROW(HA)        BBS PLANT PURCHASES
LEAF(HA)         SLEEVE PURCHASES
OX(HA)           BOX PURCHASES
WIN(HA)          TWINE PURCHASES
COVER(HA)        CROWNPAD PURCHASES
IRE(HA)          WIRE PURCHASES
NLC(HA)          NEW LAND CLEARING
HL(HA)           HIRED LABOUR IN MANDAYS
OPCOST(HA)       OPERATING COSTS IN DOLLARS
LN(HA)           LOAN TAKINGS
NR(HA)           NET REVENUE
Z                DISCOUNTED NET REVENUE;
```

```
POSITIVE VARIABLES
ACRE,FERT1,FERT2,FERT3,FERT4,CHEM1,CHEM2,CHEM3,
                CHEM4,PURBLO,PURPA,PURPASS,BET,CAT,SWEET,EAT,
                BOW,ARROW,LEAF,OX,WIN,COVER,IRE,NLC,HL,OPCOST,
                LN,CHEM5;
EQUATIONS
OBJECTIVE       CALCULATION OF DISCOUNTED NET REVENUES
LAND(HA)        LAND USE IN EACH YEAR
BANCON(HA)      MINIMUM CONSTRAINT ON BA ENTERPRISE
PAPCON(HA)      MAXIMUM CONSTRAINTON PAPAYA
PASCON(HA)      MAXIMUM CONSTRAINT ON PASSION FRUIT
BESCON(HA)      MAXIMUM CONSTRAINT ON BCS
BICCON(HA)      MAXIMUM CONSTRAINT ON BCE
CACCON(HA)      MAXIMUM CONSTRAINT ON CCS
CECCON(HA)      MAXIMUM CONSTRAINTON CCE
BIBCON(HA)      MAXIMUM CONSTRAINT ON BBE
BSBCON(HA)      MAXIMUM CONSTRAINT ON BBS
FE1(HA)
FE2(HA)
FE3(HA)
FE4(HA)
CH1(HA)
CH2(HA)
CH3(HA)
CH4(HA)
CH5(HA)
PLBAN(HA)       BA PLANT CONSTRAINT
PLPAP(HA)       PP OLANT CON
PLPAS(HA)       PF PLANT CON
PLBES(HA)       BCS PLANT CON
PLBIC(HA)       BCE PLANT CON
PLCAC(HA)       CCS PLANT CON
PLCEC(HA)       CCE PLANT CON
PLBIB(HA)       BBE PLANT CON
PLBSB(HA)       BBS PLANT CON
SLECON(HA)      SLEEVE CON
XCON(HA)        BOX CON
TWN(HA)         TWINE CON
CWPCON(HA)      CROWNPAD CON
WICON(HA)       WIRE CON
LABOUR(HA)
COST(HA)
LOAN(HA)
NETREV(HA)      ANNUAL PROFITCON;
```

```
OBJECTIVE  .. Z=E=SUM(HA,DISCOUNT(HA)*NR(HA));
LAND(HA)   .. SUM((CR,ST),FRUIT(CR,ST,HA)*ACRE(CR,ST,HA))=L=5;
BANCON(HA) .. SUM(ST,FRUIT("BA",ST,HA)*ACRE("BA",ST,HA))=G=2;
PAPCON(HA) .. SUM(ST,FRUIT("PP",ST,HA)*ACRE("PP",ST,HA))=L=1;
PASCON(HA) .. SUM(ST,FRUIT("PF",ST,HA)*ACRE("PF",ST,HA))=L=1;
BESCON(HA) .. SUM(ST,FRUIT("BCS",ST,HA)*ACRE("BCS",ST,HA))=L=1;
BICCON(HA) .. SUM(ST,FRUIT("BCE",ST,HA)*ACRE("BCE",ST,HA))=L=1;
CACCON(HA) .. SUM(ST,FRUIT("CCS",ST,HA)*ACRE("CCS",ST,HA))=L=1;
CECCON(HA) .. SUM(ST,FRUIT("CCE",ST,HA)*ACRE("CCE",ST,HA))=L=1;
BIBCON(HA) .. SUM(ST,FRUIT("BBE",ST,HA)*ACRE("BBE",ST,HA))=L=1;
BSBCON(HA) .. SUM(ST,FRUIT("BBS",ST,HA)*ACRE("BBS",ST,HA))=L=1;
FE1(HA)    .. SUM((CR,ST),FERTREQ1(CR,ST,HA)*ACRE(CR,ST,HA))
              -FERT1(HA)=L=0;
FE2(HA)    .. SUM((CR,ST),FERTREQ2(CR,ST,HA)*ACRE(CR,ST,HA))
              -FERT2(HA)=L=0;
FE3(HA)    .. SUM((CR,ST),FERTREQ3(CR,ST,HA)*ACRE(CR,ST,HA))
              -FERT3(HA)=L=0;
FE4(HA)    .. SUM((CR,ST),FERTREQ4(CR,ST,HA)*ACRE(CR,ST,HA))
              -FERT4(HA)=L=0;
CH1(HA)    .. SUM((CR,ST),CHEMREQ1(CR,ST,HA)*ACRE(CR,ST,HA))
              -CHEM1(HA)=L=0;
CH2(HA)    .. SUM((CR,ST),CHEMREQ2(CR,ST,HA)*ACRE(CR,ST,HA))
              -CHEM2(HA)=L=0;
CH3(HA)    .. SUM((CR,ST),CHEMREQ3(CR,ST,HA)*ACRE(CR,ST,HA))
              -CHEM3(HA)=L=0;
CH4(HA)    .. SUM((CR,ST),CHEMREQ4(CR,ST,HA)*ACRE(CR,ST,HA))
              -CHEM4(HA)=L=0;
CH5(HA)    .. SUM((CR,ST),CHEMREQ5(CR,ST,HA)*ACRE(CR,ST,HA))
              -CHEM5(HA)=L=0;
PLBAN(HA)  .. SUM(ST,PLANTS("BA",ST,HA)*(ACRE("BA",ST,HA)))
              -PURBLO(HA)=L=0;
PLPAP(HA)  .. SUM(ST,PLANTS("PP",ST,HA)*(ACRE("PP",ST,HA)))
              -PURPA(HA)=L=0;
PLPAS(HA)  .. SUM(ST,PLANTS("PF",ST,HA)*(ACRE("PF",ST,HA)))
              -PURPASS(HA)=L=0;
PLBES(HA)  .. SUM(ST,PLANTS("BCS",ST,HA)*(ACRE("BCS",ST,HA)))
              -BET(HA)=L=0;
PLBIC(HA)  .. SUM(ST,PLANTS("BCE",ST,HA)*(ACRE("BCE",ST,HA)))
              -CAT(HA)=L=0;
PLCEC(HA)  .. SUM(ST,PLANTS("CCE",ST,HA)*(ACRE("CCE",ST,HA)))
              -EAT(HA)=L=0;
PLCAC(HA)  .. SUM(ST,PLANTS("CCS",ST,HA)*(ACRE("CCS",ST,HA)))
              -SWEET(HA)=L=0;
```

```
PLBIB(HA)  ..  SUM(ST,PLANTS("BBE",ST,HA)*(ACRE("BBE",ST,HA)))
            -BOW(HA)=L=0;
PLBSB(HA)  ..  SUM(ST,PLANTS("BBS",ST,HA)*(ACRE("BBS",ST,HA)))
            -ARROW(HA)=L=0;
SLECON(HA)  ..
SUM(ST,PASLEV(ST,HA)*(ACRE("BA",ST,HA)))-LEAF(HA)=L=0;
XCON(HA)  ..  SUM(ST,PABOX(ST,HA)*(ACRE("BA",ST,HA)))-OX(HA)=L=0;
TWN(HA)  ..
SUM(ST,PATWINE(ST,HA)*(ACRE("BA",ST,HA)))-WIN(HA)=L=0;
CWPCON(HA)  ..
SUM(ST,CROWN(ST,HA)*(ACRE("BA",ST,HA)))-COVER(HA)=L=0;
WICON(HA)  ..  SUM(ST,WIRE(ST,HA)*(ACRE("PF",ST,HA)))-IRE(HA)=L=0;
LABOUR(HA)  ..
SUM((CR,ST),LABREQ(CR,ST,HA)*ACRE(CR,ST,HA))-HL(HA)=L=320;
COST(HA)  ..
0.5*FERT1(HA)+0.58*FERT2(HA)+0.39*FERT3(HA)+0.5*FERT4(HA)

+26.63*CHEM1(HA)+48.83*CHEM2(HA)+29.5*CHEM3(HA)+15*CHEM4(HA)

+0.356*CHEM5(HA)+1.0*PURBLO(HA)+0.25*PURPA(HA)+1.0*PURPASS(HA)

+0.05*BET(HA)+0.05*CAT(HA)+0.05*SWEET(HA)+0.05*EAT(HA)+0.05*

BOW(HA)+0.05*ARROW(HA)+20.0*HL(HA)+195*LEAF(HA)+2.25*OX(HA)

+37.0*WIN(HA)+240.0*IRE(HA)+7.8*COVER(HA)-OPCOST(HA)
            =L=0;
LOAN(HA)  ..  OPCOST(HA)-LN(HA)=L=0;
NETREV(HA)  ..
SUM((CR,ST),YIELD(CR,ST,HA)*ACRE(CR,ST,HA)*0.9*PRICE(CR))
            -(OPCOST(HA)+0.07*LN(HA))-NR(HA)=G=0;

MODEL ACCABRE/ALL/;
OPTION LIMROW=100;
SOLVE ACCABRE USING LP MAXIMIZING Z;
```

Equation Listings for Irrigated Farm Model

VARIABLES	
ACRE(CR,ST,HA)	ACRES IN HARVESTING YEAR
FERT1(HA)	15-7-21+2 FERTILISER PURCHASES
FERT2(HA)	TRIPHOSPHATE PURCHASES
FERT3(HA)	SULPHATE PURCHASES
FERT4(HA)	16-16-16 PURCHASES
CHEM1(HA)	GRAMOXONE AND VYDATE PURCHASES
CHEM2(HA)	RACUMEN PURCHASES
CHEM3(HA)	MALATHION PURCHASES
CHEM4(HA)	CHAMPION WP PURCHASES
CHEM5(HA)	
PURBLO(HA)	BANANA PLANT PURCHASES
PURPA(HA)	PAPAYA PLANT PURCHASES
PURPASS(HA)	PASSIONFRUIT PLANT PURCHASES
BET(HA)	BCS PLANT PURCHASES
CAT(HA)	BCE PLANT PURCHASES
SWEET(HA)	CCSPLANT PURCHASES
EAT(HA)	CCE PLANTPURCHASES
BOW(HA)	BBE PLANT PURCHASES
ARROW(HA)	BBS PLANT PURCHASES
LEAF(HA)	SLEEVE PURCHASES
OX(HA)	BOX PURCHASES
WIN(HA)	TWINE PURCHASES
COVER(HA)	CROWNPAD PURCHASES
IRE(HA)	WIRE PURCHASES
NLC(HA)	NEW LAND CLEARING
HL(HA)	HIRED LABOUR IN MANDAYS
OPCOST(HA)	OPERATING COSTS IN DOLLARS
LN(HA)	LOAN TAKINGS
NR(HA)	NET REVENUE
Z	DISCOUNTED NET REVENUES
ARIG(HA)	IRRIGATION MOISTURE PURCHASED FOR BA
BRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR PP
CRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR PF
DRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR BCS
ERIG(HA)	IRRIGATION MOISTURE PURCHASED FOR BCE
FRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR CCS
GRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR CCE
HRIG(HA)	IRRIGATION MOISTURE FOR BBE
IRIG(HA)	IRRIGATION MOISTURE PURCHASED FOR BBS;

```
POSITIVE VARIABLES
ACRE,FERT1,FERT2,FERT3,FERT4,CHEM1,CHEM2,CHEM3,
              CHEM4,PURBLO,PURPA,PURPASS,BET,CAT,SWEET,EAT,
              BOW,ARROW,LEAF,OX,WIN,COVER,IRE,NLC,HL,OPCOST,
              LN,CHEM5,ARIG,BRIG,CRIG,DRIG,ERIG,FRIG,GRIG,
              HRIG,IRIG;
EQUATIONS
OBJECTIVE     CALCULATION OF DISCOUNTED NET REVENUES
LAND(HA)      LAND USE IN EACH YEAR
BANCON(HA)    MINIMUM CONSTRAINT ON BA ENTERPRISE
PAPCON(HA)    MAXIMUM CONSTRAINTON PAPAYA
PASCON(HA)    MAXIMUM CONSTRAINT ON PASSION FRUIT
BESCON(HA)    MAXIMUM CONSTRAINT ON BCS
BICCON(HA)    MAXIMUM CONSTRAINT ON BCE
CACCON(HA)    MAXIMUM CONSTRAINT ON CCS
CECCON(HA)    MAXIMUM CONSTRAINTON CCE
BIBCON(HA)    MAXIMUM CONSTRAINT ON BBE
BSBCON(HA)    MAXIMUM CONSTRAINT ON BBS
FE1(HA)
FE2(HA)
FE3(HA)
FE4(HA)
CH1(HA)
CH2(HA)
CH3(HA)
CH4(HA)
CH5(HA)
PLBAN(HA)     BA PLANT CONSTRAINT
PLPAP(HA)     PP OLANT CON
PLPAS(HA)     PF PLANT CON
PLBES(HA)     BCS PLANT CON
PLBIC(HA)     BCE PLANT CON
PLCAC(HA)     CCS PLANT CON
PLCEC(HA)     CCE PLANT CON
PLBIB(HA)     BBE PLANT CON
PLBSB(HA)     BBS PLANT CON
SLECON(HA)    SLEEVE CON
XCON(HA)      BOX CON
TWN(HA)       TWINE CON
CWPCON(HA)    CROWNPAD CON
WICON(HA)     WIRE CON
LABOUR(HA)
COST(HA)
LOAN(HA)
```

```
NETREV(HA)   ANNUAL PROFITCON
AWA(HA)     IRRIGATION CON ON BA
PWA(HA)     IRRIGATION CON ON PP
FWA(HA)     IRRIGATION CON ON PF
CSWA(HA)    IRRIGATION CON ON BCS
CEWA(HA)    IRRIGATION CON ON BCE
CWA(HA)   IRRIGATION CON ON CCS
EWA(HA)   IRRIGATION CON ONCCE
DEWA(HA)   IRRIGATION CON ON BBE
BSWA(HA)   IRRIGATION CON ON BBS;


OBJECTIVE   ..  Z=E=SUM(HA,DISCOUNT(HA)*NR(HA));
LAND(HA)    ..  SUM((CR,ST),FRUIT(CR,ST,HA)*ACRE(CR,ST,HA))=L=5;
BANCON(HA) ..  SUM(ST,FRUIT("BA",ST,HA)*ACRE("BA",ST,HA))=G=2;
PAPCON(HA)  ..  SUM(ST,FRUIT("PP",ST,HA)*ACRE("PP",ST,HA))=L=1;
PASCON(HA)  ..  SUM(ST,FRUIT("PF",ST,HA)*ACRE("PF",ST,HA))=L=1;
BESCON(HA)  ..  SUM(ST,FRUIT("BCS",ST,HA)*ACRE("BCS",ST,HA))=L=1;
BICCON(HA)  ..  SUM(ST,FRUIT("BCE",ST,HA)*ACRE("BCE",ST,HA))=L=1;
CACCON(HA)  ..  SUM(ST,FRUIT("CCS",ST,HA)*ACRE("CCS",ST,HA))=L=1;
CECCON(HA)  ..  SUM(ST,FRUIT("CCE",ST,HA)*ACRE("CCE",ST,HA))=L=1;
BIBCON(HA)  ..  SUM(ST,FRUIT("BBE",ST,HA)*ACRE("BBE",ST,HA))=L=1;
BSBCON(HA)  ..  SUM(ST,FRUIT("BBS",ST,HA)*ACRE("BBS",ST,HA))=L=1;
FE1(HA)      ..  SUM((CR,ST),FERTREQ1(CR,ST,HA)*ACRE(CR,ST,HA))
                 -FERT1(HA)=L=0;
FE2(HA)      ..  SUM((CR,ST),FERTREQ2(CR,ST,HA)*ACRE(CR,ST,HA))
                 -FERT2(HA)=L=0;
FE3(HA)      ..  SUM((CR,ST),FERTREQ3(CR,ST,HA)*ACRE(CR,ST,HA))
                 -FERT3(HA)=L=0;
FE4(HA)     ..  SUM((CR,ST),FERTREQ4(CR,ST,HA)*ACRE(CR,ST,HA))
                -FERT4(HA)=L=0;
CH1(HA)     ..  SUM((CR,ST),CHEMREQ1(CR,ST,HA)*ACRE(CR,ST,HA))
                -CHEM1(HA)=L=0;
CH2(HA)     ..  SUM((CR,ST),CHEMREQ2(CR,ST,HA)*ACRE(CR,ST,HA))
                -CHEM2(HA)=L=0;
CH3(HA)     ..  SUM((CR,ST),CHEMREQ3(CR,ST,HA)*ACRE(CR,ST,HA))
                -CHEM3(HA)=L=0;
CH4(HA)     ..  SUM((CR,ST),CHEMREQ4(CR,ST,HA)*ACRE(CR,ST,HA))
                -CHEM4(HA)=L=0;
CH5(HA)     ..  SUM((CR,ST),CHEMREQ5(CR,ST,HA)*ACRE(CR,ST,HA))
                -CHEM5(HA)=L=0;
PLBAN(HA)      .. SUM(ST,PLANTS("BA",ST,HA)*(ACRE("BA",ST,HA)))
                   -PURBLO(HA)=L=0;
```

```
PLPAP(HA) .. SUM(ST,PLANTS("PP",ST,HA)*(ACRE("PP",ST,HA)))
             -PURPA(HA)=L=0;
PLPAS(HA) .. SUM(ST,PLANTS("PF",ST,HA)*(ACRE("PF",ST,HA)))
             -PURPASS(HA)=L=0;
PLBES(HA) .. SUM(ST,PLANTS("BCS",ST,HA)*(ACRE("BCS",ST,HA)))
             -BET(HA)=L=0;
PLBIC(HA) .. SUM(ST,PLANTS("BCE",ST,HA)*(ACRE("BCE",ST,HA)))
             -CAT(HA)=L=0;
PLCEC(HA) .. SUM(ST,PLANTS("CCE",ST,HA)*(ACRE("CCE",ST,HA)))
             -EAT(HA)=L=0;
PLCAC(HA) .. SUM(ST,PLANTS("CCS",ST,HA)*(ACRE("CCS",ST,HA)))
             -SWEET(HA)=L=0;
PLBIB(HA) .. SUM(ST,PLANTS("BBE",ST,HA)*(ACRE("BBE",ST,HA)))
             -BOW(HA)=L=0;
PLBSB(HA) .. SUM(ST,PLANTS("BBS",ST,HA)*(ACRE("BBS",ST,HA)))
             -ARROW(HA)=L=0;
SLECON(HA) ..
SUM(ST,PASLEV(ST,HA)*(ACRE("BA",ST,HA)))-LEAF(HA)=L=0;
XCON(HA) .. SUM(ST,PABOX(ST,HA)*(ACRE("BA",ST,HA)))-OX(HA)=L=0;
TWN(HA) ..
SUM(ST,PATWINE(ST,HA)*(ACRE("BA",ST,HA)))-WIN(HA)=L=0;
CWPCON(HA) ..
SUM(ST,CROWN(ST,HA)*(ACRE("BA",ST,HA)))-COVER(HA)=L=0;
WICON(HA) .. SUM(ST,WIRE(ST,HA)*(ACRE("PF",ST,HA)))-IRE(HA)=L=0;
LABOUR(HA) ..
SUM((CR,ST),LABREQ(CR,ST,HA)*ACRE(CR,ST,HA))-HL(HA)=L=320;
COST(HA) ..
0.5*FERT1(HA)+0.58*FERT2(HA)+0.39*FERT3(HA)+0.5*FERT4(HA)

+26.63*CHEM1(HA)+48.83*CHEM2(HA)+29.5*CHEM3(HA)+15*CHEM4(HA)

+0.356*CHEM5(HA)+1.0*PURBLO(HA)+0.25*PURPA(HA)+1.0*PURPASS(HA)

+0.05*BET(HA)+0.05*CAT(HA)+0.05*SWEET(HA)+0.05*EAT(HA)+0.05*

BOW(HA)+0.05*ARROW(HA)+20.0*HL(HA)+195*LEAF(HA)+2.25*OX(HA)

+37.0*WIN(HA)+240.0*IRE(HA)+7.8*COVER(HA)+1600-OPCOST(HA)
             =L=0;
LOAN(HA) .. OPCOST(HA)-LN(HA)=L=0;
NETREV(HA) ..
SUM((CR,ST),YIELD(CR,ST,HA)*ACRE(CR,ST,HA)*0.9*PRICE(CR))
             -(OPCOST(HA)+0.07*LN(HA))-NR(HA)=G=0;
AWA(HA) ..
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SUM(ST,WATER("BA",ST,HA)*(ACRE("BA",ST,HA)))-ARIG(HA)=L=55;
PWA(HA)   ..
SUM(ST,WATER("PP",ST,HA)*(ACRE("PP",ST,HA)))-BRIG(HA)=L=55;
FWA(HA)   ..
SUM(ST,WATER("PF",ST,HA)*(ACRE("PF",ST,HA)))-CRIG(HA)=L=55;
CSWA(HA) ..   SUM(ST,WATER("BCS",ST,HA)*(ACRE("BCS",ST,HA)))

               - DRIG(HA)=L=55;
CEWA(HA)  ..  SUM(ST,WATER("BCE",ST,HA)*(ACRE("BCE",ST,HA)))
              -ERIG(HA)=L=55;
CWA(HA)   ..  SUM(ST,WATER("CCS",ST,HA)*(ACRE("CCS",ST,HA)))
              -FRIG(HA)=L=55;
EWA(HA)   ..  SUM(ST,WATER("CCE",ST,HA)*(ACRE("CCE",ST,HA)))
               -GRIG(HA)=L=55;
DEWA(HA)  ..  SUM(ST,WATER("BBE",ST,HA)*(ACRE("BBE",ST,HA)))
              -HRIG(HA)=L=55;
BSWA(HA)  ..  SUM(ST,WATER("BBS",ST,HA)*(ACRE("BBS",ST,HA)))
              -IRIG(HA)=L=55;

MODEL ACCABRE/ALL/;
OPTION LIMROW=100;
SOLVE ACCABRE USING LP MAXIMIZING Z;
```