DETERMINATION OF AGRICULTURAL PRODUCTION CONSTRAINTS AND OPTIMAL ENTERPRISE MIX IN AN IRRIGATION SCHEME: THE CASE OF HOLA IRRIGATION SCHEME IN KENYA

By

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A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Agricultural Economics, University of Nairobi.

August, 1992.

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as university supervisors.

20/8/92
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ACKNOWLEDGEMENTS

I wish to humbly admit that on my own, the work contained in this thesis would not have been accomplished. Several people assisted me in several ways.

First and foremost I wish to thank the Almighty God who in His wisdom and goodness deemed it fit to grant me - a frail mortal, a peasant's son, - the wondrous and golden chance to undertake postgraduate studies in the Agricultural Economics Department of the University of Nairobi. And then throughout the period of the study, He granted me patience, courage, comfort, hope and health amidst discouragements, trials and disappointments. Verily, these favours were unmerited.

My University Supervisors, Dr. Stephen G. Mbogoh and Professor Ackello-Ogutu, offered me their time, valuable suggestions, constructive criticism and guidance. They treated me kindly and with extreme understanding. I am proud to have been their student.

The University of Nairobi awarded me the scholarship which enabled me to undertake the studies. I trust that I have not disappointed the University.

My fellow students in the graduate school provided me with very good and exciting company. The thought-provoking discussions we had, the sweet humorous jokes we exchanged, the trials, agonies and disappointments we went through together will linger in me for a long time.

Rose Ayiro, Roselyn Anyango and Mrs. M. Musonye greatly assisted me with typing work; Mr. Mbizi Buko assisted me with data collection at the Hola Irrigation Scheme; Mr. Luke Oyugi availed to me the DHLLP Computer Programme which was valuable in data analysis.

To all others who assisted me in this study and to whom I have not directed specific words of acknowledgement, I do sincerely apologize. It is space which does not permit. Know for sure that I highly esteem your assistance.

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ABSTRACT

This study arose out of the need to address the problem of poor performance of Kenya's large scale irrigation schemes. The poor performance has been evidenced by the negative cash flows that these schemes have consistently recorded since their inception (with the exception of the Mwea Tabere Rice Irrigation Scheme in Kirinyaga district) and the low incomes received by the tenant farmers. The study focused on the Hola Irrigation Scheme which was chosen because of its location in the Tana River Basin which possesses the greatest potential for irrigation development in the country. The scheme's farm plans were investigated under the null hypothesis that poor enterprise combinations and resource misallocation were the primary sources of its poor performance. Both primary and secondary data were gathered on inputs, outputs, prices and family characteristics, among others. The gross margins of the various crop enterprises were then computed as a basis for determining the relative profitability. The computed gross margins were also used to formulate an objective function which was an integral component of linear programming, the analytical technique that was employed. A linear programming problem matrix was then constructed and fed into a computer to determine the optimal farm plans. These were compared with the existing farm plans and were found to differ significantly. It was therefore inferred that the existing enterprise combinations and resource allocation patterns were inefficient and that farm incomes could therefore be increased through resource reallocation. From the dual values, the constraints to increased farm incomes were deduced to be April labour, November labour, capital and subsistence requirements. A marketing constraint was also identified as the cause of the wide fluctuations in commodity prices, especially for onions and tomatoes and lack of adequate storage. The conclusions of the study were that resource use patterns be altered by adopting the optimal farm plans and that the existing structural and institutional constraints be eased to make the change possible. Such constraints include transport infrastructure, credit and storage.

CHAPTER ONE

INTRODUCTION

1.1 Role of Irrigation in Kenya's Agriculture

Kenya has a land area of 44.6 million hectares out of which 20 per cent (i.e. 8.6 million hectares) is medium to high potential agricultural land. The remaining 80 percent of her land area is classified as arid and semi arid land and has an agricultural potential which is largely unexploited because of inadequate rainfall (Kenya, 1986). The increasing demand for food as a consequence of the rapid rate of population growth (estimated at about 4 percent per annum) necessitates that the country's agricultural potential be fully developed in order to address this challenge. In the medium and high potential areas, intensification of agricultural production is the option to pursue since there is limited scope for increasing the cropped area due to scarcity of suitable arable land. Intensification mainly entails developing and using land-saving technical innovations like high yielding crop varieties and fertilizers. Also, plans need to be devised to bring the marginal lands into productive use.

Since rainfall is a key constaint to agricultural production in the marginal lands, irrigation development would be vital as it would permit the extension of cultivation into these lands (Carruthers, 1985). Indeed various authorities estimate that Kenya's crop land could be expanded greatly through irrigation (IBRD, 1984). According to FAO (1986) and Ruigu (1987) the benefits to be derived from irrigation development include:

a) improved crop yields over rainfed agriculture;

b) improved economic security for the farmers through stabilized agricultural production;

c) control of timing for delivery of agricultural produce to the market;

d) greater human carrying capacity and more accetable incomes within the existing rainfed arable farming systems; and

e) increased opportunities for the introduction of more valuable crops through an assured water supply.

It is vital that policies be formulated and programmes designed to develop the country's irrigation potential which according to Aldington and Smith (1973) is estimated at about 600,000 hectares.

Already only a small proportion of land consisting of about 43,000 hectares which represent about 7.2 percent of the total irrigation potential are under irrigation. Out of this irrigated area, 16,000 hectares (37 percent) are under the private irrigation sector, 9,000 hectares (21 percent) are under the National Irrigation Board (NIB), 15,000 hectares (35 percent) under the small scale irrigation project of the Ministry of Agriculture and the rest are under the Regional Development Authorities like the Kerio Valley Development Authority (KVDA), the Tana and Athi Rivers Development Authority (TARDA) and the Lake basin Development Authority (LBDA) - IDB, 1987.

1.2 The NIB Schemes

There are at present six operating large scale irrigation schemes in Kenya that are being managed by the National Irrigation Board (NIB). The Bura Irrigation Scheme used to be managed by the National Irrigation Board but due to its extremely poor performance, a commission took over. Table 1 shows the various NIB schemes, their cropped areas and main crops.

Table 1: The NIB Schemes by Cropped Area and Crops

Scheme	Area (ha)	Main Crops
Mwea	6,299	Rice
Ahero	840	Rice
Bunyala	212	Rice
West Kano	895	Rice
Hola	870	Cotton
Perkerra	200	Tomatoes/Onions
Total	9,316	

Source: National Irrigation Board - Various Annual Reports

The NIB was formed in 1966 under the Irrigation Act (Chapter 347 of the Laws of Kenya). Its principal functions under the Act, among others, are:

a) to conduct research and investigation into the establishment of National Irrigation schemes;

b) in conjunction with the Water Resources Authority established under the Water Act (Chapter 372 of the Laws of Kenya) to formulate policy in relation to National Irrigation schemes;

c) to raise funds for the development of National Irrigation schemes;

d) to coordinate and plan settlement on National Irrigation schemes;

e) to design, construct, supervise and administer the National Irrigation schemes.

The large scale irrigation schemes have been very costly investments to the country (the capital cost of irrigation development being of the order of Kenya pounds 200 - 400 per acre). Similarly the cost of operating the irrigation schemes in Kenya has been very high compared to World Bank financed schemes in other countries. These costs are shown in Table 2.

Table 2: Costs per Hectare of Selected Irrigation Schemes

Scheme	Costs/ha US $
Mwea	197
Perkerra	1573
Tana (Hola)	628
Ahero	422
West Kano	489
Bunyala	393
World Bank Funded:	
Water Pumping Projects	145
Gravitation Projects	31

Source: Calculated from the NIB Annual Reports for 1980 through 1984. Costs of World Bank Funded Projects obtained from World Bank Report No. 3421 (obtained from Ireri, 1986 pg. 13)

With the exception of the Mwea-Tabere Rice Irrigation Scheme, Kenya's large scale irrigation schemes, though costly to establish and operate, have had a very poor financial performance. The poor financial performance has been indicated by the negative cash flows they have recorded over a long period of time. They have, as a consequence, been forced to rely heavily on subsidies from the government. Estimates are that about 25 percent of the budget of the Ministry of Agriculture is used to support the irrigation schemes (Kenya, 1986). Economically, however, they have made substantial contributions in terms of creating employment, alleviating landlessness and enhancing food self-sufficiency. Coupled with these social contributions, it is desirable that the schemes be financially viable so that the returns from them are able to cover the costs.

Given that resources are scarce and that the setting up of new large scale irrigation projects involves huge construction and operation costs, the present approach in irrigation development is to give priority to low cost smallholder irrigation projects. Such small scale irrigation projects can and have contributed significantly to rural development (Kangangi, 1982). Already plans are under way to raise the budget for small scale irrigation from the 1985/86 level of Kenya pounds 213,000 to Kenya pounds 2,000,000 by the year 2000 (Kenya, 1986).

Further to this strategy, the government also regards the rehabilitation of large scale irrigation schemes as a priority. Not only would this make them economically viable and thus independent of the need for subsidies, but they would also generate resources which could be invested in other sectors or used to develop the country's irrigation potential further.

1.3 The Hola Irrigation Scheme

1.3.1 General:

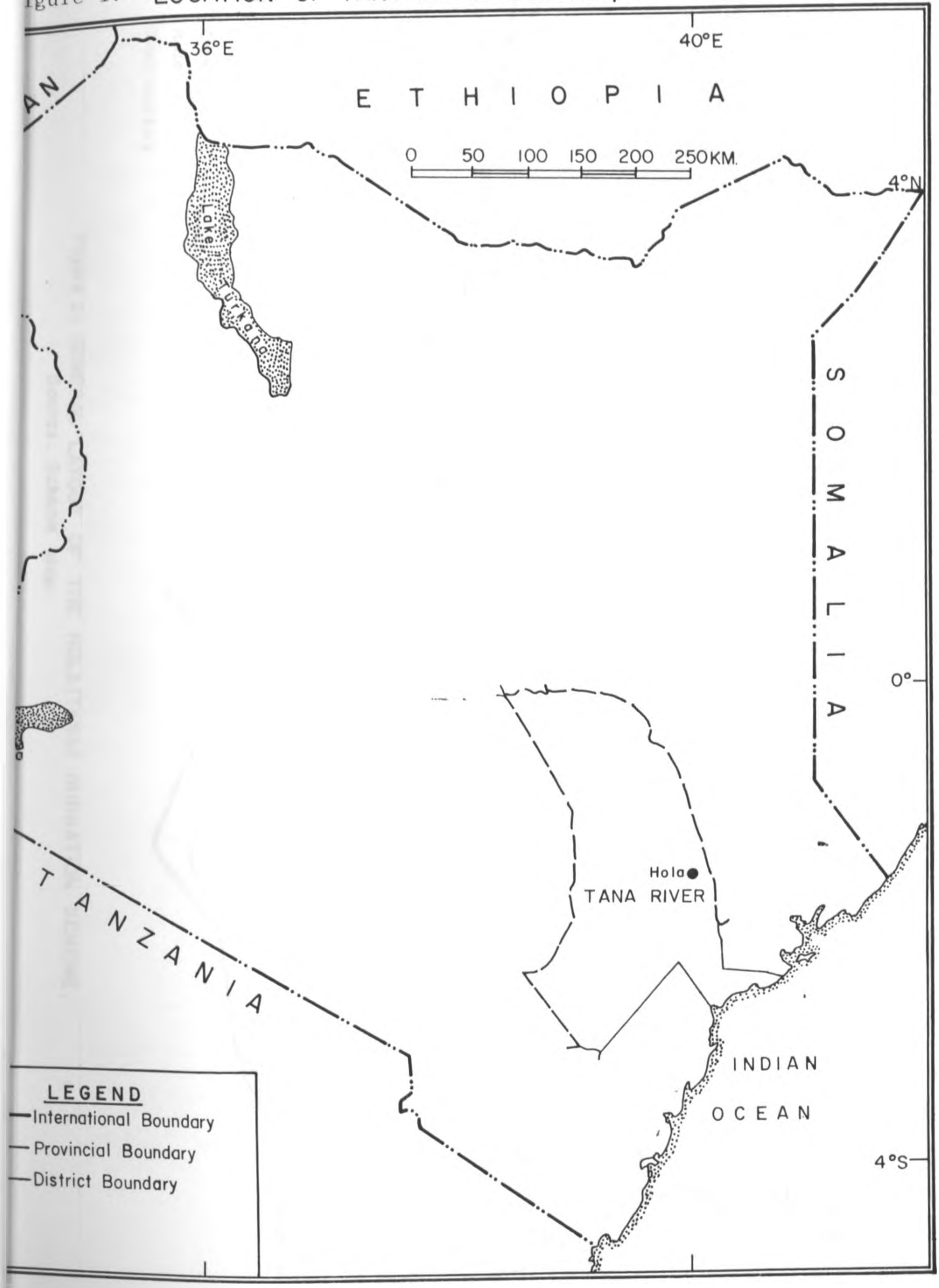
The Hola Irrigation Scheme (also known as the Tana Irrigation Scheme) is one of the six national large scale irrigation schemes controlled by the National Irrigation Board. It was established in the year 1953 with the major objective of settling the landless and the unemployed Mau Mau detainees. During its inception the scheme comprised an irrigated area of 577 hectares. In the early 1970s the scheme was extended with another 280 hectares, making the total area under irrigation 857 hectares.

1.3.2 Location:

The Hola Irrigation Scheme is located in Galole division of the Tana River district in the Coast Province. Its coordinates are approximately 1x30' South and 40x00' East and its altitude is about 90 metres above the sea level. The nearby village of Hola where the headquarters of both the scheme and the district are located is about 200 kilometers North of the Coastal town of Malindi on the road leading to Garissa (Anon, 1985). The general location and layout of the scheme are shown in Figures 1 and 2, respectively.

At present 857 hectares of land are furrow irrigated using water from the Tana River. Tana River is the largest river in Kenya, with a catchment area including large sections of the highlands East of the Rift Valley. It flows first to the East and North, skirting the foothills of Mount Kenya, before curving southwards through vast areas of semi-arid lowlands. The Hola scheme is situated on the west bank of the river in the lower basin, some 120 kilometres north of the estuary into the Indian Ocean.

igure 1: LOCATION OF TANA RIVER DISTRICT, KENYA.



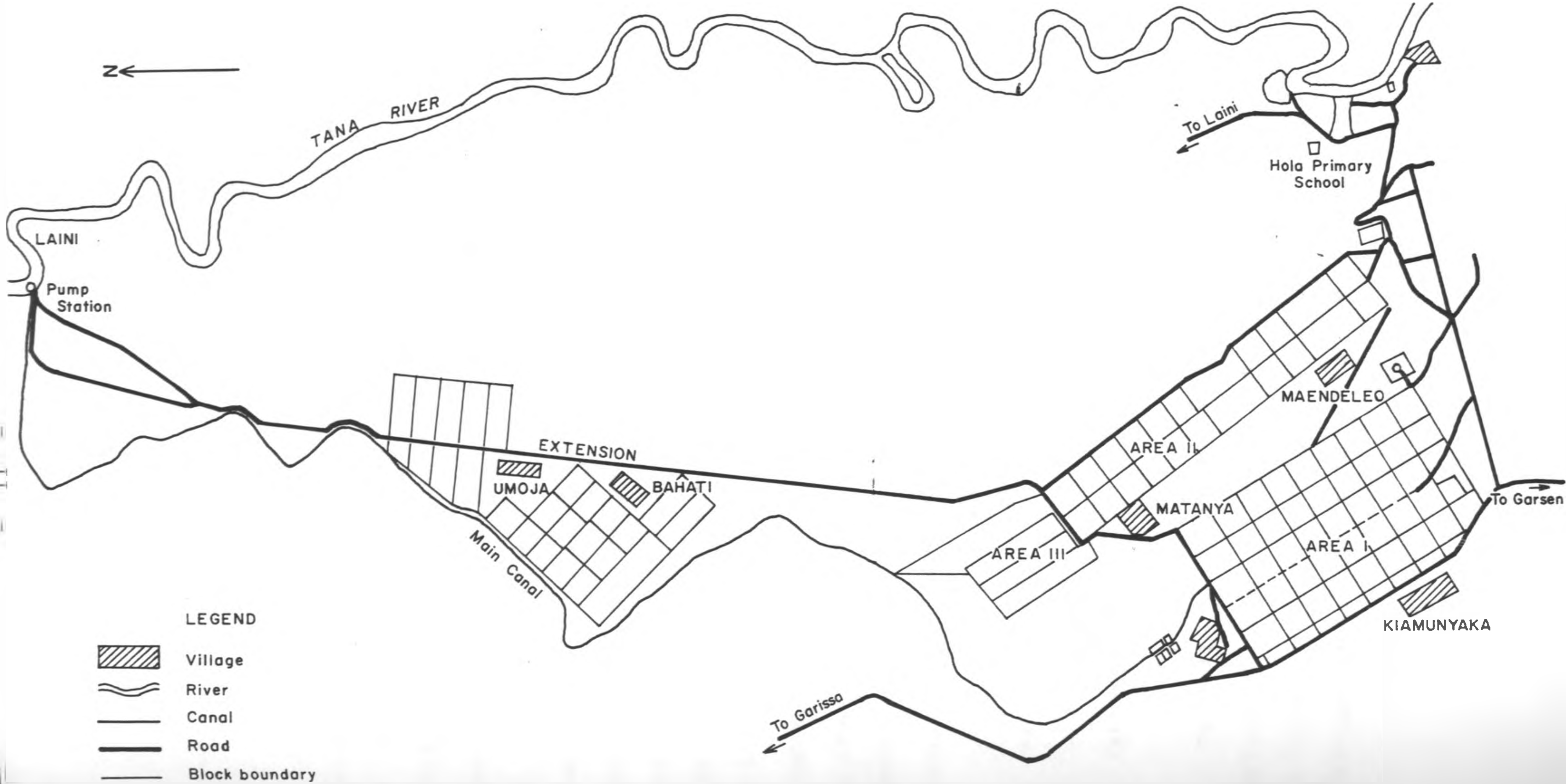


Figure 2: GENERAL LAYOUT OF THE HOLA(TANA) IRRIGATION SCHEME.
Source: Scheme Map.

1.3.3 Soils:

The soils in the scheme vary widely in their chemical and physical properties. The soil reaction of most of the soils is mildly alkaline to strongly alkaline. The exchange complex is dominated by calcium, magnesium and sodium. The soils are adequately supplied with calcium, magnesium and potassium. However, phosphorus and nitrogen are deficient in them, and cotton and maize in particular respond to applications of nitrogenous fertilizer (Muchena, 1987; Anon, 1985). Therefore for agricultural production, it is necessary that the soils be supplied with both phosphatic and nitrogenous fertilizers. Sulphate of ammonia, $(NH_4)_2SO_4$, is the preferred source of nitrogen as the slightly acid reaction of this fertilizer is an advantage on the alkaline soils (Anon, 1985).

1.3.4 Climate:

(a) Rainfall:

Rainfall amount and distribution are the two most important factors which determine agricultural activities in an area. For successful rainfed agriculture it is vital that rainfall be available in adequate amounts. Further, the distribution should be such that the crop water requirements are met throughout the growing season.

In the Tana River District where the Hola Irrigation Scheme is located, rainfall is very unreliable in both amount and distribution (Anon, 1985). The absolute minimum rainfall recorded for every month, except November, is zero. The monthly rainfall which is received in at least 4 out of 5 years (80 percent values) is very low and hardly significant, except possibly in April and November. The monthly rainfall data for a period of 10 years (1979 - 1988) are shown in Table 3.

Table 3: Monthly Rainfall at Hola in mm for the last 10 years (1979 - 1988)

MONTH	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
January	108.1	-	9.1	74	40.4	10.2	24.5	6	0.3	59.4
February	2.9	8.1	-	-	88.6	-	44.0	-	-	3.2
March	56.0	2.9	107.4	133.4	8.7	8.0	50.8	4.1	1.4	126.1
April	70.3	12.9	63.2	183.9	230.3	27.9	18.2	113.6	92.2	47.7
May	212.9	-	53.1	301.7	313.2	34.1	29.1	122.9	36.2	8.1
June	231.4	9.2	6.3	33.5	114.5	10.4	1.6	3.3	6.6	39.3
July	35.3	16.8	7.0	43.0	19.9	24.8	21.6	23.2	10.4	2.8
August	2.4	87.2	98.2	18.5	0.5	0.2	38.1	16.7	60.0	1.8
September	2.0	12.6	59.6	71.6	56.0	15.9	26.3	10.5	8.9	25.5
October	12.3	5.3	240.5	535.5	10.3	42.6	42.6	43.5	6.5	3.1
November	23.6	91.1	63.5	325.8	16.4	44.5	44.4	71.6	119.1	76.6
December	81.0	15.9	114.1	207.8	100.3	66.2	22.0	111.6	5.9	72.0
Total	843.4	261.8	822.0	1862.2	998.9	284.8	363.2	521.0	377.5	703.9

Source: Kenya Meteorological Department (1984): Climatalogical statistics for Kenya; & Anonymous (1985): The Tana Irrigation Scheme. A reference document, N.I.B., Nairobi.

Muchena (1987) using rainfall data for 51 years calculated the probabilities that certain amounts of rainfall would be exceeed annually. These probabilities are given in Table 4.

Table 4: The Probability that Certain Amounts of Rainfal are Exceeded at Hola Annually during the Rainy Season

	PROBABILITY		
Rainfall in mm	March - May	Oct - Dec	Annually
500	p 0.02	p 0.02	p 0.18
400	0.02	0.02	0.29
300	0.04	0.16	0.49
250	0.10	0.22	0.63
200	0.18	0.31	0.76
150	0.27	0.49	0.86
100	0.55	0.69	0.94
50	0.71	0.94	1.00

Source: Muchena (1987)

The net rainfall is also determined by the evapotranspiration. The 1984 monthly evapotranspiration figures are given in Table 5.

Table 5: Evapotranspiration at Hola in mm in 1984

	J	F	M	A	M	J	J	A	S	O	N	D	Total for the Year
Evapotranspiration	140	135	157	134	135	135	130	137	148	157	132	124	1660

Source: Kenya Meterological Department (1984): Kenya Climatological Statistics

The data on rainfall indicate that the rainfall at Hola is too low for successful rainfed crop production. Also indicated is the fact that the potential evaportranspiration is quite high and exceeds the rainfall by a factor of 2 or more. Reliable crop production is therefore possible only if this climatic constraint is eased. Irrigation is the option which must be pursued in any agricultural undertaking in the area. To enable irrigation, water has to be pumped from the Tana River and conveyed to the fields via canals and canal structures.

(b) Temperature

The temperatures in the Hola Irrigation Scheme are high throughout the year, with little annual variation. Absolute minima are never lower than 17°C·The hottest months are February and March, and the coolest are July and August. The temperatures are generally not limiting for the crops grown in the scheme. Vegetables, however, make rather poor growth in the hot months from January to February (Anon, 1985). A summary of the mean monthly maximum and minimum temperatures for 16 years over the period 1966 - 1982 is presented in Table 6.

Table 6: Average Temperatures over the Period 1966 - 1982 at Hola in °C

Month	Mean Maximum	Mean Minimum	Average
January	34.9	22.3	28.6
February	35.8	22.9	29.4
March	35.7	23.8	29.8
April	34.7	24.0	29.4
May	32.7	22.7	27.7
June	31.8	20.7	26.2
July	31.4	20.1	25.8
August	31.6	20.0	25.8
September	34.2	21.8	28.0
November	34.3	23.0	28.6
December	34.1	22.6	28.4
Year	33.7	22.0	27.9

Source: Anon, 1985

1.3.5 Vegetation

The Hola area is covered mainly with open bush and rather dense scrub vegetation with some areas of shrub grassland. There are also areas where the ground is bare. The typical vegetation cover in the uncultivated areas of the scheme is characteristic of arid and semi-arid areas.

1.3.6 Population

Hola is in Tana River District. The population of the Tana River District in 1979, according to the census that was conducted then was 92,401. At an estimated annual growth rate of about 3.6 percent, the population in the district by the end of the last year 1988 is estimated at about 130,341. The peoples of the district belong mainly to the cattle herding normadic tribes comprising Pokomo, Orma, Somali, Mijikenda and Boran. During the 1979 census, 35 percent were Pokomo, 37 percent were Orma, 9.5 percent were Somali, 2.7 percent were Mijikenda and 1.2 percent were Boran. The population of the district is relatively young, with 40 percent under 15, and 59 percent under 20 years of age (Anon, 1985).

A very large proportion of the Hola population in 1979 never attended school. During the 1979 census, 11 percent were currently attending school, and 10 percent had attended school in the past. Of the total population, 12 percent had attended school between Standards 1 to 4, and 7 percent between Standards 5 to 7. About 2 percent had received some secondary education, and only a mere 0.2 percent had advanced beyond Form 4.

In 1979 the Hola trading centre had a population of 5,352 in 1,227 households, with an average household size of 4.4 people. Males comprised 54 percent of the population. The area of the trading centre was 9 square kilometres giving a population density of 595 people per square kilometre.

On the Hola scheme itself there are presently 690 tenant families located on the outskirts of the scheme: Kiamunyaka and Kiarukungu near Area I with 115 and 113 tenants respectively; Matanya and Maendeleo near Area II and III with 120 and 106 tenants respectively, and Bahati and Umoja near the Extension with 116 and 120 tenants respectively. These residential areas are shown in Figure 2 which depicts the general layout of the scheme. The tenants have plots in adjacent areas, although some tenants in Maendeleo have plots in Area I. Houses in the villages are made of mud and wattle and have corrugated iron roofs. There are treated domestic water supply points and central showers and toilets. Every village has an area of land where vegetables and fruit trees are grown.

1.3.7 Land Use and Land Tenure

The Hola Scheme Area comprising 857 hectares is under irrigation. The major crop grown in the scheme is cotton. It is cultivated on the total irrigable area on 3 acre plots. Some tenants however have 4 acre plots on which they grow cotton. The cropping period for cotton is from February to September. After cotton has been harvested, the tenants grow maize and groundnuts on 1 to 1.5 and 0.25 acre plots respectively. Maize is grown mainly for the subsistence of the tenants. The fields on which cotton is harvested late, the 'late' cotton fields, remain fallow to allow timely land preparation for the next crop. The tenants are also allocated 0.25 acre plots near the villages. On these plots they grow vegetables - kales, onions and tomatoes. These are mainly for family consumption but the excess is sold in the local market. The non-cultivated areas and the immediate surroundings are under natural vegetation and are used for grazing domestic livestock.

In the scheme all the land belongs to (or is owned) by the National Irrigation Board. All the farmers in the scheme are tenants who have been granted permission to cultivate the land under a license which is automatically renewable from year to year subject to satisfactory performance. The yields the tenants obtain and whether or not they observe the recommended crop husbandry practices are the criteria for gauging the performance. The consistently poor performers are chased away and their plots allocated to other applicants. The tenants are obligated to plant, irrigate, weed and harvest the scheme crops namely cotton, maize and groundnuts. Further, each tenant is expected to clear and maintain the irrigation channels and works on or serving his holding, and to observe instructions concerning crop husbandry practices. The Board provides various services to the tenants at a cost. These include land preparation and supply of water, seeds, fertilizers, pesticides and marketing services.

1.3.8 Marketing:

The marketing system for cotton which is the major crop grown in the Hola Irrigation Scheme is controlled and comprises a single channel. Cotton is sold to the Cotton Board of Kenya and all payments to the tenants are made through the NIB in order to enable the NIB to recoup the costs for water, land preparation, seeds, fertilizers, pesticides and other inputs. The price of cotton is administratively determined and is currently

KShs. 6.00 per kilogram for the AR grade. Most of the cotton produced in Hola falls within this grade. The other commodities, namely, maize, groundnuts, greengrams, tomatoes and onions are marketed locally, and it is through individual negotiations between the buyers and the sellers that their prices are determined. The local market supply and demand forces therefore greatly influence the prices of these commodities. The wide fluctuations in the supply of these commodities between seasons results in wide fluctuations in their prices.

1.3.9 Impact of Irrigation on Environment

Environmental considerations are becoming increasingly important due to the heavy bearing they have on economic development: Tolba's (1989) considered opinion is that sustained economic development can only be realised if environmentally sound development policies are purused. Moi (1989) also shares this opinion. A dilemma therefore arises when irrigation is being considered since on the one hand it makes possible the use of the arid and semi arid areas for crop production while on the other hand the environment is adversely affected. This is the reality of the Hola Irrigation Scheme. Due to the poor drainage of the soils and the continued application of water, salinity build-up has been reported. To deal with such problems, research into appropriate and better irrigation methods is urgently needed. This however falls outside the ambit of this study.

1.4 Problem Statement and Justification of the Study

Kenya is a predominantly agricultural country with quite limited areas of high potential land, a high birth rate and a substantial degree of unemployment (Giglioli, 1973). It is therefore vital that investments be undertaken that will result in an addition to the area of productive land and/or sharply increase the human carrying capacity of the land. Particular attention needs to be directed towards developing the arid and semi-arid lands which comprise about 80 percent of the country's total land mass and whose agricultural potential is largely unexploited because of lack of adequate rainfall (Kenya, 1981; Kenya, 1986). This is why irrigation in Kenya has gained greater importance as it is not only the key to the easing of climatic constraints which are binding on agricultural production, but also one of the few policy options of expanding food production, providing employment, absorbing the landless, achieving food self-sufficiency and raising the levels of incomes (Kenya, 1978; FAO, 1986). But even in the high potential areas, intensification of land use is to a large degree dependent on irrigation. Despite the recognition of the importance of irrigation in Kenya's agriculture, the country's vast irrigation potential estimated at about 600,000 hectares has been developed only minimally (Kenya, 1978). This can be attributed to the high costs involved in establishing and operating the irrigation projects and inadequate water resources (Ireri, 1986). Hence in its policies to develop irrigated agriculture, the government is presently placing increasing emphasis on small-scale irrigation projects due to the low costs involved and also because of the fact that the large scale irrigation projects have recorded very poor performance yet they have been the most expensive of agricultural investments. They have used the greater portion of borrowed capital allocated to agriculture and more than 20 percent of the budget of the Ministry of Agriculture (Kenya, 1978; Kenya, 1986; FAO, 1986; IBRD, 1987). Of the seven large scale irrigation schemes in Kenya, only one - the Mwea Tebere Rice Irrigation Scheme - has been economically viable and the other six schemes - Hola, Ahero, West Kano, Bunyala, Perkerra and Bura - are not self-supporting (they have continued to record negative cash flows). The Bura Irrigation Scheme is included in this number because it is actually a large scale irrigation scheme though not now being managed by the National Irrigation Board. The six schemes are thus net users of resources which are scarce and should be employed in the most rewarding uses. As a consequence of their poor performance these large scale irrigation schemes have been heavily reliant on subsidies from the government for their operation and maintenance. These subsidies as a percentage of the operation and maintenance expenditure in these schemes range from 20 percent to 50 percent, and over Kenya pounds 900,000 annually. Cost recovery is so low in these schemes that the government has often contemplated closing them down (Ireri, 1986).

The prices of all the major crops grown in these schemes happen to be among those controlled by the government and which often are maintained at low levels relative to the production costs (op cit). This has implications on the incomes of the tenants. These incomes are generally low and result in indebtedness and a quality of life that is unsatisfactory. They thus act as a disincentive to the tenants in their production activities (Migot- Adhola, 1982; Ruigu et al, 1984; Ireri, 1986; Ruigu, 1987). For some tenants, the debts exceed KShs. 10,000 per year. The income classes of the tenants in the Hola Irrigation Scheme are shown in Table 7.

Table 7: Income Classes for Farmers in the Hola Irrigation Scheme (1987-1988)

Income Class	Net Annual Income	No of Tenants	Percentage
A	<1000	12	1.76
B	1000 - 2000	102	15
C	2001 - 3000	308	45.4
D	3001 - 4000	197	29.1
E	4001 - 5000	47	6.9
F	>5000	12	1.76
TOTAL		678	100.0

Source: The 1987/88 Hola Irrigation Scheme's Annual Report

Table 7 above shows that of the 678 tenant farmers in the Hola Irrigation Scheme in the 1987/88 financial year, 422 (about 62 percent) had net annual incomes which were below KShs. 3,000 per year. This is in congruence with the views of the other researchers cited earlier that the tenant incomes in the schemes are generally low.

Besides placing greater emphasis on small scale irrigation projects in view of their low costs, the government regards as a priority the rehabilitation of the large scale irrigation projects to make them economically viable. An important component of such efforts is raising production to improve their performance by generating profits, and ensuring that the available scarce land, water and financial resources are optimally utilized.

In this study therefore, the basic problem of the poor performance of the Hola Irrigation Scheme as is manifested in the low incomes of the farmers, is addressed. Resource allocation and enterprise combination, among other issues are specifically examined as contributing factors with the aim of determining the efficient resource allocation patterns. According to Doyle (1975), Heyer (1977), Randal (1981), Gatere (1982) and Mbogoh (1982), this is one of the critical research priority areas in agricultural policy and constitutes this study's justification. Through such efficient resource allocation methods (optimal farm plans) the farm incomes and the standards of living can be raised to the benefit of the tenants. Ceteris paribus conditions are assumed.

1.5 Objectives and Hypothesis

1.5.1 Objectives

This study was undertaken to accomplish the following three objectives:

1. to describe the present farming system in the Hola Irrigation Scheme;
2. to examine the major constraints to agricultural production in the scheme;
3. to examine the present farm plans in the scheme, and determine if a reallocation of the scheme's resources would improve the farm incomes.

1.5.2 Hypothesis Tested

The hypothesis that was tested in this study is that resource allocation in the Hola Irrigation Scheme is suboptimal so that a reallocation of the scheme's resources would be needed in order to optimize the returns to the tenant farmers. This hypothesis was tested through:

1. examining the present farm plans for the scheme;

2. determining the optimal farm plans for the scheme through the use of a linear programming model;

3. comparing the optimal farm plans with the existing farm plans in the scheme, and then assessing if resource reallocation would lead to higher returns to the farmers' labour input.

To accept the hypothesis, optimal plans determined through the use of a linear programming model should generate higher returns than the existing plans. If the contrary is true, the hypothesis is rejected and a conclusion drawn that the present resource allocation is optimal and therefore higher returns cannot be realized through resource allocation.

CHAPTER TWO

LITERATURE REVIEW

In this study, the basic problem that was being addressed was the poor performance of the Hola Irrigation Scheme which like the other large scale irrigation Scheme irrigation schemes in Kenya has not been self-supporting since its inception. The only exception is the Mwea-Tabere Rice Irrigation Scheme in Kirinyaga District. The Mwea Irrigation Scheme relies on gravity assisted water conveyance while in the other large scale irrigation schemes the pumping of water is essential. These differences in water conveyance technologies are engineering considerations which bear importantly on the economic performance of the irrigation schemes. This is because the water pumping projects differ markedly from the gravitation projects in terms of their costs. Generally, the water pumping projects have higher costs per hectare as compared to the gravitiation projects. In Ireri (1986), this difference is clearly depicted (details are presented in Table 2). The large scale irrigation schemes have also been characterised by delays in construction, low yields and damage to the enviroment (Carruthers, 1985).

Other indicators of the poor performance of these large scale irrigation schemes have been their low net present worth (NPW) and low internal rates of return (IRR) which, as Gitteinger (1982) and IBRD (1987) contend, are valuable tools in project planning and evaluation. The NPW and IRR are discounted cashflow measures defined respectively as the present worth of the cashflows stream, and the discount rate which just makes the NPW of the cashflow equal zero. They are mathematically expressed as follows:

$$NPW = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^n}$$

IRR is the discount rate such that

$$\sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^n} = 0$$

Where:

B_t = Benefits in each year

C_t = Costs in each year

n = number of years

i = interest (discount) rate

The NPW and IRR essentially compare the benefits and costs of any project, such as irrigation projects. The implication of the low NPW and IRR is that the benefits derived from these schemes are less than those derived from projects with higher NPW and IRR. From a purely financial point of view, these schemes are therefore net users of scarce productive resources which could be employed in ventures from which the most benefits would be obtained. This, however, does not diminish the importance of irrigation in rural development since certain benefits accrue which, though intangible and cannot be valued in monetary terms, override financial consideration. Such intangible benefits include the settlement of the landless people and the creation of employment opportunities. Financial viability is, however, a desirable objective in the planning of these schemes. The rehabilitation of the large scale irrigation schemes to make them finacially viable would therefore be of great value because it would reduce their heavy reliance on subsidies from the government. Such subsidies are large and have been estimated to be over Kenya Pounds 900,000 annually and range from 20 percent to 50 percent of the operation and maintenance expenditure of these schemes.

The contention that the large scale irrigation schemes have recorded poor performance can only be justified by examining their actual performance and comparing these with the objectives for which they were set up. According to Kenya (1986) and FAO (1987) these objectives include the generation of economic growth, the enhancement of the food security position through the reduced reliance of agricultural production in general and food production in particular on natural weather conditions which are subject to wide fluctuations, increased incomes to rural families and hence raised living standards, settlement of the landless and employment creation.

Since in Kenya's irrigation experience some of these objectives have not been attained, the conclusion that they have performed poorly has been drawn. As a result, though irrigation development still holds great promise of improved quality of life to the concerned communities, considerable doubts as to the precise merits of irrigation have been raised. Among those who have expressed such sentiments are Migot-Adholla (1982), Ruigu et al (1984) and Ireri (1986). These analysts are all in agreement that further to the large scale irrigation schemes being financially unviable (as reflected in the negative cashflows), the standards of living for the tenant farmers in these schemes have been unsatisfactory due to the low incomes they receive and the narrow production range of the crops that are permissible in the schemes. This seems to be the reason why Moris and Thom (1985) are of the view that since the large scale irrigation schemes have high costs the application of irrigation technology be restricted to high value crops or export crops where costs are more readily recovered.

Despite the doubts that have been raised concerning irrigation development, irrigation is not without ardent defenders. Such defenders include FAO (1987) and IBRD (1987) who attribute the poor performance of Africa's irrigation schemes to the economic crisis the continent has been facing, the essential elements of which are the dwindling markets for many of her products, dwindling commodity prices and declining levels of external aid. This explanation is certainly only partial and therefore other factors which have contributed to the poor performance must be sought. The views of Gittinger (1982) are useful in this respect. Gittinger (1982) regards the poor performance of many agricultural projects as being due to poor planning. His recommendation is that careful planning be done for these agricultural projects to record success, and that in such a planning exercise, consideration be given to all the aspects of the projects: technical, managerial, organizational, commercial and economic aspects. The defence for this approach is that project success depends importantly on these aspects.

An important specific factor to which the poor performance of the irrigation schemes can be attributed is how the resources are allocated between and within the various enterprises being operated. For optimal performance, efficient resource allocation is a necessary condition (Henderson and Quandt, 1980). When efficiency in resource allocation is attained the possibilities for increasing farm incomes through resource reallocation are exhausted.

The studies by Irea (1979), Makanda (1984), Mukumbu (1987) and Kamunge (1989) were attempts to examine the patterns of resource allocation in Perkerra, Kibirigwi, West Kano and Mitunguu Irrigation Schemes, respectively. These studies found that through an alteration of the resource allocation patterns and enterprise combinations, it was possible to increase the farm incomes significantly. Therefore, as compared to the determined optimal farm plans, the existing farm plans were sub-optimal. These studies further identified the constraints to increased agricultural production as labour and working capital. The studies by Irea and Makanda however have some shortcomings which considerably reduce their applicability to real farming situations. In Irea's study an activity calendar reflecting the status quo of the tenants in the scheme was put aside and instead one was designed in which tenants were expected to grow one onion crop each month of the year. In Makanda's study, major farming activities carried out in the scheme were omitted mainly because they were perennial crops. Only horticultural crops which contributed only 8.63 percent of the total farm income were considered and coffee which earned 46 percent of the total farm income was omitted. For the same reason, livestock activities were also left out. A further weakness of Makanda's study is that his optimality analysis was based on three specific farms which were assumed to be representative of the general area. As a result, the optimal farm plans recommended by these two analysts must be questioned, or their findings should be interpreted and applied with caution.

In his study, Mukumbu (1987) was faced with a problem similar to that which Makanda faced: how to deal with sugarcane, a perennial crop with a five year cycle and which was the major enterprise in the West Kano Pilot Irrigation Scheme where his study was conducted. Instead of omitting the sugarcane enterprises from the farm plan on the grounds that it was a perennial crop, he incorporated it into his model by defining his objective function as the maximization of net returns over the period covered by the life cycle of the sugarcane crop. Discounting was then done to find the present value of the total returns from the perennial crop enterprise. Little and Mirrless (1974) contend that such discounting of the cashflow from an enterprise is the best method of combining data to get a measure of the enterprise's profitability over its lifetime. Mukumbu (1987) further assumed that the relative prices for both inputs and outputs would remain constant over the planning period and hence any changes in the prices for inputs and outputs (changes in the market prices) would not affect the optimal plans. In the present study, the crops grown by the Hola farmers were annual and so problems regarding the incorporation of perennial crop enterprises into the model were not encountered. Like Irea's study, livestock activities have been omitted on the grounds that the grazing of livestock was done mainly on non scheme land and that it was difficult to determine accurately or even estimate the size of scheme land utilized by the livestock.

Several other resource allocation studies exist but they have not been concerned with irrigation schemes. Inspite of this, they possess a great resemblance to the studies cited above. These studies include those by Clayton (1963), Odero-Ogwel and Clayton (1973), Kange (1980), Asamenew (1980), Rop (1981), Ateng (1977), Ruigu (1978) and Heyer (1965, 1966, 1967, 1971, 1972), Oyugi (1984), Mbai (1984), Kamau (1981) and Msechu (1971). All these studies examined the enterprise combinations and resource allocation patterns, and the constraints to increased agricultural production and hence farm incomes in the localities in which they were conducted. With the exception of Msechu's study, the common finding of all these studies was that the resource allocation patterns and enterprise combinations were sub-optimal and therefore considerable scope existed for improved farm incomes through resource reallocations. Msechu's study which focussed on coffee-banana holdings in Moshi District of Tanzania revealed that farmers in the district were efficiently utilizing the resources available to them as a result of which there was little potential for increasing their incomes through reorganization. Labour, capital and land in some cases were found to be the major constraints to increased agricultural production.

The cited studies, besides being concerned principally with resource allocation, addressed several other issues of importance. For example, in Makanda's study, a comparison was made between irrigated areas and non irrigated areas with respect to the farm incomes that were obtained in both cases. It was shown that the farm incomes on the irrigated areas were significantly higher than those on unirrigated areas, and that the contribution of horticultural crops to farmers' incomes had surpassed that of coffee on the irrigated areas. A strong case for irrigation development is thus presented since its potential to raise farm incomes is clearly evidenced. The study demonstrated empirically that the choice of crop enterprises was an important determinant of farm income. It is however worth noting that Makanda's study was concerned with a small-scale irrigation scheme and not a large scale irrigation scheme. However, this distinction may not be critical since the concept of large, medium, and small scale as applied to irrigation systems do not seem to have precise definitions (Dittoh, 1988). They could be defined according to the size of the irrigated land or the type of irrigation structure or type of management/ ownership or other criteria (op cit). However, for the purposes of his study, Makanda (1984) adopted the definition of small scale irrigation provided by Underhill (1984):

> "Small scale irrigation schemes are those schemes which are under local responsibility controlled by the local people in response to their felt needs".

This definition hinges on how irrigation schemes are managed and it implies that the large and medium scale irrigation schemes are those established and managed formally by a government or other body external to the community. The government's present emphasis on small scale irrigation schemes as outlined in Kenya (1986) can therefore be seen as an avenue for involving the concerned communities in the irrigation projects. This dimension appears to have been overlooked in the conceptualization, planning and implementation of large scale irrigation projects despite its great importance in determining project success. This view is supported by many researchers and writers (e.g. Nwa, 1976; IBRD, 1986; Moris, 1984; FAO, 1986) who are all in agreement that the management of the large scale irrigation schemes has a bearing on their performance and includes issues like the choice of crop enterprises, the levels of these enterprises, the inputs to use in the respective enterprises and the husbandry practices.

For the success of irrigation projects, community support is vital and this can be secured by incorporating the community input into decision making. Also, tenant security needs to be guaranteed since it determines not only the extent of participation in specific projects but also the management practices that are employed. It is in this light that land tenure problems must be viewed. Land tenure refers to the system of ownership and use of land and is regarded as an important ingredient of land reform programs (Mbithi, 1974). Land tenure systems which favour increased agricultural production are generally preferred to those which act as a disincentive to the users of land. This is one of the major reasons why a freehold system of land ownership is advocated by many. In the Kenyan large scale irrigation schemes, land ownerships is under tenancies which are granted for specific time periods and whose renewal is subject to satisfactory performance. The poor performers usually have their tenancies discontinued. Their plots are then allocated to other applicants on similar conditions and terms. The way the land granted under a tenancy is used is determined by the scheme's management and influences the performance.

The design and implementation of policies aimed at increasing agricultural production and hence farm incomes (e.g. Irrigation Programs) must be coordinated for the aims to be realised. The failure of several projects can indeed be attributed to uncoordinated strategies and the omission of crucial provisions. The development of the marketing system to handle the expected increase in production is one such area. This is warranted because the expansion of agricultural output together with the increase in the interregional commodity movement from surplus to deficit areas has the effect of imposing severe strains on the marketing system (Kenya, 1981). It is also warranted that the marketing system be such as to provide marketing margins whose levels would provide adequate incentives for nationwide distribution (op cit). If the marketing system is not developed, problems of diverse types can be expected, including unavailability of transportation, inadequate processing capacity, lack of storage facilities, unavailability of inputs and depressed commodity prices due to increased market supply among other factors. The depressed commodity prices are likely to cause an increase in commodity demand. But this does not cause an increase in farm incomes because agricultural commodities in general have low price elasticities of demand. One of the implications of the low price elasticities of demand is that a price decline is associated with a demand increase of a lesser percentage. It is for this reason that farm incomes do not rise in the circumstances outlined above. It is clear therefore that the scope for raising farm incomes is severely constrained if markets are non- existent and vice-versa. Odero-Ogwel and Clayton (1973) in their regional planning study reached this conclusion. Their study's concern was to explore the efficiency of a regional aggregate model as a planning tool for Kenyan agriculture. The importance of marketing was vividly highlighted by their findings that there were great possibilities for expanding tea production if market opportunities existed, and that expanded dairying depended on expanded domestic and external markets. The study also revealed that it was not advisable to increase coffee and banana acreages because of market limitations.

Compared to rainfed farming systems, irrigated agriculture is more intensive with regard to resource utilization. This can be seen in the patterns of labour use which emerge when irrigation is adopted. In his study on the use qf labour in the Kano River Project, Baba (1981) confirmed this view. His study made specific findings that the labour input increased by over 47 percent in the case of irrigated wheat and by about 120 percent in the case of irrigated tomato production in the project area. In Kenya similar trends are expected and this could partly explain why labour has been identified as a binding constraint to increased agricultural production in several irrigation schemes, both large scale and small scale (Irea, 1979; Mukumbu, 1987; Kamunge, 1987; Makanda, 1984). But even in rainfed farming systems, labour has been found to be a factor constraining increased agricultural production (Clayton, 1963; Asamenew, 1980; Rop, 1981; Ateng, 1971; Oyugi, 1984; Mbai, 1984). It is on account of such empirical findings that the contention that "labour is a surplus resource in agriculture" has been contested.

Those analysts who assert that labour is a surplus resource in agriculture include Lewis (1954) and Ranis and Fei (1964). In their studies of dual sector models, they regarded the withdrawal of labour from the agricultural sector to the industrial sector as desirable for economic development, and that because labour was surplus in the agricultural sector, its withdrawal would not depress agricultural production. This, they held, was due to labour in agriculture having a marginal productivity of zero. These conclusions cannot be accepted uncritically. Indeed many empirical studies tend to suggest that the marginal productivity of labour is greater than zero (Todaro, 1986). An actual appraisal of labour use in agriculture reveals that in all the countries of the world agricultural work is highly seasonal and that a substantial part of the agricultural labour force may be unemployed during a part of the year without being redunant as asserted by Lewis (1954) and Ranis and Fei (1964).

Policy makers in their analysis of agricultural production systems regard the commodity and factor pricing policy as an important determinant of their economic performance. This stems from the fact that the commodity and factor pricing policy greatly influences the manner in which resources are allocated in farming systems. In his study on resource allocation, income distribution and agricultural policies in Kenya, Smith (1969) examined the country's pricing policies among other issues. The study established that the country's pricing policies did not optimize resource use, and that if such pricing rules were retained, resources would continue being directed to heavily subsidized commodities and hence suboptimally used. Alibaruho (1974) in his study on resource allocation, commodity supply and agricultural pricing policy in Kenya reached a similar conclusion. It is therefore not surprising that agricultural pricing policies have featured prominently in attempts to reform the African agricultural economies. The World Bank and the International Monetary Fund assert that the suboptimal performance of the African economies is due to bad pricing policies which do not optimize resource use. This is why these international financial institutions are strongly advocating the removal of subsidies in an attempt to improve the performance of the agricultural sector. A consequence of subsidized pricing is that the consumer prices are maintained at an artificially low level. The returns to producers are then greatly reduced and this acts as a disincentive to them in their production activities. The use of resources to produce commodities whose prices are subsidized therefore does not lead to their efficient employment. In the case of irrigation which is a high cost undertaking, it is vital that a pricing policy be pursued that will generate attractive returns.

There are several methodologies that have been used to study resource allocation issues in agriculture. These include the production function approach, the linear programming approach, multiple integer models, dynamic and recursive models, non linear models, simulation and stochastic programming models, the dummy variable approach and the Utility- based Trade-off Analysis approach. Those who have employed the production function approach in empirical analysis are, inter-alia, Matovu (1979), Shultz (1964, Wolgin (1973), Welsch (1965), Chennareddy (1967), Sahota (1968), Yotopoulos (1964), Massell and Johnson (1968) and Kimenye (1984). A common issue which these studies examined was the efficiency with which resources were being used in agricultural production. A detailed discussion of the concept of efficiency is provided in chapter three. In the production function approach, producvitity is given by the production function estimates which are obtained by fitting input and output data into a Cobb-Douglas production function. A formal mathematical expression of the model is as follows:

$$Q = AX_1^{B1}X_2^{B2} \dots X_n^{Bn}$$

Where:

Q = The Gross Value of Production

$X_1 \dots X_n$ = The inputs

A = A Positive Constant

$B_1 \dots B_n$ = Elasticities of Production for the respective inputs and

$\sum B = 1$

In the cited studies the fitted Cobb-Douglas production functions were partially differentiated with respect to the various inputs. By multiplying the resultant marginal products with the output prices, the marginal value products were computed according to the formula:

$$MVP_x = MP_x.P_y$$

Where:

MVP_x = The Marginal Value Product of input x in Producing Commodity y.

MP_x = The Marginal Product of input x in Producing Commodity y.

P_y = The Unit Price of Commodity y.

The computed marginal value products were then compared with the Unit Input Prices to determine if they differed from each other significantly. There being no significant difference between the marginal value products and the unit input prices the conclusion that the existing resource allocation both within and between enterprises was efficient and hence improving the production through resource reogranization was not feasible was drawn. The policy implication of this conclusion was that the only option through which output, and hence incomes, could be increased was the introduction of new production technologies. The results from Kimenye's study suggested that there was inefficiency in the use of fertilizers in Kenya's agricultural sector, and that production increase had been influenced more by factors other than fertilizers. This was attributed to underutilization of fertilizers which directly resulted from non-availability of the input. The use of the Cobb-Douglas Production function in examining economic efficiency issues, however, has been criticised because price is not incorporated into it as an exogenous variable. This is in view of the arguments advanced by Farrell (1957) that economic efficiency has two components: technical and price or allocative efficiencies with technical efficiency referring to the proper choice of a production function among all those actually in use while price efficiency refers to the proper choice of input combination. It is because of this weakness that an alternative analytical methodology, the Normalized Restricted profit function, has been suggested by Yotopolous and Lau (1979). This function is mathematically expressed as follows:

$$II^* = II/p = f_1 (q,z) - \sum_{i=1}^{n} q_i f_i (q,z)$$

Where:

II = The Profit

II^* = II/p = The Normalized Profit

p = The Price (or Weighted Price of the output)

q_i = The Normalized Prices of the ith variable input

q = Vector of the Normalized Prices of variable inputs

z = Vector of quantities of fixed inputs

According to Yotopolous and Lau (1979) the major advantages of the Normalized Restricted Unit Profit function approach are:

a) the Normalized Restricted profit function is estimated as a function of the prices of the variable inputs and the quantities of the fixed inputs of production under the assumption that they are independent (exogenous) variables. Often, factor demand functions are estimated jointly with the normalized profit function.

b) farms are assumed to behave in accordance with empirically estimable rules which include profit maximization as a special case. This implies no need to make a profit maximization assumption;

c) supply and demand functions are derived from the normalized profit function rather than an attempt to solve a profit maximization problem;

d) the effects of institutional characteristics are introduced directly into both the normalized profit function and behavioural rules;

e) the profit function yields statistically consistent estimates under standard assumption because the input prices and the quantities of fixed inputs are truly exogenous and simultaneous equations bias cannot therefore be present. This contrasts with the direct production function approach in which the use of the ordinary least squares estimator could result in a simultaneous equation bias and inconsistency.

The Normalized Restricted profit function has been employed in several empirical studies of efficiency. These studies include those by Lau and Yotopolous (1971), Lau et al (1970), Yotopolous and Lau (1973), Kalijaran (1981a, 1981b), Kalijaran and Shand (1982) and Garcia et *al* (1982). Among these studies, it is those by Kalijaran (1981a, 1981b) and Kalijaran and Shand (1982) that have examined the economic efficiency in the irrigation sector. They particularly focussed on irrigated rice in India. The estimation procedure adopted was of the Atkin's generalised least squares through Lagrangian multipliers. Kalijaran's studies showed that small and large irrigated rice farms had equal relative economic efficiencies while that by Kalijaran and Shand showed that the rice enterprise had the capacity to absorb considerable amount of hired labour. These findings would imply that on the basis of economic efficiency alone, equal preference should be given to both small and large irrigated farms. They also highlight the labour shortages that are likely to result when irrigation is adopted. In the present study, the use of the restricted profit function was considered inappropriate because the conditions under which the method can be used were not satisfied. These conditions are:

a) that there exist differences in technology between farms;

b) that there exist differences in price efficiency between farms; and

c) that there exist differences in prices received by different farmers.

Irrigation and other development projects are usually undertaken to accomplish multiple objectives. For this reason, it would be faulty to base an appraisal on a single objective. The need therefore exists to evolve techniques for multi-criteria planning. The Utility-based Trade-off Analysis (UTA) is one such technique and it has been used jointly by the World Bank, the Government of Kenya and the Government of the Netherlands to analyse irrigation in Kenya. The joint study's specific aim was to assess and rank the irrigation projects in Kenya. The principal national objectives, namely economic growth, food security and employment generation, and two resource constraints, namely funds and manpower capacity, were used. The application of the UTA methodology enabled project's ranking to be done under alternative weight sets placed on both objectives and constraints. Hence as many ranking orders were generated as there were alternative weight sets determined. This is the major advantage of the UTA methodology. The cited study has, however, been criticised for not addressing such important issues as institutional arrangements, marketing, funding and cost recovery.

Linear programming models, mixed integer models, dynamic and recursive models, non-linear models and simulation and stochastic programming models have been spelt out by Heady (1972) as the appropriate methodologies for the determination of the optimal use of water and land development programme in an irrigation project. The situation under which the various methodologies are used as follows:

a) Linear programming model: where water is scarce and profitable. Linear programming models in such cases simultaneously indicate the optimum allocation of the water resources among farms, soil zones, crops and time periods.

b) Mixed integer models: their use is employed in the selection of sub-systems, particularly where the assumption of infinite divisibility of resources and activities entering the linear programming model may be impractical.

c) Dynamic and recursive models: these models are mostly applied in the selection of the optimal plan over time. In dynamic models, sequential decisions are prodivided while in recursive models the optimal plan in defined within a specific point in time.

d) Non-linear models: these are employed in analysing maximization or minimization problems in which diminishing or increasing returns are present.

e) Simulation and stochastic programming models: these are used to incorporate variations in rainfall and prices into the economic analysis. The simulation models are suitable for handling very complex systems since the variables are not linked by explicit mathematical functions while the stochastic programming is suitable for risk programming.

The Hola farms which were the focus of this study were characterized by, among others, uncertainty, production of several commodity and the use of several production factors. Linear programming was considered to be the appropriate analytical methodology because of its ability to generate an optimal farm plan and reveal the binding agricultural production constraints. Linearity, infinite-divisibility, additivity and single-value expectations assumptions were made in applying the technique. These assumptions do not reflect real Hola situation in that production functions are usually non-linear. Also factors and products are not directly additive. Further, the lack of perfect knowledge regarding yields and prices makes the single-value expectation assumption unjustified. Hence the use of non-linear, dynamic, recursive, simulation and stochastic programming models would have been more appropriate to this study because they better reflect reality. Linear programming was however used because it was easy to apply. It was considered to be the most appropriate in view of the objectives and hypothesis of the study. The technique has been used by various analysts in their respective studies (Mukumbu, 1987; Kamunge, 1987; Irea, 1979; Clayton, 1963; Odero-Ogwel and Clayton, 1973; Heyer, 1972; Mukhebi, 1977; Asamenew, 1980; Kange, 1980; Rop, 1981; Ateng, 1977; Oyugi, 1984; Mbai, 1984; Ruigu, 1978; Makanda, 1984; Msechu, 1979). These studies addressed several issues including the determination of optimal farm plans, determination of agricultural production constraints, and the examination of the impact of cash crop growing on food crop production. They showed that as compared to the optimal farm plans, the existing farm plans were sub-optimal and therefore the incomes could be increased through reallocation of the available resources. Land, labour, capital and marketing were identified as some of the binding constraints to increased agricultural production.

In Oyugi's study, it was further shown that the growing of tobacco, a cash crop, did not depress food production in Migori. In the present study, similar issues were investigated. The study was based on the Hola Irrigation Scheme which is situated in a region with different agro-ecological, socio-cultural and economic conditions. Also, different enterprises with different requirements for the various productive resources are considered.

CHAPTER THREE

METHODOLOGY

3.1 Analytical Framework

This section outlines the basic economic principles that underly the present study whose key concerns were to examine the way the tenant farmers in the Hola Irrigation Scheme allocate productive resources among the various enterprises and to explore ways of increasing their incomes through resource reallocations. Hence the determination of an efficient resource allocation pattern for the scheme was important in realizing the objectives of the study. According to Henderson and Quandt (1970) such an efficient allocation is one in which farm incomes cannot be increased through resource reallocation. It would also minimize wastage of scarce resources, a desirable goal in economic planning.

In the context of this study, efficiency refers to the degree to which producers are achieving the greatest possible output given the available resources and techniques. It has two major components namely technical efficiency and allocative efficiency. The former refers to whether firms obtain the maximum amount of output given the inputs of production (i.e. a technically efficient firm is on the boundary of its production possibility surface) while the latter refers to whether the net incomes are at a maximum given the technology and the prevailing prices (i.e. a firm that is allocatively efficient is on the point of the boundary which is tangent to the output price line) (Pachico, 1980). For an economically efficient firm the marginal value products of the variable inputs equal the marginal costs of the variable inputs.

For the Hola farmers, several products (cotton, maize, groundnuts, greengrams, tomatoes and onions) are produced using several productive factors (land, labour, capital: seeds, tractors, fertilizers, pesticides and herbicides). Whereas cotton is the only crop that is regarded as a commercial crop in the scheme, the inclusion of the other crop enterprises in optimality analysis is necessary because they also contribute in important ways towards the gross farm incomes (Upton, 1973). Hence a typical farm is essentially a multiproduct firm with an implicit production function defined by:

$$Q_i = f(X_{1i}, X_{2i}, \ldots, X_{mi}, Y_{1i}, Y_{2i}, \ldots Y_{ri}) \ \ldots \ \text{Eq. 1}$$

Where:

Q_i = quantity of the ith product produced, for $i = 1, 2, \ldots, n$

X_{ji} = quantity of the jth variable input used in the production of the ith product, for $j = 1, 2, \ldots, m$

Y_{ki} = quantity of the kth fixed input used in the production of the ith product, for

$k = 1, 2, \ldots, r$

From the production function, the total variable cost, the total revenue and profit are respectively derived as follows:

$$\text{Total Variable Cost} = \sum_{j=1}^{m} \sum_{i=1}^{n} C_j X_{ji} \text{ ..... Eq. 2}$$

Where:

C_j = the Unit Price of the jth variable input

$$\text{Total Revenue} = \sum_{i=1}^{n} P_i f_i \quad \text{... Eq. 3}$$

Where:

P_i = the Unit Price of the ith Product

Gross margin = Total Revenue − Total Variable Costs

$$= \sum_{i=1}^{n} P_i f_i - \sum_{j=1}^{m} \sum_{i=1}^{n} C_j X_{ji} \text{ ... Eq. 4}$$

In carrying out production in order to maximize profits, firms are faced with constrained availability of inputs. Such constraints can be defined by:

$$\sum_{i=1}^{n} Y_{ki} \leq Y_k \text{ .... Eq. 5}$$

This can be rewritten as:

$$\sum_{i=1}^{n} Y_{ki} - Y_k \leq 0 \text{ .... Eq. 6}$$

Maximizing profits subject to the input constraint requires that a Lagrangian function to be maximized be constructed from equations 4 and 6. Such a Lagrangian function can be written as follows:

$$L\,(X,Y,\lambda) = \sum_{i=1}^{n} P_i f_i - \sum_{j=1}^{m} \sum_{i=1}^{n} C_j X_{ji} - \sum_{k=1}^{r} (Y_{ki} - Y_k)\lambda_k \quad \ldots \text{ Eq. } 7$$

Where λ_k is the Lagrangian multiplier associated with the constraint of the kth input. From the Lagrangian Equation above the following Kuhn-Tucker conditions can be derived:

(a) $$\frac{\partial L}{\partial X_{ji}} = P_i \frac{\partial f_i}{\partial X_{ji}} - C_j \leq 0 \quad \ldots\text{. Eq. } 8$$

(b) $$\frac{\partial L}{\partial Y_{ki}} = P_i \frac{\partial f_i}{\partial Y_{ki}} - \lambda_k \leq 0 \quad \ldots\text{. Eq. } 9$$

(c) $$\sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{\partial L}{\partial X_{ji}}\right) X_{ji} + \sum_{i=1}^{n} \sum_{k=1}^{r} \left(\frac{\partial L}{\partial Y_{ki}}\right) Y_{ki} = 0 \quad \text{.. Eq. } 10$$

(d) $X_{ji} > 0, \; Y_{ki} > 0$

(e) $$\frac{\partial L}{\partial \lambda_k} = Y_k - \sum_{i=1}^{n} Y_{ki} \geq 0 \quad \ldots \text{ Eq. } 11$$

(f) $$\sum_{k=1}^{r} \left(\frac{\partial L}{\partial \lambda_k}\right) \lambda_k = 0 \quad \ldots \text{ Eq. } 12$$

(g) $\lambda_k \geq 0$ (Intrilligator, 1971; Chiang, 1984).

The above conditions are important in profit maximization decisions. By equating equation 8 to zero we obtain:

$$P_i \frac{\partial f_i}{\partial x_{ji}} - C_j = 0 \Rightarrow P_i \frac{\partial f_i}{\partial x_{ji}} = C_j$$

this implies that for profit maximization, the marginal value product of the jith variable input in production of the ith product should equal the marginal factor cost of the jth variable input. For optimality this condition should hold for all i and all j. If two variable inputs 1 and 2 are used in the production of the ith product, profit maximization is attained if the condition

$$\frac{\partial f_i / \partial x_{1i}}{\partial f_i / \partial x_{2i}} = \frac{C_1}{C_2} \quad \ldots\ldots\ldots\ldots\ldots \text{ Eq. 13}$$

is satisfied. This implies that optimality is attained if the marginal rate of technical substitution between a pair of variable inputs equals their price ratio. The foregoing condition, when the jth variable input is used in producing products 1 and 2 becomes

$$P_1 \frac{\partial f_1}{\partial x_{j1}} = P^2 \frac{\partial f_2}{\partial x_{j2}} \quad \ldots\ldots \text{ Eq. 14}$$

Equation 14 gives the principle of equimarginal returns, stating that profits are maximized when the marginal value product of a variable input is the same in all its uses.

3.2 The Linear Programming Model

In this study, the Linear Programming technique was used in determining the binding production constraints and the combination of enterprises and resources that are optimal. Its suitability in the study derives from the fact that it is an optimization technique with the ability to handle a large number of interrelated variables. The model can be considered as a linear production function formed from a collection of linear production activities that may be utilized simultaneously. In these production activities one or more outputs are produced by the application of one or more inputs in fixed proportions. The production function is therefore homogenous of degree one and thus exhibits a constant returns to scale (Chiang, 1984; Henderson and Quandt, 1980).

A linear programming problem consists of three main components:

a) A linear objective function

b) Linear inequality constraints

c) Non-negativity condition

The general algebraic formulation of the linear programming model is as follows:

$$\text{Maximize } Z = \sum_{j=1}^{k} p_j x_j \quad \text{.... Eq. 15}$$

subject to:

$$\left.\begin{array}{lcl} \sum a_{1j} X_j & \leq & b_1 \\ \vdots & & \vdots \\ \sum a_{ij} X_j & \leq & b_i \\ \vdots & & \vdots \\ \sum a_{nj} X_j & \leq & b_n \end{array}\right\} \quad \text{... Eq. 16}$$

and $X_j \leq 0$.

Where:

Z = the total gross margin

P_j = the gross margin from a unit of the jth activity

X_j = the level of activity j ($j = 1, \ldots, K$)

a_{ij} = amount of the ith resource required to produce a unit of the jth activity

b_j = quantity available of the ith resource.

Assuming gross margin maximization as the motive for production in the Hola Irrigation Scheme the objective function was expressed as follows:

$$\text{Maximize } Z = P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 + P_5X_5 + P_6X_6$$

Where:

Z = the maximand, the gross margins in this case

P_i = the net return (gross margin) from a unit of activity X_i

X_i = amount of a particular activity.

$P_1X_1, \ldots, P_6X_6$ as specified in the above model denote the gross margins from cotton, maize, groundnuts, greengrams, onions and tomatoes respectively. For a particular enterprise, the gross margins were computed from:

Gross Margins = Total Revenue - Total Variable Costs

Gross Margins and not profits were used in this case because of the difficulty involved in identifying and computing the fixed costs which are needed in the calculation of profits.

The values of enterprise gross outputs and variable costs included only the outputs obtained and expenses incurred during the accounting year under consideration. The gross margins for use in this study were obtained by using the current market prices.

The major restrictions that were incorporated into the linear programming model are those due to land, labour, capital availability, and subsistence requirements. Specifically, the inequality constraints were derived as follows:

a) <u>The Land Constraint</u>:

This was obtained from the amount of land allocated to each of the scheme tenants and the proportions they are required to allocate to specific crop enterprises in the two seasons, namely the short and the long rain seasons. With a few exceptions, the farmers in the Hola Irrigation Scheme are each allocated 3 acres of land on which they are required to grow cotton which is the major scheme crop during the long rains season. Because only cotton is grown on the scheme lands during the long rains season from February to September, the long rains land constraint (LLR) per farmer becomes:

$$LLR = Lx_1 \leq 3$$

Where:

Lx_1 = land under cotton.

After cotton has been harvested, the farmers are allowed to grow upto 1.0 acre of maize and 0.25 acres of groundnuts. This is from September to January, the short rains season. Also, during the short rains season, the tenants are allowed to grow vegetables, onions, tomatoes, greengrams on plots not exceeding 0.25 acres that they are each allocated near the villages. Hence a second land constraint, the short rains land constraint (LSR) per farmer can be expressed as follows:

$$LSR = Lx_2 + Lx_3 + Lx_4 + Lx_5 + Lx_6 \leq 1.5$$

Where:

LSR = Land utilized during the short rains season

Lx_2 = Land under maize

Lx_3 = Land under groundnuts

Lx_4 = Land under greengrams

Lx_5 = Land under onions

Lx_6 = Land under tomatoes

b) Labour Constraints

The labour constraint was formulated by considering the average family sizes and proceeding on the premise that an adult is expected to work for 6 hours a day. Child labour ("child" refers to family members aged below 15 years) and can be considered at 0.5 adult labour equivalent (Houtman, 1981). It was recognized in the course of the study that certain family members, though children were too young to do farm work. But regarding a child as providing 0.5 adult equivalent of labour was a working average and it took into account that certain adult members of the family can work for more than 6 hours a day. The average total available labour in manhours was then calculated as follows:

An average family had 4 adults and 6 children.
In a month of 25 working days, 4 adults working for 6 hours a day would provide 25 x 6 x 4 manhours of labour = 600 manhours of labour.
The 6 children would provide 0.5 x 6 x 6 x 25 manhours of labour = 450 manhours.
The total labour available to an average family was 600 + 450 manhours = 1050 manhours per month.

Child labour was considered to be available only during the school holiday months of April, August and December.

During the survey most of the respondent farmers reported little use of hired labour. Hence hired labour was not considered in the analysis.

c) Capital Constraint

The capital available consisted of all the purchased inputs used by the farmers in their production activities. The inputs considered were fertilizer, seeds, herbicides, pesticides, hired labour, water and land preparation expenses. For the scheme crops (i.e. cotton, maize and groundnuts) the capital input figures were on the scheme records since the scheme management supplies these inputs on credit and recovers the same from the proceeds of cotton sale.

d) The Subsistence Constraint

This was included in the analysis because of its crucial role in the agricultural production decisions. It was derived by regarding maize as the major subsistence crop and specifying that the acreage under maize be equal to or greater than 1 acre per farmer.

This was because the scheme management required each farmer to grow at least one acre of maize for their subsistence.

e) Non Negativity Constraints

These specify that all the activities should take on zero or positive values. These non negativity constraints are expressed as:

$X \geq 0$

Where:

X is the vector of activity levels.

3.3 Limitations of Linear Programming Models

The weaknesses of linear programming models derive from their basic assumptions; for instance, linearity in the objective and constraint functions and single value expectations. In real situations, production relationships exhibit economies or diseconomies of scale. The linearity assumption, therefore, renders linear programming models inadequate in analysing such problems. This problem can be solved by employing non-linear models which are more complicated. The single value expectation assumption of linear programming implies that prices, outputs and inputs and output coefficients are known with certainty. This is rarely the case. By performing sensitivity analysis (also known as post-optimality analysis) this latter limitation can be overcome. Obtaining the data for linear programming analysis is also regarded as a drawback in its use as a planning tool. This is so because detailed data is required before the technique can be used.

3.4 Data and Data Sources

To enable the running of the linear programming problem as formulated in equations 15 and 16, data were required and derived on the following:

1. resource constraints defining the availability of land, labour and capital resources;

2. the technical coefficients (input-output coefficients) for each of the activities being operated by the tenants;

3. the input prices; and

4. the output prices.

Data on the above were generated from both primary and secondary sources. Forty (40) farmers were randomly chosen and then interviewed by using a structured questionnaire to obtain information on inputs, outputs, labour availability, cultural practices and prices of both inputs and outputs. The random selection of the forty farmers was facilitated by the existence of current records on farmer tenancy. The local market at Laza was also visited and traders were asked questions on the prices of crop products like greengrams, maize, tomatoes, onions and groundnuts. From secondary sources, mainly scheme records, information was obtained on inputs, outputs, and costs of production. The two data sources corroborated each other especially with regard to capital use and farmer outputs.

3.5 Data Analysis

The data gathered were first averaged to obtain the figures for the average farm. Gross margins computation then followed. The resultant gross margins were used to construct the Linear Programming objective function. Using this objective function, the resource amounts, the input-output coefficient and the subsistence requirements, a Linear Programming Problem matrix was constructed. This problem matrix is shown in Appendix 7. The Linear Programming Problem was then optimized through a DHLLP Computer Programme. After the optimization, sensitivity analysis was done to show the range within which the obtained optimal farm plan would remain optimal, to determine the entering values for the non-basic variables and to derive the shadow prices or the marginal value products of the resources in the optimal solution. The binding constraints were deduced from the shadow prices which take positive values only for limiting resources.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This study's major objectives were:

1. to describe the existing farming system in the Hola Irrigation Scheme;

2. to examine the major constraints to agricultural production in the scheme;

3. to examine the existing farm plans in the scheme, and determine if a reallocation of the scheme's resources would improve the incomes of the farmers and therefore lead to more efficient use of the available production resources.

The hypothesis that resource allocation in the Hola Irrigation Scheme was sub-optimal (so that a reallocation of the scheme's resources would be needed to optimize the returns of the tenant farmers) was postulated and tested by determining the optimal enterprise combination and resource use in the scheme and comparing these with the existing farm plans. Specifically, the total farm gross margins realized under the two situations were compared.

As described in Chapter Three, the optimal enterprise combination and the resultant optimal total farm gross margins were determined by using the Linear Programming technique. This was preceded by calculations of the gross margins for each of the enterprises operated by the farmers. Only the major enterprises were considered. The enterprise gross margins obtained were then used to construct the linear programming objective function. A linear programming problem matrix was then constructed and optimized with the aid of a computer.

Based on the results generated for the surplus amounts of the various productive resources, and the corresponding dual values giving the shadow prices, the principal agricultural production constraints were inferred. Sensitivity analysis, an important variant of linear programming was then carried out to establish how the optimal plan is affected by changes in the resource constraints, prices and costs. The sensitivity analysis results further indicated the entering values for the non-basic activities. In this chapter, the empirical results of this study are presented.

4.2 Results of Gross Margin Analysis

The gross margins of the various enterprises farmers operate in the Hola Irrigation Scheme were obtained by deducting from the value of the total production the respective total variable costs of production. The major components of the variable costs were the costs of cultivation, seeds, fertilizers, herbicides, pesticides, water and labour. In the analysis only the values of the enterprise gross outputs obtained and variable costs incurred during the 1988/89 cropping year were considered. The gross margins included the value of farm produce consumed on the farms. Except for cotton whose value was found by using the administratively determined price of KShs. 6.00 per kg, the output values of the other commodities namely, maize, groundnuts, greengrams, tomatoes and onions were found by using the mode of the local market prices. This approach was considered appropriate because the local market prices of these commodities exhibited considerable seasonal variability and the mode represented the prevalent prices. For example, it was reported that the local market prices of both onions and tomatoes ranged between KShs. 2.00 and KShs. 10.00 per kg. However the prevalent price for both commodities was KShs. 5.00 per kg (these are the 1988/early 1989 figures).

The computed gross margins for the various enterprises are presented in Table 8. Details of the components in the gross margins calculations are presented in Appendices 1 - 6.

Table 8: Results of Gross Margin Analysis for Hola Irrigation Scheme, 1988/89

Enterprise	Gross Output Output (KShs/Acre)	Total Variable Costs (KShs/Acre)	Gross Margin (KShs/Acre)
Onion	8360.00	2308.00	6052.00
Tomatoes	6800.00	849.00	5951.00
Cotton	5466.00	2709.55	2756.45
Groundnuts	3176.00	980.00	2196.00
Maize	2375.00	1840.00	534.35
Greengrams	1200.00	794.00	406.00

Source: Author's Work, 1989

Besides being important in the construction of the linear programming objective function, the enterprise gross margins computed above were used in comparing the performance of the various enterprises in terms of the net returns they generated to the farmers.

The analysis in Table 8 showed that the enterprise gross margins varied widely and that onions were the most profitable, with a net return of KShs. 6052.00 per acre, while greengrams were the least profitable, with a net return of KShs. 406.00 per acre. Cotton and maize, which dominated the cropping pattern in the scheme, were not the most profitable enterprises. Their gross margins were KShs. 2756.45 and KShs. 534.35 per acre, respectively. Theoretically, therefore, the farmers should give priority to onion and tomato growing and least emphasis to maize and greengrams growing. They are then likely to obtain higher returns from their resources through such a strategy since the maximization on the most constraining resources would be realised by undertaking those activities which provide the highest returns per unit of available resource (Upton, 1973). This, however, was not the case in Hola.

Two main reasons can be advanced for the predominance of cotton and maize in the cropping pattern in the scheme. Firstly, an important objective in small farmers' production appears to be the meeting of subsistence requirements (Heyer, 1972). Secondly, the scheme's policy required the farmers to grow at least one acre of maize to meet their subsistence needs. The growing of maize was undertaken after the cotton had been harvested. Given that the Hola farmers had relatively low levels of income (Migot-Adholla, 1982; Ruigu et al., 1984; Ireri, 1986; Ruigu, 1987), it was not surprising that subsistence production was given such prominence. As such, it is expected that even in the absence of a scheme policy requiring farmers to grow one acre of maize for subsistence purposes, they would still grow it despite its low profitability as compared to the other enterprises.

Cotton, the most important crop in the scheme, was less profitable than onions and tomatoes, which, though more profitable, were given less priority in the scheme's cropping pattern. Production decisions with a profit maximization objective would therefore require that less emphasis be given to cotton and more emphasis be given to onions and tomatoes, Ceteris paribus. But such an arrangement would not be a sufficient condition for profit maximization. The increased supply of the onions and tomatoes would be likely to depress the local market prices of these commodities. This would in turn lead to lower returns. This was evidenced by the reported wide seasonal fluctuations in the market prices. With an efficiently functioning marketing system, however, such an arrangement in which greater emphasis is given to tomatoes and onions would be expected to maximize the returns to the farmers' efforts. In such a situation, the scheme's policy that required farmers to grow 3 acres of cotton would be preventing the farmers from realizing the highest returns to their efforts.

4.2.1 Returns to Labour

Returns to labour input play an important role in agricultural production decisions. Generally, the higher the value of the crop, the greater will be its return to labour relative to other crops. In this study the returns to labour were computed by dividing the various enterprises gross margins by the respective total labour input. Table 9 shows the returns to labour per enterprise.

Table 9: Returns to Labour at Hola Irrigation Scheme, 1988/89

Enterprise	Gross Margin (KShs/Acre)	Total Labour Input (Mhrs/Acre)	Returns to Labour (KShs/Mhr)
Onions	6052.00	351	17.20
Tomatoes	5951.00	200	29.80
Cotton	2756.45	1180	2.30
Groundnuts	2196.00	250	8.80
Maize	534.35	212	2.50
Greengrams	406.00	176	2.30

Source: Author's Work, 1989

The returns to labour in KShs/mhr in the respective enterprises depends on both the value of the crop product under consideration and the total labour requirement in the crop's production. It is expected that high-value crops will give higher returns to labour as compared to lower value crops. Further, it is also expected that crops with a higher total labour requirement will give lower returns to labour as compared to crops with a low labour requirement. In Table 9 above, these expectations are confirmed. Onions and tomatoes which are high value crops had the highest returns to labour of KShs. 17.20 and KShs. 29.80 per manhour respectively.

Though onions had higher gross margins per acre compared to tomatoes, the latter required a lower amount of labour in its production. This is why tomatoes had a higher return to labour. The cotton enterprise, though the most dominant in the scheme in terms of acreage, had the lowest return to labour of about KShs. 2.30 per mhr. The high labour requirement in cotton production seems to be the reason for this low return to labour. Indeed, of all the enterprises operated by the farmers in the scheme, cotton had the highest labour requirement of some 1180 mhr/acre with harvesting being the activity consuming the greatest amount of labour. It was estimated that about 41 percent of the labour input in cotton production was employed in its harvesting.

Therefore if production decisions were to be based on the returns to labour, profit maximization would be likely to be attained by placing the greatest emphasis on onion and tomato production and least emphasis on cotton and greengram production.

In the field survey only a few of the respondent farmers were growing greengrams. This seems to be a rational decision since the greengrams yielded low returns to labour input (about KShs. 2.30 per mhr). On similar grounds, it is questionable if, in the absence of policy intervention, farmers would continue to grow cotton. This view was actually reflected by the majority of the respondent farmers when they asserted that they would opt to grow other crops if the "compulsion" was removed.

4.2.2 Returns to Capital

These were computed by dividing the gross margins by the amount of capital input required for one acre of each of the activities being operated. The computed figures for the returns to capital are shown in Table 10.

Table 10: Returns to Capital at Hola Irrigation Scheme, 1988/89

Enterprise	Gross Margin (KShs/Acre)	Capital Amount Required (KShs/Acre)	Returns to Capital
Onions	6052.00	1610.00	3.80
Tomatoes	5951.00	508.00	11.70
Cotton	2756.45	1514.05	1.80
Groundnuts	2196.00	590.00	3.70
Maize	534.35	1352.65	0.39
Greengrams	406.00	390.00	1.04

Source: Author's Work, 1989

The returns to capital indicate the monetary returns in KShs. that are obtained when one KShs. is spent in purchase of capital inputs. Like in the case of labour, the returns to capital depend on both the value of the crop product under consideration and the total amount of capital used. They can be used as yardstick in deciding on how to employ capital. It would be justified that capital be used in enterprises in which returns to capital is greater than one. However, those enterprises with higher returns to capital are preferred to those with lower returns to capital. Hence, on the basis of returns to capital alone, the growing of maize would not be justified. Its growing was however rationalized by the important role it played in the provision of subsistence requirements. Table 10 reveals that of all the enterprises operated in the scheme, tomatoes yielded the highest returns to capital of 11.7 while maize yielded the least returns to capital of 0.4. The patterns of capital use are also shown in Table 10. It is in onion production that the greatest amount of capital was required, with seeds being the most expensive of the capital items. In greengrams production, the least amount of capital was used and this could partly explain its low yields. It was also clear that the scheme crops were allocated a greater amount of capital as compared to the non scheme crops.

4.3 The Linear Programming Results

The Hola farmers were found to exhibit a high degree of homogeneity in terms of their land sizes, the crops, types and amounts of inputs used, input sources, cultural practices, technology and input and output prices. Therefore only one representative linear programming problem matrix was constructed and optimized. The linear programming problem matrix is presented in Appendix 7. It consisted of constraints listed on the left hand side to form rows, and their appropriate levels listed on the right hand side.

The use of the linear programming technique necessitated that the following assumptions be made:

1. additivity and linearity of activities;
2. divisibility of activities and resources;
3. finiteness of alternative activities and resource restrictions; and
4. single value expectations ... meaning that resource supplies, input coefficients and commodity and factor prices are assumed to be known with certainty (Baumol, 1977).

The Linear Programming results that have been presented show the optimal enterprise combination and resource allocation patterns, the limiting constraints to agricultural production in the scheme, the shadow prices (the marginal value products) of the resources and the sensitivity analysis results.

4.3.1 Existing and Optimal Farm Plans

As already stated in Chapter One, the existing cropping pattern in the Hola Irrigation Scheme which was prescribed by the schemes management required each tenant to grow 3.0 acres of cotton during the long rains season (from the months of February to September), 1.0 acre of maize and 0.25 acres of groundnuts during the short rains season (from the month of September to February). Each tenant was also allocated 0.25 acres on plots near the villages. The tenants were allowed to grow crops of their own choice on such plots. The crops they grew on these plots included tomatoes, onions, kales and greengrams. Though experience had shown that these crops could be raised successfully under irrigation in the Hola area, only a small proportion of these plots was being used to grow onions, tomatoes and kales and by few farmers. Most of the farmers interviewed (29/40 or 73%) reported that they used these plots largely to grow greengrams. From these findings, a farm plan for the existing situation was deduced. This farm plan is presented in Table 11.

Table 11: The Existing Farm Plan for Hola Irrigation Scheme in 1988/89

Type of Enterprise	Gross Margin/Acre (KShs.)	Size (Acres)	Gross Margin
Cotton	2756.45	3.00	8269.35
Maize	534.35	1.00	534.35
Groundnuts	2196.00	0.25	549.00
Onions	6052.00	0.00	0.00
Tomatoes	5951.00	0.00	0.00
Greengrams	406.00	0.25	101.50
Total Gross Margin			9454.20

Source: Author's Work, 1989

The existing farm plan showed that the cotton enterprise dominated the cropping pattern and that it was the most important enterprise in terms of acreage and farm gross margin. Its contribution to the total gross margin was about 88 percent. The table further shows that when cotton, maize, groundnuts and greengrams were grown at acreages of 3.0, 1.0, 0.25, and 0.25 respectively, the resulting total farm gross margin was KShs. 9454.20.

From the linear programming technique, an alternative farm plan (the optimal farm plan) was generated. The alternative and optimal farm plan is shown in Table 12.

Table 12: The Optimal Farm Plan for Hola Irrigation Scheme, 1988/89

Type of Enterprise	GM/Acre (KShs)	Size (Acres)	Total Enterprises GM (KShs)
Cotton	2756.45	2.80	7718.10
Maize	534.35	1.00	534.35
Groundnuts	2196.00	0.00	0.00
Onions	6052.00	0.23	1392.00
Tomatoes	5951.00	0.27	1606.80
Greengrams	406.00	0.00	0.00
Total FARM GM			11,154.00

Source: Author's Work, 1989

The optimal farm plan, under the existing levels of technology and resource contraints, showed a marked divergence from the existing situation. A comparison between the two (the existing farm plan and the optimal farm plan) revealed that through reorganization of the existing farm plans, Ceteris paribus, the incomes of the farmers could be increased significantly by about 18 percent from KShs. 9454.20 to KShs. 11,154.00. Such a reorganization of the existing agricultural production system would entail the omission of groundnuts and green grams from the farm plans and reduction in the land area under cotton by about 7 percent from 3.0 to 2.8 acres. Also, such a reorganization would require that increased emphasis be placed on the growing of onions and tomatoes at 0.23 and 0.27 acres respectively. The land area under maize does not change though such a reorganization.

The contribution of the various enterprises to the total farm gross margin changed significantly in the optimal farm plan. Under the optimal farm organization, the contribution of cotton to the total farm gross margin was about 69 percent while under the existing farm organization, its contribution is about 88 percent. The contribution of the high value crops, namely tomatoes and onions, when the optimal plans are adopted increased significantly to about 27 percent.

It is clear, therefore, that sufficient potential exists for increasing farm returns by reorganizing the existing enterprise combination and resource use patterns. On the basis of this finding, the stipulated hypothesis that the enterprise combination and resource allocation in the Hola Irrigation Scheme are suboptimal was accepted.

4.3.2 Agricultural Production Constraints

These refer to the factors which prevent farmers from realising higher farm incomes and improving on the utilization of the available resources. In this study, the major binding agricultural production constraints were determined from the optimized linear programming tableau. Inference on them was then drawn from the column showing the dual values. These dual values are also known as the shadow prices and they give the marginal value products of the various contraining resources. They indicate by how much the total gross margins are decreased or increased whenever a unit of the constraining resource is withdrawn from or added to the production system, Ceteris paribus. Whenever a constraining resource is not used up entirely in the optimal solution, it will have zero marginal value product. On the other hand, when such a resource is used up, it becomes limiting (binding) constraint with a marginal value product which is positive (>0). Using this criterion, that is, the shadow prices of the various resource restraints, the binding agricultural production constraints in the Hola Irrigation Scheme were identified as:

a) Land

b) Labour

c) Capital

d) Subsistence

Land

Under the existing level of technology and resource availability, the short rains land (LSR) was found to be a binding constraint to agricultural production in the Hola Irrigation Scheme. This is the land that was used to grow maize, groundnuts and greengrams; and maize, onions and tomatoes under the existing and optimal conditions, respectively. The short rains land (LSR) was a limiting constraint in the sense that it was not enough to permit the maximum use of the available factors of production, especially the family labour. The LSR is used up when optimal farm plan is adopted and its dual value was found to KShs. 5904. It follows therefore that if a farmer was allocated an extra acre of land during the short rains season, under optimal conditions the total farm returns would increase by KShs. 5904 from KShs. 11,154.00 to KShs. 17,058. A further implication was that if extra rental land were available during the short rains season and farmers had enough money for hiring the land, then under optimal conditions the maximum rent charged would be KShs. 5904 per acre. Hiring land at rents higher than KShs. 5904 per acre would consequently be uneconomical.

However, during the long rains season, land (LLR) was not found to be a binding constraint. It was found that LLR was available in surplus amounts under optimal conditions since the optimal plans indicated that cotton should be grown on 2.8 acre plots of land while the farmers were allocated 3.0 acre plots by the scheme´s management. The finding that the farmers under optimal farm organization would be faced with a shortage of land in the short rains season and a surplus of land in the long rains season would justify a reallocation of land to improve the efficiency with which it is utilized. But because LLR and LSR are cultivated in different seasons, a simple reallocation of the land would not be possible. However, the surplus land during the long rains season could be used for growing onions which had the highest gross margin. This would then yield an additional income of KShs. 1210.40 and hence increase the total farm income from KShs. 11,154.00 to KShs. 12.364.40. It is expected though that such a scheme would lead to labour and capital problems. These problems have been examined in later sections.

Labour

Family labour was found to exist in surplus amounts during most of the months except February and July when the available family labour was exhausted. This reflects a characteristic feature regarding labour use in agricultural production: seasonality in its use and demand. Agricultural operations have a temporal distribution and consequently labour use is also distributed similarly. Certain farm operations have high labour requirements and therefore during the months when such operations are performed labour use peaks are manifested. In Hola the planting of cotton which is coupled with the application of Diammonium Phosphate fertilizer, and the harvesting of groundnuts are undertaken in February while the harvesting of cotton (picking) is undertaken in the months of June, July, August and September. In the optimal plan (Table 12) in which cotton alone is the recommended enterprise for the long rains season, labour shortage is experienced and this is evidenced by the positive dual value for February. February labour constrains cotton production to 2.8 acres since it is not enough to permit the cultivation of the 3.0 acres allocated to the crop. Therefore the cultivation of the entire 3.0 acres allocated to cotton critically depends upon the use of hired labour to supplement the family labour. The shortage of labour in the month of February was acute as the dual value indicated. Under optimal conditions, therefore, the hired labour should be paid a high wate rate of Kshs. 12.05 per mhr. But the use of hired labour requires that cash be available and this implies the need for credit to the Hola farmers. Such a credit should be provided in adequate amounts and under reasonable terms. During the actual field survey, most of the farmers reported little use of hired labour. They, however, expressed their need for hired labour. But since they lacked cash, they were unable to hire the extra labour they needed. Labour shortages which are not reflected in the linear programming tableau were also reported. The most important of these labour shortages was during the harvesting season. It seems therefore that not all of the family labour was available for scheme farm work. This could be partly attributed to the fact that a portion of the family labour was deployed in "non scheme" work. Such "non scheme" work includes the cultivation of farm land outside the scheme and employment in non-farm work.

Capital

Improved agricultural production critically depends on the use of capital inputs in the form of seeds, fertilizers, herbicides, pesticides and hired labour (Mosher, 1967). As earlier mentioned, most of the capital inputs used in the Hola Irrigation Scheme were supplied to the farmers by the scheme's management. The inputs were supplied to them on credit which was recovered from the proceeds of the cotton sale. This seems to be a sound policy since studies such as those by Ruigu and Ireri have shown that farmers in the large scale national irrigation schemes have low incomes and would therefore be unable to afford such essential capital inputs if not provided on credit.

An important finding of this study with regard to working capital usage was that the amount available was exhausted. Working capital was therefore identified as a limiting constraint with a dual value greater than zero. This would therefore explain why capital use was minimal in the enterprises the Hola farmers operate with the exception of cotton, maize and groundnuts which utilized capital inputs supplied by the scheme. The respondent farmers actually reported little or no use of fertilizers and other capital inputs in the onion and tomato enterprises which appear in the optimal farm plans. The reason given for this was its high price. This was also the reason why some farmers opted to use seed from the "tomato fruit" rather than purchasing the same from the stockists.

It can therefore be urgued that the low usage of capital inputs contributed to the low yields and consequently low monetary returns to the Hola farmers.

The need for credit was accordingly further revealed since it was crucial in easing the capital constraint. But, like in the case of labour, credit for easing the capital constraint needs to be provided to the farmers in adequate amounts and under favourable terms. Through this avenue there would be an improvement in the utilization of the available resources because more units of the enterprises would then enter into the farm plans.

Subsistence

The subsistence constraint was incorporated into the linear programming model because in real situations, small farmers tend to give priority to the growing of subsistence crops. This constraint in the optimized linear programming tableau had a dual value which was greater than zero. Hence, it was found to be a binding constraint to increased farm incomes. It has been shown earlier that of the enterprises the farmers operate in the scheme, the maize enterprise did not have the highest returns to land, labour and capital. Its inclusion into the optimal farm plan at an acreage of 1.0 therefore has a negative effect on the farm incomes that would be realized without it.

Marketing

Cotton was the major crop in the scheme in terms of land allocation and returns and its marketing was undertaken through a centralized channel. The tenants sell their produce to the Cotton Board of Kenya and payments to them are made through the scheme's management. Prior to paying them, however, the credit advanced to them in the form of fertilizers, seeds, pesticides, herbicies, irrigation water and land preparation is deducted. The net incomes accruing to farmers was therefore dependent on the output of cotton, the price of cotton, the amounts of various inputs used and the respective prices of the inputs. These variables were in turn influenced by the cultural practices and the pricing and marketing policies. But the prices of cotton and the various inputs used in its production were determined administratively and not by the market supply and demand forces. It follows therefore that the levels at which these prices were set constrained the incomes that the farmers realized. Specifically, it is expected that the low commodity prices and high factor prices will lead to low returns while high commodity prices and low factor prices will lead to high returns. In this study, the factor prices were found to be high. The setting of the cotton price at KShs. 6.00 per kg therefore caused the farmers to realise lower incomes than they would otherwise obtain, *ceteris paribus*, if the prices were set at higher levels. The other crops grown in the scheme were sold through the local market at Hola where the prices were determined by individual negotiations between the buyers and the sellers. The market supply and demand forces played an important role in determining the price levels of these commodities (reference here is to the surplus output over the domestic consumption requirements though the value of the produce consumed on the farms was included in the farm gross margin). The prices of these commodities especially tomatoes and onion fluctuated widely and were generally low during the harvest season on account of the increased market supply. Hence the farmers were faced with low and fluctuating incomes during the harvesting season. This is indicative of a marketing problem which was a constraint to increased farm incomes in the scheme. By acting as a disincentive these low and fluctuating incomes constrain increased agricultural production in the scheme since the farmers would not venture into the intensive production of these commodities in the face of such uncertainty in the prices. The problem of marketing was also identified as affecting the availability of inputs. This particularly applied to the availability of fertilizers. It was recommended that the tenants use the fertilizer Sulphate of Ammonia in the growing of cotton and maize. But for the last two years (1987 and 1988) they had instead been using the fertilizer Ammonium Sulphate Nitrate. This departure from the recommended practice was attributed mainly to the unavailability of the fertilizer Sulphate of Ammonia. Since these two fertilizer types had different prices (Sulphate of Ammonia cost KShs. 169.75 per 50 kg bag while Ammonium Sulphate Nitrate cost KShs. 292.75 per 50 kg bag), the type used had an important bearing on the farm incomes. Data analysis indeed revealed that when farmers used Ammonium Sulphate Nitrate the cotton and maize gross margins were KShs. 2756.45 and KShs. 534.35 per acre, respectively, while when they used Sulphate of Ammonia, the respective gross margins were KShs. 2879.45 and KShs. 657.35 per acre. It is clear therefore that farmers in the scheme were using a fertilizer which had a downward effect on their farm incomes. Through the use of the recommended fertilizer, higher incomes could be realized. But this was not the case due to the inadequacy of the marketing system which led to the unvailability of the recommended fertilizer.

Infrastructure

The success of a farming business depends on the availability of markets for the farm produce and if ample markets do not exist in the production regions, the commodity prices are likely to be depressed due to the high supply. Such depressed commodity prices do not result in an appreciable increase in the demand because agricultural commodities in general are characterized by a low price elasticity of demand (Meir, 1984; Todaro, 1986; Bressler & King, 1970). A situation of high commodity supply, low commodity prices and low price elasticity of demand inevitably leads to depressed farm incomes which are undesired by agricultural producers. To reverse this situation, ample storage facilites, suitable and adequate means of transportation to the alternative markets are needed. These provisions would enable the producers to realise higher commodity prices and consequently higher incomes by exploiting and taking advantage of both the temporal and spatial dimensions of the market. Further, these provisions would exert a stimulatory effect on agricultural production possibility curve by better use of resources and encouraging them to use more labour and other variable inputs to reach higher production function and output levels (Meir, 1984).

Infrastructure therefore becomes an important factor in realising these benefits since it plays a crucial role in facilitating interregional trade if already different prices exist in spatially separated markets. An incentive to such a trading arrangement would be price differentials which are greater than the transfer costs (Bressler and King, 1970). Potential markets for the Hola produce, especially tomatoes and onions, included Garissa, Bura, Garsen, Malindi and Mombasa. Significant price differentials existed between these towns and Hola. Therefore, there was scope for realising increased profits by producing for these markets. During this study, an examination into the condition of the roads linking these towns was undertaken. It was found that the roads were poor and impassable during the rainy season. They were also found to be highly insecure as evidenced by frequent attacks on passengers by "Shifta" bandits. These two factors have indeed been a hindrance to trade between these regions. Lack of market information was also suspected to have been a contributory factor.

4.4 Sensitivity Analysis Results

Sensitivity analysis (also known as post-optimality analysis), according to Aggrawal and Heady (1972), represents an important variant of linear programming and it is usually carried out in studies utilizing the linear programming technique to examine how the optimal solution is affected by changes in resource restraints, prices and costs. Such an analysis is crucial to decision making since it gives recognition to the fact that the variables in the production process, e.g. labour and land availability, are subject to changes. These changes, in turn, influence the optimal plans in diverse ways. The sensitivity analysis that was carried out in this study encompassed two major processes, namely the Right Hand Side Ranging and the Objective Function Ranging.

4.4.1 Right Hand Side Ranging

This primarily examines how the optimal plan is affected by changes in the resource levels (i.e. the Right Hand Side Values). Detailed results of the Right Hand Side Sensitivity Analysis are presented in Appendix 8. These results showed that the constraints to which the optimal plan earlier determined was most sensitive were the short rains land area (LSR), February labour, working capital and subsistence. The optimal plan will remain optimal only within a narrow range in the levels of these contraints. When the values of these constraints (defining the resource availability) fall out of the defined ranges, the optimal plan ceases to be optimal.

4.4.2 Objective Function Sensitivity Analysis

The objective function sensitivity analysis results are presented in Appendix 9. These results show the ranges of the returns from the various enterprises that will maintain the optimal farm plans. These ranges are presented in Table 13 below.

Table 13: Range for Optimal Plan Stability

Crop	Range in KShs/Acre
Onions	5951.00 - 7957.30
Tomatoes	4045.70 - 6052.00
Cotton	138.80 - >138.80
Maize	0 - 6028.40

Source: Author's Work, 1989

Cotton remains in the optimal plan as long as the returns per acre are at least Kshs. 138.80. This can be partly attributed to the scheme's cropping policy which required that the available land be allocated to cotton during the long rains season. It can also be seen from the results that maize will remain in the optimal plan even if it has a very low return as it is the major subsistence crop. This is also the reason why farmers may undertake to produce crops for subsistence even if the costs of production are high.

Groundnuts and greengrams are not in the optimal plan. This is due to their low returns. When their returns are increased they enter into the optimal farm plan. The results, however, show that their entry into the optimal plan is possible only if their returns are at least KShs. 7044.20 per acre for groundnuts and KShs. 6905.20 per acre for greengrams (these increases in returns are about 69 percent for greengrams and about 94 percent for groundnuts). These increments are quite high and would be difficult to attain in the short run.

Three approaches are, however, available through which the returns from these enterprises could be increased. These three approaches consist of increasing the yields, increasing the prices and reducing the costs. The yields can be increased by encouraging farmers to follow the recommended crop husbandry practices through enhanced extension effort. Specific aspects of this approach include the use of recommended high yielding crop varieties, fertilizers, pesticides and other capital inputs in adequate amounts. This would however be accompanied by some increase in production costs. But the recommended practices would be expected to lead to higher returns due to the increased yields. Costs could also be substantially reduced by either lowering the prices of the various inputs or increasing the efficiency with which the inputs are used. The option of increasing the prices, however, has limited scope as farmers sell their produce in commodity markets over which they have no control and where the prices are determined by supply and demand. For the groundnuts and greengrams to enter into the basis, yields and production costs being the same, price increases from KShs. 4.00 to KShs. 10.10 and KShs. 10.00 to KShs. 64.10 per kilogram respectively would be warranted. Alternatively, if the production costs and prices remain the same, the yields for both crops would need to increase three-fold. It follows therefore that under the present conditions at the Hola Irrigation Scheme, the growing of groundnuts and greengrams would have a depressing effect on farm incomes. The shadow prices indicate that growing an acre of groundnuts would reduce the total returns by KShs. 4848.20 while growing an acre of greengrams would reduce it by KShs. 6499.20.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this study the agricultural production constraints and the optimal enterprise mix for the Hola Irrigation Scheme have been determined. It has been established that scope exists for increasing the farm incomes through a reallocation of the available resources. This was determined by comparing the existing farm plan with the optimal farm plan. In the optimal farm plan, the cotton acreage is lower than it is in the existing farm plan, and groundnuts and greengrams do not appear in it. Tomatoes, onions and maize, besides cotton, are the main activities in the optimal farm plan. Tomatoes and onions were found to be the enterprises with the highest gross margins per unit of land, labour and capital. Maize was found to have a low return, but its appearance in the optimal farm plan is largely due to the fact that it is the major subsistence crop. The major constraints to increased agricultural production and hence increased farm incomes were found to be the short rains land area, February family labour, working capital, subsistence, production and marketing.

The marketing constraint affected mainly those crops sold in the local market but its greatest effect was on the tomato and onion enterprises. The market prices of these two commodities exhibited wide fluctuations as a consequence of the marketing problems.

It is evident that the farm incomes at Hola can be increased through resource reallocation. However, the structural and institutional obstacles mentioned above should first be removed to pave way for farmers to adopt the determined optimal farm plan. The following recommendations are therefore made:

a) that the marketing system be improved especially for tomatoes and onions whose prices fluctuate widely. This would both stabilize their prices and make the farmers obtain higher incomes. It is specifically suggested that the Hola Farmers Cooperative Society be strengthened and diversified for it to have the capacity for marketing these commodities;

b) that the tenant farmers at the Hola be provided with credit in adequate amounts and under suitable terms and conditions. This would go a long way towards assisting the farmers to overcome the capital constraint;

c) that the infrastructure be improved to facilitate the transportation of produce to markets which exist in the towns of Garissa, Bura, Garsen, Malindi and Mombasa. This should be coupled with improving the security situation which has hitherto been extremely poor in the area;

d) that the farmers' and scheme's resources be reallocated by the adoption of the determined optimal farm plan. This would involve reducing the cotton acreage from 3.0 to 2.8 acres, excluding groundnuts and greengrams from the farm plan and growing tomatoes and onions at 0.27 and 0.23 acres respectively. The maize acreage should however remain unaltered.

It is expected that implementation of the above measures would not only raise farm incomes but improve on the resource use in the scheme.

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APPENDICES

Appendix 1: Gross Margin Calculation for Cotton

Average output per acre = 911 kg

Price of cotton = KShs. 6.00 per kg.

[Administratively determined]

Gross income from cotton = [911 x 6] Shs/acre = 5466 Shs/Acre.

Costs in Cotton Production per Acre

.	Land Preparation	150.00
.	Planting Labour	50.00
.	Fertilizing Labour	50.00
.	Weeding Labour	640.00
.	Fertilizers 3 bags/acre @ 292.45	877.35
.	Herbicides	86.70
.	Picking Labour 0.5 Shs/kg x 911 kg	455.50
.	Water	400.00

	Total Cost	2709.45
	GROSS MARGIN: 5466 - 2709.55 =	2756.45

Appendix 2: Gross Margin Calculation for Maize

Average output per acre = 950 kg

Price of maize in local market = KShs. 2.50 per kg

Gross income from maize = 950 x 2.50 =

KShs. 2375

Costs in Maize Production per Acre

. Land Preparation	150.00
. Planting Labour	50.00
. Fertilizing Labour	50.00
. Weeding Labour	320.00
. Fertilizers 3 bags/acre @ 292.45	877.35
. Seed 10 kg (1 pkt)/acre)	109.90
. Pesticide 1.7 kg (1 pkt)/acre	15.40
. Water	200.00
. Harvesting Labour	68.00

Total Cost	1840.65

GROSS MARGIN: 2375 - 1840.65 = 534.35

Appendix 3: Gross Margin Calculation for Groundnuts

Average output per acre = 794 kg (unshelled)

Price of groundnuts in local market = 4 Shs/kg of unshelled groundnuts

Gross income from groundnuts = 794 x 4 = 3176 Shs/acre

Costs in Groundnut Production in KShs. per Acre

Land Preparation	150.00
Planting Labour	50.00
Seed 16 kg/acre at 15 Shs/kg	240.00
Weeding Labour	200.00
Harvesting Labour	140.00
Water	200.00

Total Cost	980.00
GROSS MARGIN: 3176 - 980 =	2196.00

Appendix 4: Gross Margin Calculation for Greengrams

Average output per acre = 120 kg

Market price of greengrams = 10 Shs per kg

Gross income from greengrams = 120 x 10 = 1200/-

Costs in Greengram Production in KShs. per Acre

. Land Preparation	150.00
. Planting Labour	50.00
. Seed 4 kg @ 10 Shs.	40.00
. Weeding Labour	218.00
. Harvesting Labour	136.00
. Water	200.00

Total Cost	794.00
GROSS MARGIN: 1200 - 794 =	406.00

Appendix 5: <u>Gross Margin Calculations for Onions</u>

Average output per acre = 1672 kg though variable from 468 - 4857

Price of onions per kg = KShs. 5 though variable from (KShs. 2 - 10 per kg)

Gross income from onions = 8360 Shs.

<u>Costs in Onion Production in KShs. per Acre</u>

• Land Preparation	150.00
• Seed 800g/acre	1360.00
• Water	200.00
• Labour planting 83 manhours	142.00
weeding 138 manhours	235.00
harvesting 130 manhours	221.00
Total Costs	2308.00
GROSS MARGINS:	6052.00

Appendix 6: Gross Margin Calculation for Tomatoes

Average output per acre = 1360 kg

Price of tomatoes per kg = KShs. 5 though variable from (Kshs. 2 - 10 per kg)

Gross income from tomatoes = KShs. 6800

Costs in Tomato Production in KShs. per Acre

Land Preparation	150.00
Seed 60g/acre	158.00
Labour planting 70 manhours	120.00
weeding 50 manhours	85.00
harvesting 80 manhours	136.00
Water	200.00
Total Costs	849.00
GROSS MARGINS:	5951.00

RESULTS

APPENDIX 7: THE LP PROBLEM MATRIX

```
 JW/COL        COTTON     MAIZE      G/NUTS     G/GRAMS    ONIONS     TOMATOES  RHS

RETURNS       2756.450   534.350  2196.000    406.000  6052.000  5951.000      0.0000
LAND 1           1.000       X        X          X         X         X         3.00001
LAND 2            X        1.000     1.000      1.000     1.000     1.000      1.50001
JAN LAB         39.000    40.000      X          X         X         X       600.00001
FEB LAB        217.000       X       90.000     80.000     X         X       600.0000L
MAR LAB         50.000       X        X          X         X        ,X       600.0000L
APR LAB        184.000       X        X          X         X         X      '1050.00001
MAY LAB        184.000       X        X          X         X         X       600.0000L
JUN LAB        122.000       X        X          X         X         X       600.0000L
JUL LAB        122.000       X        X          X         X         X       600.0000L
AUG LAB        122.000       X        X          X         X         X      1050.0000L
SEP LAB        122.000    15.000    32.000       X         X       35.000     600.0000L
OCT LAB          X       157.000   128.000·    24.000    83.000    35.000     600.0000L
NOV LAB          X          X         X        12.000   138.000    50.000     600.0000L
DEC LAB         18.000      X         X        60.000   130.000    80.000    1050.0000L
WORK CAP      1514.050  1352.650   590.000    390.000  1610.000   508.000    6042.2998L
SUBS             X         1.000      X          X         X         X         1.0000G
```

```
 ER.  V-IN   OBJECT VAL             NET VAL                    LEVEL                          V-I
      2      534.3499755859375      999999996438.35            1                              5
      5      6052                   6052                       .5                             8
      1      2756.449951171875      2756.449951171875          2.565734060957996              21
      6      5951                   1905.279679157578          .273742031570329               1

PROBLEM NAME = AYODLP
STATUS = OPTIMAL
 OJECTIVE FUNCTION 'RETURNS' VALUE =  11154.22263271588

  WS SECTION:

  ROW      ROW              INITIAL        ACTUAL        SLACK        SHADOW
  NUMBER   NAME             LEVEL          LEVEL         AMOUNT       PRICE
  ----------------------------------------------------------------------------
   1      *LAND 1            3.00000        2.76498      0.23502       0.00000
   2       LAND 2            1.50000        1.50000      0.00000   -5904.44090
   3      *JAN LAB         600.00000      147.83410    452.16589       0.00000
   4       FEB LAB         600.00000      600.00000      0.00000     -12.06306
   5      *MAR LAB         600.00000      138.24885    461.75116       0.00000
   6      *APR LAB        1050.00000      508.75576    541.24426       0.00000
   7      *MAY LAB         600.00000      508.75576     91.24424       0.00000
   8      *JUN LAB         600.00000      337.32719    262.67282       0.00000
   9      *JUL LAB         600.00000      337.32719    262.67282       0.00000
  10      *AUG LAB        1050.00000      337.32719    712.67279'      0.00000
  11      *SEP LAB         600.00000      361.90816    238.09184       0.00000
  12·     *OCT LAB         600.00000      185.36038    414.63962       0.00000
  13'     *NOV LAB         600.00000       44.91070    555.08929       0.00000
  14      *DEC LAB        1050.00000      101.08248    948.91754       0.00000
  15        WORK CAP      6042.29980     6042.29980      0.00000      -0.09165
  16        SUBS             1.00000        1.00000      0.00000   -5494.06350

  - BASIC VARIABLE
   - ALTERNATE OPTIMA
```

SOURCE : COMPUTER PRINTOUT

APPENDIX 8: RIGHT HAND SIDE RANGING

```
   ***** RIGHT HAND SIDE SENSITIVITY *****
PROBLEM NAME = AYOOLP
OBJECTIVE FUNCTION 'RETURNS' VALUE =    11154.22263271588

ROWS:
                                                                   RANGE
ROW      ROW            INITIAL       ACTUAL       SLACK
NUMBER   NAME           LEVEL         LEVEL        AMOUNT       LOW          HIGH
------------------------------------------------------------------------------------
  1     LAND 1          3.00000      2.76498      0.23502      2.7650    *********
  2     LAND 2          1.50000      1.50000      0.00000      1.3126       1.9908
  3     JAN LAB       600.00000    147.83410    452.16589    147.8341    *********
  4     FEB LAB       600.00000    600.00000      0.00000    556.7643     635.7360
  5     MAR LAB       600.00000    138.24885    461.75116    138.2489    *********
  6     APR LAB      1050.00000    508.75576    541.24426    508.7558    *********
  7     MAY LAB       600.00000    508.75576     91.24424    508.7558    *********
  8     JUN LAB       600.00000    337.32719    262.67282    337.3272    *********
  9     JUL LAB       600.00000    337.32719    262.67282    337.3272    *********
 10     AUG LAB      1050.00000    337.32719    712.67279    337.3272    *********
 11     SEP LAB       600.00000    361.90816    238.09184    361.9082    *********
 12     OCT LAB       600.00000    185.36038    414.63962    185.3604    *********
 13     NOV LAB       600.00000     44.91070    555.08929     44.9107    *********
 14     DEC LAB      1050.00000    101.08248    948.91754    101.0825    *********
 15     WORK CAP     6042.29980   6042.29980      0.00000   5792.9634    6343.9634
 16     SUBS            1.00000      1.00000      0.00000      0.0000       1.2952
```

APPENDIX 9: OBJECTIVE FUNCTION RANGING

```
   ***** OBJECTIVE FUNCTION SENSITIVITY *****
PROBLEM NAME = AYOOLP
OBJECTIVE FUNCTION 'RETURNS' VALUE =  11154.22263271588

COLUMNS:

 VARIABLE VARIABLE     BASIS      RETURNS              RANGE              MIN
 NUMBER   NAME         LEVEL      VALUE          LOW          HIGH        VALUE
-------------------------------------------------------------------------------
    5     ONIONS       0.22626 6052.00000   5951.00000   7957.27980
    6     TOMATOES     0.27374 5951.00000   4045.72020   6052.00000
    1     COTTON       2.76498 2756.45000    138.76502    *********
    2     MAIZE        1.00000  534.34998    *********   6028.41360
    3     G/NUTS       0.00000 2196.00000                          7044.19120
    4     G/GRAMS      0.00000  406.00000                          6905.23025
```