OPTIMAL FARM PLANS FOR SMALL HOLDER FARMERS PRACTISING IRRIGATION ALONG YATTA CANAL OF MACHAKOS DISTRICT, KENYA: A LINEAR PROGRAMMING APPROACH

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ECONOMICS, UNIVERSITY OF NAIROBI, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL ECONOMICS

MAY 1992

DECLARATION

I, Samson M. Nguta, declare that this thesis is my original work and has not been presented for a degree in any University.

Signature.. 29th MAY 199

Samson M. Nguta.

This thesis has been submitted for examination with our approval as University Supervisors.

Signature.. 29th may 1992

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Signature..

Professor O. L. E. Mbatia. May 29, 19

ACKNOWLEDGEMENT

The present shape of this thesis has been achieved through efforts and contribution of numerous people. Although the author bears responsibility of all mistakes detected in the work, all the efforts and contribution from the various people are greatly appreciated.

Specifically I am deeply indebted to my University supervisors Dr. K. C. Sharma and Professor O. L. E. Mbatia for their continuous and very able guidance. I am also very greatful to Dr. D. Ireri for his valuable suggestion and criticisms towards this study. I also appreciated the generosity of the University of Nairobi for granting me a scholarship thus making my studies possible.

The Ministry of Agriculture staff in Yatta Division extended great assistance to me. To all of them and in particular Mr. Thomas Njoroge and Mr Geoffrey Muiva, I owe gratitude.

Special thanks is to Elizabeth my wife for her inspiration and ceaseless encouragement through out the entire study period. I also wish to thank my parents Mr. Charles Nguta Mbai and Mrs. Rhoda Mbai for their love and unwearing support all through my academic endeavours.

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ABSTRACT:

The main objective of the study was to develop optimal farm plans for irrigation farmers along the Yatta canal who are permitted to irrigate a maximum area of 0.5 hectare per growing season. Other objectives of the study were:

1) to describe the existing farming system in the study area
2) to identify the main constraints faced by the irrigation farmers along the Yatta canal.

A random sample of 60 farmers was used in this study. Optimal farm plans were developed using linear programming farm planning technique and are meant to guide the farmers in their farming activities to ensure maximization of farm income. This would mean that maximum benefits are gained from the irrigation water.

The study tested the hypothesis that the present level of resource use is sub-optimal and hence higher farm income could be realized by reorganizing the existing crop enterprises. Total gross margin comparisons of the developed optimal farm plans and the existing farming system are used to test the hypothesis. When the comparisons considered the existing farming system which is based on an average farm, net increments in total gross margin resulting from the optimal farm plans were found to range between 27.6 percent and 120.6 percent. Similar comparisons made under the assumption that the available irrigable land is fully utilized in the existing farming system had net increments

ranging between 7.5 percent and 30.8 percent. Based on this findings the hypothesis was accepted.

Working capital was found to be a limiting resource in all the farm models considered. Results of the study showed that the marginal value product for capital ranged between Kshs. 1.483 and Kshs. 12.70. Such findings imply that the increments to every additional Kenya Shilling of working capital invested in the optimal farm plans are higher than the current lending rate of 14% charged by lending institutions for agricultural loans. Assuming other factors constant, it is therefore economically feasible to obtain credit from the lending institutions.

Both irrigated and unirrigated land were found to be limiting resources in most of the farm plans. Comparatively irrigated land had higher shadow prices than the unirrigated land in most of the cases. In most of the developed farm models the irrigated land shadow price values are more than Kshs. 25,000, with the highest observed value being Kshs. 32,606. For the unirrigated land, only two of the developed farm models have shadow price values above Kshs. 5,000, with the highest observed value being Kshs. 5652. These findings mean irrigated land could be increased at the expense of unirrigated land if conditions allowed.

CHAPTER 1

INTRODUCTION

1.1 Background Information :

Alleviation of poverty is one issue that has been of great concern to the Kenya Government. This is evident in various Kenya's Development Plans. The current 1989 - 1993 Development Plan under the theme "Participation for progress" cites poverty and unemployment among the worst results of inadequate development. The Plan notes that Kenyans must be actively involved in productive work in order to improve their own welfare and ensure that basic needs are met. In the 1984 - 1988 development plan, it was noted that poverty alleviation must claim the highest priority in the allocation of public sector resources. The 1979 - 1983 Development Plan had its primary objective as the "alleviation of poverty:" and priority being given to rural development. The plan noted that rural development will in a large measure be achieved through higher incomes, more rural employment and improved diets. While rural development includes non-agricultural production, provision of welfare services and improved infrastructure, it is agricultural production which provides the core to rural development (Republic of Kenya, 1979).

Some of the strategies outlined for handling the poverty problem are: devoting resources to inexpensive and easily repairable technologies which will promote small scale farm productivity; credit and extension to be directed more vigorously to small scale farmers; improvement of rural access roads to enhance the flow of farm inputs to farmers and expand the amount of farm produce that reach the markets (Republic of Kenya 1979, op cit.). This further shows that the agricultural sector and especially the small scale holdings are the most relevant in as far as handling the poverty problem is concerned. The agricultural sector qualifies for the challenge since it employs 70 percent of the total Kenyan population with small scale holdings accounting for 85 percent of the total agricultural employment (World Bank Report, 1990). A small scale farm is a farm with its hectarage ranging between 0.2 and 12 hectares (Republic of Kenya, 1985). Most small scale farms rely on family members for labour requirements and management; and produce staple food crops primarily for subsistence needs with the surplus for sale.

Small scale farmers have been identified among the five target groups forming the nation's poor [1] . These are farm families who work on small plots of land. They must be assisted to improve their basic incomes. Improvement in crop yields and better selection of crops is one way the basic income of such farmers can be improved (Republic of Kenya, 1983). The other target groups forming the nation's poor are the Pastoralists, the landless rural workers, the urban poor

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[1] **Nation's poor refers to the people or groups of people with very slim or without income earning opportunities.**

and the handicapped (Republic of Kenya, 1983, op. cit).

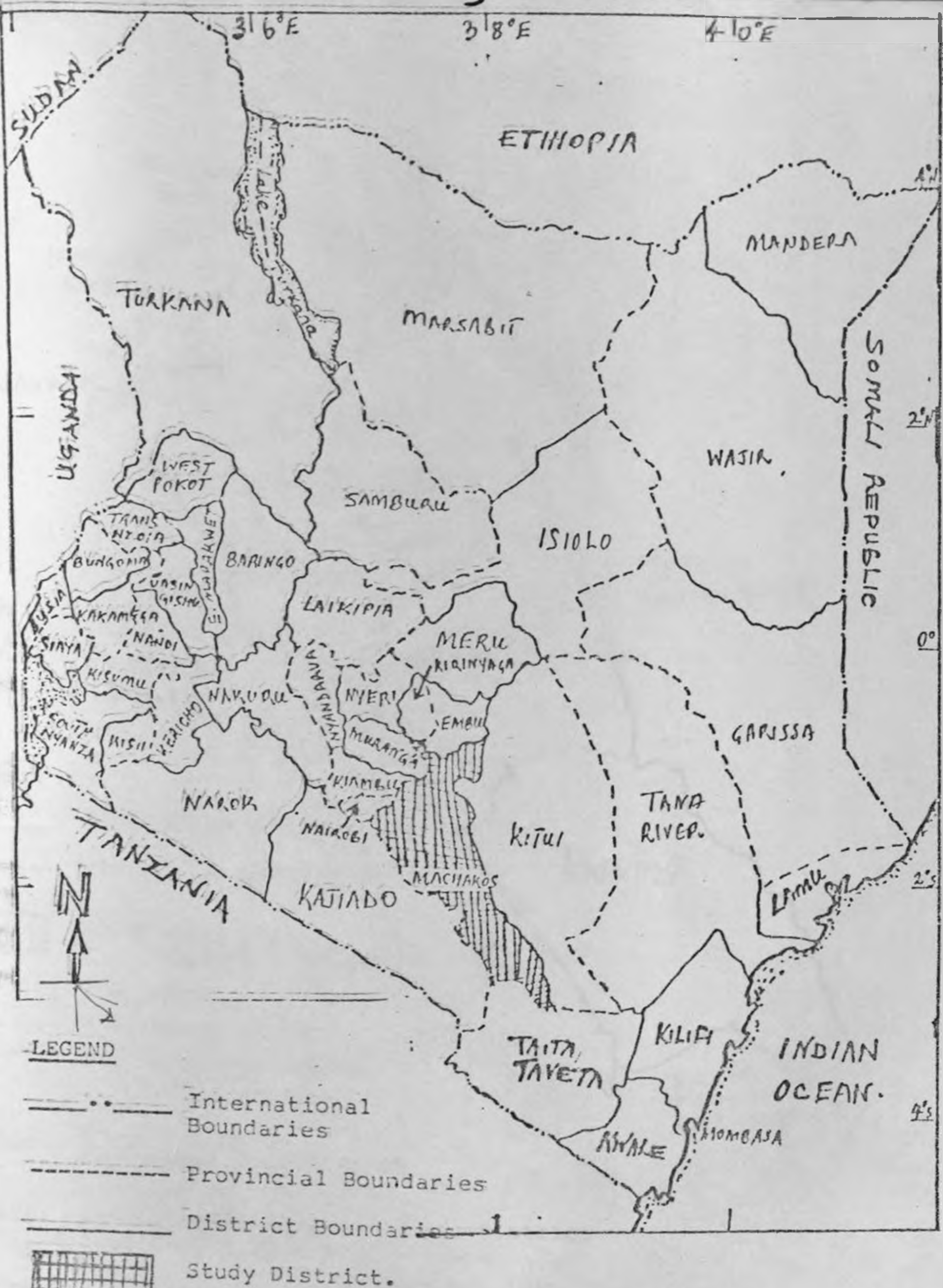
The poverty problem is worse in the medium and low potential areas which receive inadequate rainfall. International Labour Office (1972) stated that majority of farm families in the medium and low potential areas here in Kenya have farm incomes of less than 60 Kenya Pounds per annum. Muriithi (1979) noted that marginal areas of eastern Kenya experience famine regularly owing to the hostile environmental conditions especially the inadequate rainfall. Ghai et al (1983) stated that nearly 50 percent of the 2.1 million household in Kenya receive average household income of 100 Kenya Pounds per annum or less. They further noted that 44 percent of the small holder farmers in Kenya receive average income of less than 100 Kenya Pounds per annum. With such a low level of income, it is inevitable that these families exist in extreme poverty conditions.

Improving land productivity in the semi-arid and arid areas has been in the focus of Kenya government. Kenya's 1989 -1993 development plan focuses attention on self-sustaining innovations and production activities in the small scale dryland farming and irrigated agriculture. Kenya has an estimated irrigation potential of 500,000 hectares. The current irrigation coverage totals to 36,000 hectares. Thus only 7.2 percent of the irrigation potential has been utilized (Republic of Kenya, 1983). Out of the 36,000 hectares under irrigation, 12,600 hectares are under public management and 23,400 hectares are under private management. Those under public management are managed by the National Irrigation Board (NIB) and are mainly the large scale irrigation schemes. Most small scale irrigation schemes are included in the 23,400 hectares and are under private management.

Irrigation farming in marginal areas could be an important source of income, employment, food security and improved diet especially for young children (Heyer et al, 1976). It's successful operations would reduce dependency on famine relief donations especially during drought years. Optimal farm plans can greatly assist small scale farmers improve their farm incomes through better selection of crop enterprises. This can lead to improvements in the farmers' standards of living since the higher farm incomes can be used to meet the farmers' wants.

1.2 The Study Area:

The study specifically focuses on small holder farmers practising irrigation along the Yatta canal. Yatta canal starts from Thika river and passes through Ndalani and Matuu Location in Yatta division of Machakos district before draining to Mwita Syano river in the Machakos - Kitui border. The canal has a total length of 60 Kilometres (see figures 1, 2 and 3).



Scale 1cm: 50KM,

SOURCE: Republic of Kenya: Machakos District Development Plan 1989 - 1993.

Figure 1: Map of Kenya Showing Location of Machakos District.

SOURCE: Republic of Kenya: Machakos District Development Plan 1989 - 1993.

Figure 2: Position of the Study Area within Machakos District:

1:2:1 Rainfall:

Yatta division is a marginal area and receives mean annual rainfall of 730 mm per annum (Republic of Kenya 1978). The rainfall distribution is bimodal in nature, with the long rains occurring in March, April, May and June while the short rains occur in October, November and December.

1:2:2 Temperature:

In general, Yatta has a mean minimum temperature of 12^{0} C occurring in July and a mean maximum of 27^{0} C in February. For the other months temperature averages between 15^{0} C and 25^{0} C (Republic of Kenya 1978).

1:2:3 Soils:

Soils in the study area are dominantly well drained, moderately deep to very deep, dark yellowish brown , friable to firm sandy clay to clay, with top soil of loamy sand to sandy loam. However, there are pockets of imperfectly drained to poor drained, deep to very deep, dark red to black, friable to firm cracking clay (Jaetzold et al, 1983).

1:2:4 Land Tenure:

Interviews with farmers during the field survey indicated that permanent settlement in Yatta occurred between mid 1960s and early 1970s. The Post-colonial Kenya Government settled some of the people who were landless within Machakos district and the neighbouring Kiambu and Murang'a districts in this area. Each family was allocated plots of 2 to 3.3 hectares (5-8 acres).

1:2:5 Yatta Canal:

Yatta canal was constructed in 1953 by Mau Mau[2] detainee arrested for their involvement in the struggle for Kenya's independence. The objectives of constructing the canal by then were: a political objective of rehabilitating the Mau Mau detainees and an economic objective of supplying water for domestic and livestock use. The canal's irrigation potential was then not considered. The canal was inaugurated in 1959 and water has been flowing since then. At present the Ministry of Water Development is responsible for the maintenance of the main canal and water distribution operations. It can literally be said that Yatta canal is owned by the Ministry of Water development.

Although irrigation was not a priority during the construction of the Yatta canal, its development has of late taken up very fast and is evident from Table 1.1.

Table 1:1 Trend In Hectarage Under Irrigation

Year	Hectarage Under Irrigation
1978	200 hectares
1985	685 "
1990	863 "

Source: Republic of Kenya, 1978; 1990a.

[2] Mau Mau was an underground group of freedom fighters who struggled with the colonial government with the aim of liberating Kenya from the British rule.

Permits to use the canals water for irrigation are obtainable from the Ministry of Water Development on application. A fee of Kenya shillings (Kshs) 300 per hectare payable on two half yearly instalments of Kshs. 150 is paid by every irrigation water user.

There is a great potential for irrigation farming along Yatta canal. Kalders (1984) indicated that the total area within the supply limit of Yatta Canal is 10300 hectares. The supply limit mentioned here refers to some distance from the canal which vary mainly with the topography while considering gravity water conveyance system.

1.3 Problem Statement

As it was noted earlier, Yatta canal is managed by the Ministry of Water development. All the irrigation water users have to be permitted by the Ministry. The maximum hectarage each farmer is allowed to irrigate per growing season is 0.5 hectares (Kalders, 1984). Most of the crops grown under irrigation are annuals and farmers can irrigate a maximum of one hectare in a year. It is upon each farmer to choose the crop(s) or crop mixtures to grow as well as arrange for acquisition of inputs and also the marketing of output. A wide range of crops are grown which include: French beans (*Phaseolus vulgaris*); Asian vegetables with the main ones being Karella (*Memontica charanta*), Duthi (*Cucurbita spp*), Thin Chillies (*Capsicum spp*), Bullet chillies (*Capsicum spp*), Long chillies (Capsicum spp), Valore (Dolicos Lab - Lab), Brinjals (Aubergine or Solanum melongena), Okra (Hibiscus esculentus), Tulia (Cucurbita spp), Turwel (NPP-670 [3] pigeon peas sold when green, Cajanus cajan), chola (cowpeas sold when green; Vigna unguiculata); local vegetables and fruits such as onions, cabbages, tomatoes, bananas, citrus and passion fruits are all grown in the irrigated plots. There are no proposed farm plans to guide farmers on what to grow especially in the irrigated plots. Given that the maximum area allowed for irrigation is restricted, it is important to propose farm plans for the farmers to ensure maximum benefits are gained from the irrigation water. This study is an effort to meet this challenge.

1.4 Justification Of The Study

The current Development plan (Republic of Kenya, 1989) indicates that the area under irrigation will be expanded from the 1989 level of 36000 hectares to 45000 hectares during the five year plan period, with emphasis being made on small irrigation projects. Experience has shown that the large irrigation schemes are expensive to implement and operate especially if requiring pumped water (Ireri, 1986). To realize such an ambitious expansion rate, irrigation

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[3] **NPP - 670 is a name of an early maturing variety of pigeon peas and NPP means National Pigeon peas Programme. It is this early maturing variety which is grown in the irrigated plots.**

farming has to be made more attractive especially where farmers are doing it on their own initiative as is the case in Yatta canal. Proposing optimal farm plans to such farmers with the aim of increasing their farm income is therefore quite desirable.

The study was being carried in a marginal area experiencing inadequate rainfall. With irrigation, this major climatic constraint is overcome. The irrigated land should then be put into the best use to generate the maximum possible income. Some questions this study will focus on are: What are the possibilities of generating more farm income just by reorganizing the existing resources and enterprises through obtaining optimal farm plans? How superior in terms of income generated are the optimal plans over the existing farming systems? What policy recommendation can be made to improve crop farming in the study area?

Finally, the study focuses on small holder farmers and aims at improving the farmers' living standard. Small farm survival is dependent upon maximising cash income while keeping production cost low. The aim of the study is therefore quite in agreement with the country's development policies and aspirations.

1.5 Objectives Of The Study:

The specific objectives of this study are:

(i) To describe the existing farming systems in the small holder farms along the Yatta canal citing the enterprises undertaken, the present level of resources and their utilization and the estimated level of farm income attained.

(ii) To develop optimal farm plans for the small holder farms along Yatta canal using gross margin maximization criterion. This will show the crop enterprises to be grown and the maximum total gross margin attainable.

(iii) To make comparison of the existing farming system and the optimal farm plans with a view to measure the gap in income between the two systems. This would help to show the potential of the optimal farm plans in increasing farm income.

(iv) To identify the main constraints to higher incomes for small holder farmers along the Yatta canal.

1.6 Hypothesis To Be Tested:

The study will test the hypothesis that the current level of resource use is sub-optimal and hence higher farm income can be realized by reorganizing the crop enterprise combinations. This hypothesis implies that farm income is below what can be achieved with optimal allocation of the present resource levels. Total gross margins comparisons for the optimal farm plans developed and the existing farming system are used to test the hypothesis.

1.7 Farm Plan:

A farm plan is a programme of the total farm activities of a farmer drawn up in advance. A farm plan should show the crops to be grown, the practices to be followed in their production; the combinations of other enterprises; the use of labour; the investments made in farm inputs, equipment and buildings and similar other details (Johl et al, 1973).

A common assumption made in farm planning is that a farmer is primarily interested in maximizing his farm income. This is probably valid to most farmers since a higher farm income provides the means for satisfying many of the farmer's wants. Because of this assumption, farm plans are evaluated on the basis of the income derived from them. In this study, gross margins are used as the measure for farm income .

Optimum Plan: An optimum or maximum feasible plan is one which is consistent with resource supplies or restrictions and for which no improvement can be made on the objective. That is profit or production cannot be increased or costs cannot be decreased (Heady et al, 1958).

1.8 Plan Of The Thesis:

This thesis is composed of five chapters. Chapter 1 is the introductory chapter. It highlights some background information, the study area, research problem, justification of the study, objectives and hypothesis. Chapter 2 presents the literature review. Chapter 3 discusses the various farm planning methods/techniques, data requirements and sources, and the specific linear programming models used for the study. Chapter 4 presents the results of the study which include the description of the existing farming system and the linear programming results. Chapter 5 presents a summary of the whole thesis, conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

The present study was done in an area where farmers practise irrigation . Therefore irrigation farming in Kenya as evident from the performance of Kenya's irrigation schemes is reviewed in this chapter. The current irrigation policy is cited. Some criticisms against irrigation schemes as well Kenya's experience with regard to such criticisms are also noted in this chapter. Studies related to small holder agriculture farm planning which used linear programming technique are critically reviewed in this chapter.

Policies that will optimize the allocation of resources to their most productive use must be given prime importance (Republic of Kenya, 1986). In view of this, the current irrigation policy is in favour of small scale irrigation schemes as is evident in Kenya's 1989 - 1993 Development Plan. The shift in policy to favour small scale irrigation schemes is due to the fact that the large irrigation schemes have proved unsuccessful. Kamunge (1988) noted that:

> "...Example of unsuccessful rural projects are Kenya's large scale irrigation schemes. All the seven government run irrigation schemes except Mwea have annual expenditures being in excess of annual revenues. This indicates that they are not financially feasible ...."

The government run irrigation schemes under question here above are: Mwea, Hola, Perkerra, Ahero, West Kano, Bunyala and Bura. Ireri (1986) attributed the success of Mwea to it's gravitational water conveyance system and also the support farmers get from their local cooperative society which provides supplementary financing. Through the same cooperative, farmers own equity shares in some of the schemes operations. Ireri (1986) also noted that monoculture situation contributes to the success of Mwea. In a monoculture situation, it is easier to plan for the various farm operations such as planting, weeding, spraying and harvesting as well as engage machinery to undertake such operations. Added to this, it is possible that the attitude of the farmers towards rice farming is also a contributory factor towards the success of Mwea.

Some of the criticisms against irrigation schemes are: huge costs of establishment, delays in construction, low yields, poor financial performance and environmental damage (Carruthers, 1985). Delays in construction may be due to bureaucracy especially in financing and implementation stages. On Kenyan experience, these criticisms hold for the large irrigation schemes which have proven to be too expensive to implement and operate thus representing a serious drain on the economy (Republic of Kenya, 1988).

Despite these criticisms, irrigation remains the principal means by which rainfall inadequacy climate constraint can be overcome. The current shift in policy to favour small irrigation schemes is quite in order since small irrigation schemes can be of great use in improving the standards of living of the farmers who own the land at the time such irrigation development occurs. With small irrigation schemes, there is minimum disruption of settlement patterns (Palufikof, 1981 and Small, 1982). Along the Yatta canal where the present study is based, farmers practise irrigation on their own farms. Irrigation development there has not interrupted the settlement pattern in the area.

Farm planning studies done so far in some of the country's large and small scale irrigation schemes have identified resource misallocation through use of sub-optimal farm plans as the reason for poor performance of such irrigation schemes. Irea (1979) used linear programming to investigate the optimality of resource use in Perkerra irrigation scheme. Irea's findings showed that optimal resource use in Perkerra would raise the tenants income by 300 percent. With such a raise in the tenants farm income, it is clear that the financial performance of the scheme would greatly be improved.

Mukumbu (1987) similarly used linear programming to investigate whether farm plans in West Kano Pilot irrigation scheme are optimal. Like Perkerra, West Kano is a large irrigation scheme which was characterised by poor financial performance. The finding of the study showed that with adoption of optimal farm plans the tenants income would rise from Kshs. 30,996 to Kshs. 63,439 per annum. This shows the income would more than double.

Irea (1979) and Mukumbu (1987) worked on irrigation schemes managed by the National Irrigation Boards (NIB). In these schemes, the board is engaged in all aspects of irrigation including water management, organization of farmers production operations, marketing, and financing all operations. Therefore the farmers operate under a programmed kind of system. The present study will carry out similar investigations as both Irea (1979) and Mukumbu (1987) did, but in a case where there is no institution engaged in the various production and marketing operations.

Makanda (1984) undertook a study to determine the significance of irrigation water on farm income. The study was done at Kibirigwi, a small irrigation scheme. Linear programming technique was used to obtain optimal farm plans. Results of the study showed that adoption of optimal farm plans would more than double the farmers' income. Just like

Irea's (1979) and Mukumbu's (1987) findings, Makanda's (1984) results revealed use of sub-optimal farm plans in small irrigation schemes. In his conclusion, Makanda (1984) called for more research in other small irrigation schemes using linear programming models to allow for generalization of all small irrigation schemes. The present study heeds Makanda's (1984) call but unlike Makanda who used the individual farm approach, average farm approach will be used in the present study. Individual farm approach may not be a good representative of the farms in an area since only one farm is considered. The average approach is a better representative of an area's farming situation since an average of several individual farms is taken and used in the analysis.

Kamunge (1989) used linear programming to study the role of optimal resource utilization in improving farm income. A case study of Mitunguu Irrigation Project in Meru was considered. Four farm models categorised on the basis of the crops grown were considered. In all the farms models, the existing farming systems were found to be sub-optimal. This study agreed with other previous farm planning studies in irrigation schemes where optimal farm plans were shown to have a great potential of increasing farms income.

Several studies in Kenya's rainfed farming systems have also shown that reorganization of the existing farming system to come up with optimal farming systems would greatly increase farm incomes (Kange, 1980; Asamenew, 1980; and Mukhebi, 1981). Such findings, which also agree with the previously discussed findings from irrigated farming studies, show that use of sub-optimal farm plans is a serious problem in Kenya's agricultural sector. All the above referred studies done on rainfed farming use linear programming technique. Kange's study mainly aimed at developing optimal farm plans for farmers in Kaloleni Location of Kilifi District, Coast Province. The study used primary data representative of small, medium and large farm size groups. In each of the farm size categories, the study examined the potential of increasing farm income through reorganization of enterprise and farm resources under existing and improved technology. In all the models the increment in farm income ranges from 46 percent on small size holding with food requirement constraint to 187 percent on the large size holdings without food requirement constraint. Kange's study did not consider capital constraint though capital is quite an important input in agricultural production.

Asamanew's (1980) study aimed at determining enterprise combinations which maximize farm income and also identify the factors which constraint agricultural production on small scale farms in the star grass zone in Embu district. The results of the study showed that farm income can be increased by 28 percent, 31 percent and 27 percent for small, medium and large farm sizes respectively if optimal farm plans are used. Although the present study aims at coming up with optimal farm plans, it differs from Asamanew's (1980) study on the grounds that Asamanew's (1980) study was on a medium potential area and a totally different geographical location while the present study is being done in a marginal area and in a case where irrigation is being practised.

Mukhebi's (1981) study was meant to investigate the feasibility of generating higher incomes and employment in Kenya's small scale agriculture. The study used primary data. With a multi- objective model of maximizing both income and employment, the study results indicated a 45% and 60% increase in income and employment respectively with adoption of optimal farm plans.

Some short-comings of the study which even Mukhebi (1981) pointed out include the observation that the study area was not a representative of the majority of Kenyan small scale agriculture for it falls in a semi arid zone while majority of Kenyan small scale farmers are located in the higher and medium potential agricultural zones. Also the sample size of 38 farmers used in the study was extremely small compared to the then estimated 1.5 million small scale farmers in Kenya hence the results of the study may have little validity to the entire small scale agricultural sub-sector. Further to this the farm sample was limited to only farmers who had received the Integrated Agricultural Development Programme Loans and had membership in the local farmers' co-operative society. Such farmers are likely to be more progressive than the rest in the location and hence the sample not being a good representative of the small scale farmers in the location and more so for the country as a whole. In view of these shortcomings, the present study will be restricted to the problem of farm planning in a particular area. Sampling procedures used in this study will ensure that a good representative sample, of all the small scale farmers practising irrigation in the study area, is obtained. By having the study problem restricted in a particular area and by having a good representative sample, the validity and applicability of the results of the study to the study area would greatly be improved.

In conclusion, the studies reviewed have provided a more comprehensive view of the dimensions of farm planning problem in Kenya's small holder agriculture. The studies have also cited some potential difficulties in the field of investigation. The studies reviewed have also helped in the clarification of the unique context and potential contribution of the present study. Finally, the studies reviewed have shown that farm income could greatly be improved if optimal farm plans are adopted by farmers.

CHAPTER 3

METHODOLOGY

3.1 Introduction:

In this chapter a variety of farm planning techniques are discussed and their strengths and weaknesses are cited. Detailed account of the theory behind linear programming technique is also given in the chapter. This involves discussing the quantitative components in a linear programming problem, the general linear programming model formulation and the assumptions and conditions for the model. There is also a discussion on data requirements and sources. Details on the specific linear programming models used for the study are also covered in this chapter. Such details include the objective function, activities, resource constraints and technical coefficients. Finally there is a discussion on how the analysis is done.

3.2 Farm Planning Methods/Techniques:

This is basically a farm planning study involving choice of crop enterprises where there are numerous possible alternatives and some resource constraints. There are several quite popular farm planning techniques such as budgeting methods which include partial budgeting, complete budgeting and programme planning. However, this study uses linear programming as the analytical tool. Although linear programming has it's own weaknesses as it will be mentioned later, the choice of the method as the study's analytical tool is based on some of it's outright advantages namely: the ability of linear programming to allow for as many alternatives as possible; the fact that linear programming has less burden of clerical operations as compared to other farm planning techniques such as budgeting; the fact that linear programming provides a mechanism for a careful analysis of constraints; and the fact that linear programming problem matrix can be designed to relate to selection of activities which may include not only real production but activities of subsistence, marketing activities as well as resource hiring activities (Agrawal et al, 1972 and Low, 1978)

Generally, budgeting method provides the means to choose between alternatives through examination of returns to important resources such as land or labour or capital. At the end budgeting gives expense and income accounts which show where the highest returns are possible. Specifically, partial budgeting method refers to estimating the outcome or returns for part of the business. That is, returns to one or a few activities. Complete farm budgeting considers all farm enterprises and estimates costs and returns for the whole farm. Allocation of resources is based on the profitability of an enterprise and the plan is acceptable as long as it is within the main constraints and the profitability is satisfactorily based on the planners view (Johl _et al_, 1973). Programme Planning identifies the most limiting resources and returns are maximized to those resources. Marginal adjustments are then made with respect to other limiting resources afterwards. This is quite satisfactory where the number of limiting resources is small. But in practice, the number of limiting resources tends to be quite large in farm production problems. Hence maximization of returns to only one or two of the resources is likely to lead to substantially sub-optimal results (Johl _et al_, op. cit). While the simplicity of budgeting methods aid the communication of results to farmers, their arithmetic calculations burden narrows their scope and potential of application is solving farm planning problems. Further, budgeting methods do not allow many alternatives to be considered nor do they ensure that an optimal solution is obtained (Agrawal _et al_, 1972; Steward, 1961). Such shortcomings make budgeting methods inadequate representation of intra-farm relationships.

Another alternative is the production function analysis which involves fitting a production function either for a single enterprise or for the whole farm. The contributions made by the different resources to production as observed in the field are then measured. A big problem with this approach is that it is difficult to include all variables since problems of econometric estimations can easily arise. Also the form of production function is not known. The approach therefore is not followed here.

Other techniques which could be used for solving farming planning problems are;

(i) Non Linear programming: used where the Linear assumptions need to be relaxed

(ii) Dynamic programming: Useful where the results of one time period significantly influence the decision of the next time period (Agrawal et al, 1972; Johl et al, 1973). However both techniques are too sophisticated and quite advanced, therefore they are not followed for this study.

3.3 Linear Programming: Heady et al (1958) referred to Linear Programming as a systematic and accurate method of determining mathematically the optimum combination of enterprises or inputs so as to maximize income or minimize costs within the limits of the available resources. Linear Programming serves as an important farm management and research tool. Problems to which linear programming can be applied have three quantitative components namely:

(i) Objective function: Which has to be precisely defined and expressed in quantitative terms. For example, a farmer may be interested in maximizing total farm income or minimizing costs and any of these can form the farmer's objective function.

(ii) Alternative methods or processes of attaining the objective: These may be different enterprises, different methods or techniques of production by which the objective can be obtained.

(iii) Resources restrictions: These may be fixed quantities of certain resources. For example, given amounts of land, labour, machinery, working capital and so forth. There also can be subjective, institutional and other types of restrictions. For example, hectarage limitation for certain crops, limitation on the quantities marketed and the like.

<u>General Model Formulation</u>

Maximise $Z = C_1X_1 + C_2X_2 + \ldots\ldots + C_nX_n$ (objective function).

Subject to

$a_{11}X_1 + a_{12}X_2 + \ldots\ldots + a_{1n}X_n \leq b_1$ (resource constraint).

$a_{21}X_1 + a_{22}X_2 + \ldots\ldots + a_{2n}X_n \leq b_2$ (").

.

$a_{m1}X_1 + a_{m2}X_2 + \ldots\ldots + a_{mn}X_n \leq b_m$ (").

$X_j \geq 0$ (non negativity of activity requirement).

Using the summation sign the above equations are rewritten as:

Maximise

$$Z=\sum_{j=1}^{n} C_j X_j$$ (Linear Objective Function)

Subject to:

1) $$\sum_{j=1}^{n} a_{ij} X_j \leq b_i$$ (Linear Resource Constraints)

2) $X_j \geq 0$ --------- (Non Negativity of Activity)

where;

C_j is net value of output per hectare of activity j and j = 1, 2, ..., n.

x_j is number of hectares of activity j.

a_{ij} represents the number of units of resource i which are used by one hectare of activity j and i = 1 , 2,......,m

b_i is the unit of i th resource available.

In matrix notation, the model takes the form:

Maximise

$$Z = C'X \quad \text{(Objective function)}$$

Subject to

$$AX \leq B \quad \text{(Resource Constraints)}$$

$$X \geq 0 \quad \text{(Non Negativity of Activity)}$$

where A is a m x n matrix of technical coefficients

C is a n x 1 vector of prices or other weights for the objective function

X is a n x 1 vector of activities

B is a m x 1 vector of resource or other constraints.

Assumptions And Conditions For The Model:

The basic assumptions of a conventional Linear programming problem are:

1) Additivity of Resources And Activities: Activities must be additive in the sense that when two or more activities are considered their total product must be the sum

of the individual products. Similarly the sum of resources used by different activities must equal the total quantity of resources used by each activity for all resources individually or collectively. This implies absence of any interaction among the activities for the resources. However, in actual farm production, interaction of activities for resources do occur. This can be noted where there are crop mixtures. Crop mixtures were quite common in the study area. To overcome the effect of interactions of activities in crop mixtures, the study treated each of the crop mixtures as one activity rather than separate activities.

2) Linearity: The objective function is linear and the the resource constraints are linear. By having a linear objectuve fuction, it means that there is no interdependence in the valuation of output of different activities. Going by the objective function of the study as given in the above general model formulation, this assumption implies that the net value of output of any activity does not depend on the level of output for the activity. In other words the selling price of any product does not depend on the quantity produced and sold.

3) Proportionality of Activity Level to Resources. This assumption implies constant resource productivity and constant returns to scale. This means that if output is to

be doubled, then just double the resources. Proportionality assumption implies there is linear relationship between activities and resources.

4) Non Negativity Of The Decision Variables: Activities and decision variables have positive values. A farmer can not grow a negative hectarage of an activity or apply a minus amount of an input such as fertilizer or chemical.

5) Divisibility of Activities And Resources: This assumption implies continuity of resources and output. That is resources and products are considered to be infinitely divisible. This means use of resources in fractional quantities and also production of output in fractions is acceptable. Relating this assumption to the present study, it should be noted that crop activities produce products in fractional amounts such as a fraction of a given weight measure. Also most farm inputs such as fertilizer, chemicals, and even land can be used in fractional amounts. So this assumption is not a serious limitation.

6) Finiteness Of Activities And Resource Restrictions: This means the Linear programming problem must have a finite number of activities and resource constraints. If farmers had unlimited number of alternatives , the alternative activities can not be programmed since the farmers could

never finish describing additional ones.

7) Single-Value Expectations: This means resource supplies, input- output coefficients, prices of resources and output, levels of output of the activities are known with certainty.

Some shortcomings of linear programming technique , a number of which arise from it's assumptions and conditions are :1) Linear programming only deals with a single linear objective function and a set of linear constraints. In the present study the objective function is maximization of farm gross margin. However this might conflict with the objective of some farmers for whom the profit motive does not greatly influence their farming decisions.

2) The assumption of single value expectation imparts to the linear programming model the property of being deterministic. As an example, this assumption implies input - output coefficients and also prices are known with certainty. Changing input- output coefficients in the model represent change in technology. In such a case different linear programming model with different coefficients have to be used. But still the static assumptions hold. Although prices are assumed to be constant, where they (prices) are likely to change or are particularly uncertain, parametric programming is done to investigate the sensitivity of the programmed

solution to price changes.

3) Linear programming technique does not explicitly consider natural and economic risks and uncertainties of the various alternatives faced by farmers. Further more, the linear programming model is time static in that resources can not be transferred from one time period to the other.

Linear programming is mainly a procedure for providing normative solutions to problems. The simplex procedure is used to arrive to the optimum plan. Details on this procedure are not covered here since they are available in standard text books such as Heady _et al_ (1958) and Agrawal _et al_ (1972).

3.4 Data Requirements And Sources:

The Linear programming problem definition for this study requires quantitative data which include:

(i) Supplies of fixed resources or other restrictive requirements which will limit the plan.

(ii) Input - output coefficients which define the per unit requirements of enterprises or activities for resources.

(iii) Net value of output per unit activity. This requires data on prices of the products and variable resources used.

These quantitative data were obtained from primary and secondary sources. Primary data were directly collected from the farmers using a structured questionnaire (See appendix 1). Prior to the actual data collection, the questionnaire was pretested on a sample of five farmers in the same area but a different sublocation from where the actual data were collected. The actual data were collected by trained enumerators under the author's supervision.

Secondary data used in this study were obtained from reports published by Government Ministries especially the Ministry of Agriculture, Ministry of Water Development, Government Development Plans and TARDA (Tana and Athi Rivers Development Authority).

Sampling: In the study area, there are irrigation groups where each group is made up of the farmers sharing a common offtake furrow from the main canal. A list of all the groups was available with the Ministry of Water Development. Up-to-date lists of all the farmers in the groups were available with the respective group chairmen. Using these lists, a two stage stratified random sample was selected. This involved randomly selecting 6 irrigation groups from a total of 14 groups and then randomly selecting a sample of 60 farmers from a total of 322 farmers in the 6 selected groups. From each group, a proportional number of farmers was randomly selected depending on the group size. This was done to ensure that the group with more members also had greater representation. Further details are in table 3.1.

Table 3.1: Groups sampled and the number of farmers sampled from each group:

Group	Loc.	Sub-Loc.	No.Farms.	No.Sampled
Mamba	Ndalani	Mamba	26	5
Simba	"	"	53	10
Kithendu	Matuu	Matuu	46	8
Kaluluini	"	"	52	10
Scheme A	"	Kithimani	88	16
Muthesya	"	"	57	11
	Total		322	60

The study used 57 sample farms since 2 questionnaires were spoiled and 1 farmer had not irrigated his farm hence a total of 3 farms were discarded.

3.5 Specific Linear Programming Model Used For The Study:

Maximise

$$Z=\sum_{j=1}^{n} C_j X_j$$ (Objective function)

Subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \le L_i$$ (Irrigated Land Constraint).

$$\sum_{j=1}^{n} b_{ij} X_j \le D_i$$ (Unirrigated Land Constraint)

$$\sum_{j=1}^{n} m_j X_j \le M$$ (working capital constraint)

$$\sum_{j=1}^{n} h_{kj} X_j \le H_k$$ (Human labour constraint).

$X_j \geq$ E Minimum area constraint for subsistence maize and Beans (Ha.)

$X_j \geq$ F Minimum area constraint for some priority crops (Ha).

L_i, M, H_k, E, F $\geq$ 0 (Non-negative constraint).

where:

Z = Total gross margin in Kenya shillings (Kshs).

C_j = Gross margin per hectare of the jth crop. (kshs/Ha). j = 1, 2, ...,n

X_j = Number of hectares under the jth crop

L_i = Total irrigated land available in season i; where i = 1 or 2 for short rains and long rains respectively.

D_i = Total unirrigated land available in season i; where i = 1 or 2 for short rains and long rains respectively.

a_{ij} = Irrigated Land required for one unit of jth crop activity in season i ; it has a value of one in the problem matrix.

b_{ij} = Unirrigated land required for one unit of jth crop activity in season i ; it has a value of one in the problem matrix.

h_{kj} = Human labour requirement in kth month for one hectare of jth crop activity (Man hours per hectare). k = 1, 2,....,12.

H_k = Total labour available in man hours in the kth month

m_j = Working Capital requirement per hectare of jth crop activity in Kshs.

M = Total working capital available per year in Kshs.

E = Subsistence maize and Beans area.

F = Priority crop area.

<u>The Objective Function:</u> In this study the objective function is the maximization of total gross margins subject to some constraints; namely; land, labour, working capital, subsistence needs and other crop constraints based on farmers priorities. Gross margin for any activity is the total value of output at market prices less variable costs. The sum of the gross margins of all the activities in a farm plan gives the total gross margin.

<u>Activities</u>: Agrawal <u>et al</u> (1972) defined the term activity as used in Linear programming to denote what is being produced, an enterprise undertaken, or a method of production used and is characterised by a specific proportion of various resources. Real activities are those which are either produced for sale in the market or in the case of resources, they are purchased in the market and used on the farm. Intermediate activities are those produced in the farm but become a resource for another real activity. Disposal activities are included in solving the linear programming problem to allow for non-use of resources. Real activities considered in this study are:

(i) Irrigated crop enterprises such as Karella (Memontica charanta), Duthi (Cucurbita spp), Thin chillies (Capsicum spp), Long chillies (Capsicum spp), Bullet chillies (Capsicum spp), Valore (Dolicos Lab-Lab), Brinjals (Aubergine), Okra (Hibiscus esculentus), Tulia (Cucurbita spp), Turwel (Pigeon Peas), French beans (Phaseolus vulgaris), Chola (cowpeas or Vigna unguiculata), Onions (Allium cepa), Cabbages (Brassica spp), Kale (Brassica spp), and Tomatoes (Lecopersicon esculentum).

(ii) Unirrigated crop enterprises: These include maize, beans, pigeon peas, maize beans and pigeon peas intercrop, maize and beans intercrop, maize and pigeon peas intercrop.

There are other irrigated crop enterprises which were considered as minor activities and hence have been excluded since farmers could not identify the hectarage occupied by such crops, the inputs used by such crops and the yields obtained from such crops. These include, bananas, citrus, passion fruits, arrow roots and sugar canes. Similar unirrigated crop enterprises are cassava, cow peas and bananas.

The study considered two crop growing seasons in a year as that is the practice in the study area. First growing season is marked by the short rains and is between the months of October and February. The second growing season is marked by the long rains and is between the months of March and September. For every growing season, a portion of the available arable land is set aside for irrigated enterprises.

Twelve labour hiring activities are also incorporated in the model with each of them representing labour hiring during each of the twelve months of a year. This is necessitated by the fact that casual labour hiring is quite common in the study area due to the high labour demand of the horticultural crops grown in the irrigated plots.

Resource constraints: The main resource constraints specified for the Linear Programming models are land, labour and operating capital.

Land: Four land constraints were defined namely, arable land available for rainfed cultivation during the first season (october - december) rains; arable land available for rainfed cultivation during the second season (march - june) rains; arable land available for irrigated farming during the first season; arable land available for irrigation farming during the second season. As it was noted earlier, field observations by the author revealed that only a portion of the farmed land is set aside for irrigation during each cropping season. This necessitated the incorporation of two irrigated land constraints.

High quality land is scarce but land is treated as homogenous in this study. Assessing quality of land involves considerations on soils; topography, fertility measures and so forth. Owing to the difficulties in data collection for the evaluation of the various quality factors coupled with the problems of limited time and finances, this study ignored the issue of land quality.

Labour: Farm labour is scarce in the sense that it's shortage at certain times of the year prevents increase in production from taking place. Thus the role of labour in determining farm production patterns and the way in which labour at particular times of the year limit production are examined. Twelve monthly labour constraints are considered in this study. It is assumed that it is immaterial at which time during the month a labour input is used. That is it makes no difference to output if a labour input takes place at the beginning or end of the monthly labour time period.

No distinction was made between men and women labour hours since farmers in the study area indicated there was none. A weighting system (see table 3.2) was used to discount the labour of children and older adults.

Table 3.2: Labour weighting system in Man-Equivalents:

Age category	Man-equivalent
Children between 0-6 yrs	0.00
Children between 7-14 yrs	0.50
Adults between 15-64 yrs	1.00
Adults over 64 yrs.	0.50

Source: Adopted from Norman, 1973.

Working Capital: Working capital was estimated using the total amount of cash expenditure in the 1989/1990 cropping season. This involved all cash expenditure for fertilizers, chemicals, seeds, manure, land preparation and casual labour. Thus working capital was estimated from the variable costs for the enterprises in the farm. This approach has been used before by Mbai (1984), Kamunge (1989) and Barasa (1989) and is supported by Pandey and Kaushal (1980) who argued that due to insufficient records available with farmers and also due to the difficulties in sorting out family and farm expenditure the total cash expenditure on the farm during the year in question, is the best estimator for the total capital available for farming.

<u>Subsistence Constraint:</u> Preference of farmers to meet their subsistence needs necessitates the incorporation of the subsistence requirement as a constraint (Johl <u>et al</u>, 1973; Upton, 1987). The incorporation of subsistence requirement in the model is quite in accordance with the Kenya Government's food policy since food self sufficiency is given priority. That is, produce enough food to meet domestic demand (Republic of Kenya, 1986).

Maize and beans are the most popular subsistence crops in the study area. Consumption figures with respect to these two crops as indicated in the food balance sheet, show that 118 Kg of maize and 11 Kg of beans are the annual subsistence requirements per capita in Kenya (Republic of Kenya, 1979). These figures were multiplied by the average number of persons in the average farm model and used to calculate the minimum area required to meet subsistence need for the two crops. Such a procedure has been proposed by Upton (1987). The most popular subsistence cropping system is the maize, beans and pigeon peas intercrop. This is the cropping system which was used to meet the subsistence requirement constraint.

<u>Other constraints:</u> These are specific crop constraints incorporated in the model on the basis of the farmers'

priorities. The basis for this is the fact that farm plans should take into account farmers likes and dislikes (Johl *et al*, 1973; Steward, 1961). More details will come under specific farm models in Chapter 4.

Water Resources: Though quite important, water resource is just discussed here but was not considered as a constraint in this study. This is due to the difficulties involved in estimating specific crop water requirements and also in estimating the actual amount of water available to each farmer. The irrigating farmers practise furrow irrigation method. They just obstruct water from the main canal to the offtake furrows and have further obstruction in the offtake furrows to individual farmers' farms. There are no gauges or metered control gates to indicate how much water flows to each individual farm or in each offtake furrow.

Each permitted irrigation farmer is authorized to obstruct 30 m^3 per day for irrigation purposes (Kalders, 1984). However this figure is based on the assumption that all the off-take furrows and the individual farm furrows are lined - up while in practise this is not the case. It also assumes a case where the flow in the main canal is at it's maximum capacity of 1.699 m^3 per second.

During the field survey, irrigation water shortage was cited as a problem by some farmers. They attributed the shortage to reduced water flow rate in the main canal and identified siltation and vegetative growth in the canal as the main causes. Discussions on the water shortage issue with Ministry of Water Development officials in the locality who are responsible to oversee the canal's maintenance operations (desilting and vegetation clearing) revealed that there is no machinery to do such operations hence this is done manually by casual labourers. At times, prolonged rains and lack of funds for hiring casual labour lead to delays in those operations and hence temporary irrigation water shortages are experienced. The official view was that a permanent solution will be obtained by lining-up the canal for this will not only ease maintenance operations but also reduce water seepage losses. Table 3.3 shows the uses of the yatta canal.

Table 3.3 Water uses in the Yatta Canal:

Water use	Percentage (%):
Public and Domestic	30
Seepage	26.5
Irrigation	42.5
Others	1.0

Source: Republic of Kenya, 1990a.

From the Table 3.3 above, it can be noted that irrigation is the leading water user. However seepage loss is quite high amounting to 26.5 percent of the total obstructed water.

The farm plans developed in this study are based on the assumption that maintenance operations will be improved to ensure that there is sufficient water to irrigate the permitted area for all authorised farmers.

<u>Technical coefficients:</u> These are also called the input - output coefficients. They represent the resource requirements per unit of activity. Gross margins were calculated for each of the crop enterprises and entered as the coefficients for the objective function.

Crop enterprises were expressed on per hectare basis, so a value of one was used for each of the crop enterprises as the crop enterprise coefficient with regard to land. The amount of variable costs per hectare of each crop enterprise was calculated and this was used as the technical coefficient of the particular crop enterprise with respect to capital constraint.

Labour requirements per hectare of each of the crop enterprises with respect to land preparation, planting, weeding, spraying, staking and harvesting were obtained for each of the sampled farmers. An average for all the farmers was then calculated for each of the crops' operations. From the average figures, monthly labour coefficients were obtained. The labour coefficient for any crop represents the number of man hours required per hectare of the crop in a given month and it depends on the operations of that crop which take place during the given month.

Labour hiring activities were incorporated in this study. These activities increase the supply of a scarce resource namely labour and reduce the supply of another limited resource namely capital. Therefore these activities have negative coefficients with respect to labour and positive coefficients with respect to capital. Consequently there will be negative net revenue coefficients for labour hiring activities (Heady et al, 1958). In the study area, farmers hired labour at a rate of Kshs. 20 per six hours working day. This means the per hour labour charge is Kshs. 3.30. Therefore the coefficient with regard to these activities were -3.30, -1 and 3.30 for the objective function, labour constraint and capital constraint respectively.

3.5 Methods Of Analyses

Tabular analyses are used mainly in the description of the existing farming system. To develop optimal farm plans, linear programming is used. Average approach is used and this involves pooling and averaging all the individual farm observations hence generating an average farm model. This average farm model is the one used for this study for it is a good representative of the farms in the study area.

Optimal farm plans are developed considering the relevant constraints that vary from plan to plan. The results of analyses are presented in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

The results of this study are presented and discussed in this chapter. First, the existing farming system is described whereby the availability and utilization of the various farm resources such as land, labour, and capital are considered. Second, the optimal farm plans developed for Yatta farmers as well as their limiting resources are presented.

4.1 Description of The Existing Farming System

4.1.1 Land Availability And Use: Table 4.1, here below shows details on farm holding sizes in hectares.

Table 4.1 Land Availability In The Study Area (hectares).

	Average land holding	Highest observed	Lowest observed
Total farm size	2.63	4.86	0.40
Irrigated area			
- first season	0.228	0.4	0.05
- second season	0.233	0.41	0.05
Unirrigated farmed area			
- first season	1.34	4.05	0.30
- second season	1.17	3.60	0.20
Total farmed area	2.971	8.46	0.60

As it can be noted from Table 4.1, farm holdings along Yatta Canal are quite small. This is mainly due to the settlement history as was noted in chapter one. The highest observed total farm size is 8.46 hectares and the mean total farm size was 2.63 hectares.

In this study, total farm size refers to the cultivated and uncultivated holdings owned by a farm family within the study area. It should be noted that the practice of having two crop growing seasons per year makes the total farmed area per year appear larger than the total farm size.

The average irrigated area per farm family in a year is 0.461 hectares which is about 15% of the average total farmed area per farm family. The average irrigated area per farm family is by far less than the maximum area permitted for irrigation which sums up to one hectare in a year. Some problems raised by the farmers during the field survey which possibly hinder full utilization of the area permitted for irrigation are lack of working capital and labour scarcity. Temporary irrigation water shortages were also cited as a problem by some farmers . In addition to these problems, lack of suitable optimal farm plans for guiding farmers in their farming activities may also lead to under utilization of the permitted irrigable area.

Table 4.2 shows the average area in hectares for the various crop enterprises, the number and percentage of farmers growing each particular crop and the average gross margin per crop per hectare.

Table 4.2: Hectarage under various crops in the study area

	Average Area (Ha)	No. of farmers and Percentage based on entire sample		Average GM per crop perHa (Kshs)
(Irrigated)				
Karella	0.119	34	(59.6%)	50364
Duthi	0.106	21	(36.8%)	30604
Valore	0.114	18	(31.6%)	45202
Brinjals	0.128	8	(14.0%)	34104
Okra	0.115	17	(29.8%)	41619
Thin Chillies	0.107	14	(24.6%)	41329
Long Chillies	0.096	10	(17.5%)	36193
Bullet Chillies	0.121	11	(19.3%)	49973
Onions	0.072	10	(17.5%)	27409
French Beans	0.087	18	(31.6%)	20959
Chola	0.069	4	(7.0%)	12764
Kale	0.080	13	(22.8%)	26170
Tulia	0.087	10	(17.5%)	30687
Turwel	0.073	4	(7.0%)	32782
Tomatoes	0.083	12	(21.1%)	31205
Cabbage	0.101	6	(10.5%)	38227
(Unirrigated)				
Maize A	0.810	22	(38.6%)	2626
Maize B	0.789	20	(35.1%)	2440
Beans A	0.587	12	(21.1%)	4518
Beans B	0.478	11	(19.3%)	3757
Pigeon peas	0.405	5	(8.8%)	5661
Maize + Beans + Pigeon peas intercrop	1.105	31	(54.4%)	8610
Maize+ Beans A	0.890	14	(24.6%)	5997
Maize+ Beans B	0.951	13	(22.8%)	3977
Maize+Pigeon peas intercrop.	0.658	4	(7.0%)	5681

Note: A refers to first season (October to February).
B refers to second season (March to September).
GM refers to Gross Margin.

As it can be noted from Table 4.2, farmers in the study area prefer pure stand cropping in their irrigated plots. The irrigated crop enterprises are mainly cash crops. The irrigated crops given first priority by the farmers are Karella, French Beans and Kale while the others are either given second or third priority. The first priority crop are those which the farmers must grow in their irrigated plots every year.

Karella, an Asian vegetable mainly grown for export is the most popular horticultural crop in the study area. It was grown by 59.6 percent of the farmers in the entire sample of 57 respondents. 35.3 percent of those farmers who had grown Karella, which is equivalent to 21.1 percent of the sampled farmers, indicated that they give it first priority every year in their irrigated plots. It is the crop given first priority by the largest number of farmers. The farmers argued that the crop could be grown in any of the two seasons and must occupy at least 0.1 to 0.2 hectares. According to the farmers views once Karella is established, it continues yielding for a longer time compared to other crops, provided proper care especially on protection against diseases and insect pests is maintained. Of all the crops grown along the Yatta canal, Karella had the highest gross margin per hectare. Duthi, another Asian vegetable mainly grown for export is the second most popular crop. However no respondent had this crop as the first priority every year in the irrigated plots.

French beans, also grown for export had the third position in popularity as shown in Table 4.2. 31.6 percent of the respondents in the entire sample had grown French beans. However the crop's average gross margin per hectare which is Kshs.20959 is quite low compared to the gross margins of most of the crops. 50 percent of those farmers who had grown french beans, which is equivalent to 15.8 percent of the sampled farmers, had French beans as their first priority crops in their irrigated plots every year. The farmers' argument was that french beans take a very short time to mature (45 days) and therefore one starts earning from the crop quite early compared to other crops. The farmers also indicated that they grow the crop every season and it must occupy at least 0.1 to 0.2 hectares.

Kale was another crop given first priority by some farmers. The crop was mainly grown for local consumption. It was grown by 22.8 percent of the respondents in the entire sample. 38.5 percent of those farmers who had grown Kale, which is equivalent to 8.8 percent of the sampled farmers, indicated the crop as their first priority crop every year in their irrigated plots. Farmers indicated they grow the crop in any of the seasons and must occupy at least 0.1 to 0.2 hectares. All those farmers with Kale as their first priority had Tomatoes as their second priority crop every year.

The unirrigated plots were mainly for food crops production. In those plots, intercropping was found to be the most common practice. The most popular intercrop was the maize, beans and pigeon peas intercrop (Mixture). It was grown by 54.3 percent of the entire sample. Intercropping has well known advantages over sole cropping namely: the need to maximize the returns from the most limiting factor, land; the need for security in case of natural crop catastrophies such as drought, diseases and/or pest outbreaks; and the beneficial effect of legumes on other crops (Norman, 1973; Mukhebi, 1981).

4.1.2 Labour Availability And Use:

The survey took account of the available family and permanently hired labour to determine the potential labour supply. From the field survey data, 56.4 percent of the sampled farms had one or more permanently hired labourer.

Hired casual labour was considered under working capital. The field survey revealed that 60 percent of the sampled farmers had hired casual labourers at one time of the year or another. The wage for casual labourers was Kshs.20

per six hours per working day.

From the survey data, an average farm family had 2 school children aged between 7 and 14 years, 1 school child aged above 14 years, 2 adults aged between 15 and 64 years and 1 permanent hired labourer. Therefore the average available labour per farm family including school children total to 6 persons.

Average monthly and yearly total average labour supply depends on the number of family members available for farm work at any one particular month. Observation during the field survey revealed that farmers avail themselves for farm work all days of the month except on Sundays and during public holidays. Therefore there are 26 working days for all other months except the months of February, April and December. February has 24 working days since it is shorter than the other months. December and April were taken to have 23 working days since they have many holidays. School children were only available for farm work mainly during their school holiday months (April, August and December). However, those from nearby schools were available for farm work on Saturdays. Labour supply in this study is given in man-hours and one full working day was taken to have 8 working hours.Table 4.3 shows the average monthly and yearly total labour supply in man hours . The weighting system adopted from Norman (1973) mentioned earlier in Table 3.2 in chapter 3 was used in the calculations of the figures given.

Table 4.3 Average monthly and yearly Total Labour Supply. In man-hours (m-hrs) per farm.

MONTH	MAN-HOURS
JANUARY	577
FEBRUARY	536
MARCH	577
APRIL	797
MAY	577
JUNE	577
JULY	577
AUGUST	906
SEPTEMBER	577
OCTOBER	577
NOVEMBER	577
DECEMBER	797
TOTAL	7652

The total annual labour supply is 7652 man-hours. The School holiday months of April, August and December are shown to have a higher labour supply level.

Since livestock enterprises were not considered in this study, the above indicated labour supply levels are less 5 man-hours a day for livestock use. (The field survey revealed that on average, each farm family required 5 man-hours a day for livestock use).

A calendar of operations which is based on the demand seasons of the various horticultural crops and the climatic factor mainly rainfall and the cold July weather conditions is shown in Appendix 2.

4.1.3 Capital Availability And Use:

Capital was estimated using total cash expenditure by each farmer on the various farm inputs such as seeds, fertilizers, crop protection chemicals, casual labour, and land preparation for all crops. An average for all the farmers was calculated to give the capital available for an average farmer for use in the production of the various crops. From the calculations, an average farmer requires Kshs. 3,086 per year for the irrigated crop enterprises and Kshs.1,475 per year for the unirrigated enterprises. Hence the total cash required by an average farmer per year is Kshs. 4,561. Therefore irrigated enterprises required 67.7 percent of the total cash.

Demand for capital per crop as reflected by the cost of production for various crop enterprises is shown in Table 4.4

Table 4.4 Average Cost of Production for crop enterprises (Kshs per hectare).

Crop	Average Cost per Hectare(Kshs)	Crop	Average Cost per Hectare (Kshs)
(Irrigated)		(Unirrigated)	
Karella	10749	Maize A	1694
Duthi	5252	Maize B	785
Valore	5078	Beans A	1261
Brinjals	6152	Beans B	867
Thin Chillies	5901	Pigeon peas	667
Bullet Chillies	9307	Maize+Beans+ Pigeon peas	788
Long Chillies	6073	Maize + Beans A	642
Okra	10519	Maize + Beans B	496
Onions	6362	Maize+P.Peas	198
French Beans	13346		
Chola	4150		
Kale	4923		
Tulia	4890		
Pigeon peas	4433		
Tomatoes	6699		
Cabbages	3002		

Note: A and B refers to 1^{st} and 2^{nd} season crops respectively

As it was indicated earlier, a crop's average cost of production per hectare estimates the capital demand for that particular crop. On the irrigated crop enterprises, French beans had the highest demand for capital of Kshs. 13,346 per hectare, followed by Karella with a capital demand of Kshs 10,749 per hectare. Field survey interviews indicated crop protection chemical and fertilizers are the most expensive components.

On the unirrigated crop enterprises, an interesting observation is that, second season crops have less demand for capital. The reason is that during this season, farmers hardly use any fertilizer or purchased manure since the rain normally comes when the first season crops have not fully been removed from the farms. So farmers do the land preparation and planting in hurry.

4.1.4 Income Obtained under the Existing farming system

Gross margins for all the irrigated crop enterprises were calculated for each of the sampled farmers. These gross margins were then summed up and averaged for all the farmers to give the average gross margin per farmer. Similar calculations were done for the unirrigated crop enterprises.

Sum of the average gross margin for the irrigated crops and the unirrigated crops gave the average total gross margin per farmer. The latter was used as an estimator of the total farm income. From the calculations, the estimated total farm income was Kshs. 23,219 out of which Kshs. 13,609 are contributed by the irrigated crops and Kshs. 9,610 are contributed by the unirrigated crops.

Irrigated crop enterprises contribute 58.6 percent of the total farm income. This is quite a high contribution especially when it is considered they occupy only 15.5 percent of the farmed land per average farm family holding.

The average gross margin of Kshs. 13609 for the irrigated crops in the existing farming system is obtained from an average farm where the irrigated hectarage is 0.461 hectares per year. Based on these figures a gross margin of Kshs. 29,521 for irrigated crops would be obtained if the maximum permitted irrigable area of 1 hectare per year is fully utilized by the farm family. The total gross margin would then be Kshs. 39,131.

4.2 Linear Programming Results

4.2.1 Specific Linear Programming Models

The key issue in this study was to develop optimal farm plans for the farmers. To ensure realism in the study, specific linear programming models were developed. This involved developing a general unrestricted linear programming model on which specified constraints, such as subsistence requirement and specific priority crops, were introduced. The specific priority crops considered are those given first priority by the farmers as discussed under section 4.1 and they include Karella, French beans, and Kale. On the subsistence requirement constraint it should be noted that farmers in the study area expressed their desire to meet their basic subsistence needs from their own farms. Hence introduction of subsistence requirement constraint in the linear programming models is quite in order with the farmers' liking.

This approach of developing specific linear programming models is quite realistic and ensures the results obtained have a wide scope of application. The approach has the support of Blagburn (1972); Stewart (1961) and Johl _et al_ (1973).

Blagburn (1972) argued that the choice of a particular farming system may be influenced by personal preferences for particular kinds of crops or livestock even at the expense of maximization of profits. He further noted that with limited capital, the need for quick cash returns may be an overriding factor. Stewart (1961) cited soil fertility and crop husbandry as reasons for imposing specific crop restrictions in a linear programming problem. Johl _et al_, (1973) stated that farm plans should take account of farmers likes and dislikes. This means farmers' preferences and priorities should be considered in farm planning problems.

Going by the above discussion, three general farm models were developed; three Karella farm models were developed; one French beans farm model was developed and two Kale farm models were developed. Common constraints to all the specific linear programming models are: two unirrigated land constraints, two irrigated land constraints, twelve labour constraints and working capital constraint. Details about each specific linear programming model are given here below.

The three General Farm Models

General farm model 1: based on the aggregate data; without labour hiring activities and subsistence requirement constraint.

General farm model 2: based on the aggregate data; without labour hiring activities and with subsistence requirement constraint.

General farm model 3: Also based on the aggregate data; with labour hiring activities and subsistence requirement constraint.

The three Karella Farm Models:

Karella farm model 1: Is like general farm model 3 but with at least 0.1 hectares of Karella crop in the first season as an added constraint.

Karella farm model 2: Is like general farm model 3 but with at least 0.1 hectares of Karella crop in the second season as an additional constraint.

Karella farm model 3: Is like general farm model 3 but with at least 0.1 hectares of Karella crops in the first and second seasons as additional constraints.

The French beans Farm model:

The French beans farm model is based on the aggregate data and like general farm model 3, it has labour hiring activities and subsistence requirement constraints but in addition, it has at least 0.1 hectares of French beans crops constraints in the first and second seasons.

The Two Kale Farm Models:

Kale farm model 1: Is just like general farm model 3 but with at least 0.1 hectares of Kale crop in either/or both the first and the second seasons as added constraint(s).

Kale farm model 2: It is like Kale farm model 1 but with at least 0.1 hectares of tomatoes crop in either/or both the first or/and second seasons as additional constraint(s).

As it was mentioned earlier, the subsistence requirement constraint is met using the maize, beans and pigeon peas intercrop since it is the most popular food cropping method in the study area. 0.75 hectares of this intercrop is sufficient to give the minimum required maize and beans per annum.

4.2.2 Specific Model Results And Discussion

(a) Results of general farm models 1,2 and 3

Table 4.5 shows the optimal farm plans for the three general farm models. This indicates the optimal combination of crop enterprises, the level of production of each of the crop enterprises in hectares and the gross margin earned from each of the crop enterprises in Kshs.

Table 4.5 Optimal farm plans for the three General farm models

Activity	Model 1		Model 2		Model 3	
(Irrigated Enterprises)	Levels (Ha)	GM (Kshs)	Level (HA)	GM (Kshs)	Level (Ha)	GM (Kshs)
Cabbage A	0.2928	11416	0.3817	14591	0.4235	16188
Valore A	0.2014	9104	0.1183	5347	0.0765	3459
Cabbage B	0.2316	8853	0.3433	13120	0.382	14603
Valore B	0.2536	11463	0.1453	6566	0.0963	4353
Okra B	0.0148	616	-	-	-	-
Bullet Chillies B	-	-	0.0115	576	0.0217	1087
(Unirrigated crop enterprises)						
Maize and Bean Mixture A	0.382	2296	0.17	1019	0.17	1019
Maize and Pigeon peas Mixture	0.8129	6644	0.0876	716	0.42	3433
Pigeon peas	0.1443	816	0.3324	1882	-	-
Maize Beans Pigeon peas Mixture	-	-	0.75	6457	0.75	6457
Total GM		51207		50275		50318
GM from Irrigated crop		41452		40200		39690
GM from Unirrigated crops		9755		10075		10909

<u>NOTE</u>: 1) In addition to the above, general farm model 3 had labour hiring activities for the month of March where 84 man-hours were taken, requiring Kshs.279.70.

2) A and B refer to first and second seasons respectively.

3) GM refers to Gross Margin.

Table 4.6 shows the limiting resources for the optimal farms plans in Table 4.5. The shadow prices of the limiting resources are also shown. Shadow price is the marginal value productivity of a resource at the optimal solution level. It indicates the increase or reduction in total gross margin that would occur if one unit more or one unit less of a resource was used while all the other constraints and activities in the optimal plan remain constant. Limiting resources take positive shadow prices.

Table 4.6: Limiting Resources and their shadow prices for the three optimal farm plans in Table 4.5

Limiting Resources	Shadow Price (Kshs)		
	Model 1	Model 2	Model 3
January labour	1.10	-	-
February labour	0.50	4.70	4.65
March labour	10.45	9.75	9.40
October labour	17.25	0.75	0.25
Working capital	1.483	1.774	1.831
Unirrigated land A	2,405	3,426	3,472
Unirrigated land B	-	960	1,062
Irrigated land A	22,545	25,760	25,925
Irrigated land B	26,021	32,555	32,606

NOTE: A and B refer to first and second season respectively.

The three optimal farm plans for the general farm models, fully utilize the available irrigable land. Except for model 1, the others fully utilize the available unirrigated land. General farm model 1 leaves 0.2128 hectares of second season unirrigated land unutilized (See Appendix 4). The shadow prices for the irrigated land constraints are quite high and this shows there is a great potential to increase the farmers income even further by increasing the area under irrigation.

Labour during the months of February, March and October is found to be a limiting resource in all the three optimal farm plans as shown in Table 4.6. It is during those months when the seasonal rains begin in the study area, hence farmers are busy involved with harvesting, land preparation and planting operations especially for the unirrigated crop enterprises. Such operations added to the operation undertaken for the irrigated crop enterprises lead to quite a high demand for labour. In addition, farm model 1 has January labour as a limiting resource. March labour is the most limiting resource in the three farm plans since in the three farm plans, the shadow price (marginal value product) of March labour is above the market price of labour which is Kshs.3.30 per hour. This means it is economically feasible to hire casual labour during that month for all the three optimal farm plans. The February labour resource, though limiting in all the three plans, has it's shadow price above the market price for the second and third farm models. Therefore it is only in those two models' optimal farm plans where it is economically feasible to hire casual labour during the month of February. For October labour, shadow price is above the market labour price in the first general farm model. Thus in the optimal farm plan of general model 1, it is economically feasible to hire casual labour during the month of October.

Working capital was found to be a limiting resource in all the three optimal farm plans. From the shadow prices (marginal value products) it can be noted that the increments on every Kenya Shilling (Kshs) invested in the optimal farm plans for farm models 1, 2 and 3 are 48.3%, 77.4% and 83.1% respectively. Comparing such increments with the current interest rate charged by lending institutions for agricultural loans which is 14% (Republic of Kenya, 1990b), it is paying for farmers to obtain such loans.

The income levels, (in terms of total gross margins) obtainable with the three optimal farm plans are Kshs.51,207; Kshs.50,275; and Kshs.50,318 for models 1, 2 and 3 respectively as shown in Table 4.5 . Contributions of the irrigated crops to the total gross margin figures given above are Kshs.41,452, Kshs. 40,200 and Kshs. 39,690 for farm models 1, 2 and 3 respectively while the contributions of the unirrigated crops are Kshs. 9,755, Kshs. 10,075 and Kshs. 10,909 for farm models 1, 2 and 3 respectively. As can be noted from Table 4.5 above, irrigated crop occupy a total area of 1 hectare for the two growing seasons in a year for all the farm models while the unirrigated crops occupy a total area of 2.3 hectares for the two growing seasons in a year for farm model 1 and 2.51 hectares per year for farm models 2 and 3. Comparing the total income levels obtainable with the developed optimal farm plans and the income level of Kshs. 23,219 obtainable under the existing farming system which is based on an average farm, it is noted that the total average farm income per farm family would be increased by 120.6%, 116.5% and 116.7% as a result of the three optimal farm plans namely general farm models 1, 2 and 3 respectively. In the three optimal farm plans, the percentage contribution of irrigated crop enterprises to total income (total gross margin) is quite high. These contributions are 80.9%, 80% and 78.9%. for models 1, 2 and 3 respectively. Compared to the existing farming system, income from irrigated enterprises increased by 204.6%, 195.6% and 191.6% while income from unirrigated enterprises increased by 1.5%, 4.8% and 10.6% for farm models 1, 2 and 3 respectively as a result of the optimal farm plans.

Since the developed optimal farm plans fully utilized the available irrigable land, a further comparison in income levels is made for the developed optimal farm plans and a case where the existing farming system is assumed to fully utilise the available irrigable land. In this case the existing farming system would have a total gross margin of Kshs. 39,131 with irrigated crops contributing Kshs. 29,521 and the unirrigated crops contributing Kshs. 9610. Results of the comparison show that farm family income would be increased by 30.8%, 28.5% and 28.6% for farm models 1, 2, and 3 respectively. Similarly, income from irrigated crops would increase by 42.4%, 36.2% and 34.4% while that from unirrigated crops would increase by 1.5%, 4.8% and 10.6% for farm models 1, 2 and 3 respectively as a result of the optimal farm plans.

Other details for the above farm models such as the value at which a nonbasic variable enters the solution, the range of feasibility for the basic variables and the range of feasibility for the constraints are given in Appendices 3, 7 and 8 respectively.

(b) Results for Karella Models 1,2 and 3

Table 4.7 shows the optimal farm plans for the three Karella constrained farm models. The table shows the various activities and their levels in hectares as well as their gross margins in Kshs.

Table 4.7: Optimal plans for the Karella constrained farm models

Activity	Model 1		Model 2		Model 3	
(Irrigated crop Enterprises)	Levels (Ha)	GM (Kshs)	Level (HA)	GM (Kshs)	Level (Ha)	GM (Kshs)
Cabbage A	0.4	15291	0.5	19113	0.1786	6827
Karella A	0.1	5036	-	-	0.1	5036
Cabbage B	0.5	19113	0.4	15291	0.4	15291
Karella B	-	-	0.1	5036	0.1	5032
(Unirrigated crop enterprises)						
Maize and Bean Mixture	0.0803	482	-	-	-	-
Maize and Pigeon peas Mixture	0.2951	2412	0.1182	966	0.42	3433
Maize Beans Pigeon peas Mixture	0.75	6457	0.75	6457	0.75	6457
Pigeon peas	0.1249	707	0.2547	1442	-	-
Total GM		49499		48306		42082
GM from Irrigated crop		39441		39441		32191
GM from Unirrigated crops		10058		8865		9891

NOTE: A refers to first season
B refers to second season

Table 4.8 shows the limiting resources for the optimal farm plans in Table 4.7. Shadow prices for the limiting resources are also given.

Table 4.8 Limiting resources for the Karella constrained farm models

Limiting Resource	Shadow Price (Kshs)		
	Model 1	Model 2	Model 3
March labour	20.65	21.25	-
Capital	8.05	8.45	12.70
Unirrigated land B	268	-	5652
Irrigated land A	4674	3190	-
Irrigated land B	13954	12748	0.0039

NOTE A refers to first season
B refers to second season

Except for farm model 3, all the other optimal farm plans fully utilize the irrigable land. The optimal farm plan for farm model 3 has 0.221 hectares of irrigable land in first season unutilized (see Appendix 11). For the unirrigated land, the optimal farm plans for the three Karella farm models do not fully utilize the first season unirrigated land. 0.0897, 0.2171 and 0.17 hectares of first season unirrigated land are not utilized for farm models 1, 2 and 3 respectively. (see Appendices 9, 10, and 11). Optimal farm plan for farm model 2 leaves 0.0471 hectares of second season unirrigated land unutilized (see Appendix 10). The other optimal farm plans fully utilize second season unirrigated land. The shadow prices especially for irrigated land during the second season are quite high and this shows there is a great potential to increase farm family income by increasing the area under irrigation.

March labour is the only labour limiting resource and it holds for the optimal farm plans for models 1 and 2. The shadow prices for March labour for models 1 and 2 are Kshs.20.65 and Kshs.21.25 respectively. This means one additional man-hour invested in the optimal farm plan during the month of March would generate Kshs.20.65 and Kshs.21.25 for farm models 1 and 2 respectively. Compared to the current market price for labour in the study area which is Kshs.3.30 per manhour, there is a net gain of Kshs.17.35 and Kshs.17.95 from every man-hour invested in optimal farm plan for farm models 1 and 2 respectively. With such increments to the total gross margin, it is economically feasible to hire casual labour during the month of March in the two optimal farm plans.

Working capital is a limiting resource to all the three optimal farm plans with it's shadow prices being Kshs. 8.05, 8.45 and 12.70 for farm models 1, 2 and 3 respectively. The net increments for every Kenya Shilling of Working capital invested in the optimal farm plans are Kshs.7.05 (705%); 7.45 (745%) and 11.70 (1170%) for farm models 1 , 2 and 3 respectively. Compared to the current interest rate of 14%

charged by lending institutions for agricultural loans, such substantial increments show it is economically feasible to obtain credit from such lending institutions.

As shown in Table 4.7, the farm income (total gross margin) obtainable with the Karella constrained optimal farm plans are Kshs. 49,499, Kshs. 48,306 and Kshs. 42,082 for farm models 1, 2 and 3 respectively. Out of the total gross margin figures given above, the contributions of irrigated crops are Kshs. 39,441, Kshs. 39,441 and Kshs. 32,191 for farm models 1, 2 and 3 respectively while the contributions of unirrigated crops are Kshs. 10,058, Kshs. 8,865 and Kshs. 9,891 for farm models 1, 2 and 3 respectively. As can be noted from Table 4.7 above, irrigated crops occupy a total area of 1 hectare during the two growing seasons for farm models 1 and 2. Farm model 3 has the total area occupied by irrigated crops as 0.779 hectares. During the two growing seasons unirrigated crops occupied a total area of 2.42 hectares for farm model 1, 2.29 hectares for farm model 2 and 2.34 hectares for farm model 3.

The net increments in total farm income resulting from the optimal farm plans above the average farm income of Kshs.23,219 under the existing farming system are 113.2%, 108% and 81.2% for Karella farm models 1, 2 and 3 respectively. The increments in farm income from irrigated crop enterprises as a result of the optimal farm plans are 189.8%, 189.8% and 136.5% for Karella farm models 1, 2 and 3 respectively. Increments in farm income from unirrigated crop enterprises as a result of the optimal farm plans are 4.66%, -7.75% and 2.92% for Karella farm models 1, 2 and 3 respectively.

The contributions of irrigated crop enterprises to the total farm income in the three optimal farm plans are: 79.7%, 81.6% and 76.5% for Karella farm models 1, 2 and 3 respectively.

The optimal farm plans fully utilize the available irrigable area and hence a further comparison of farm income levels is made for the developed optimal plans and a case where the existing farming system also fully utilizes the irrigable land available. In this case the net increments resulting from the optimal plans would be 26.5% 23.5% and 7.5% above the considered existing level of Kshs. 39,131 for Karella farm models 1, 2 and 3 respectively. Similarly, income from irrigated crops would increase by 30,2%, 33.6% and 9% above the considered existing level of Kshs. 29,521 for farm models 1, 2 and 3 respectively while the net increments for unirrigated crop would be 4.66%, -7.75% and 2.92% above the considered existing level of Kshs. 9,610 for farm models 1, 2 and 3 respectively.

Other details for the Karella constrained farm models such as the value at which a nonbasic variable enters the solution, the range of feasibility for the basic variables and the range of feasibility for the constraints are given in Appendices 3, 12 and 13 respectively.

(c) Results for French Beans Farm Model:

Table 4.9 shows the optimal farm plan for a French beans farm model. This is a farm model which ensures there is at least one french bean crop enterprise in each of the growing seasons. Activities undertaken and their levels in hectares as well as their gross margins are shown in the table.

Table 4.9: Optimal farm plan for the French beans farm model

Activity	Level (Ha)	Gross Margin (GM) (kshs)
(Irrigated Crop Enterprises)		
Cabbage A	0.3429	13108
F/beans A2	0.1	2096
Cabbage B	0.0627	2397
F/beans B1	0.1	2096
(unirrigated Crop enterprises)		
Maize & P.peas mixture	0.42	3433
Maize beans & P.peas mixture	0.75	6457
Total GM		29587
GM from irrigated crops		19697
GM from unirrigated crops		9890

NOTE: A refers to first season.
B refers to second season.
A2 refers to second F/beans crop during first season.
B1 refers to first F/beans crop during second season.

Table 4.10 shows the limiting resources and their shadow prices for the optimal farm plans in table 4.9.

Table 4.10 Limiting resources for the French Beans constrained optimal farm plan.

Limiting Resources	Shadow Price
March labour	1.526 x 10-5
Capital	12.70
Unirrigated B	5652

NOTE : A refers to first season.
B refers to second season.

The optimal farm plan for the French beans farm model underutilize most of the available resources. It leaves 0.17 hectares of unirrigated land in first season, 0.0571 hectares of irrigated land in first season and 0.3373 hectares of irrigated land in second season unutilized (see Appendix 14).

In this optimal farm plan, labour is only a limiting resource on the month of March and even then, the shadow price is too low and is rounded to zero. Thus it is not at all economically feasible to hire labour during that month.

Working capital is a limiting resource in that optimal farm plan and it's shadow price is Kshs.12.70. This means that an additional Kenya Shilling of working capital invested in the optimal farm plan would have a net increment of Kshs.11.70 which is the same as 1170% increment. Compared to the current interest rate of 14%, such an increment makes obtaining credit with this optimal farm plan worth paying.

The total farm income (total gross margin) for this optimal farm plan is Kshs.29,587. Out of the total gross margin figure, irrigated crops contribute Kshs. 19,697 while unirrigated crops contribute Kshs. 9,890. The irrigated crops occupied a total area of 0.6 hectares during the two growing seasons while the unirrigated crops occupied a total area of 2.34 hectares during the two growing seasons. Comparing the total gross margin of the optimal farm plan to the total farm income of Kshs.23,219 under the average existing farming system, there is an increment of 27.4% as a result of the optimal farm plan. Farm income from irrigated crop enterprises would increase from the existing level of Kshs.13,609 to Kshs.19,697 with the optimal farm plan. This represents a net increment of 44.7%. Unirrigated crop enterprises income would increase from the existing level of Kshs.9,610 to Kshs.9,891 with the French beans constrained optimal farm plan. This represents a net increment of 2.9%.

As mentioned earlier the French beans optimal farm plan utilizes 0.6 hectares of the available irrigable land per year. For comparison purposes, the optimal plan's total gross margin is viewed against an existing farming system which is taken to utilize 0.6 hectares of irrigable land in a year. Based on the figures on income given earlier in section 4.1.4, such an existing farming system would have a total gross margin of Kshs. 27,322 with the contribution of irrigated crops being Kshs. 17,712 while that for unirrigated crops is Kshs. 9610. From the comparison, the optimal farm plan would be superior by 8.29% in terms of total gross margin, by 11.2% in terms of gross margin from irrigated crops and by 2.9% in terms of the income from unirrigated crops.

Other details for the French Beans constrained farm model such as the value at which a nonbasic variable enters the solution, the range of feasibility for the basic variables and the range of feasibility for the constraints are given in Appendices 3, 17 and 18 respectively.

(d) <u>Results For the Kale Farm Models 1 & 2</u>

Table 4.11 shows the optimal farm plans for two Kale constrained farm models. The activities to undertake, their levels given in hectares and their gross margins given in

Kenya shillings are indicated.

Table 4.11: Optimal farm plans for Kale farm models

Activity	Model 1		Model 2	
(Irrigation Crop Enterprises)	Levels (Ha)	GM (kshs)	Level (Ha)	GM (Kshs)
Cabbage A	0.3454	13204	0.4386	16766
Valore A	0.0546	2468	-	-
Kale A	0.1	2617	-	-
Tomatoes A	-	-	0.0614	1916
Cabbages B	0.4148	15857	0.3614	13815
Valore B	0.0668	3019	-	-
Bullet Chillies B	0.0184	920	-	-
Kale B	-	-	0.1	2617
Tomatoes B	-	-	0.0386	1204
Unirrigated crops enterprises)				
Maize + Beans mixture A	0.17	1019	0.1469	881
Maize + Pigeon peas Mixtures	0.42	3433	-	-
Maize + Beans + Pigeon peas	0.75	6457	0.75	6457
Pigeon peas	-	-	0.42	2378
Total Gross Margin (GM)		48778		46004
GM from Irrigated crops		38085		36318
GM from Unirrigated crops		10909		9716

NOTE: 1) In addition to the activities in the above table, there is March labour hiring activity with a level of 64.7 man-hours for Kale farm model 1 and October labour hiring activity for Kale farm model 2 at a level of 9.5 man hours.

2) A refers to first season.

3) B refers to second season.

4) The total gross margins are less the amount of money required for labour hiring activities in the optimal farm plans .

Table 4.12 shows the limiting resources for the optimal farm plans in Table 4.11 here above and their shadow prices:

Table 4.12: Limiting Resources for the Kale constrained optimal farm plans

	Shadow Price (Kshs)	
Limiting Resources	Model 1	Model 2
February labour	4.65	-
March labour	9.40	15.65
October labour	0.25	19.30
Capital	1.831	4.806
Unirrigated land A	3472	-
Unirrigated land B	1062	154
Irrigated land A	25924	10447
Irrigated land B	32605	15118

NOTE: A refers to first season

B refers to second season

The two optimal farm plans shown in Table 4.11 fully utilize the irrigable land available in the two seasons. The shadow prices for irrigated land are quite high and this shows farmers farm income could greatly be increased if the areas under irrigation is increased. Unirrigated land in the second season is fully utilized by the two optimal farm plans. However 0.0231 hectares of the first season unirrigated land is unutilized by Kale farm model 2 (see Appendix 16)

In both optimal farm plans, March and October labour resources are limiting, in addition, February labour is a limiting resource for farm model 1. As far as the limiting labour resources are concerned, it is not economically feasible to hire casual labour during the month of October since the shadow price is far below the current labour hiring price.

Working capital is a limiting resource in both the optimal farm plans. The net increments to every additional Kenya Shilling of working capital invested in the optimal farm plans are 83.1% and 380.1% for models 1 and 2 respectively. Compared to the interest rate of 14% charged by lending institutions for agricultural loans, such increments are too great. It is therefore economically feasible to obtain credit to invest in the optimal farm plans while holding all other factors constant.

As shown in Table 4.11 , the total farm income (total gross margin) obtainable with the Kale constrained optimal farm plans are Kshs. 48,778 and Kshs. 46,004 for Kale farm models 1 and 2 respectively. Out of the total farm income figures given above, irrigated crops contributions are Kshs. 38,085 and Kshs. 36,318 for farm models 1 and 2 respectively while the contributions of the unirrigated crops are Kshs. 10,909 and Kshs. 9,716 for farm models 1 and 2 respectively. During the two growing seasons, irrigated crops occupied a total area of 1 hectare for both farm models while unirrigated crops occupied a total area of 2.51 hectares for both farm models.

With the optimal farm plans, net increments of 110% and 98.1% above the average total farm income of Kshs. 23,219 for the existing cropping system would be realized for models 1 and 2 respectively. Income from irrigated crop enterprises could be increased by 179.9% and 166.9% while that from unirrigated crop enterprises could be increased by 13.5% and 1.1% with adoption of the developed optimal farm plans for kale models 1 and 2 respectively.

The contributions of the irrigated crop enterprises to the total farm income are quite substantial for they represent 78.1% and 78.9% of the total farm income obtainable with the optimal farm plans for Kale farm models 1 and 2 respectively.

As noted earlier, both Kale optimal farm plans fully utilize the available irrigable land. For comparison purposes, the total gross margin of the developed optimal plans is viewed against an existing farming system which is also taken to fully utilize the available irrigable area.

From the comparisons, the optimal farm models 1 and 2 were found to be superior by 24.65% and 17.57% respectively over the considered existing farming system which has a total gross margin of Kshs. 39,131. Considering the gross margin from irrigated crops ,the optimal farm plans 1 and 2 are superior by 29% and 23% respectively over the considered existing farming system level of Kshs. 29,521. Regarding the gross margin from unirrigated crops, the optimal farm plans are superior by 13.5% and 1.1% over the considered level of Kshs. 9610.

Other details for the Kale constrained farm models such as the value at which a nonbasic variable enters the solution, the range of feasibility for the basic variables and the range of feasibility for the constraints are given in Appendices 3, 17 and 18 respectively.

4.3 Comparative Discussion Of Alternative Optimal Farm Plans

Table 4.13 summarizes all the optimal farm plans developed by considering some of the important factors such as irrigated area (Irr.L), unirrigated area (Unirr.L), gross margins from irrigated enterprises (GM.Irr.L) and unirrigated crop enterprises (GM.Unirr.L), total gross margins (TGM), marginal value product for capital (MVP.Cap), and marginal value product for irrigated land (MVP.Irr.L) during each of the seasons.

Table 4.13 Summary of all optimal farm plan

Model	Irr.L.		Unirr.L.		GM.Irr.L.	GM.Unirr.L.	TGM.	MVP Cap.	MVP Irr.LA.	MVP irr.LB.
	A	B	A	B	(Kshs).	(Kshs).	(Kshs).	(Kshs).	(kshs).	(kshs).
GFM 1	0.5	0.5	1.34	0.9572	41452	9755	51207	1.483	22545	26021
GFM 2	0.5	0.5	1.34	1.17	40200	10075	50275	1.774	25760	32555
GFM 3	0.5	0.5	1.34	1.17	39690	10628	50318	1.831	25925	32606
KRFM 1	0.5	0.5	1.25	1.17	39441	10058	49499	8.05	4674	13954
KRFM 2	0.5	0.5	1.12	1.12	39441	8865	48306	8.45	3190	12748
KRFM 3	0.5	0.5	1.17	1.17	32191	9891	42082	12.70	-	0.0039
F/BFM	0.44	0.16	1.17	1.17	19697	9890	29587	12.70	-	-
KLFM 1	0.5	0.5	1.34	1.17	38085	10909	48778	1.831	25924	32605
KLFM 2	0.5	0.5	1.31	1.17	36318	9716	46004	4.806	10447	15118
EFS 1	0.228	0.233	1.34	1.17	13609	9610	23219	-	-	-
EFS 2	0.5	0.5	1.34	1.17	29521	9610	39131	-	-	-

NOTE: GFM refers to general farm model.
F/BFM refers to French bean farm model.
KRFM refers to Karella farm model.
KLFM refers to Kale farm model.
EFS 1 refers to existing farming system based on an average farm.
EFS 2 refers to existing farming system when the irrigated land is comparable to that appearing in most of the optimal farm plans.
A and B refers to first season and second season respectively

From Table 4.13 it can be noted that most of the developed optimal farm plans fully utilize the irrigable land available in both seasons. However unirrigated land especially during the first season is underutilized in some of the cases. Irrigated land is a limiting resource in almost all the developed plans and has quite high shadow prices.

Considering the total gross margins, the highest obtainable is Kshs. 51,207 and is for general farm model 1 while the lowest obtainable is Kshs. 29,587 for the French beans farm model. When the developed optimal farm plans are compared to the existing farming system which is based on an average farm, general farm model 1 gives the highest net increment in total gross margin with a value which is 120.6% above the existing level of Kshs. 23,219. French beans farm model gives the lowest net increment in total gross margin with a value which is 27.4% above the existing level. When the developed optimal farm plans are compared to the existing farming system which is taken to fully utilize the available irrigable land as is the case in most of the optimal farm plans, the highest percentage net increment noted is 30.8% and is for the general farm model 1 while the lowest percentage net increment noted is 7.5% and is for Karella farm model 3. Since the French beans farm model utilizes 0.6 hectares of the irrigable land, it was compared with an existing farming system which also utilizes 0.6 hectares and the total gross margin of the optimal farm plan was higher by 8.29% over that of the considered existing farming system.

The contribution of irrigated crop enterprises to the total gross margin are quite substantial, ranging between

81.6 percent for Karella farm model 2 and 66.6% for the French beans farm model. Under the existing farming system which is based on an average farm, irrigated crop enterprises contribute 58.6% of the total farm income. The contribution of the irrigated crops to total gross margin in the existing farming system where it is assumed the available irrigable land is fully utilized is 75.44% .

Capital is a limiting resource in all the cases. It is least limiting in the general farm model 1 where it's shadow price is Kshs 1.483 and most limiting in the French beans farm model and in the Karella farm model 3 which tie at a shadow price of Kshs.12.70.

CHAPTER 5

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary And Conclusions:

This study is a challenge to one of the priority issues in rural development namely improving small scale farmers income. This is being met through proposing optimal farm plans, with gross margin maximization as the objective function, to smallholder farmers practising irrigation along the Yatta Canal.

The specific objectives of the study are to describe the existing farming system for the smallholder farmers practising irrigation along the Yatta Canal; to develop optimal farm plans for those farmers under the existing resource constraints and other restrictive requirements; to show the superiority of the obtained optimal farm plans over the existing cropping system using gross margin comparisons criteria; to identify the main constraints to irrigated and unirrigated crop production along the Yatta Canal.

From the objectives, one hypothesis was postulated for testing. The hypothesis is that the current level of resource use is sub-optimal and hence farmers income can be increased by reorganising the existing resources and enterprises.

In all the optimal farm plans developed, the increments to total farm income (total gross margin) above the average existing farming system income level were found to be quite substantial. The lowest increment was 27.4 percent and was recorded for the optimal farm plan for French beans farm model. All the other plans, except for Karella farm model 3 and Kale farm model 2, had increments above 100 percent. This meant farm income more than doubled. The highest increment in income was 120.6 percent and was recorded for general farm model 1 optimal plan. In all the cases, irrigated crops enterprises had the highest contribution to total farm income. This ranged from 66.6 percent to 81.6 percent for French beans and Karella farm model 2 plans respectively. Such a contribution is an indicator of the importance of irrigation in the study area. In all the cases, increments in incomes from irrigated crops enterprises (gross margins from irrigated crop enterprises) were quite high. These ranged from 44.7 percent with the French beans farm model optimal plan to 204.6 percent with the general farm model 1 optimal farm plan. Minor increments in income from unirrigated crops enterprises were noted with the highest increment shown as 10.6 percent for general farm model 3 plan.

Further comparisons of income were made whereby each developed optimal farm plan was compared to an existing farming system with the same irrigated hectarage as the respective optimal plan. In all the cases, positive net increment in total farm (total gross margin) over the considered existing farming system levels were noted. The increments ranged between 7.54% and 30.86%. This shows that the superiority of the optimal farm plans developed in this study over the existing farming system can not be solely attributed to the underutilization of the irrigable land in the existing farming system based on an average farm.

In view of the above findings, it is evidently clear that adoption of the developed optimal farm plans would increase farmers income. This implies that resource allocation in the existing farming system is sub-optimal and especially so in the irrigated plots. Therefore, the hypothesis for this study is accepted.

Working capital was found to be a serious limiting resource in all the farm models considered. The lowest and highest observed marginal value product for capital figures were Kshs. 1.483 and Kshs. 12.70 respectively. This means that the increments to every additional Kenya shilling of working capital invested in the optimal farm plans are higher than the current lending rate of 14 percent charged by leading institutions for agricultural loans. Assuming all other factors constant, this means it is economically feasible to obtain credit from such institutions. Such a finding with regard to working capital confirms a general complaint raised by majority of the farmers during the field survey interviews. Farmers complained that some key horticultural crop inputs, namely, pesticides and fertilizers are too expensive. These coupled with the high demand for labour during certain months which necessitates casual labour hiring, make horticultural farming too expensive and prohibitive in terms of increasing area under these crops. As a solution to the capital problem, the farmers argued that since their farms have been adjudicated, they should be given the title deeds to use them as security to acquire loans from lending institutions. In addition, labour during some months was a limiting resource at varying degrees from model to model. In most of the farm models, labour hiring activities, though allowed for on monthly basis, did not enter the optimal solution even for those months when labour was a limiting resource as indicated by very high shadow prices of labour. Such a situation can only be explained by acute working capital scarcity.

The study also revealed that both irrigated and unirrigated lands were limiting resources in most of the farm models. Comparatively, irrigated lands had higher shadow prices than unirrigated lands in most of the cases. This meant that other factors held constant, irrigated land could be increased at the expense of unirrigated land. One possible way of increasing the area under irrigation is by reducing the current seepage water loss in the canal which amount to 26.5 percent of the total water obstructed, equivalent to 62.4 percent of that available for irrigation. If seepage is reduced more water would be availed for irrigation use.

5.2 Recommendations

1. All the developed optimal farm plans are superior to the existing farming system in terms of farm income. Hence this study recommends adoption of these farm plans. Adoption of the plans would ensure that the existing resoure are optimally used. These optimal farm plans should also be reviewed overtime to ensure farmers continue to enjoy the maximum possible income from their resources.
2. As mentioned earlier, capital is a serious limiting resource in the developed farm models for Yatta farmers. This study therefore recommends that the farmers in the study area be assisted financially. This can be achieved through availing credit facilities to the farmers. Lending institutions should therefore be encouraged to avail credit facilities to small scale farmers and this may require government policy interventions. Further, since land in the study area has been adjudicated, the government can also

intervene by providing the farmers with their title deeds so that they can be used as security to obtain loans from lending institutions. With financial assistant, the farmers income would greatly be improved.

3. The study also recommends that a detailed study on the economic and technical aspects of lining -up the main canal and all the offtake furrows should be undertaken. This recommendation is based on the observation that seepage water loss is quite high amounting to 26.5% of the total water obstructed. With the canal lined up, seepage water loss would be reduced and hence more water would be availed for irrigation use. This could also ease the canals maintenance operations.

4. On maintenance of the canals, this study recommends that the farmers should be more involved not only in the cleaning of the offtake furrows but also in the cleaning of the main canal. Such a participatory approach would reduce dependency on treasury funds for the maintenance operations. Delays in obtaining the treasury funds cause delays in the canal's cleaning operations and this leads to temporary water shortages at times. With the farmers involved in the cleaning operations, such delays can be avoided.

5. One more way the government can influence farming activities in the study area is through relevant research and

extension. Intensive research work especially on the agronomic aspects of the horticultural crops grown in the study area is recommended. Aspects of nutrient requirements, pathology, climatic requirement, water requirements, as well as breeding should all be considered. Such studies should aim at increasing the yields of such crops per unit area. Such work would generate quite useful information since some of the crops do not have any literature available in the country. Apart from equipping extension officers with better skills for assisting farmers in their decision making, the information generated would be of great use to other researchers.

In addition there are some potential problems which can easily crop up where farmers venture into irrigation without seriously considering some technical aspects such as those of soil salinity and rising water tables. Such problems make land totally unproductive. Yatta can easily fall into such problems since farmers have just gone into irrigation on their own initiative. This study therefore recommends intensive research work to be done specifically on the water characteristic in relation to it's suitability for irrigation use; the soil characteristics and it's suitability for irrigation; and suitable irrigation methods.

REFERENCES

Agrawal, R.C. and Heady, O.E. (1972); Operations Research Methods For Agricultural Decisions: IOWA State University Press, Ames, IOWA, USA.

Ateng, B.A. (1977): "Linear Programming: An Application To the Identification Of The Best Existing Strategy For Peasant Farmers In Kenya". Unpublished MA. Thesis University Of Nairobi.

Asamenew, G (1980): "Resource Allocation For Small Scale Farmers Of The Star Grass Zone In Embu District, Kenya. A Linear Programming Approach". Unpublished MSc. Thesis, University of Nairobi.

Barasa, R. N. (1989): "The Economics Of Cotton Production In Funyula Division, Busia District, Kenya". Unpublished MSc. Thesis , University Of Nairobi.

Blagburn, C. H. (1972): Farm Planning And Management Longman Group Limited, Fourth impression.

Carruthers, I (1985): "Protecting Irrigation Investment". Ceres, FAO, No.106, Vol.18. No.4.

Ghai D. and S. Radwan (1983): "Agrarian Policies And Rural Poverty In Africa:" Inequalities Within The Rural Economy. International Labour Office, Geneva.

Heady, O.E. And Candler,W. (1958): Linear Programming Method. The IOWA State University Press, Ames, IOWA, USA.

Heyer, J.U. (1967): Agricultural Development And Peasant Farming In Kenya: Unpublished Ph.D Thesis, London.

Heyer, J.U: Maitha, J.K. And Senga W.M. (1976): Agricultural Development In Kenya: An Economic Assessment. Oxford University Press, Nairobi.

International Labour Office, Geneva, (1972): Employment Income And Equity. "Strategy For Increasing Productive Employment In Kenya".

Irea, S.M. (1979): " A Linear Programming Approach To Optimal Allocation And Combination Of Crop Enterprises In Perkerra Irrigation Scheme, Kenya". Unpublished MSc. Thesis, University Of Nairobi.

Ireri, D. (1986) " Mwea Tebere Irrigated Scheme" An Issue Paper Prepared For An Agricultural Sector Planning And Management Course. Institute Of Development Studies, University Of Nairobi.

Jaetzold, R. and Schmidt, H. (1983): Farm Management Hand Book Of Kenya Vol. II/C. Nature Conditions And Farm Management Information; Ministry Of Agriculture, Nairobi, Kenya.

Johl, S.S. And Kapur, T.R. (1973). Fundamentals Of Farm Business Management. Kalyani Publishers, Ludhiana, New Delhi.

Kalders, J. (1984). " Yatta Canal Rehabilitation Proposal". Ministry Of Agriculture, Irrigation Section, Government Printers, Nairobi.

Kange, M.C. (1980): "Optimal Farm Plan For Small Holdings In Kaloleni, An IADP (Integrated Agricultural Development Programme) Location Of Kilifi District Kenya: Linear Programming Approach". Unpublished MSc. Thesis, University Of Nairobi.

Kamunge, J. (1989): "The Role Of Resource Optimization In Improving Farm Income In Smallscale Irrigation Schemes. A Case Study Of Mitunguu Irrigation Project In Meru District, Kenya". Unpublished, MSc. Thesis, University Of Nairobi.

Kamunge, J.N. And Schemi, W.N. (1988) " Failures Of Rural Development Projects". Proceedings Of A Seminar Held At Naivasha, Kenya, On 28-30th April, 1988. Edited By A.C. Ackello-Ogutu.

Low, A.R.C. (1978) " Linear Programming And The Study Of Peasant Farming Situations". Journal of Agricultural Economics. May, 1978 p. 189-190.

Makanda, D.W. (1984): "The Utilization Of Kenya's Irrigation potential: A Case Study Of Kibirigwi Irrigation Scheme". Unpublished M.A. Thesis, University of Nairobi.

Mbai, J.K. (1984):"Economics Of Pyrethrum Production By Smallholders In Kiambu District". Unpublished MSc. Thesis, University Of Nairobi.

Mukhebi, A.W. (1981): "Income And Employment Generation In Kenyan Small Scale Agriculture". Unpublished Ph.D Thesis, Washington State University, USA.

Mukumbu, J.M. (1987): "Determination Of Optimal Enterprise Mix And Allocation Of Resources For West Kano Pilot Scheme". Unpublished MSc. Thesis, University Of Nairobi.

Muriithi N.G. (1979): "Factors Influencing Farm Income In Marginal Areas Of The Lower Cotton Zone Of Eastern Kenya: Machakos, Embu And Kitui". Unpublished MSc. Thesis, University Of Nairobi.

Norman, D.W. (1973): African Rural Employment Study: "Economic Analysis Of Agricultural Production And Labour Utilization Among The Hausa In The North of Nigeria." Department Of Agricultural Economics, Michigan State University, East Lausing, Michigan.

Pandey, K. and Kaushal, K. (1980): "Prospects Of Increasing Farm Income In Small Farms Of Ambula District (Haryana)". Indian Journal Of Agricultural Economics. Vol 35, No.3.

Palufikof, J. (1981): The Development Of Kenya's Semi-arid Lands; "Irrigation In Kenya With Special References To The Dry Areas". Institute Of Development Studies, University Of Nairobi. Edited By Campbell, D And Migot, S.E.

Republic Of Kenya (1977): Integrated Rural Survey. Ministry Of Planning And National Development. Government Printers, Nairobi.

Republic Of Kenya (1978): " Upper Tana Catchments. Development Potential Of The Yatta Canal: Preliminary Study". Ministry Of Water Development, Government Printers, Nairobi.

Republic Of Kenya (1979): Development Plan 1979-1983. Ministry Of Planning And National Development. Government Printers, Nairobi.

Republic Of Kenya (1983): Development Plan 1984-1988. Ministry Of Planning And National Development. Government Printers, Nairobi.

Republic Of Kenya (1985): Statistical Abstract Central Bureau Of Statistics, Ministry of National Development, Government Printers, Nairobi.

Republic Of Kenya (1986) Sessional paper No. 1 of 1986 On Economic Management For Renewed Growth. Ministry Of Planning And National Development, Government Printers, Nairobi

Republic Of Kenya (1988): Development Plan 1989-1993, Ministry Of Planning And National Development, Government Printers, Nairobi.

Republic Of Kenya (1990a): " Ndalani And Yatta Canal Rehabilitation Proposal". Ministry Of Water Development, Government Printers, Nairobi.

Republic Of Kenya (1990b): Economic Survey 1990, Central Bureau Of Statistics, Ministry Of Planning And National Development, Government Printers, Nairobi.

Small, L.E. (1982): "Irrigation And Human Welfare"; International Agricultural And Food Workshop Report , Cook College, Rutgers University, New Brunswick New Jersey.

Stewart J.D. (1961): "A Study In The Application Of Linear Programming To An Oxfordshire Farm". University Of Reading, Department of Agricultural Economics, Miscellaneous Studies No.21.

Upton, M. (1987): African Farm Management: Cambridge University Press, Cambridge.

World Bank Sector Report (1990): "Kenya Agricultural Growth, Prospects, and Strategy Options". World Bank Sector Report Vol. 1. Agricultural Operations Division, Eastern Africa Department, Nairobi, Kenya.

APPENDIX 1

QUESTIONNAIRE

(A) IDENTIFICATION:

1. Farmer's name.....................................

2. Location...

3. Enumerator's name...............................

4. Date of survey..................................

5. Type of farm ownership (Permanent or Leased)

....

(b) BACKGROUND INFORMATION

6. What is the total size of your farm (acres).....

7. What size was actually farmed under irrigation during last year's cropping season i.e. 1989/1990 cropping season starting October 1989 and ending September 1990 (acres)

   ....

8. What size was farmed during last year's cropping season but not under irrigation..................

9. What is the maximum area in acres, that can be allowed for irrigation farming....................

10. Do you own any other farm anywhere else (Yes/No)

11. How big is that other farm (acres).............

12. How is that farm utilized......................

13. At what level of education did you reach at school.

(C) ENTERPRISES: (Fill answers to Question 14 in the space below it).

14(i) What crops and/or crop mixtures did you have in the irrigated portion during last year's cropping season?

(ii) What was the acreage for each of these enterprises?

(iii) When did you plant each of the enterprises?

(iv) What yields were realized for each enterprise and what was the price per unit for each?

Crop or crop mixture	Area (Acres)	Amount of seed or No. of plants	Planting Date	Harvesting Period (Time of month)	Yield Harvested	Amount Sold	Prices

15) What crops or crop mixtures did you grow in the unirrigated portion during last year's cropping season.

(i) First season - October/January rains

(ii) Second season - March/May rains

Crop or crop Mixture	Area (Acres)	Yield Harv.	Amount Sold or	Amount for home	Amount retained as seed

(i) (First season)

....

....

(ii) (Second season)

....

....

(C) ENTERPRISE INPUTS (Use the space below Q.15 for information on fertilizer)

15(i) What types of fertilizer did you use during last year's cropping season in the various crop enterprises in your farm?

(ii) In what amounts did you apply each of the fertilizers types to the various enterprises.

(iii) What was the price of each of the fertilizer type.

a) Irrigated enterprises (crops & crop mixtures	Fertilizer name	Amount applied (specify units)	Price per unit (Kshs)	Total cost (Kshs)

....

....

....

b) First season un-irrigated enterprises

....

....

c) Second season un-irrigated enterprises

....

....

....

(16) Did you buy manure in any of last year's crop enterprises? Yes/No. If yes give the details here below:

(a) Irrigated enterprise	Amount of bought	Price/ unit	Total cost

applied

....
....
....

(b) First season unirrigated enterprises

....
....
....

(c) Second season unirrigated enterprises

....
....
....

17) What types of pesticides did you use in the various crop and/or crop mixtures during last year's cropping season. (Give the details here below)

(a) Irrigated enterprises (crops or and crop mixture	Pesticide name	Amount applied (specify units)	Price unit (Kshs)	Total cost (Kshs)

....
....
....

(b) 1st season unirrigated enterprises

....
....
....

(c) 2nd season unirrigated enterprises

....
....
....

(18) For which of the various crops and crop mixtures

grown during last year's growing season did you buy seeds? (Give the details here below).

a) Irrigated crop or crop mixture	Amount of Seed used (specify units)	Price per unit (Kshs)	Total cost (Kshs.)
....	....	....	....
....	....	....	....
....	....	....	....
b) 1st season unirrigated crop/crop mixture			
....	....	....	....
....	....	....	....
....	....	....	....
c) 2nd season unirrigated crop/crop mixture			
....	....	....	....
....	....	....	....
....	....	....	....

19) For which of the various crop or/and crop mixtures did you use a tractor, oxen or casual labourer for land preparation? Give the details here below.

(i) Tractor use	Enterprises	Area	Total cost
....	....	....	....
....	....	....	....
....	....	....	....
ii) Oxen use	Enterprises	Area	Total cost
....	....	....	....
....	....	....	....
....	....	....	....
iii) Casual labour	Enterprises	Area	Total cost
....	....	....	....
....	....	....	....

(E) <u>LIVESTOCK:</u>

(E) LIVESTOCK:

20(i) State the livestock heads you owned last year 1989/90

....

(ii) What were the feed costs per month (Kshs)............

(iii) What were the veterinary drugs cost

drugs and dipping costs) per month Kshs

drugs per month.................

dipping per month.............

(iv) How many manhours are spent on livestock per day

....

(v) During which months last year were you milking your

cows...

(vi) What was the average milk production per day (tree top

bottles)...

(vii) How much was consumed at home........................

(viii) How much was sold...................................

(ix) What was the average price per bottle

(Kshs)................................

(F) OTHER ACTIVITIES:

21. Apart from farming, are you involved in any other

money making activity? Yes/No, Give details here below:

Activity	Months of earning	Amount per month	Total per year
....			
....			

22(i) Did you obtain credit either in kind or in cash in farming during last year's cropping? Yes/No.

(ii) If yes, from where................

(iii) How much was the value (cash/kind) or your borrowing? Kshs.............

(iv) For what purpose did you borrow?...............

23)(i) Do you plan to get any (more) loans in future? Yes/No.

(ii) If no, why not...........................

(H) <u>LABOUR AVAILABILITY:</u>

24) Who among the family members are available for farm work and for how long? (Give details here below).

Member	Age	Number	Period available for farm work (months)	Number of hours worked/ day	Number of days worked/ week	Type of work
Husband wife (wives)						
Children (i) > 7 < 14						
(ii) > 14						
Other relatives						

(ii) > 7 < 14

(iii) > 14 < 64

(iii)> 64

---

(25)(i) How many permanent labourers did you employ during last year's cropping season...........

(ii) What specific duties are the permanent labourers Meant to do?............

(26)(i) Did you employ casual labourers?

Yes/No.

(ii) If yes during which months and for which operations?

(iii) How many days do they work per month

(iv) How many hours do they work per day?

(v) How much are casuals paid per day?

Kshs......................

Month	Operation	No. of Labourers	No. of Hours worked/ day	No. of Days worked/ month	Amount Paid (Kshs)	Total Amount paid
....	....	....	....	....	....	....
....	....	....	....	....	....	....
....	....	....	....	....	....	....

(I) <u>FARM OPERATIONS AND LABOUR UTILIZATION:</u>

27(i) When did you do the following operations (nursery establishment and management, land preparation, manuring, planting/fertilizer application, weeding, spraying/dusting, harvesting/grading/packing) on the farm for the various crop enterprises grown last year?

(ii) Approximately how long in days, does it take a man working 5 hrs per day to do the following operations on one ACRE of enterprises?

Enterprise	Operation	Date of operation (month)	Days required for the operation per acre of enterprise.
....	....	....	....
....	....	....	....
....	....	....	....

J: <u>IRRIGATION PRACTICES:</u>

(28) (i) What is the frequency of water application in the dry months for each enterprise?

(ii) What is the frequency of application in the wet months for each enterprise?

(iii) Approximately how many hours would a man working 5 hrs per day take to irrigate one acre of cropped area?

Enterprise	Frequency of water application in dry months	Frequency of water application in wet months	Hours required to irrigate per acre

....
....
....

(K) <u>ESTABLISHMENT COST FOR IRRIGATED PERENNIAL CROPS OR CROP MIXTURES</u>

(29) (i) When were the various perennial crops established?
....

(ii) When did you start harvesting?

(iii) What was the planting hired labour cost?
(iv) What was the seed/seedlings cost?

(v) Before the crop started yielding

(a) what were the yearly fertilizer costs?

(b) What were the yearly manure costs?

(c) What were the yearly protection chemicals costs?

and (d) what were the yearly hired labour charges?.

Crop or/and crop mixture	Planting date	Start of harvesting date	Planting labour costs	Seed/ seedling costs	Yearly ferti-lizer costs	Yearly manure costs	Yearly chemicals costs	Yearly hired casuals labour costs

....
....
....
....
....

(L) <u>SUBSISTENCE REQUIREMENTS:</u>

30 (i) How do you meet your family's subsistence food requirements? (tick correct answer).

a) Produce enough food from your farm

b) Produce some food then buy what remains

c) Produce cash crops sell them and buy food.

(ii) In the case where you supplement the family food supplies with some purchases, during which months do you have to buy food?................

(iii) How many bags of maize and beans does your family consume per 6 months season?

Maize bags.............

Bean bags..............

(iv) What other food stuff does your family use and at what rates?

Food stuff	Weekly rate	Cost
....	....	....
....	....	....
....	....	....

(M) COMPULSORY ENTERPRISES

(31) (i) Are there some crops/crop mixtures that must be grown each year in your irrigated plots (yes/no).

(ii) If yes, list them in the table here below showing the minimum area for each of them, and the time during the year it has to be planted. (On the minimum area choose among 0.125, 0.25, 0.5 and

1 acres categories);

Compulsory crops or crop mixtures	Minimum area	Time when the compulsory crop has to be planted

....

....

....

(N) PROBLEMS AND COMMENTS:

32(i) What are the major problems you have been facing in relation to irrigation farming (i.e. in regard to labour, input acquisition, credit (working capital, marketing, extension and such others).

....

....

....

(ii) What are your suggested solutions to these problems?.

....

....

APPENDIX 2 CALENDAR OF OPERATIONS

		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
KARELLA (A-1st Season)	A	IR X4 SP X1 HV X8 WD X1	IR X4 SP X1 HV X8 WD X1	IR X2 HV X4					L/P	CC PL IR X8	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 STK	IR X4 SP X1 HV X8 WD X1
KARELLA (B-2nd Season)	B			L/P	CC PL IR X4	IR X4 WD X1 SP X2	IR X8 WD X1 SP 2 STK	IR X4 WD X1 SP X2 HV X8	IR X8 WD X1 SP X1 HV X8	IR X8 WD X1 SP X1 HV X8	IR X1 HV X4		
DUTHI	A	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4					L/P	CC PL IR X4	IR X8 WD X1 SP X2	IR X4 WD X1 SP X2 STK
DUTHI	B				L/P	CC PL IR X4	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 STK	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4	
TULIA	A	IR X8 SP X2 WD X1	IR X8 SP X2 WD X1 STK	IR X8 SP X2 WD X HV X8	IR X4 SP X2 WD X1 HV X8	IR X4 SP X2 WD X1 HV X8	IR X4 HV X4					L/P	CC PL IR X4
TULIA	B	IR X4 HV X4					L/P	CC PL IR X4	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 STK	IR X8 WD X1 SP X2 HV X8	IR X4 WD X2 SP X2 HV X8	IR X4 WD X2 SP X2 HV X8
VALORE	A	IR X8 WD X1 SP X2 HV X8	IR X8 WD X1 SP X2 HV X8	IR X4 HV X4					L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X2 SP X2 STK	IR X4 WD X2 SP X2 HV X8
VALORE	B			L/P	CC PL IR X4	IR X4 WD X2 SP X2	IR X8 WD X1 SP X2 STK	IR X8 WD X1 SP X2 HV X8	IR X8 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4		

		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
OKRA	A	IR X4 HV X4						L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X8 WD X1 SP X2	IR X4 WD X2 SP X2 HV X8	IR X4 WD X2 SP X2 HV X8
OKRA	B				L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 HV X8	IR X8 WD X1 SP X2 HV X8	IR X4 HV X4		
CHILLIES	A	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4						N/E	CC T/PL IR X4	IR X4 WD X2 SP X2
CHILLIES	B					N/E L/P	CC T/PL IR X8	IR X8 WD X2 SP X2	IR X8 WD X1 SP X2	IR X8 WD X1 SP X2 HV X8	IR X8 WD X1 SP X2 HV X8	IR X4 HV X4	
F/BEANS	A4	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X2 HV X4								L/P
"	A5	L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4							
"	B1		L/P	CC PL IR X8	IR X4 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4						
"	B2						L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X2 HV X4		
"	B3							L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X2 HV X4	

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
F/BEANS A1								L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X4 WD X1 SP X2 HV X8	IR X2 HV X4
" A2	IR X8 WD X1 SP X2 HV X8	IR X4 HV X4								L/P	CC PL IR X4	IR X4 WD X2 SP X2
" A3	IR X8 WD X2 SP X2	IR X8 WD X1 SP X2 HV X8	IR X2 HV X4								L/P	CC PL IR X4
BRINJALS A	IR X4 WD X1 SP X2	IR X4 WD X1 SP X2 HV X4	IR X4 WD X1 SP X2 HV X8	IR X4 WD X2 SP X2 HV X8	IR X2 HV X4			N/E L/P	CC T/PL IR X8	IR X8 WD X2 SP X2	IR X8 WD X2 SP X2	IR X4 WD X2 SP X2
BRINJALS B		N/E L/P	CC T/PL IR X8	IR X4 WD X2 SP X2	IR X4 WD X2 SP X2	IR X4 WD X1 SP X2	IR X4 WD X1 SP X2	IR X4 WD X1 SP X2	IR X4 WD X1 SP X2 HV X 4	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X2 HV X4
ONION A	IR X8 WD X1 SP X1	IR X8 WD X1 SP X1	HV							N/E L/P	CC T/PL	IR X4 WD X2 SP X2
ONION B				N/E L/P	CC T/PL IR X4	IR X8 WD X2 SP X2	IR X8 WD X2 SP X2	IR X8 WD X2 SP X1	IR X2 HV			
C/K A	IR X8 WD X2 SP/DS HV(K)X8	IR X8 WD X1 SP/DS HV(K)X8	IR X4 HV (K)X8 HV (C)							N/E L/P	CC T/PL IR X8	IR X4 WD X2 SP/DS
C/K B					N/E L/P	CC T/PL IR X8	IR X8 WD X2 SP/DS	IR X8 WD X2 SP/DS HV(K)X4	IR X8 WD X1 SP/ DS HV(K)X8	IR X4 HV(K)X8 HV(C)		

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
TOMATO A	IR X8 WD X2 SP X2 STK	IR X8 WD X1 SP X2 HV X4	IR X8 WD X1 SP X2 HV X8	HV X4						N/E L/P	CC T/PL IR X4	IR X4 WD X2 SP X2
TOMATO B				N/E L/P	CC T/PL IR X4	IR X8 WD X2 SP X2	IR X8 WD X2 SP X2 STK	IR X8 WD X1 SP X2 HV X4	IR X8 WD X1 SP X2 HV X8	IR X4 HV X4		
TURWEL	IR X4 WD X1 SP X2 HV X8	IR X4 WD X1 SP X2 HV X8	IR X4 HV X4	L/P	CC PL	IR X4 WD X2 IR X4	IR X4 WD X2	IR X4 WD X1	IR X4 WD X1 SP X1	IR X4 WD X1 SP X2 HV X4	IR X4 WD X1 SP X2 HV X4	IR X2 WD X1 SP X2 HV X8
CHOLA A	IR X4 WD X1 SP X2	IR X8 SP X2 HV X8	IR X4 HV X8							L/P	CC PL IR X4	IR X4 WD X2 SP X2
CHOLA B					L/P	CC PL IR X8	IR X8 WD X2 SP X2	IR X8 WD X1 SP X2 HV X8	IR X8 SP X2	IR X4 HV X8		
MAIZE A/B	WD 1	HV 1	HV 1 L/P 2 PL 2	PL 2 WD 2	WD 2	WD 2	HV 2	HV 2		L/P 1 PL 1	PL 1 WD 1	WD 1
BEANS A/B	HV 1	HV 1	L/P 2 PL 2	PL 2 WD 2	WD 2	HV 2	HV 2			L/P 1 PL 1	PL 1 WD 1	WD 1
PIGEON PEAS	WD			WD	WD			HV	HV	L/P PL	L/P PL	WD

WHERE:
- N/E REPRESENTS NURSERY ESTABLISHMENT.
- L/P REPRESENTS LAND PREPARATION.
- T/PL REPRESENTS TRANSPLANTING.
- PL REPRESENTS PLANTING.
- CC REPRESENTS CANAL CLEARING.
- IR REPRESENTS IRRIGATION.
- WD REPRESENTS WEEDING.
- SP REPRESENTS SPRAYING; and DS REPRESENTS DUSTING CHEMICALS.
- STK REPRESENTS STAKING.
- HV REPRESENTS HARVESTING.
- C/K REPRESENTS CABBAGE OR/AND KALE.
- X MULTIPLICATION SIGN AND INDICATES THE NUMBER OF TIMES AN OPERATION IS DONE.

APPENDIX 3

THE VALUE AT WHICH A NONBASIC VARIABLE ENTERS THE SOLUTION FOR THE VARIOUS OPTIMAL FARM PLANS

VARIABLE	CURRENT VALUE	ENTERING VALUE GFM 1	GFM 2	GFM 3	KRFM 1	KRFM 2	KRFM 3	F/BFM	KLFM 1	KLFM 2
KARELLA A	50364	52212.71	53264.23	53629.83		102187.7		136876.1	53629.77	77142.16
KARELLA B	50364	53360.95	56654.38	56980.17	110931.4			136876.1	56980.23	81461.3
DUTHI A	30604	43344.42	45438.42	45508.57	61669.39	62730.21	66878.15	66878.15	45508.57	51722.34
DUTHI B	30604	45950.20	42414.76	42417.27	56419.41	57323.32	66878.14	66878.15	42417.27	53951.92
TULIA A	30687	38663.27	46023.84	46174.60	59734.55	60679.6	62268.5	62268.49	46174.64	45707.03
TULIA B	30687	46547.77	41809.39	41767.72	53492.45	54250.93	62268.5	62268.5	41767.67	53140.13
VALORE A	45202				55467.25	56314.85	64662.46	64662.46		51487.95
VALORE B	45202				61957.38	62998.95	64662.46	64662.46		53890.7
CHOLA A	12764	51972.31	52181.41	51851.29	63837.84	64787.07	52845.46	52845.45	51851.32	59825.65
CHOLA B	12764	56336.60	40995.05	40592.26	47509.17	47970.37	52845.45	52845.45	40592.27	62112.36
OKRA A	41619	47880.84	44840.80	45334.99	89725.34	92467.84	133947.3	133947.3	45334.83	71462.81
OKRA B	41619		51219.27	51866.71	99005.81	102025.7	133947.3	133947.3	51866.73	65673.84
F/BEANS A4	20959	58589.99	68732	69124.72	143008.2	147795.7	169945.9	20959.01	69124.73	97636.73
F/BEANS A5	20959	52256.85	59403.89	60025.89	130999.4	135428	169945.9	20959.01	60025.88	88540.09
F/BEANS B1	20959	48862.59	60768.56	61466.97	127485.6	131809.2	169945.9		61467.09	83519.63
F/BEANS B2	20959	56743.51	56722.52	57218.50	121863.6	126019.1	169945.9	20959	57218.45	91499.83
F/BEANS B3	20959	71233.81	57368.19	57450.97	121863.6	126019.1	169945.9	20959	57450.98	107721.5
F/BEANS A1	20959	57723.18	50126.21	50608.34	112583.1	116461.4	169945.9	20959	50608.26	91816.95
F/BEANS A2	20959	51250.44	52727.23	53415.10	112583.1	116461.4	169945.9		53415.08	82323.7
F/BEANS A3	20959	50732.11	62536.70	63172.35	125666.7	129935.9	169945.9	20959.01	63172.28	84500.63
BRINJALS A	34104	49979.65	47876.08	47830.88	67561.52	68942.52	78338.6	78338.61	47830.93	61785.33
BRINJALS B	34104	47936	46853.50	46878.06	69566.43	71007.34	78338.661	78338.61	46878.6	60210.53
ONIONS A	27409	45922.66	45172.23	45283.58	66655.16	68042.66	81012.71	81012.71	45283.55	57535
ONIONS B	27409	35454.79	43843.30	44254.97	65394.33	66744.17	81012.72	81012.71	44254.98	45694.55
KALES A	26170	41512.14	41466.86	41564.73	51919.72	52636.47	62688.71	62688.71		27734.73
KALES B	26170	39538.47	41567.06	41719.83	53759.28	54531.01	62688.71	62688.72	26325.07	
CABBAGE A	38227									
CABBAGE B	38227									
TOMATOES A	31205	59693.99	63080.46	62760.52	94741.08	97022	85304.02	85304.03	62760.58	
TOMATOES B	31205	63518.75	45669.47	45314.22	68119.16	69604.36	85304.02	85304.02	45314.27	
IRR. P/PEAS	32782	47359.63	50897.31	50757.72	60669.38	61569.21	56449.13	56449.13	50757.75	53050.12
MAIZE A	2626	7586.559	7268.284	7334.843	14470.62	15173.65	21520.2	21520.2	7334.849	11033.89
MAIZE B	2440	3959.993	4956.455	5018.762	12141.85	12354.6	15660.5	15660.5	5018.756	8112.495
BEANS A	4518	6535.564	6628.221	6677.101	10228.18	10736.37	16108.31	16108.31	6677.086	8380.635
BEANS B	3757	4854.598	5821.35	5864.709	14326.3	14617.3	16691.94	16691.94	5864.71	9660.411
P/PEAS	5661			5789.135			14145.17	14145.17	5789.127	
MAIZE+BEANS+ P/PEAS	8610	9541.743								
MAIZE+BEANS A	5997					6279.009	8175.127	8175.127		
MAIZE+BEANS B	3977	4074.215	4948.664	4977.981	10871.85	11000.22	11967.69	11967.68	4977.972	7532.847
MAIZE+P/PEAS	8173									8182.232
T/CHILLIES A	41329	52156.23	54087.20	53932.93	76383.38	77987.85	75142.41	75142.42	53933	65163.9
T/CHILLIES B	41329	57586.06	44041.91	43776.86	61666.91	62831.55	75142.41	75142.41	43776.84	69019.9
B/CHILLIES A	49973	55604.08	58020.72	58114.38	100904.9	103787.6	118513.9	118513.9	58114.41	79247.87
B/CHILLIES B	49973	60115.06			89206.17	91739.13	118513.9	118513.9		82566.9
L/CHILLIES A	36193	51489.16	53178.47	53065.46	76037.88	77659.57	77332.64	77332.63	53065.49	64675.39
L/CHILLIES A	36193	56390.32	44282.43	44068.50	63057.62	64291.35	77332.63	77332.61	44068.54	68222.46
L/H/JANUARY	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/FEBRUARY	-3.33			1.4485	26.92477	28.26255	4240369	42.40369	1.448416	16.0046
L/H/MARCH	-3.33				6.255561	6.975582	42.40369	42.4037	-	0.3477783
L/H/APRIL	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/MAY	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/JUNE	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/JULY	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/AUGUST	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/SEPTEMBER	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/OCTOBER	-3.33			5.8204	26.92477	28.26255	42.40369	42.40369	5.820314	[illegible]
L/H/NOVEMBER	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097426	16.00459
L/H/DECEMBER	-3.33			6.0974	26.92477	28.26255	42.40369	42.40369	6.097532	16.00459

WHERE:

GFM	REPRESENTS	GENERAL FARM MODEL
KRFM	"	KARELLA FARM MODEL
F/BFM	"	FRENCH BEANS FARM MODEL
KLFM	"	KALE FARM MODEL
T/CHILLIES	"	THIN CHILLIES
B/CHILLIES	"	BULLET CHILLIES
L/CHILLIES	"	LONG CHILLIES
L/H/	"	LABOUR HIRING
P/PEAS	"	PIGEON PEAS
A	"	FIRST SEASON
B	"	SECOND SEASON

APPENDIX 4

SLACK AND SURPLUS; GENERAL FARM MODEL 1:

CONSTRAINT		RESOURCE	TYPE
September	Labour	28.[illegible]	Slack
April	Labour	562.4964	Slack
May	Labour	237.1272	Slack
June	Labour	238.3456	Slack
August	Labour	258.2395	Slack
November	Labour	41.0170	Slack
December	Labour	114.8659	Slack
July	Labour	100.6576	Slack
Unirr.L. 2nd season		.2128227	Slack

Where

Unirr.L. Represents Unirrigated Land.

APPENDIX 5

SLACK AND SURPLUS;GENERAL FARM MODEL 2

CONSTRAINT		RESOURCE	TYPE
January	Labour	101.8639	Slack
April	Labour	327.5183	Slack
May	Labour	328.6285	Slack
June	Labour	204.8906	Slack
July	Labour	150.3764	Slack
August	Labour	331.0607	Slack
September	Labour	69.19198	Slack
November	Labour	50.23249	Slack
December	Labour	1.322098	Slack

APPENDIX 6

SLACK AND SURPLUS: GENERAL FARM MODEL 3

CONSTRAINT		RESOURCE	TYPE
January	Labour	[illegible]	Slack
April	Labour	345.9026	Slack
May	Labour	335.8448	Slack
June	Labour	231.7626	Slack
July	Labour	224.3752	Slack
August	Labour	384.8132	Slack
September	Labour	74.70995	Slack
November	Labour	59.09681	Slack
December	Labour	34.11283	Slack

APPENDIX 7

RANGE OF FEASIBILITY FOR THE BASIC VARIABLES FOR GENERAL FARM MODELS' 1, 2 AND 3

		GENERAL FARM MODEL 1		GENERAL FARM MODEL 2		GENERAL FARM MODEL 3	
VARIABLE	CURRENT VALUE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
(IRRIGATED ENTERPRISES)							
CABBAGE A	38227	33603.65	39110.67	36632.89	41294.96	37206.79	41151.22
VALORE A	45202	44318.33	50938.52	42388.56	46796.11	42277.78	46222.22
CABBAGE B	38227	37582.88	38486.73	37816.39	39519.18	38032.73	39974.62
VALORE B	45202	44933.66	45743.95	43925.75	45424.58	43483.74	45297.83
OKRA B	41619	38202.38	49618.38				
BULLET CHILIIES B	49973			49486.95	60771.40	49783.89	56078.92
(UNIRRIGATED ENTERPRISES)							
MAIZE + BEANS A	5997	5818.812	6307.373	3886.779	6956.742	33837.9	6997.98
MAIZE + P/PEAS	8173	8028.924	8801.581	7972.786	9008.354	8044.865	4.10475E+09
P/PEAS	5661	4985.607	5807.08	4825.646	5861.241		
MAIZE+BEANS+P/PEAS	8610			-1391757	10314.89	-1391814	10324.67
L/HIRING MARCH	-3.33					-3.836985	-3.0448

Note: The figures in Appendix 7 show how much a value can vary without changing the solution.

APPENDIX 8

RANGE OF FEASIBILITY FOR THE CONSTRAINTS FOR GENERAL FARM MODELS' 1, 2 AND 3

		GENERAL FARM MODEL 1		GENERAL FARM MODEL 2		GENERAL FARM MODEL 3	
CONSTRAINT	UNITS OF RESOURCE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
JANUARY LABOUR	577	523.2107	634.7631	475.1361	1E+38	441.56	1E+38
FEBRUARY LABOUR	536	467.2479	577.1937	458.8863	537.3361	487.8601	569.0107
MARCH LABOUR	577	274.8385	623.0788	571.6015	686.0398	490.1346	687.5555
APRIL LABOUR	797	234.5036	1E+38	469.4817	1E+38	451.0974	1E+38
MAY LABOUR	577	339.8728	1E+38	248.3715	1E+38	241.1552	1E+38
JUNE LABOUR	577	338.6544	1E+38	372.1094	1E+38	345.2374	1E+38
JULY LABOUR	577	476.3424	1E+38	426.6237	1E+38	352.6248	1E+38
AUGUST LABOUR	906	647.7605	1E+38	5749393	1E+38	521.1868	1E+38
SEPTEMBER LABOUR	577	548.4335	1E+38	507.808	1E+38	502.29	1E+38
OCTOBER LABOUR	577	543.2275	584.7565	573.5128	619.0173	562.1559	610.3076
NOVEMBER LABOUR	577	535.983	1E+38	526.7675	1E+38	517.9032	1E+38
DECEMBER LABOUR	797	682.1341	1E+38	795.6779	1E+38	762.8872	1E+38
CAPITAL	4561	3995.594	4730.711	4196.098	4591.285	4271.738	4929.15
UNIRR. LAND A	1.34	1.268487	1.681581	1.17	1.344425	1.17	1.469613
UNIRR. LAND B	1.17	0.9571773	1E+38	1.15648	1.34	0.9770833	1.34
IRR. LAND A	0.5	0.4786391	0.6458663	0.3942582	0.5380939	0.3731532	0.582672
IRR. LAND B	0.5	0.4815007	0.553751	0.3168699	0.5180097	0.2925624	0.5346559
SUBSISTENCE REQ.	0.75			0.7421905	0.9804581	0.5570833	1.206451

WHERE

UNIRR. REPRESENTS UNIRRIGATED; IRR. REPRESENTS IRRIGATED;

A " FIRST SEASON; B " SECOND SEASON; REQ. REPRESENTS REQUIREMENT.

Note: The figures in the Appendix 8 show the range in which the same variables remain in solution.

APPENDIX 9

SLACK AND SURPLUS;KARELLA FARM MODEL 1

CONSTRAINT		RESOURCE	TYPE
January	Labour	[illegible]	Slack
February	Labour	33.99455	Slack
April	Labour	368.8174	Slack
May	Labour	340.8174	Slack
June	Labour	280.25	Slack
July	Labour	286.6113	Slack
August	Labour	420.8941	Slack
September	Labour	153.5328	Slack
October	Labour	24.7094	Slack
December	Labour	60.83552	Slack
Unirr. L. 1st season		.0896586	Slack

WHERE

Unirr. L. Represents Unirrigated Land

APPENDIX 10

SLACK AND SURPLUS; KARELLA FARM MODEL 2:

CONSTRAINT		RESOURCE	TYPE
January	Labour	196.361	Slack
February	Labour	106.6624	Slack
April	Labour	347.8201	Slack
May	Labour	31.02	Slack
June	Labour	222.45	Slack
July	Labour	219.5365	Slack
August	Labour	430.3669	Slack
September	Labour	153.6805	Slack
October	Labour	63.77311	Slack
November	Labour	147.4366	Slack
December	Labour	168.0201	Slack
Unirr.L.	1st season	.2170849	Slack
Unirr.L.	2nd season	4.708472E-02	Slack

APPENDIX 11

SLACK AND SURPLUS; KARELLA FARM MODEL 3:

CONSTRAINT		RESOURCE	TYPE
January	Labour	270.2029	Slack
February	Labour	158.7328	Slack
April	Labour	344.2401	Slack
May	Labour	327.44	Slack
June	Labour	222.45	Slack
July	Labour	247.07	Slack
August	Labour	382.34	Slack
September	Labour	100.12	Slack
October	Labour	115.0588	Slack
November	Labour	167.8272	Slack
December	Labour	201.4668	Slack
Unirr.L.	1st season	.1700001	Slack
Irr. L.	1st season	.2213724	Slack
March	Labour	15.74622	Slack

Where
Unirr. L. Represents Unirrigated Land
Irr. L " Irrigated Land

APPENDIX 12

RANGE OF FEASIBILITY FOR THE BASIC VARIABLES FOR KARELLA FARM MODELS' 1, 2 AND 3

		KARELLA FARM MODEL 1		KARELLA FARM MODEL 2		KARELLA FARM MODEL 3	
VARIABLE	CURRENT VALUE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
[IRRIGATED ENTERPRISES]							
KARELLA A	50364	-1.0445E+07	99129.28			-1.037E+07	136876.1
KARELLA B	50364			-1.04327E+07	114344.5	-1.037E+07	136876.1
CABBAGE A	38227	33553.2	1E+38	35036.57	1.8285E+11	28042.05	38227
CABBAGE B	38227	24272.72	1.066E+12	25478.74	1.02348E+10	38227	4.375E+11
[UNIRRIGATED ENTERPRISES]							
MAIZE + BEANS A	5997	2828.324	6279.01				
MAIZE + P/PEAS	8173	5967.538	10831.84	5967.542	10340.22	2521.305	5.7496E+11
MAIZE+BEANS+P/PEAS	8610	-1390722	14018.25	-1389132	14287.4	-1380833	15685.97
P/PEAS	5661	5355.98	12553.99	5355.98	6446.095		

Note: The figures in Appendix 12 show how much a value can vary withuot changing the solution.

APPENDIX 13

RANGE OF FEASIBILITY FOR THE CONSTRAINTS FOR KARELLA FARM MODELS' 1, 2 AND 3

		KARELLA FARM MODEL 1		KARELLA FARM MODEL 2		KARELLA FARM MODEL 3	
CONSTRAINT	UNITS OF RESOURCE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
JANUARY LABOUR	577	432.8185	1E+38	380.633	1E+38	306.7371	1E+38
FEBRUARY LABOUR	536	502.0055	1E+38	429.3376	1E+38	377.2672	1E+38
MARCH LABOUR	577	540.3237	617.9296	540.96	597.5237	561.2538	1E+38
APRIL LABOUR	797	428.1826	1E+38	449.1799	1E+38	452.76	1E+38
MAY LABOUR	577	236.1836	1E+38	245.98	1E+38	249.56	1E+38
JUNE LABOUR	577	296.75	1E+38	354.55	1E+38	354.55	1E+38
JULY LABOUR	577	290.3887	1E+38	357.4634	1E+38	329.93	1E+38
AUGUST LABOUR	906	485.1059	1E+38	475.6331	1E+38	523.66	1E+38
SEPTEMBER LABOUR	577	423.4672	1E+38	423.3195	1E+38	476.88	1E+38
OCTOBER LABOUR	577	552.2906	1E+38	513.2269	1E+38	461.9412	1E+38
NOVEMBER LABOUR	577	513.4951	1E+38	429.5634	1E+38	409.1728	1E+38
DECEMBER LABOUR	797	727.1645	1E+38	628.9799	1E+38	595.5331	1E+38
CAPITAL	4561	4504.603	4623.938	4391.103	4592.405	4024.76	4666.279
UNIRR. LAND A	1.34	1.250341	1E+38	1.122915	1E+38	1.17	1E+38
UNIRR. LAND B	1.17	1.027868	1.254554	1.122915	1E+38	0.75	1.227179
IRR. LAND A	0.5	0.482955	0.5152738	0.4914946	0.5626807	0.2786276	1E+38
IRR. LAND B	0.5	0.4790348	0.5187866	0.4895385	0.5565947	0.4649305	0.6786277
SUBSISTENCE REQ.	0.75	0.6658199	0.8439423	0.6490195	0.7968766	0.33	1.184444
KARELLA A	0.1	9.2597E-02	0.1082619			5.011255E-02	0.112671
KARELLA B	0.1			7.7136E-02	0.1036966	3.078092E-02	0.1234425

WHERE
UNIRR. REPRESENTS UNIRRIGATED; IRR. REPRESENTS IRRIGATED:
A REPRESENTS FIRST SEASON B REPRESENTS SECOND SEASON.

Note: The figures given in Appendix 13 show the range in which the same variables remain in solution.

APPENDIX 14

SLACK AND SURPLUS; FRENCH BEANS FARM MODEL:

CONSTRAINT		RESOURCE	TYPE
January	Labour	[illegible]	Slack
February	Labour	63.42578	Slack
April	Labour	281.8401	Slack
May	Labour	338.7252	Slack
June	Labour	394.479	Slack
July	Labour	482.0598	Slack
August	Labour	706.8386	Slack
September	Labour	402.6187	Slack
October	Labour	257.4818	Slack
November	Labour	172.2435	Slack
December	Labour	156.2335	Slack
Unirr. L.	1st season	.1700001	Slack
Irr. L.	1st season	.05712694	Slack
Irr. L	2nd season	.3372635	Slack

APPENDIX 15

SLACK AND SURPLUS; KALE FARM MODEL 1

CONSTRAINT		RESOURCE	TYPE
January	Labour	132.44	Slack
April	Labour	353.5792	Slack
May	Labour	337.6997	Slack
June	Labour	246.9766	Slack
July	Labour	247.2646	Slack
August	Labour	411.0991	Slack
September	Labour	101.1185	Slack
November	Labour	69.27559	Slack
December	Labour	49.27354	Slack

APPENDIX 16

SLACK AND SURPLUS; KALE FARM MODEL 2;

CONSTRAINT		RESOURCE	TYPE
January	Labour	[illegible]	Slack
April	Labour	312.6632	Slack
May	Labour	339.2282	Slack
June	Labour	271.4722	Slack
July	Labour	232.5828	Slack
August	Labour	419.0883	Slack
September	Labour	146.2046	Slack
November	Labour	94.38178	Slack
December	Labour	75.25829	Slack
Unirr. L.	1st season	.02306132	Slack
February	Labour	12.21989	Slack

APPENDIX 17

RANGE OF FEASIBILITY FOR THE BASIC VARIABLES FOR THE FRENCH BEANS FARM MODEL AND THE KALE FARM MODELS' 1 AND 2

		FRENCH BEANS FARM MODEL		KALE FARM MODEL 1		KALE FARM MODEL 2	
VARIABLE	CURRENT VALUE	LOW HIGH	HIGH RANGE	LOW HIGH	HIGH RANGE	LOW RANGE	HIGH RANGE
(IRRIGATED ENTERPRISES)							
CABBAGE A	38227	38227	38227	37206.85	38425.66	36773.11	38267.59
VALORE A	45202			42277.77	45908.82		
F/BEANS A2	20959	20958.99	169945.9				
KALE A	26170			26014.93	41564.71		
KALE B	26170					24605.27	45738.91
TOMATOES A	31205					31164.41	35841.8
CABBAGE B	38227	38227	38227	38032.75	39974.59	38186.41	39680.89
VALORE B	45202			44944.22	45297.82		
F/BEANS B1	20959	20959	169945.9				
TOMATOES B	31205					26568.2	31245.59
B/CHILLIES B	49973			49783.9	50820.21		
(UNIRRIGATED ENTERPRISES)							
MAIZE+BEANS+P/PEAS	8610	-1364173	15685.97	-1389761	10324.67	-1386062	11832.04
MAIZE + BEANS A	5997			3837.914	6997.972	5967.133	6163.104
MAIZE + P/PEAS	8173	2521.305	6.0858E+11	8044.873	5.9494E+08		
P/PEAS	5661					5651.768	5.17455E+10
L/HIRING MARCH	-3.33			-3.836954	-3.044815		
L/HIRING OCTOBER	-3.33					-7.447533	-3.283938

Note: The figures in Appendix 17 show how much a value can vary without changing the solution.

APPENDIX 18

THE RANGE OF FEASIBILITY OF THE CONSTRAINTS FOR THE FRENCH BEANS FARM MODEL AND THE KALE FARM MODELS' 1 AND 2

CONSTRAINT	UNITS OF RESOURCE	FRENCH BEANS FARM MODEL		KALE FARM MODEL 1		KALE FARM MODEL 2	
		LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE	LOW RANGE	HIGH RANGE
JANUARY LABOUR	577	[illegible].0042	1E+38	444.56	1E+38	[illegible]	1E+38
FEBRUARY LABOUR	536	472.5742	1E+38	501.66	583.6816	523.7801	1E+38
MARCH LABOUR	577	425.5687	602.65	516.768	680.1317	514.6932	586.1934
APRIL LABOUR	797	515.1599	1E+38	443.4208	1E+38	484.3369	1E+38
MAY LABOUR	577	238.2748	1E+38	239.3004	1E+38	237.7718	1E+38
JUNE LABOUR	577	182.521	1E+38	330.0234	1E+38	305.5278	1E+38
JULY LABOUR	577	94.94019	1E+38	329.7354	1E+38	344.4172	1E+38
AUGUST LABOUR	906	199.1614	1E+38	494.9009	1E+38	486.9117	1E+38
SEPTEMBER LABOUR	577	174.3813	1E+38	475.8815	1E+38	430.7954	1E+38
OCTOBER LABOUR	577	319.5182	1E+38	564.4271	600.0953	526.5449	584.9186
NOVEMBER LABOUR	577	404.7565	1E+38	507.7244	1E+38	482.6182	1E+38
DECEMBER LABOUR	797	640.7665	1E+38	742.7264	1E+38	721.7417	1E+38
CAPITAL	4561	4372.665	5573.465	4360.427	5059.284	4488.656	4587.369
UNIRR. LAND A	1.34	1.17	1E+38	1.17	1.508333	1.316939	1E+38
UNIRR. LAND B	1.17	1.085902	1.34	0.8952802	1.34	1.091579	1.328017
IRR. LAND A	0.5	0.4428731	1E+38	0.3283152	0.5643071	0.4950263	0.531691
IRR. LAND B	0.5	0.1627365	1E+38	0.2764895	0.5293534	0.4941365	0.5373602
SUBSISTENCE REQ.	0.75	0.3300001	1.243269	0.4752802	1.136612	0.5949584	0.774333
F/BEANS A	0.1	8.5888E-02	0.1758628				
F/BEANS B	0.1	8.3662E-02	0.1943015				
KALES				-0.126152	0.2	6.855E-02	0.1162309
TOMATOES						7.765E-02	0.1035082

Note: The figures given in Appendix 18 show the range in which the same variables remain in solution.