AGROECONOMIC PERFORMANCE OF AGUTHI, MATANYA AND THOME SMALLHOLDER IRRIGATION SCHEMES

BY

PHARES KINYUA RAGWA

BSc. (Hons) Agriculture

University of Nairobi

Thesis Submitted to the University of Nairobi in Partial Fulfilment for a Master of Science degree in Land and Water Management

Faculty of Agriculture

Department of Agricultural Engineering

UNIVERSITY OF NAIROBI

OCTOBER 2002

DECLARATION

I declare that this is my original work and that this thesis has not been submitted for a degree in any other university.

RAGWA P. KINYUA

Signature.....................................

Date: 2/11/02

This thesis was submitted to the University of Nairobi with my permission as the university Supervisor.

Dr. F. N. GICHUKI

DEPARTMENT OF AGRICULTURAL ENGINEERING

UNIVERSITY OF NAIROBI

Signature.....................................

Date: 2/11/02

DEDICATION

To my parents

Japhet Ragwa and Evageline Ragwa

For the many sacrifices they made for my sake

and

Idah and Mwenda

For their Patience

ACKNOWLEDGEMENT

I am indebted to the Ministry of Agriculture, Livestock Development and Marketing, my employer, for granting me a two-year study leave to undertake this work. Am also indebted to Smallholder Irrigation and Drainage Project (SIDP) and Swedish Agency for Research Cooperation with Developing Countries (SAREC) for the award of scholarship and provision of research funds respectively.

I extend my special appreciation to Dr. F. N. Gichuki of the Department of Agricultural Engineering, University of Nairobi, for his invaluable guidance and resourcefulness as the supervisor during the project work. Am also grateful to the staff of the Department of Agricultural Engineering for their valuable assistance throughout the period of study at the department. I extend my appreciation to my colleagues at the graduate school for their company and encouragement that made my stay most rewarding; John Gikonyo of Department of Agricultural Engineering/Laikipia Research Programme for his assistance during the data collection and to Sammy Mundati for his assistance on computer use and operations.

Table of Contents **Page**

List of Tables **Page**

List of Figures **Page**

List of Plates

Abbreviations, Symbols and Acronyms

AEZ	Agro-Ecological Zone
Agritex	Department of Agricultural Technical and Extension Services
ASALs	Arid and Semi-arid Lands
Coeff.	Coefficient
CV	Coefficient of Variability
df	Degrees of freedom
EDF	European Development Fund
EIRR	Economic Internal Rate of Return
ET	Evapotranspiration
ET_a	Actual Evapotranspiration (mm/day)
ET_c/Et_{crop}	Crop Evapotranspiration (mm/day)
E_{pan}	Open pan evaporation (mm/day)
ET_m	Maximum Evapotranspiration (mm/day)
ET_o	Reference Crop Evapotranspiration (mm/day)
ET_p	Potential Evapotranspiration
FAO	Food and Agriculture Organisation of the United Nations
F_{cal}	Calculated F-value
Hort.	Horticultural
IDB	Irrigation and Drainage Branch
IIMI	International Irrigation Management Institute
IR	Irrigation Requirement
irr.	Irrigated/irrigation
IRRI	International Rice Research Institute
K_c	Crop coefficient
K_{pan}	Pan coefficient
K_y	Yield Response Factor
LH	Lower Highland
LRP	Laikipia Research Programme
MAZ	Moisture Availlability Zone
MoA	Ministry of Agriculture

MPND	Ministry of Planning and National Development
MS	Mean square
ns	Not significantly different
ODI	Overseas development Institute
R	Effective rainfall (mm)
RDB	Randomised Block Design
r/E_o	Rainfall-Evapotranspiration ratio
SS	Sum of Squares
Std.dev.	Stardard deviation
Y_a	Actual Yield
Y_p	Potential Yield
Y_m	Maximum Yield
<	Less than
>	Greater than

Abstract

The key objectives of smallholder irrigation projects are increasing agricultural production, household incomes, employment generation and ensuring local food security. However, performance of existing projects in line with their objectives is seldom known. This study aimed at assessing the technical and economic performance of Matanya, Thome and Aguthi smallholder irrigation schemes. The first component assessed yield response of maize (hybrid 511) to different levels of irrigation water using 33%, 66% and 100% of the computed irrigation water requirement (IR). The second component assessed agro-economic performance of the schemes with respect to cropping patterns, crop yields, cropping intensities, employment generation and primary sources of food and income by carrying out a field survey on stratified sample households representing the head, middle and tail reaches of the schemes.

The results showed that crop height, percentage cover and grain yield were significantly different for Treatment 1 and non-significantly different for Treatment 2 relative to Treatment 3 at 5% level of significance. Crop height and percentage crop cover were highly correlated with $r = 0.965$, 0.975 and 0.973 at 33%, 66% and 100% IR respectively. Yield response factors (K_y) ranged between 0.77 to 0.85 and 0.11 to 0.17 with means of 0.82 and 0.14 in Treatments 1(33% IR) and 2(66%IR) respectively relative to Treatment 3(100% IR).

Agro-economic performance was found to vary between individual farmers, schemes and scheme sections and skewed in favour of head and middle sections. Differences between scheme sections were attributed to unequitable water allocation that favours head-section farmers. Percentage of total holding size under irrigation generally decreased downstream with a mean of 44.7%, 44.8% and 34.3% for the head, middle and tail scheme sections respectively. Irrigation improved cropping patterns through introduction of horticultural crops which were not grown under rain-fed condition. The farmer-reported mean irrigated maize and bean yields were 1377 kg/ha and 1349 kg/ha. Rain-fed yields were 994kg/ha and 978 kg/ha for maize and beans respectively. Cropping intensities were higher under irrigation than under rain-fed condition with

means of 255.3% and 160.0% respectively.

Majority of sample households relied primarily on irrigation for food with 44%, 40.7% and 38.3% in Matanya, Thome and Aguthi respectively. As a primary source of income, irrigation was second after livestock with 26.8%, 26.6% and 30.0 % of sample households being dependent on irrigation in Matanya, Thome and Aguthi respectively. Thome and Aguthi schemes are commercial-oriented whereas Matanya is subsistence-oriented with 57.8%, 65.5% and 41% of the mean irrigated area per household under horticultural crops respectively.

Although majority of the sample households depended on family labour, irrigation was the major source of employment with 40%, 30.9% and 52% of the sample households allocating hired labour in irrigation-related activities in Matanya, Thome and Aguthi respectively. Poor water management, low levels of agronomic practices and poor marketing organisation were the key factors constraining agro-economic performance.

CHAPTER 1

1.0 INTRODUCTION

1.1 Background Information.

Future growth in crop production in developing countries is the critical prerequisite for progress on food and agricultural issues because crops account for about 80% of all additions to production according to projections for 1980 to 2000 (FAO, 1981). According to this projection expansion of arable land is supposed to provide 25%, increased cropping intensity 15% and increased yields 60% of the additional crop production. Irrigation has a big role to play in achieving these targets as has been demonstrated in many countries in the past. For example the substantial achievement of Indian agriculture over the past four decades has been attributed to irrigation through its contribution in expanding crop production, reducing output instability and providing protection against periodic drought (Pike, 1995). Due to the increasing populations there is need to intensify land and water utilization in order to increase and stabilise agricultural production especially in ASALs (Hillel, 1987). In Africa the need for irrigation arises from the food and agricultural crises that have been characterised by a declining per capita food production while the population continues to grow and the fact that 45% of its land area is too dry for rain-fed crop production while 8% has very variable rainfall condition (FAO, 1987).

In addition to use of fertilizers, better pest and disease management in crops and use of high yielding crop varieties, irrigation is one of the other options for the realisation of the projected production levels especially in countries with little or no new land to bring into cultivation. In this respect, most African governments have recognised irrigation as a means towards food self-sufficiency for their growing populations. Irrigation is also a source of foreign exchange earnings from export crops due to the rising demographic pressure on rain-fed land (FAO,1986).

In Kenya, irrigated agriculture is one of the options that can be employed to increase food production and create employment for the growing population (world Bank, 1986). This is the case especially in rural areas where virtually all the land suitable for rain-fed agriculture is already under cultivation. Irrigation can play a major role in intensification of land use and utilization of the marginal land for agriculture. Even in the traditional arable areas the unreliability of rainfall may necessitate supplementary irrigation in some seasons. The recognition of this potential of irrigation in increasing agricultural production has led to emphasis on irrigation development in the country's agricultural development policy (MPND,1989).

Smallholder irrigation projects have been in the recent past targeted for support because they are thought to be more sustainable in the long-term than large-scale irrigation projects (MPND,1989). In response to this policy framework many smallholder irrigation projects have been developed in different parts of the country with a total hectarage of 1339 as at the year 1990 (IDB, MoA, 1990). The major objectives aimed at in irrigation development are increasing agricultural production, rural household and national incomes, ensuring local food security and employment generation for the rural population.

Although this research focuses on the agro-economic aspects of performance, agro-economic performance is explicitly linked to landuse and water resource management on the irrigation systems (Meinzen-Dick *et al*, 1993) hence these have also been considered in the choice of performance indicators and analysis of the factors affecting scheme performance.

1.2 Justification for the Research.

The performance of smallholder irrigation projects with respect to their stated objectives has not been assessed in many projects and is affected by technical, socio-economic and institutional constraints (Carruthers and Clark, 1983; Meinzen-Dick *et al*, 1993; Tiffen, 1987). It is therefore necessary to assess the extent to which the existing smallholder irrigation projects are meeting their objectives and the factors that affect their performance. This information would be useful in formulating strategies to improve the performance of existing schemes and in planning for future development of other irrigation projects.

This Research focuses on the agro-economic performance of Aguthi, Thome and Matanya smallholder irrigation schemes and the factors that influence their performance.

1.3 Research objectives.

Broad objective

The broad objective was to assess the extent to which Aguthi, Matanya and Thome small-scale irrigation projects have led to increased agricultural production, household incomes, improved local food security and employment creation and the factors affecting their agro-economic performance.

Specific Objectives

1. To assess agronomic performance of maize in terms of yield response to water
2. To assess the economic performance of the projects with respect to agricultural production, household incomes, employment generation and food security in the projects.
3. To assess the factors affecting performance with respect to agronomic practices, irrigation water management and market availability.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Role of Smallholder Irrigation Projects in Development.

Often irrigation is aimed at improving the standards of living of rural communities by stabilising production to improve food security, generate employment, raise household incomes, improve trade and nutrition (FAO, 1987). However, the real position on the performance and profitability, and therefore the contribution of smallholder irrigation projects in development, is not clear despite the emphasis they are given in the development policies of many countries.

Lack of proper monitoring and evaluation of irrigation projects has resulted in poor identification of their impacts. This calls for periodic evaluation of project objectives, and if necessary, re-definition of project objectives based on the evaluation findings (Biswas, 1990). According to IDB, MoA (1990), in Kenya irrigation has only been profitable for non-storable crops especially horticultural crops where these cannot be produced under rain-fed conditions. The report claims that except for rice, irrigation of cereals and pulses is not economically justifiable except for the purpose of ensuring food security.

2.1.1 Increased Agricultural production

Irrigation is one of the options for increased agricultural production especially in ASALs where water is the most limiting factor in crop production. The increased agricultural production under irrigation is brought about by the increased yields per unit of land and the increased cropping intensity (Meinzen-Dick *et al*, 1993). An FAO projection gives the contribution of irrigation to the expansion of crop production as approximately 40% from 105 million ha to 148 million ha for the period 1980 to 2000 with three quarters of the expansion occurring in the Far East countries (FAO, 1981). The important role to be played by irrigation in developing countries is shown in Table 1. Agriculturalists favour irrigation because it tends to enhance yields per unit of land (Carruthers and Clark, 1983). According to Hillel (1980) irrigation can increase the potential productivity of land upto four times that of non-irrigated land through increased yield per season and multiple cropping.

Kamau (1990) reported increased annual cropping intensities from 200% under rain-fed conditions to 250% under irrigation on irrigation schemes in Kiambu district. This was because farmers could practice triple cropping under irrigation whereas only double cropping was possible under rain-fed conditions. Pike (1995) reported higher mean crop yields of 1.9 t/ha in food grain energy equivalents in India under irrigation as compared to 0.8 t/ha under rain-fed farming during the mid-1980s. Introduction of irrigation has significant impacts on traditional cropping patterns that result in greater diversity of crops grown (Casey, 1991). However, Zalla (1987) points out that many EDF-financed irrigation projects in Africa have been performing below their target cropping intensities despite attractive EIRRs as per their design documents. Mbogoh and Nyameino (1988) in a study of irrigation schemes in Baringo district established that increased cropping intensities and higher yields are rarely achieved because only one cropping season is adopted due to water shortage while inadequate use of pesticides results in crop damage by pests and diseases. According to an FAO study in West Africa, paddy rice yields are seldom higher than in unimproved swampland cultivation due to poor agronomic practices. In Madagascar only 100% cropping intensity was realised on irrigation projects planned for two crop seasons due to shortage of irrigation water (FAO, 1986). In addition, a wide variation in yields exists between farms and between schemes owing to the different levels of husbandry practised by the farmers.

Table 1: Importance of irrigation in developing countries

Region	1980		2000 (Projections)	
	Area equipped for irrigation (million ha)	Share of irrigated area in total arable area (%)	Area equipped for irrigation (million ha)	Share of irrigated area in total arable area (%)
90 countries	105.3	14	148	16
Africa	3.7	2	6	2
Far East	67.5	25	98	34
Latin America	13.4	7	19	7
Near East	20.7	23	25	27
Middle-income	34.8	9	46	10
Low-income	70.5	18	102	23

Source: FAO, 1981.

2.1.2 Increased Rural Incomes.

Increasing household incomes is one of the major objectives of smallholder irrigation schemes (Meinzen-Dick *et al*, 1993). Tiffen (1987) has proposed the use of increased incomes that would accrue to the farmers as a criterion for financing irrigation projects because this is one of the most important objectives. Since the informal non-agricultural sector has been unable to expand employment opportunities for rural communities fast enough to raise their incomes, the option for increased rural incomes lies in small-scale agriculture especially smallholder irrigation (Mukhebi, 1981). According to Casey (1991) irrigation enabled introduction of cash crops in Madura, Indonesia, resulting in a change of local economic networks to hierarchical commercial structures that went beyond the local and inter-local markets hence improving the income generating capacity of the community. In a study of pump-fed irrigation systems in Kiambu district, Kamau (1990) found that the annual benefits received by farmers after the production stabilization period were 4 to 13 times that received by farmers without irrigation. These positive incremental benefits were attributed to improved cropping patterns through crop substitution whereby farmers changed to high-value horticultural crops, intensification of land use that resulted in higher cropping intensities and total yield per year and independence from the dictates of weather such that farmers were able to plan their production to suit market demands. Chancellor (1990) argues that the sustainability of irrigation projects is largely dependent on the incomes that accrue to the farm families rather than on the profitability of one or more crop enterprises.

Although increased rural incomes are a goal in smallholder irrigation projects, Schilfgoarde (1994) has given cases where irrigation development has resulted in declining incomes and attributed this to unrealistic yield targets during project designs. Carruthers and Clark (1983) and Zalla (1987) also argue that in some cases project assumptions have been manipulated to make projects appear profitable for political reasons although data on inputs and outputs show otherwise. To quote Carruthers and Clark (1983):

"Irrigation projects, in addition, have many attributes that satisfy the objectives of politicians; particularly a rapid, visible and dramatic impact, and the tendency to be closely associated with a political promoter. Donors of economic aid favour irrigation projects for similar reasons. Engineers enjoy the challenge of designing irrigation schemes..."

2.1.3 Food Security

One of the objectives of smallholder irrigation projects is local food security especially where farmers' incomes are low hence they cannot rely on external sources of food. Irrigation was also one of the strategies that were adopted to stabilise food production in many countries during the 1972/1973 Sahelian drought (Zalla,1887). Casey (1991) found that in Madura - Indonesia, farmers perceived irrigation primarily as a means of ensuring self-sufficiency in food production and engaged in cash crops only after this basic need was met. In a study of irrigation projects in Pakistan, Schilfgoarde (1994) found that the main emphasis on smallholder irrigation projects is ensuring local self-sufficiency in food production.

2.1.4 Employment generation

The increased intensity of production under irrigation results in increased demand for labour and hence employment. Increase in employment of 300% to 400% has been reported by IDB, MoA (1990) in Kenya under horticultural production. Mukhebi (1981) suggests smallholder irrigation as an option for generating employment for the growing rural population in Kenya. Carruthers and Clark (1983) argue that irrigation projects are established to address the widespread and rising unemployment and the resultant poverty in rural areas. According to Eicher et al (1970) there is a strong consensus that significant source of employment in Africa lies in the rural areas particularly small-scale irrigation hence steps should be taken to expand research and development on smallholder irrigation to absorb agricultural labour during slack periods.

2.1.5 Cushioning effects of adverse weather

Variation in weather conditions is a constant cause of fluctuation in crop yields especially in arid and semi-arid areas and irrigation is one means of improving total volume and reliability of agricultural production through water management to suit crop needs e.g. by providing supplementary irrigation to cushion rainfall deficiency (Worthington, 1977). According to Carruthers and Clark (1983) irrigation alleviates constraints of weather brought about by inadequacy and unreliability of rainfall. Stabilization of agricultural production by eliminating the swings in production brought about by wide fluctuation in weather is one of the most important national goals in arid areas (FAO, 1987). Pike (1995) reported that irrigation reduced the coefficient of variation of total agricultural production from 11% to 5% in India especially in low rainfall areas between 1972 and 1985.

2.1.6 Other Benefits

The impacts of irrigation development extend beyond the immediate beneficiaries to the social and economic fabric of the local and national communities. These socio-economic impacts include foreign exchange earnings, drought damage prevention, stabilization of agricultural systems, modernization of rural economies and ensuring national economic efficiency (Carruthers and Clark, 1983). Although the EIRR is the definitive test which decides whether an investment is justified or not consideration for irrigation should go beyond the narrow view of the economics of irrigation and embrace the human and social benefits namely changes in non-irrigated production, employment inside and outside of project areas, reduction of famine relief expenses and beneficial dietary changes (FAO, 1986; FAO, 1987).

2.2 Irrigation development in Kenya.

Kenya is classified among the East and Central African countries in actual or potential difficulty of meeting their populations' food needs although it has sufficient irrigation water to produce significant additional food (FAO, 1987). According to Osoro (1982) irrigation and land reclamation are the only two major alternatives available for any sizeable expansion of Kenya's cultivable land since more than 75% of the country consists of ASALs. The position of irrigation development in Kenya as at 1990 was that 51,401 ha were under irrigation with commercial large-scale irrigation accounting for 45%, centrally-managed irrigation projects 20% and smallholder irrigation projects 35% of the total irrigated area (IDB, MoA, 1990). This position is not likely to have changed significantly because some of the previously existing projects have been abandoned as new ones are developed. The above figures of irrigated area vary from time to time but they are a good indication of the contribution of smallholder irrigation in the country's agricultural sector and development.

Smallholder irrigation projects vary widely in terms of farming intensity and production orientation but a common factor is that they are under the management of the farmers themselves (IDB, MOA, 1990). In Kenya the categories under which the smallholder irrigation projects fall are privately owned, group-based pump-fed and group-based gravity-fed that differ widely in holding sizes, production orientation and the range of crops grown.

2.3 Indicators of Agro-economic Performance

In this research agro-economic performance refers to the extent to which the irrigation schemes realise their objectives with respect to agronomic and economic attributes viz improved agricultural productivity and living standards of the people.

Performance indicators translate goals into quantifiable measures which can be applied for comparison of actual and potential performance. Hoecht (1990) identified five performance indictors for irrigation projects namely productivity, profitability, cost-effectiveness, quality of water delivery and environmental stability. Meinzen-Dick *et al* (1993) uses primary sources of food and income for the farm families and production orientation as indicators of the level of dependence on irrigation and agro-economic performance.

Agro-economic performance of irrigation projects is affected by technical, socio-economic, institutional or a combination of these factors (Meinzen-Dick *et al*, 1993;

Tiffen, 1987; FAO, 1986). These constraints include water delivery, scheme management, inputs availability and availability and access to markets. In order for irrigation projects to achieve increased agricultural production agronomic practices such as better weed control, use of high quality seed varieties, improved disease and pest management and use of appropriate technologies coupled with intensified irrigation extension are therefore a prerequisite (FAO, 1986; Mbogoh and Nyameino, 1988).

2.3.1 Productivity

Productivity is measured in terms of yield per hectare or per unit volume of irrigation water, cropping intensity and ratio of crop damage over the design service area of the scheme (Hoecht, 1990; Meinzen-Dick *et al*, 1993). According to Meizen-Dick *et al* (1993) yield is the most commonly cited indicator of agricultural productivity of irrigation systems. In a study of irrigation schemes in Baringo it was established that increased cropping intensity was rarely achieved as only one cropping season was adopted due to shortage of water. The crop yields were also found to be low due to crop damage by pests and diseases due to lack or inadequate use of crop protection chemicals (Mbogoh and Nyameino, 1988).

2.3.2 Cropping Patterns

Cropping patterns refer to the diversity and sequence of crops grown on a given piece of land in response to the prevailing climatic, edaphic and economic conditions. The composition of the cropping pattern is an important determinant of the economic performance of irrigation systems as it reflects either subsistence or a commercial production system. (Meinzen-Dick *et al*, 1993).

2.3.2 Profitability

Profitability refers to the net income to farm families in monetary terms after deducting the costs of production from the gross income as indicated by the enterprise gross-margins (Mbogoh and Nyameino, 1988; Mbogoh, 1989 and IDB, MoA, 1990). Hoecht (1990) and Meinzen-Dick *et al* (1993) argue that although crop budgets and gross-margins are necessary for the determination of profitability of irrigation they are cumbersome for routine evaluation of performance because of the huge data requirement and their use is practicable only when reliable production records are available. They also tell little about the efficiency of resource use in creating the higher incomes. According to Tiffen (1987) input availability and produce prices are the most important factors that determine the profitability of irrigation projects.

2.3.4 Cost-effectiveness

Cost-effectiveness refers to the extent to which the direct and indirect benefits accruing from irrigation justify the costs of irrigation development. FAO (1987) recommends clear definition of the precise role of irrigation in development and planning of projects to explicitly meet the set objectives as a prerequisite for success and sustainability of irrigation projects. In a study of Kibirigwi irrigation project Otwera (1984) identified uneconomical plot sizes and sub-optimal use of the recommended agronomic practices as the reasons for poor performance.

2.3.5 Quality of Water Delivery

Quality of water delivery refers to the timeliness, rate and equity of water distribution to the farmers' plots. A well planned, designed and constructed distribution system for irrigation should deliver water in the right quantities, rate, right pressure and right time without causing management and operational problems either to the management or farmers (Labye *et al*, 1988; Yoder and Martin, 1985). In a study using Monte Carlo simulation and statistical analysis to predict performance of an irrigation-water-delivery system, Gates and Ahmed (1995) established that the sensitivities to coefficient of variability (CV) in the predicted system performance are low to moderate, moderate to high and high with respect to application efficiency, upstream water supply and channel cross-section respectively. There is therefore need for proper maintenance of irrigation infrastructure and good water management.

A World Bank review of some irrigation projects in Africa established that 83.3 % of the major World Bank funded projects had achieved or came close to most of their targets by the end of the disbursement period whereas other projects recorded low production or were abandoned as a result of poor planning, implementation, operation and maintenance (FAO, 1986). Sagardoy et al (1982) gives weak farmers' organizations and poor management of irrigation projects as the major contributors to poor performance. Inappropriate irrigation technologies were found to contribute to poor performance in Baringo district (Mbogoh and Nyameino, 1988).

2.3.6 Environmental stability

Irrigation development often results in adverse environmental effects by transforming natural ecosystems into anthropogenetic ecosystems. Further investment in irrigation must therefore be examined in the perspective of its full environmental effects (Holy, 1971; Worthington, 1977). Among these effects are rising water tables, crop damage through water-logging and eventual salinization of the soil, creation of new ecological systems e.g. reservoirs, public health impacts characterised by increased disease prevalence and accumulation of chemical pollutants which result in economic losses and environmental deterioration (Bos and Nugteren, 1978; Holy, 1971; Joblin, 1978; Kay, 1986 and Worthington, 1977).

2.3.7 Primary Sources of food

Primary sources of food refer to the sources on which the households depend most of the time. The food could be domestically produced or acquired from outside the household using the household resources. In this study the sources are classified as irrigated agriculture, rain-fed agriculture, livestock and others that includes salaried employment and non-farm activities.

2.3.8 Primary Sources of Income

Primary sources of income refer to the activities on which the households depend for generation of money and capital. In this study these have been classified as in 2.3.7 above.

2.3.9 Production orientation

Production orientation refers to the types of crops to which the farmers give priority both in terms of area under each crop and resource allocation. Where farmers give priority to high-value cash crops like horticultural crops the production orientation is commercial whereas production is subsistence-oriented when emphasis is on food crops especially cereals (Meinzen-Dick *et al*, 1993). Production orientation has a bearing on the profitability and therefore performance of irrigation projects. Depending on the production orientation performance is assessed on the basis of income generation or self-sufficiency in food.

2.4 Crop Water Requirements (ET_c) and Irrigation Water Requirements (IR)

Crop water requirement refers to the depth of water required by a crop or a diversified pattern of crops to meet the evapo-transpiration demand during a given period (Doorenbos and Pruit, 1977). Irrigation water requirement refers to the quantity of water that must be supplied by irrigation to satisfy evapotranspiration, Leaching, crop consumptive use and miscellaneous requirements not provided by stored soil water and precipitation (Joshi *et al*, 1995). When the ET_c is not met the low water potential between the soil and plants results in water stress which limits plant growth. Plant species and varieties differ in the extent to which they are affected by water stress and the effects on growth vary with the level of stress and the physiological stage of crop growth (Carruthers and Clark, 1983). Appendix 1 shows the sensitive growth periods to water deficit for various crops.

2.4.1 Potential Evapotranspiration (ET_p)

Potential evapotranspiration is defined as the level of evapo-transpiration of a healthy crop growing in large fields where water supply is adequate such that the crop water requirements are fully met and growth and development are not restricted (Doorenbos and Kassam, 1979).

2.5.2 Actual Evapotranspiration (ET_a)

Actual evapotranspiration refers to the rate of evapo-transpiration of a crop that is equal to or less than the predicted ET_{crop} as affected by the level of available soil water, salinity, field size or other causes (Doorenbos and Pruit, 1977).

2.4.3 Factors Affecting Crop Water Requirements

Crop water requirement is affected by climatic, soil and cultural factors.

2.4.3.1 Climate

Crop water requirement varies from year to year in response to changes in weather hence adjustment is necessary when ET_{crop} is computed using mean climatic data (Doorenbos and Pruit, 1977). Carruthers and Clark (1983) reported an interaction between climate and plant characteristics in their effect on crop water requirements and this interaction increases in extreme climates e.g. arid zones.

2.4.3.2 Soil factors

Water holding capacity, effective soil volume and soil infiltration rate influence planning, operation and frequency of irrigation because they affect water movement and availability to the crops and therefore govern irrigation operation with respect to depth, duration and frequency (Bos and Nugteren, 1978; Doorenbos and Pruit, 1977 and Carruthers and Clark, 1983). Hillel (1980) points out that in a dynamic system like the soil-water-plant-atmosphere systems, static concepts like field capacity, permanent wilting point and critical moisture are physically meaningless for practical water management purposes because they are based on the assumption that processes in the field bring about static levels of soil-water content or potential. In reality, the amount and rate of water intake depends on the ability of plant roots to absorb water and the ability of the soil to supply water to the roots to meet transpiration requirements.

Soil infiltration rate, relative to the rate of water supply either through rainfall or irrigation, determines the amount of water that enters the root zone and the water economy of plants (Hillel, 1980). Information on the soil infiltration rate as affected by the soil properties, prevailing conditions and the mode of water supply is important for efficient water management in irrigation.

Sandy soils have high infiltration rates and low water holding capacity. They should therefore be irrigated at shot intervals to minimise on the deep percolation losses. Clay soils have low infiltration rates and high water holding capacity. Clay soils can be irrigated at longer intervals but are also susceptible to water logging. Loam soils have moderate infiltration rates and water holding capacity and are well drained. They are therefore better suited for irrigation. The range of maximum infiltration rate for various soil textural classes is shown in table 2.

Table 2: Soil water holding capacity and infiltration rate for different soil textures.

Soil type	Water holding capacity (mm/cm depth)	Maximum rate of water intake (mm/hr)
Very coarse sand	0.4	19 - 25.5
Sand	0.7	12.5 - 19.0
Sandy loams	1.05	12.5
Medium loams	1.60	10.0
Clay loams	1.75	7.5
Clays	1.70	

Source: Carruthers and Clark, 1983.

2.4.3.3 Cultural Practices

Use of fertilizers affect ET_{crop} only slightly as low soil fertility delays attainment of full crop cover. ET_{crop} is lower for low crop populations than for high population due to lower evaporation from drier soil surfaces under low crop population (Doorenbos and Pruit, 1977).

2.5 Yield Response to Water

Evapotranspiration (ET) deficit per se causes only a fractional reduction in crop yield whereas timing of ET deficits results in secondary reduction in yield with ET deficits at critical stages of crop growth causing relatively larger decrease (Barret and Skogerboe, 1978). The effect of water deficits on crop yield is primarily determined by the degree and timing of the deficits with deficit in the early stages of reproductive ontogeny causing the greatest reduction in yield (Goldsworthy and Fisher, 1984; Doorenbos and Pruit, 1977). This calls for water management strategies to manipulate the sequence of ET deficits to minimise yield loss. According to Goldsworthy and Fisher (1984), almost all parameters of crop growth are affected by water stress and there is therefore a need to also study the effect of water stress on crop growth during post seedling establishment period. In a study of water-yield response of a maize-bean intercrop, Lenga and Stewart (1982) also found that maize yield and ET_a were strongly correlated with r =0.95.

Yield response to water can be determined by quantifying crop water requirements, water deficit, maximum and actual yields of crops. When full crop water requirements are not met, water deficit in the crop can develop to a point where growth and yield are affected (Doorenbos and Kassam, 1979).

2.5.1 Potential Yield (Y_p)

Potential yield of a crop is defined as the harvested yield of a high-yielding variety that is well adapted to the growing environment under conditions where water, nutrients, pests, diseases and length of growing period do not limit yield (Doorenbos and Kassam, 1979). Potential yield is a function of the crop genetic potential and degree of adaptation to the prevailing environment hence is affected by crop variety, climatic factors, length of the total growing period and soil conditions.

2.5.2 Actual Yield (Y_a)

Actual yield refers to the harvested yield of a high yielding crop variety that is well adapted to the growing environment where all growth factors other than water are not limiting (Doorenbos and Kassam, 1979).

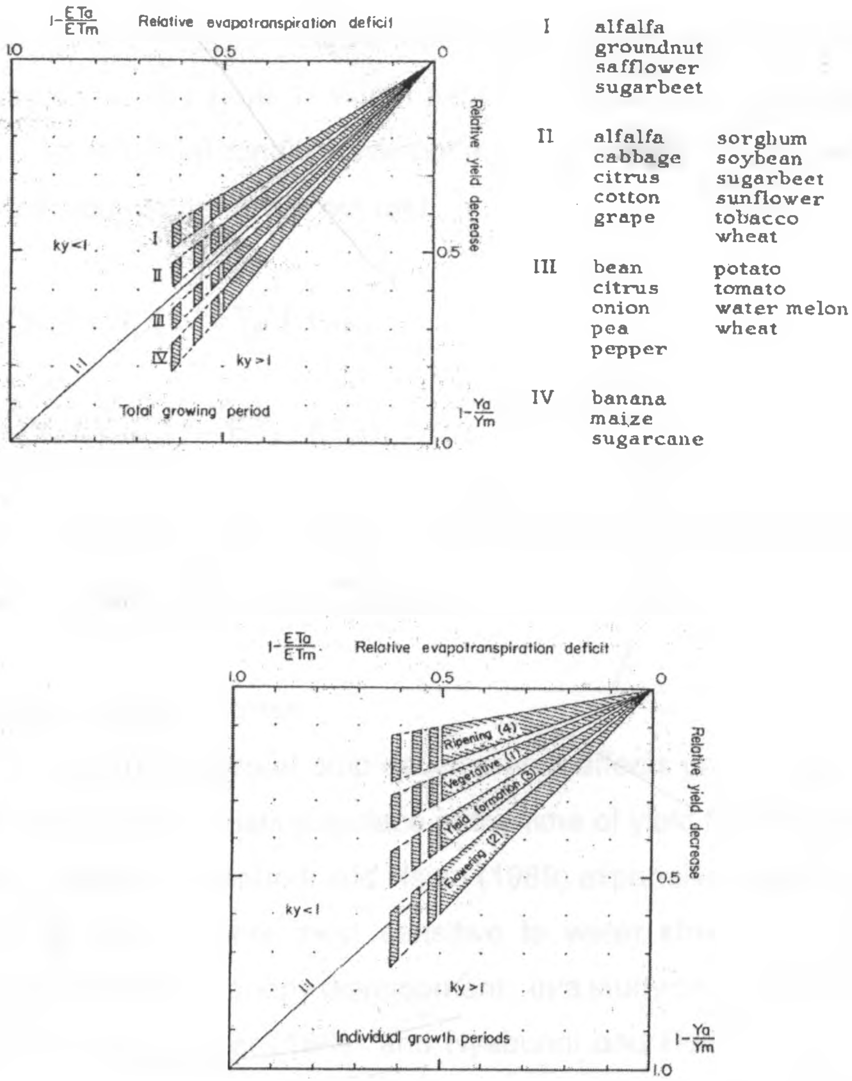


Fig. 3 Generalized relationship between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration (1 - ETa/ETm)

Fig 1.: Generalized relationship between relative yield decrease and relative evapotranspiration. Source: FAO 1979

2.5.3 Yield Response Factor (K_y)

The functional dependence of crop yields on water supply and use has grown recently because of the increasing scarcity of water for irrigation (Hillel, 1987). The yield response factor relates relative yield (Y_a/Y_p) to relative evapotranspiration deficit (ET_a/ET_p) over the total growing period or individual growth periods assuming a linear relationship between Y_a/Y_p) and ET_a/ET_p) when growth factors other than water are not limiting (Doorenbos and Pruit, 1977; Doorenbos and Kassam, 1979 and Hillel, 1980) as shown in Equation 1 and Figure 1. When full water requirements are met and the economic and environmental conditions do not restrict production $Y_a = Y_p$ whereas $Y_a < Y_p$ when full water requirements are not met.

$$[1 - Y_a / Y_m] = K_y \, [1 - ET_a / ET_m]$$

$$K_y = [1 - Y_a / Y_m] / [1 - ET_a / ET_m] \qquad (1)$$

The Ky values are also influenced by soil salinity, depth of ground water table and agronomic and irrigation practices.

2.5.4 Categories of Water Stress

Water stress in the early stages of crop development affects grain yield indirectly by reducing the size of the assimilation surface at the time of yield formation (Lenga and Stewart, 1982). According Nyabundi and Hsiao (1989) expansive growth is one of the processes of crop development most sensitive to water stress as evidenced by depressed leave growth and canopy development. In a study on response to water by plants, Goldsworthy and Fisher (1984) and Nyabundi and Hsiao (1989) found that canopy development in plants is sensitive to water stress resulting in a approximately 70% reduction in canopy cover and aboveground biomass in tomato. There are basically four types of water stress from an economic point of view as shown in Figure 2 (Carruthers and Clark, 1983).

(i) Stress that does not affect physiological processes of plants as depicted by curve (a) in Figure 2.

(ii) Stress with temporary effects that are overcome by subsequent compensatory growth as depicted in curve (d)

(iii) Stress that affects useful crop products depicted by curve (c)

(iv) Stress that results in crop death.

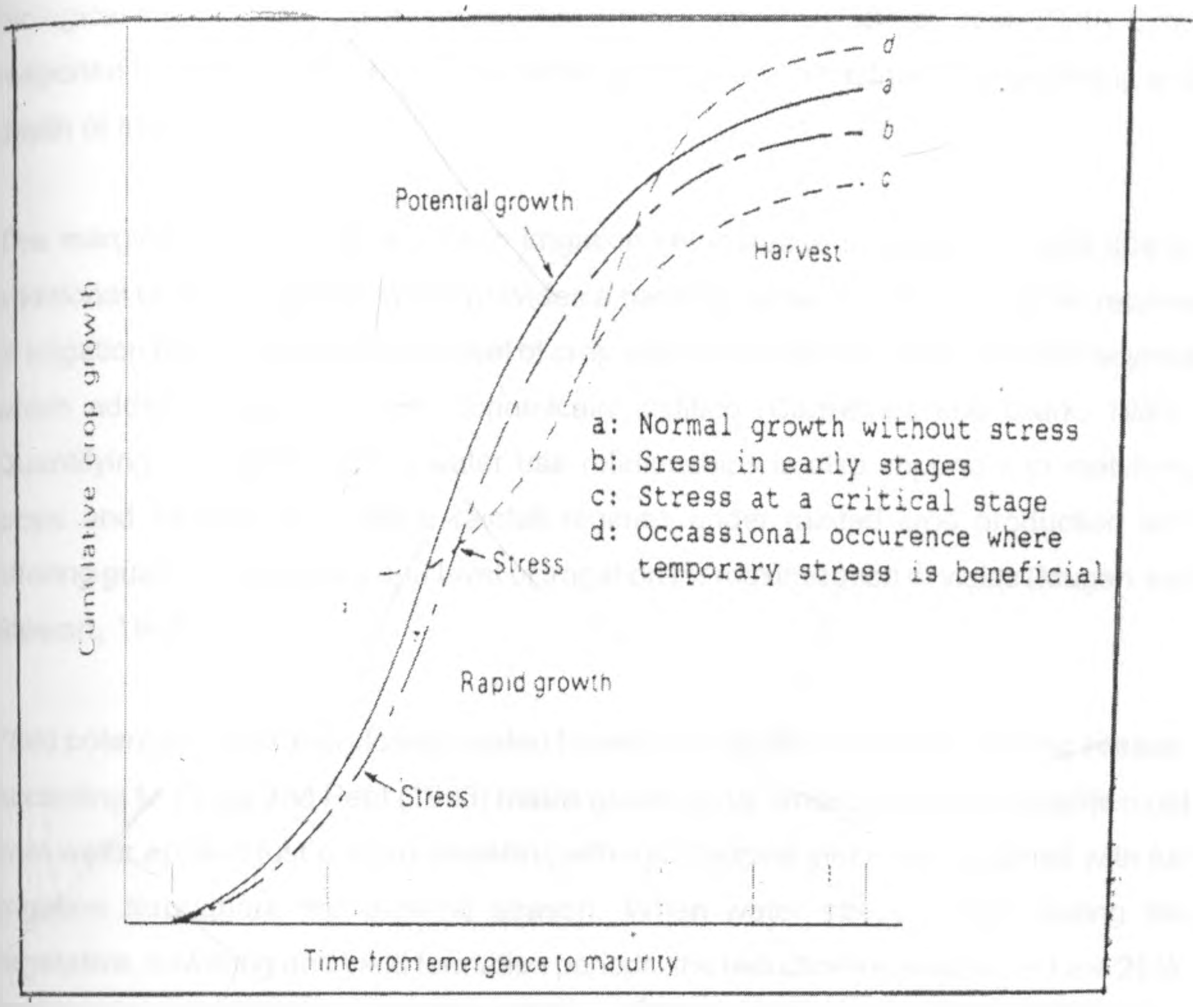


Figure 2: Hypothetical curve of response to water stress
Source: Carruthers and Clark, 1983

2.5.5 Stages of crop Growth

Crop growth is categorised into five basic phenological periods or growth stages (FAO, 1979) namely establishment, vegetative, flowering, yield formation and ripening. Water deficit may occur continuously over the total growing period of the crop or during any of the individual growth periods. Yield response to water deficit in individual growth periods is important for scheduling available but scarce water in order to maximise yields.

2.6 Crop Response to Irrigation

Water is one of the major constraints to increasing crop production (Hillel, 1987). Crop response to water is complex as it is affected by several factors namely physical, biological and biochemical processes that are site specific (Hoffman *et al*, 1990). Crop response to irrigation depends on the water application regime that includes timing and depth of irrigation.

The marginal response of a crop to irrigation i.e. increase in growth or yield due to additional units of irrigation water provides a basis for assessing the economic returns of irrigation because despite the level of crop water requirement, there is a limit beyond which additional water is not economically justified (Carruthers and Clark, 1983). Quantifying crop yield versus water use relationships is also important in matching crops and varieties to suitable rainfall regimes under rainfed crop production and offering guidance on timing and level of irrigation for maximization of yields (Mugah and Stewart, 1982)

Yield potential in maize is closely related to water availability during the growing season. According to Teare and Peet (1983) maize grown under limited irrigation benefits most from water applied just prior to tasselling although highest yields are obtained with full irrigation throughout the growing season. When water stress occurs during the vegetative, flowering and yield formation periods, the reductions in maize yield are 25%, 50% and 21% respectively (Teare and Peet, 1983). According to Hillel (1987) grain yield bears a more-or-less constant ratio to dry matter yield and a linear relationship exists between yield and water use under limited water supply. Barret and Skogerboe (1978) established that a positive correlation exists between ET and grain yield in maize and that water stress at flowering stage results in considerable yield reduction whereas irrigation during grain filling stage is significant only when full irrigation requirements were not met during the vegetative and pollination stages. Therefore irrigation can be withheld before physiological maturity without significant yield loss.

2.7 Methods of estimating Crop Water Requirements (ET_c)

2.7.1 Pan Evaporation Method

Evaporation pans can provide adequate measure for estimating crop water requirements when the pan environment is well described with the class A pan being the most adaptable because it is more widely used and has been used as interim reference for international comparations of evaporation pans (Doorenbos, 1976). Mugah and Stewart (1982) in a study of water use of Katumani composite B maize found that ET_p values obtained by Pan Evaporation Method were reasonably close to those obtained by Lysimeter method. The inputs for estimation of crop water requirement is pan evaporation, relative humidity and wind speed (Doorenbos and Pruit,1977). The equation used for estimating crop water requirement are:

$$ET_c\,(mm/day) = K_c * K_{pan} * E_{pan} \qquad (2)$$

Where:

E_{pan} = Evaporation from unscreened class A pan (mm/day)

K_{pan} = Pan coefficient

K_c = Crop coefficient

2.7.2 Penman Method

The Penman Method is applied using equation 3 as given by Doorenbos and Pruit (1977).

$$ET_c = K_c * C\,[W * R_n + (1 - W) * f(u) * (e_a - e_d)\,] \qquad (3)$$

Where:

$(e_a - e_d)$ = Vapour pressure deficit (mbar)

$f(u)$ = Wind function

R_n = Total net radiation (mm/day)

W = Temperature and altitude dependent weighting factor

C = Adjusted factor for the ratio U_{day} / U_{night}

2.7.3 Radiation Method

The Radiation Method is applied using equation 4 as given by Doorenbos and Pruit (1977).

$$ET_c = K_c * C (W * R_s) \quad (4)$$

Where:

R_s = Measured mean incoming shortwave radiation (mm/day)

W = Temperature and altitude dependent weighting factor

c = Adjustment factor on $W.R_s$

2.8 Crop cover evaluation

The various techniques used for evaluating crop cover and their merits and limitations have been reviewed by Fuchaka (1993) namely Overhead Photography, Sighting-frame, Point quadrat, Grid quadrat, Metre-stick, Line intercept, Residue dot count, Wheel point and Photosensitive light sensors.

2.8.1 The Sighting-frame

The sighting frame is based on the point quadrat with 10 holes equidistant from each other over a length of 1 metre. The frame is placed perpendicular to crop rows and the sighting effected by looking through two vertically aligned holes (Fuchaka, 1993). Fuchaka (1993) recommends the use of the sighting-frame for routine field evaluation of crop cover and research.

2.9 Crop Husbandry Practices

Low crop yields in the tropics can be explained by the level of agronomic and economic inputs that are characterised by severe problems of soil fertility, plant pests and diseases, weeds, moisture supply and poor timing of planting (Fisher and Palmer, 1983; Hubbard, 1982). Under good crop husbandry practices the yield levels that have been realised in various crops are as given in Table 3.

Table 3: Reported yields of some common crops

Crop	Yield (Tons/ha)	Crop	Yield (Tons/ha)
Potato	25 - 60	Onion	30 - 50
Maize	4 - 6	Beans	2 - 4
Cabbage	15 - 20	Peas	3 - 8
Carrots	30	Tomato	*5 - 15

Source: Lockhart and Wiseman, 1983. * Tindall (1983).

CHAPTER 3

3.0 METHODOLOGY

3.1 Research sites Description

3.1.1 Location

Aguthi irrigation scheme is located in Kieni East division of Nyeri district and lies within the Laikipia Plateau. It lies to the South-East of Naro Moru town. Matanya and Thome schemes are located in the central division of Laikipia district North-West of Naro-Moru town and South-East of Rumuruti (See Figure 3).

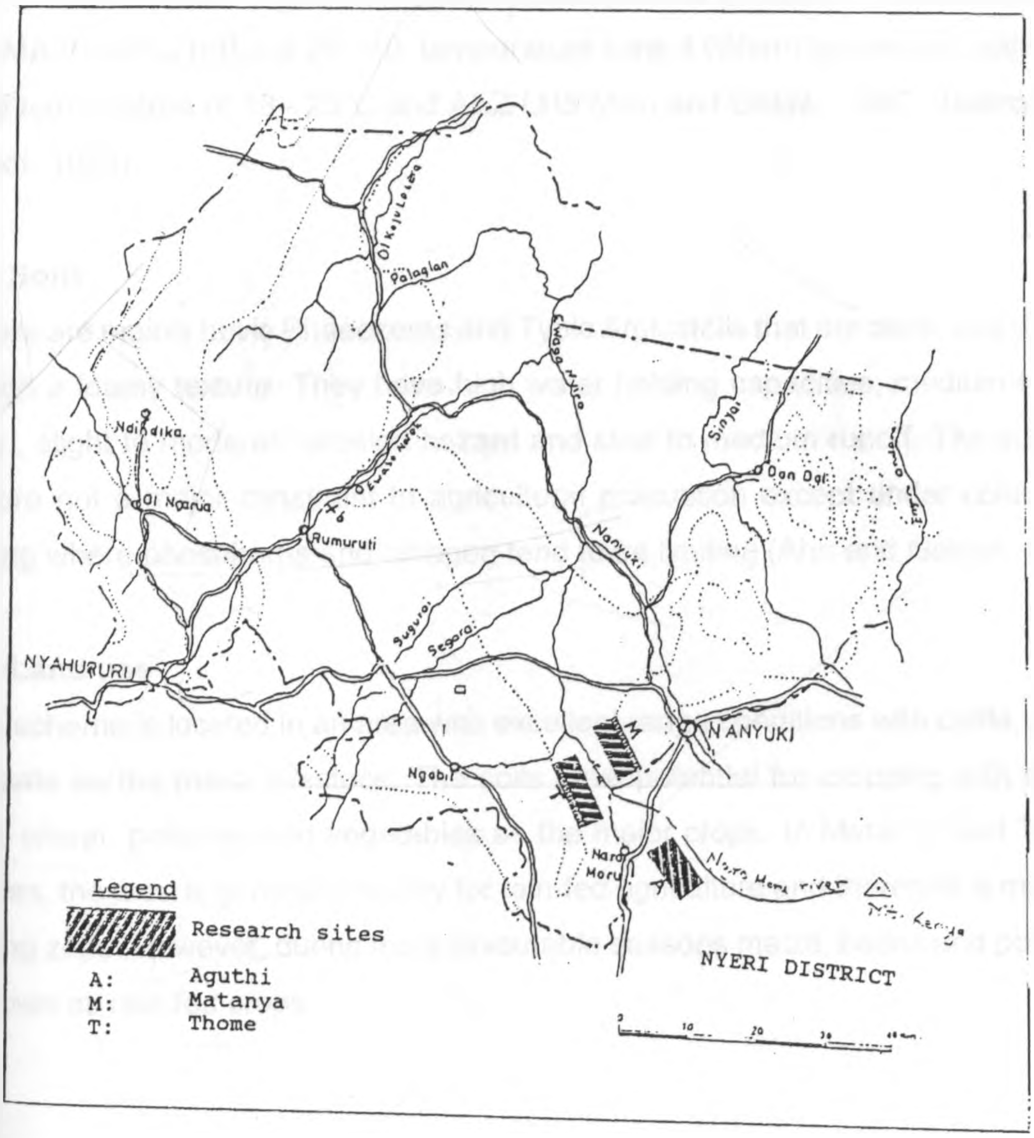


Figure 3: Location of research sites. After IDB, MoA, 1990

3.1.2 Climate

In Aguthi the mean annual rainfall is 900 mm p.a. with a bimodal distribution pattern and maxima in April and November (Ahn and Geiger, 1987; Jaetzold and Schmidt, 1983). The scheme lies within moisture availability zones (MAZs) III and IV with rainfall-evapotranspiration ratios (r/E_0) of 50 - 65 and 40 - 50 respectively, temperature zone 5 (cool temperate) with mean annual temperature of 16 - 18°C and agro-ecological zone (AEZ) LH4 (Ahn and Geiger, 1987; Jaetzold and Schmidt, 1983).

Matanya and Thome schemes occur within an area with mean annual rainfall of 700 mm p.a. with a bimodal distribution pattern and April and November maxima. They lie within MAZ5 with a (r/E_0) of 25 - 40, temperature zone 4 (Warm temperate) with mean annual temperature of 18 - 20°C and AEZ LH5 (Ahn and Geiger, 1987; Jaetzold and Schmidt, 1983).

3.1.3 Soils

The soils are mainly Luvic Phaeozems and Typic Argiustolls that are deep, well drained and with a loamy texture. They have high water holding capacities, medium to high fertility , slight to moderate erosion hazard and slow to medium runoff. The soils are therefore not a major constraint to agricultural production except under continuous cropping where phosphorus and nitrogen tend to be limiting (Ahn and Geiger, 1987).

3.1.4 Land use

Aguthi scheme is located in an area with excellent range conditions with cattle, sheep and goats as the major livestock. The soils have potential for cropping with maize, beans, wheat, potatoes and vegetables as the major crops. In Matanya and Thome schemes, the area is generally too dry for rain-fed agriculture and therefore is mainly a ranching zone. However, during more favourable seasons maize, beans and potatoes are grown as rain-fed crops.

3.1.5 Irrigation Systems

Aguthi scheme is a group-based gravity-fed irrigation system that utilises water from river Naro Moru. It consists of a main furrow that is subdivided downstream into three sub-mains. The scheme benefits about 500 farmers who use the furrow for supplying water for irrigation, domestic and watering of livestock. Sprinkler irrigation is used by majority of the farmers and a few use furrow irrigation. Irrigation is used to supplement rainfall. The major irrigated crops are maize, Snow peas, tomato and cabbage.

Both Matanya and Thome are gravity-fed furrow irrigation systems benefiting 185 and 180 households respectively. Furrow irrigation is the most common irrigation method but a few farmers use sprinkler irrigation by use of pumps to raise the water head. The type of irrigation is supplementary. The main crops grown in the two schemes are maize, beans, tomatoes, onions and potatoes. Usually irrigation is aimed at supplementing rainfall.

3.2 Site selection and Description.

The experimental sites were selected based on accessibility to irrigation water and homogeneity of soil conditions. The three sites were located on previously cultivated land with the assumption that the fertility levels of the soil were similar. The previous land use was maize, pulses and vegetable cultivation in all the three sites. The land slope was gentle and undulating for ease of irrigation water application. The sites were located within a radius of 1.5 km of the existing agrometeorological stations. For Matanya and Thome data from Matanya station was used whereas for Aguthi the data for Munyaka was used. The land was ploughed and levelled to make even seedbeds that enabled uniform application of irrigation water.

3.3 Infiltration rates determination.

The infiltration rates were determined using a double-ring infiltrometer [Bouwer,H., 1986]. The infiltrometer was driven straight down into the soil to a depth of 5 cm ensuring as little soil disturbance as possible. A graduated plastic rod attached to a float was fixed at the centre of the infiltrometer. Water was added into the infiltrometer until the levels in the inner and outer rings were the same. A stop watch was then started and the level of water in the inner cylinder noted on the graduated rod at 5, 10,15 and 30 minutes intervals for 5, 3, 3 and 4 readings respectively. The water levels in the two cylinders were maintained equal manually by frequently adding small amounts of water into the infiltrometer. When the float was just about to touch the soil surface the time was noted and the infiltrometer refilled with water and more readings taken. The measurement was continued until the rate of fall of the water level in the infiltrometer was constant. A curve of infiltration against time was plotted and used to determine the base infiltration rate. The base infiltration rate (mm/hr) was obtained by reading the point of intersection of the y-axis (infiltration rate) and a horizontal line drawn from the point on the infiltration rate curve where rate of water intake into the soil becomes constant.

3.4 Soil texture determination

The soil texture was determined by carrying out particle size analysis (PSA) using the hydrometer method (Gee and Bauder, 1986).

Soil samples were obtained by augering at depths of 0 - 20 cm, 20 - 40 cm, 40 - 60 cm, 60 - 80 cm and 80 - 100 cm. Since the size of the experimental sites was small only 3 profiles were chosen per experimental site. The soil samples were placed in polythene bags and labelled for sites and depth. The bulk samples were placed thinly on trays and air-dried. They were then thoroughly mixed and rolled with a wooden rolling pin to break up the clods and the particles that did not pass through a 2 mm sieve discarded. The samples were then oven-dried at 45^0c. 50g of each sample was placed in a plastic shaking bottle and 300 ml of distilled water added followed by 50 ml of 5 % calgon to disperse the particles.

The bottles were then stoppered and shaken with a mechanical shaker overnight. The soil suspensions were transferred into 1000 ml graduated cylinders and made up to the mark with distilled water. The hydrometer was calibrated using 50 ml of 5 % calgon solution (blank) by lowering the hydrometer into the solution and noting the scale reading (R_b) and temperature.

The soil suspensions were stirred thoroughly with a plunger and the time when stirring ceased noted and recorded. The hydrometer was then placed into the suspensions and the hydrometer reading (H_1) and temperature (T_1) recorded 40 seconds after stirring ceased. 2 hours after stirring ceased a second hydrometer reading (H_2) and temperature (T_2) were recorded for the soil suspensions and blank. The percentage sand, clay and silt were then calculated using the equations:

$$\% \text{ Sand} = 100 - [H_1 + 0.2(T_1 - 60) - 2]2 \qquad (5)$$

$$\% \text{ Clay} = [H_2 + 0.2(T_2 - 60) - 2]2 \qquad (6)$$

$$\% \text{ Silt} = 100 - (\% \text{ sand} + \% \text{ clay}) \qquad (7)$$

The textural triangle was then used to infer the textural classes of the soil based on the calculated percentages of sand, silt and clay.

3.5 Estimation of Irrigation Water Requirement (IR)

Irrigation water requirements (IR) were computed using the Pan Evaporation method with a class A pan. The input data used in the computation are pan evaporation (E_{pan}), Pan Coefficient (K_{pan}) and Crop coefficient (K_c). E_{pan} was recorded daily at Matanya and Munyaka meteorological stations over the period of the experiment i.e January to March 1995. The K_c and K_{pan} were selected depending on the stage of crop growth (Doorenbos et al, 1977; Doorenbos and Kassam, 1979). The formulae used in the computation of the irrigation water requirement are:

$$ET_0 = K_p * E_{pan} \qquad (8)$$

$$ET_c = ET_0 * K_c \qquad (9)$$

$$IR = ET_c - R \quad (10)$$

where:

ET_o = Reference crop evapotranspiration (mm)

ET_c = Crop evapotranspiration (mm)

IR = Irrigation water requirement (mm)

R = Effective rainfall (mm)

K_p = pan coefficient

E_{pan} = pan evaporation (mm)

K_c = crop Coefficient.

For a $6m^2$ (2m x 3m) plot, the irrigation requirement in litres was computed as:

$$V = 6 * IR \quad (11)$$

Where:

V = Volume in litres

IR = Irrigation requirement (mm)

The treatments were three levels of the computed irrigation water requirements i.e. 33%IR, 66%IR and 100%IR

3.6 Assessment of yield response to water.

Maize (Zea mays) hybrid 511was used as the test crop based on the criterion that it is the most commonly grown food crop in the area of study due to its ecological adaptation to the area and its short maturity period. Crop height was monitored as an indicator of water availability and water stress. Crop canopy cover affects the size of the assimilatory surface and therefore has an indirect effect on crop yield. Crop cover also determines the crop coefficient hence the water requirement of a crop during the different stages of growth. Crop yield reflects the "summation " of the whole growing period in terms of climatic condition and the influence of the different level of irrigation water applied.

3.7 Experimental Design

Randomised Block Design (RBD) was used in the experimental design comprising three treatments and three replicates designated by letter subscripts a, b and c. The treatments were randomised within the blocks such that every block contained each of the three treatments to remove any bias due to differences in soil conditions between the blocks (Steel *et al*, 1980). The basic experimental layout used in the three experiments is shown in Figure 4.

Planting of maize on the experimental plots was done at a rate of two seeds per hole and a spacing of 60 cm X 30 cm in Aguthi, Matanya and Thome on 31/12/1994, 2/1/1995 and 17/1/95 respectively. DAP was applied at a rate of 190 kg /ha i.e. 114 g per plot (Acland, 1977). Sixty litres (10 mm) of water were applied on each plot after planting to ensure germination and a uniform start.

During the establishment stage (first 14 days after planting) all the plots were uniformly watered by applying 100% of the computed IR using 10-litre watering cans (see Plate 1) as water deficit at this stage can severely reduce crop establishment and thus affect crop yield (Goldsworthy and Fisher, 1984). The crop was then thinned to retain one plant per hole and a plant population of 30 per plot. The treatments were then applied throughout the vegetative stage using an irrigation interval of 4 days.

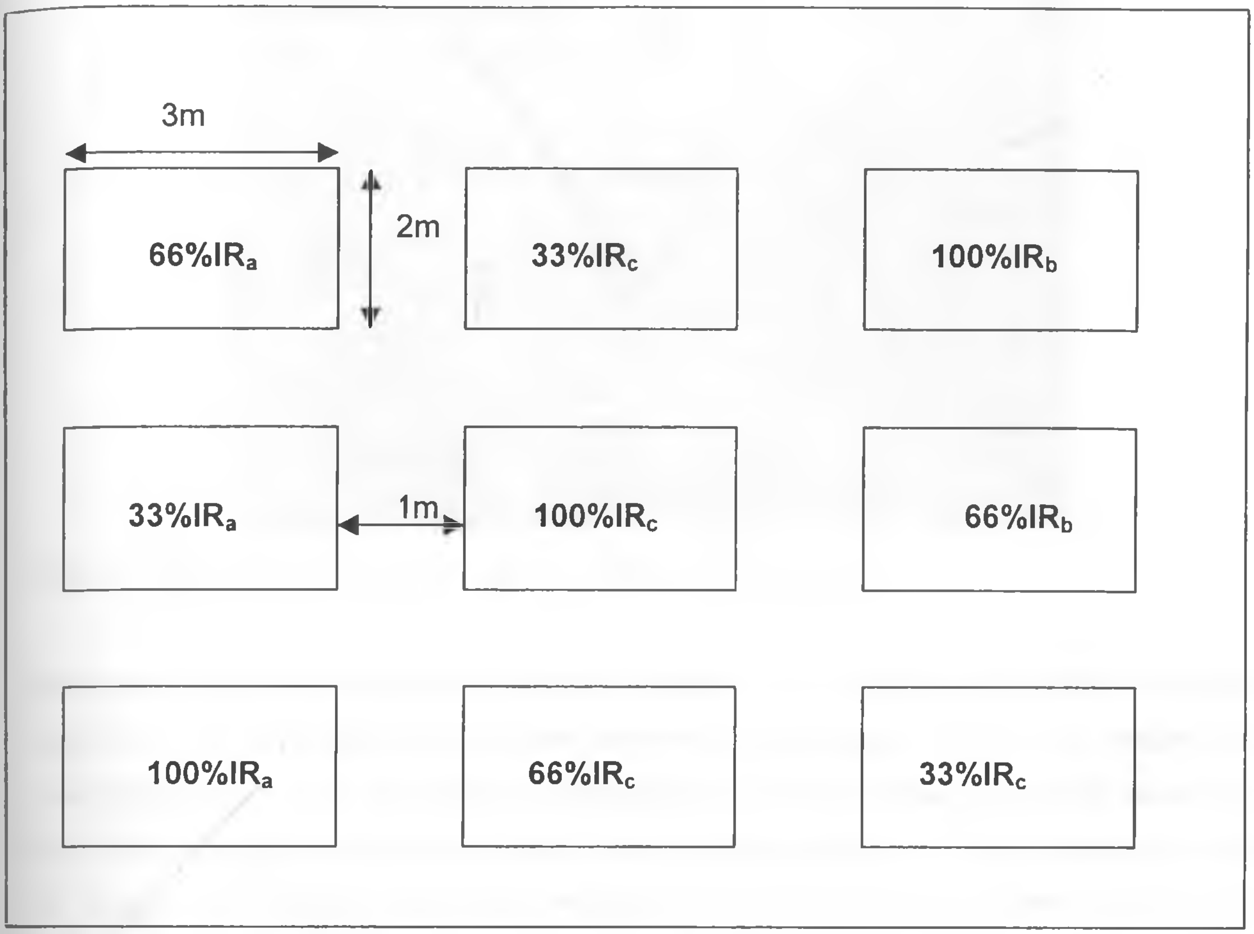


Figure 4: Basic experimental layout.

From the start of flowering that coincided with the onset of rains no irrigation water was applied hence the treatments were the same.

3.8 Data Collection and Analysis

3.8.1 Crop Height Monitoring

Crop height was monitored weekly from day 14 after planting. A 2-metre folding ruler was placed vertically with the zero mark touching the soil surface. The stems and leaves were then straightened up for consistency in the measurement and height measured to the nearest 1 cm (Todorov, 1977) as shown in Plate 2. Crop height monitoring was stopped on day 70 after planting which marked the end of the vegetative phenological phase.

Plate 1: Application of irrigation water on experimental plots.

Mean crop height was computed at day 14 from date of planting and at day 70 (end of treatments) to determine whether the treatments had any effect on crop height. The mean crop height (cm) was plotted against time to establish how crop height varied over time for the three treatments. Analysis of variance was done on mean crop height at day 70 using the COSTAT statistical program (CoHort Softwares, 1986) to determine whether the treatment heights were significantly different at 5% level of significance.

Plate 2: Measurement of crop height

3.8.2 Crop Cover Monitoring

Percentage crop cover was monitored from day 14 after planting using a modified sighting frame as recommended by Fuchaka (1993). The sighting frame was placed perpendicular to the crop rows and the height adjusted accordingly depending on the crop height. The sighting frame was maintained in a vertical position while the observer looked through the sighting holes from above as shown in Plate 3. Depending on the extent to which the sighting holes were masked by the crop foliage from below, the crop cover was recorded as:

No parts of sighting hole masked:	0 hit
Parts of sighting hole masked:	half hit
Sighting hole fully masked:	full hit.

Plate 3: Monitoring of percentage crop cover

The sighting frame consisted of 10 sighting holes of 1 cm diameter equidistant from each other within a distance of 1 m. Therefore zero hit, half hit and full hit were equivalent to 0%, 5%, and 10% cover respectively. Cover was measured at three positions per plot and the mean recorded. The mean percentage cover was plotted against time to find out how cover varies with time for the three levels of water application. Since the crop coefficient is a function of the crop cover and that crop cover determines the size of the assimilatory surface, this would give an indication of how the levels of irrigation water applied affect the crop coefficient (and therefore crop water requirement) and yield.

3.8.3 Maize Yield

The crop was harvested separately per experimental plot at physiological maturity. The ears were dehusked and dried in the sun to facilitate shelling. The grain was spread thinly and further sun-dried then weighed using a laboratory balance. The recorded yields per plot were converted into kg/ha to facilitate comparison with the yields reported by farmers.

Analysis of variance was done using the COSTAT statistical program (CoHort Softwares, 1986) to determine whether the recorded yields were significantly different between treatments and schemes at 5% level of significance. Duncan's Multiple Range Test was used to rank the yields according to treatments and schemes.

Yield response factors (K_y) were computed (See equation 1) for Treatments 1 and 2 (33% IR and 66% IR respectively) to determine the degree of yield depression relative to Treatment 3 (100% IR) as a result of the two levels of water deficit during the vegetative phase

3.9 Assessment of agro-economic performance.

The information on agro-economic performance and the determinants of performance is based on survey data for 1994/1995 production periods that the sample farmers could recall because most of the farmers interviewed did not have production records. Stratified samples of households were considered to reflect the performance in the head, middle and tail end sections of the three irrigation systems. The data on holding sizes, crop acreage, yields and crop husbandry practices were collected from the sample farmers through a survey using a pre-designed structured questionnaire

(Appendix 2) and supplemented through observations and physical measurements to estimate crop acreage by the enumerators (Bos and Nugteren, 1978; Prewitt, 1980; Yates, 1971; Yoder and Martin, 1985).

3.9.1 Sampling Method.

A stratified sampling procedure (Casley and Lury, 1987) was used whereby farmers in each project were categorised as belonging to the Head, Middle and Tail reaches based on the assumption that farmers on different sections of the schemes differ in their accessibility to irrigation water. The sampling frame consisted of a list of farmers in each category of furrow sections of all the schemes. The households were used as the sampling units. Sample households were randomly selected using a random number generator. The sample size in each project was chosen depending on the total number of households in each project (See Table 4).

Table 4: Sample sizes used in the agro-economic survey.

Scheme	No.of households	Sample size	Percentage
Thome	180	54	30
Matanya	185	56	30
Aguthi	500	60	12

3.9.2 Assessment of agronomic performance

Agronomic performance of the projects was determined by comparing crop productivity under irrigation and rain-fed conditions. The indicators of productivity that were considered are cropping intensity, cropping patterns and crop yields. The assessment was based on the acreage and yield data for 1994/95 as most farmers could not recall the crop data for the previous years because of lack of production records .

3.9.2.1 Cropping Patterns

Cropping patterns were assessed on the basis of the types and sequence of crops grown under irrigation and rain-fed condition by the sample households.

3.9.2.2 Cropping Intensity

Cropping intensity was determined using the total mean acreage of crops grown per year under rain-fed conditions and irrigation as a percentage of the holding sizes under rain-fed agriculture and irrigation respectively.

3.9.2.3 Crop Yields

The yields (kg/ha) of the crops grown under irrigation and rain-fed agriculture were computed by converting the farmer-reported yields into kilograms and cropped area into hectares depending on the cropped area reported by the sample farmers. The following conversions were adopted to standardise the yields reported by sample farmers to reduce error:

Unit of measurement	**Equivalent in Kg**
1 bag of Irish potato	130 kg
1 bag of shelled maize	90 kg
1 crate of tomato	60 kg
1 bag of beans	90 kg

Analysis of variance was done using the COSTAT statistical program with maize, bean and potato yields as the variables, irrigated head sections, irrigated middle section, irrigated tail section and rain-fed plots in each scheme as treatments 1, 2, 3 and 4 respectively and the individual schemes considered as replicates. The analysis was done to test whether the yields reported under irrigation, rain-fed agriculture and individual scheme sections were significantly different at 5 % level of significance.

3.9.3 Assessment of Economic Performance

The economic performance was determined using the proportion of the sample households who indicated primary dependence on irrigation for food and/or income, people employed in irrigation related activities and production orientation as indicators as used by Meinzen-Dick *et al* (1993).

3.10 Assessment of factors affecting agro-economic performance

The factors that constrain performance were assessed on the basis of level of crop husbandry practised by the sample households, availability of markets for the farm produce, irrigation water utilisation and management and the level of farmers organisation as indicators.

3.10.1 Level of crop husbandry

The level of crop husbandry is a function of the extent to which farmers make use of the recommended planting materials, plant nutrition management, disease and pest control. The proportions of the sample households who used hybrid seed, fertilizer / manure, pest/disease control chemicals and those that practised crop rotation were computed and used as indictors of the level of crop husbandry undertaken in the schemes.

3.10.2 Produce Market Situation

Market availability acts as a positive incentive for farmers to engage in a given production. Market availability and accessibility was assessed on the basis of the types and reliability of communication infrastructure that links the irrigation schemes to the major market centres, market outlets, mode of produce disposal and membership to marketing organisations. The marketing problems experienced by the farmers were assessed and ranked in order of importance.

3.10.3 Irrigation water utilization and management.

In irrigated agriculture, water management is the most important factor affecting the project performance. The irrigation water use function was determined by focusing on the level of farmers organisation, types of irrigation infrastructure and the mode of water distribution between individual farms. Level of irrigation technologies were assessed on the basis of methods of water abstraction from main furrows and conveyance to the fields, proportion of sample farmers using the different irrigation methods, proportion of sample farmers who own different irrigation equipment and irrigation intervals used by the sample farmers for the major crops.

CHAPTER 4

4.0 RESULTS AND DISCUSSIONS

4.1 Soil properties

4.1.1 Infiltration Rates

The intake rates of the soils on the three experimental sites are shown in Figures 5, 6 and 7 and Appendix 3. The results show that the soils have high infiltration rates of 6.3, 6.8 and 5.4 mm/hr for Matanya, Thome and Aguthi respectively which conform to findings by Ahn and Geiger (1987). The high water intake rates and retention capacity makes the soils well suited for irrigation since with good management high irrigation efficiency can be realised as water losses through runoff and deep percolation would be minimal.

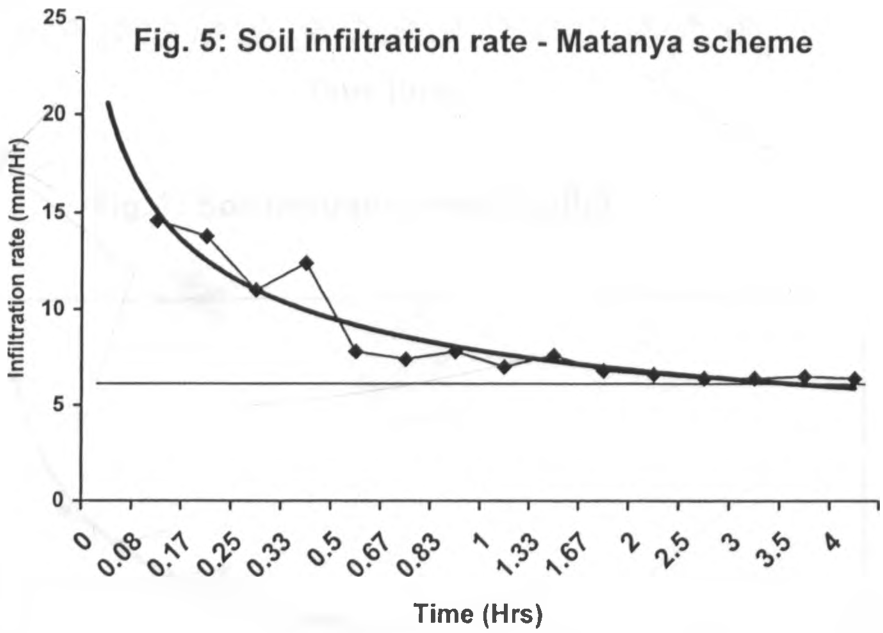


Fig 6: Soil infiltration rate(Thome)

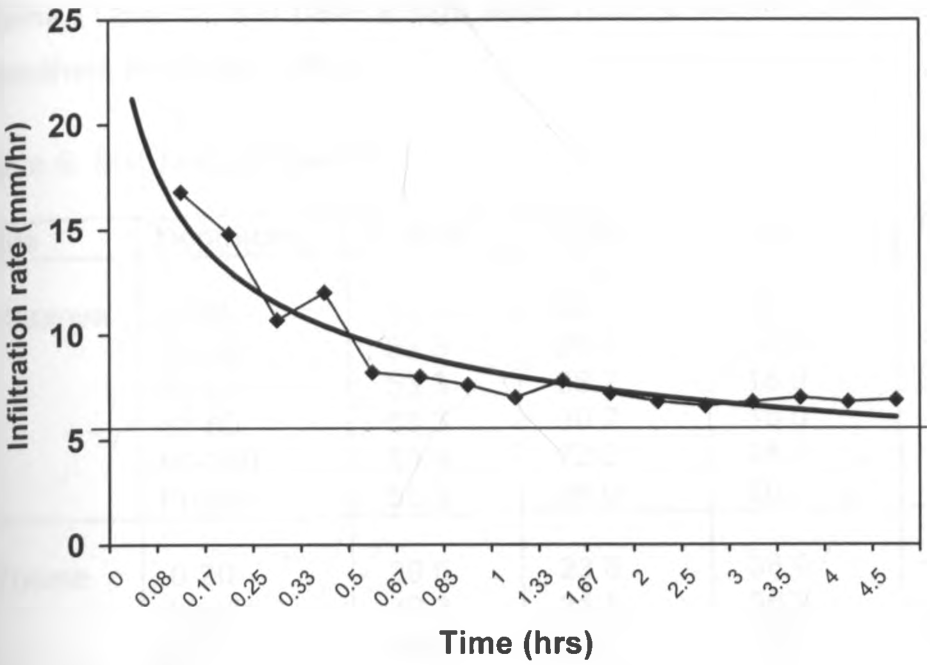
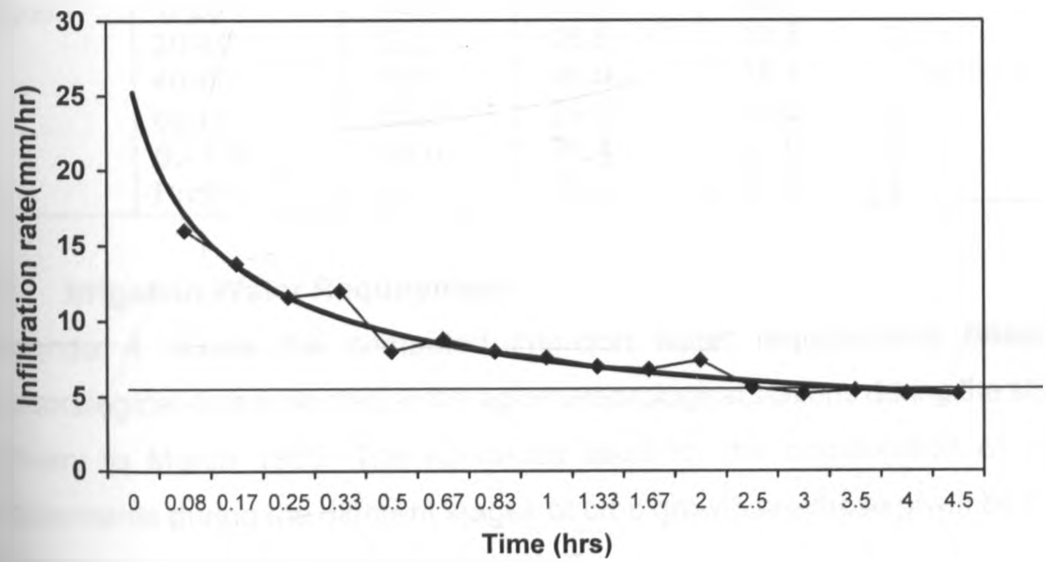


Fig. 7: Soil infiltration rate(Aguthi)



4.1.2 Soil Texture

The soils are predominantly sandy clay loams in Matanya and Aguthi and Loams in Thome (Table 5) and have a high water holding capacity (Ahn and Geiger, 1987; Carruthers and Clark 1983).

Table 5: Soil Textural classes

Site	Depth(cm)	% sand	% clay	% silt	Textural class
Matanya	0-20	53.3	22.0	24.7	Sandy clay loam
	20-40	53.3	26.7	20.0	
	40-60	53.3	28.7	18.0	
	60-80	53.3	30.7	16.0	
	80-100	53.3	22.0	24.7	
	Profile	53.3	26.0	20.7	
Thome	0-20	39.0	23.0	38.0	Clay Loam
	20-40	42.3	21.5	36.2	
	40-60	48.3	18.5	33.2	
	60-80	47.9	20.0	32.1	
	80-100	49.4	19.6	31.0	
	Profile	45.4	20.5	34.1	
Aguthi	0-20	55.0	30.2	14.8	Sandy Loam
	20-40	52.0	28.5	19.5	
	40-60	53.6	28.0	18.4	
	60-80	53.8	29.2	17.0	
	80-100	56.0	28.4	15.6	
	Profile	54.1	28.9	17.0	

4.2 Irrigation Water Requirement

Appendix 4 shows the computed irrigation water requirements based on the meteorological data collected at the agrometeorological stations during the study period January to March 1995. The K_c values used for the computation of crop water requirements during the different stages of crop growth are those given by Doorenbos and Kassam (1979) as given in appendix 5.

Tables 6, 7 and 8 show the irrigation water applied in Matanya, Thome and Aguthi respectively. Irrigation efficiency of 100% was assumed since the conveyance and distribution losses were zero because water was applied using watering cans and deep percolation loses were assumed to be zero due to the high water holding capacities of the soils. The experiments also assumed homogeneous soil conditions within the blocks, uniform application efficiency and therefore similar relative effect in all the Treatments.

Table 6: Applied irrigation water (Matanya)

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied irrigation water (litres)		
				(33IR)	(66IR)	(100IR)
2/1/95	0	0.0	10.0	60.0	60.0	60.0
6/1/95	4	0.0	6.9	41.0	41.0	41.0
10/1/95	8	0.0	5.6	34.0	34.0	34.0
14/1/95	12	0.0	4.9	29.0	29.0	29.0
18/1/95	16	0.0	5.6	11.0	22.0	34.0
22/1/95	20	0.0	6.1	12.0	24.0	37.0
26/1/95	24	0.0	3.5	7.0	14.0	21.0
30/1/95	28	0.0	7.0	14.0	28.0	42.0
3/2/95	32	0.0	6.4	13.0	25.0	38.0
7/2/95	36	0.0	15.5	31.0	61.0	93.0
11/2/95	40	23.5	0.0	0.0	0.0	0.0
15/2/95	44	8.0	0.0	0.0	0.0	0.0
19/2/95	48	6.5	0.0	0.0	0.0	0.0
23/2/95	52	0.0	0.0	0.0	0.0	0.0
27/2/95	56	17.8	9.7	19.0	38.0	58.0
3/3/95	60	60.5	0.0	0.0	0.0	0.0
7/3/95	64	12.8	0.0	0.0	0.0	0.0
11/3/95	68	0.8	0.0	0.0	0.0	0.0
15/3/95	72	10.3	0.0	0.0	0.0	0.0

Table 7: Applied irrigation water (Thome)

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied irrigation water (litres)		
				Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment3 (100IR)
17/1/95	0	0.0	10.0	60.0	60.0	60.0
22/1/95	4	0.0	6.1	37.0	37.0	37.0
26/1/95	8	0.0	3.5	21.0	21.0	21.0
30/1/95	12	0.0	7.0	42.0	42.0	42.0
3/2/95	16	0.0	6.4	13.0	25.0	38.0
7/2/95	20	0.0	15.5	31.0	61.0	93.0
11/2/95	24	23.5	0.0	0.0	0.0	0.0
15/2/95	28	8.0	0.0	0.0	0.0	0.0
19/2/95	32	6.5	0.0	0.0	0.0	0.0
23/2/95	36	0.0	0.0	0.0	0.0	0.0
27/2/95	40	17.8	9.7	19.0	38.0	58.0
3/3/95	44	60.5	0.0	0.0	0.0	0.0
7/3/95	48	12.8	0.0	0.0	0.0	0.0
11/3/95	52	0.8	0.0	0.0	0.0	0.0
15/3/95	56	10.3	0.0	0.0	0.0	0.0
19/3/95	60	-	0.0	0.0	0.0	0.0
23/3/95	64	-	0.0	0.0	0.0	0.0
27/3/95	68	-	0.0	0.0	0.0	0.0

Table 8: Applied Irrigation Water (Aguthi)

Date	Days after planting	4-day rainfall total(mm)	IR (mm)	Applied Irrigation Water (Litres)		
				(33IR)	(66IR	(100IR)
31/12/95	0	0.0	10.0	60.0	60.0	60.0
6/1/95	5	0.0	7.8	46.8	46.8	46.8
11/1/95	10	0.0	6.4	38.4	38.4	38.4
16/1/95	15	0.0	7.9	47.4	47.4	47.4
21/1/95	20	0.0	8.0	16.0	32.0	48.0
26/1/95	25	0.0	10.0	20.0	40.0	60.0
31/1/95	30	0.0	10.4	20.5	41.0	62.5
5/2/95	35	0.0	19.7	39.0	78.0	118.5
10/2/95	40	25.0	10.6	21.0	42.0	63.5
15/2/95	45	14.6	0.0	0.0	0.0	0.0
20/2/95	50	8.5	0.0	0.0	0.0	0.0
25/2/95	55	16.0	0.0	0.0	0.0	0.0
2/3/95	60	10.8	4.0	8.0	16.0	24.0
7/3/95	65	80.0	0.0	0.0	0.0	0.0
12/3/95	70	14.8	0.0	0.0	0.0	0.0

4.3 Crop height

Figures 8, 9 and 10 (See Appendix 6) show the weekly crop height for each treatment for Matanya, Aguthi and Thome respectively. The graphs show that at the start of the treatments the crop heights were not significantly different as indicated by the means. The graphs indicate that there was a difference in growth between the treatments resulting in stunted plants in Treatment 1 (33% IR). This shows that adequate water is necessary during the initial stage to give the crop a good start. It can be inferred that at 66% IR the water stress is negligible since no significant difference in crop height was observed between treats 2 and 3 during the period of the experiment. When compared to treatment 3, Treatments 1 and 2 had a mean height depression of 33% and 3.2% respectively 70 days after planting.

Fig.8: Crop growth (Matanya)

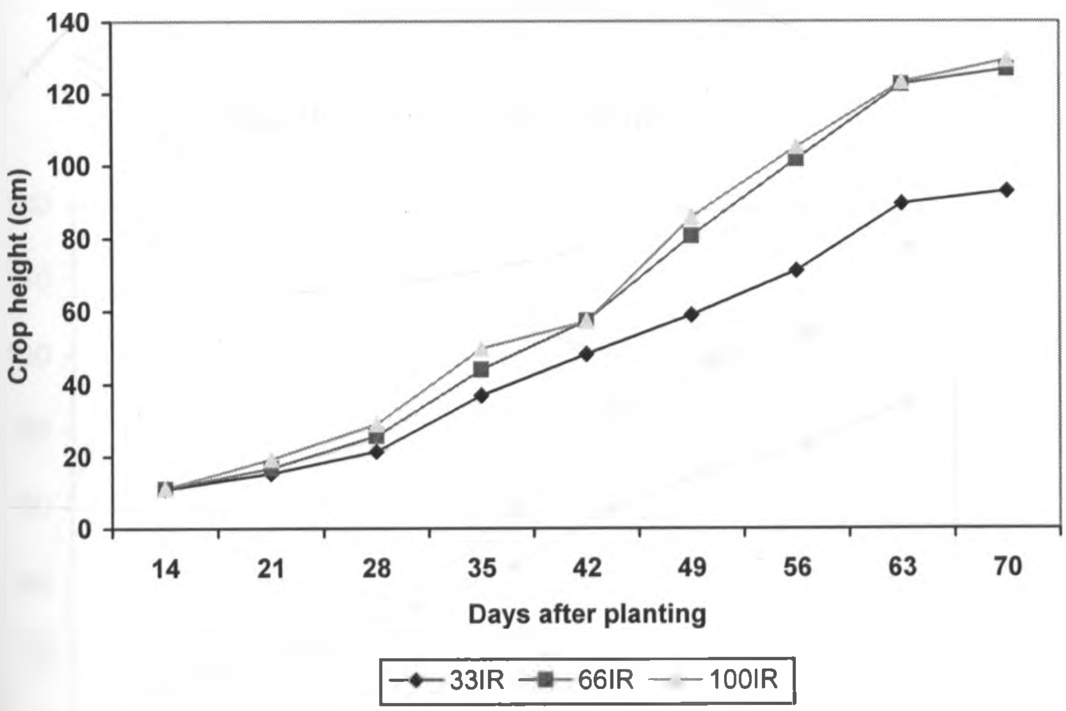


Fig. 9: Crop Growth (Aguthi)

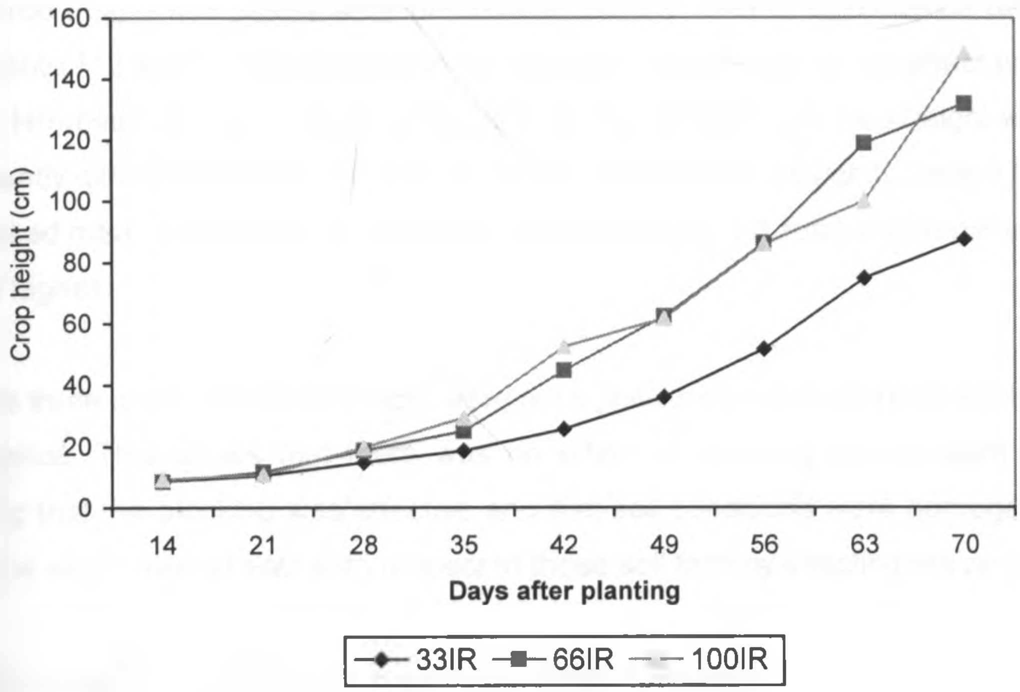
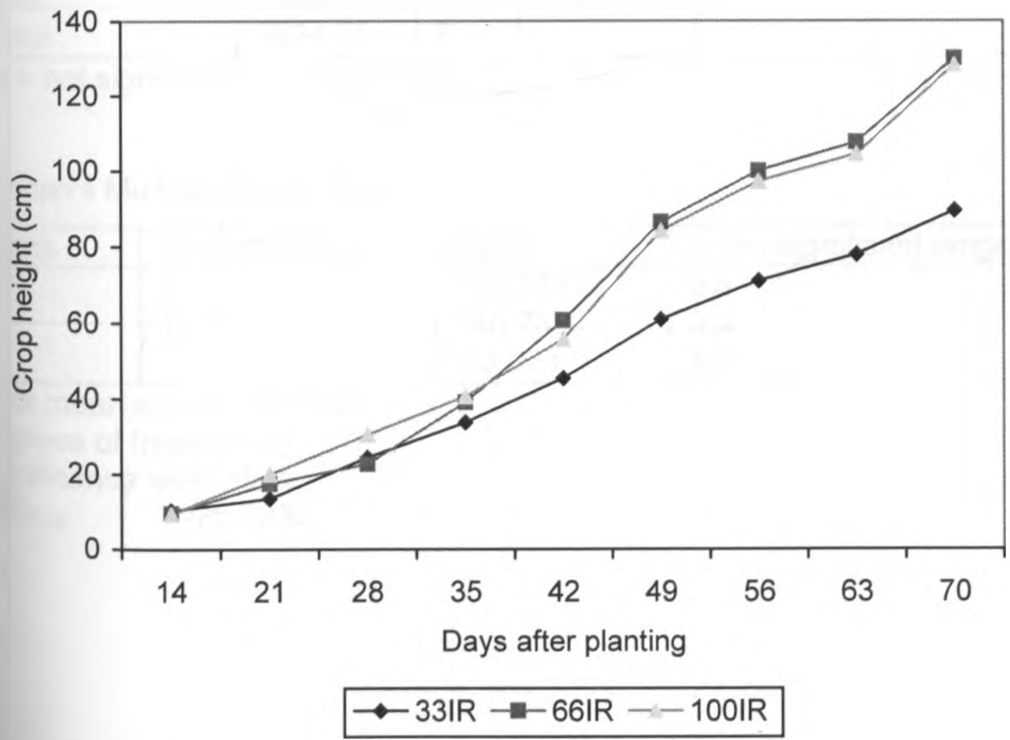


Fig. 10: Crop Growth (Thome)



Tables 9, 10 and 11 are the analyses of variance on mean crop height at 70 days after planting for Matanya, Thome and Aguthi respectively. In all the experimental sites the mean crop height was significantly different at the 5% level of significance between Treatments 1, 2 and 3. This shows that the irrigation treatments had an effect on plant height. However, Duncan's Multiple Range Test shows that mean crop height was not significantly different between treatments 2 and 3 at 5 % level of significance ($LSD_{0.05}$) and ranked mean crop height in treatment 3 in Matanya and Aguthi and treatment 2 in Thome highest.

In all the three cases the block means were not significantly different at the 5% level of significance. This shows that there was no effect of blocking on the plant height meaning that the blocking was effective and that soil conditions were homogeneous within the experimental sites with respect to those soil factors affecting maize growth.

Table 9: Analysis of variance on mean crop height (Matanya)

Source	SS	Df	MS	F	P	Result
Blocks	10.22	2	5.11	0.03685	.9641	ns
Main Effects	2460.14	2	1230.07	8.871	.0338	*
Error	554.6	4	138.65			
Total	3024.96	8				

ns = not significant. * = significant.

Duncan's Multiple Range Test

Rank	Treatment No.	Mean	n non-significant ranges
1	3	129.333	3 a
2	2	126.733	3 a
3	1	93.033	3 b

Error mean square =138.65
Degrees of freedom =4
Significance level =5 %
$LSD_{0.05}$ =26.6933

Table 10: Analysis of variance on mean crop height (Aguthi)

Source	SS	Df	MS	F	P	Result
Blocks	44.846	2	22.42	1.16	0.4004	ns
Main Effects	622.726	2	331.36	17.15	0.0109	*
Error	77.286	4	19.32			
Total	784.86	8				

ns = not significant. * = significant

Duncan's Multiple Range Test

Rank	Treatment No.	Mean	n non-significant ranges
1	2	107.5	3 a
2	3	104.37	3 a
3	1	87.93	3 b

Error mean square = 19.321
Degrees of freedom = 4
Significance level = 5 %
$LSD_{0.05}$ = 9.965

Table 11: Analysis of variance on mean crop height (Thome)

Source	SS	Df	MS	F	P	Result
Blocks	143.08	2	71.54	3.099	0.1538	ns
Main Effects	5935.56	2	2967.78	128.589	0.0002	***
Error	92.32	4	23.08			
Total	6170.96	8				

ns = not significant. *** = Highly significant

Duncan's Multiple Range Test

Rank	Treatment No.	Mean	n non-significant ranges
1	3	148.13	3 a
2	2	131.83	3 b
3	1	87.37	3 c

Error mean square = 23.079
Degrees of freedom = 4
Significance level = 5 %
$LSD_{0.05}$ 10.891

4.4 Percentage crop cover

Figures 11, 12 and 13 (See Appendix 7) show the percentage crop cover curves over time for Matanya, Thome and Aguthi respectively for the various treatments. On day 14 after planting the mean percentage crop cover indicates that there was no difference in cover for the three treatments as indicated by the small values of the standard deviation. This shows that prior to the treatments the % crop cover in all the experimental plots was uniform.

In all the three cases the percentage cover was lowest for treatment 1 indicating that there was considerable water stress that resulted in decreased vegetative growth when only 33% of the irrigation requirement was applied. In treatments 2 and 3 there was considerable overlap of the percentage cover curves indicating that the two levels of irrigation water application had similar effects on percentage crop cover.

Tables 12, 13 and 14 show the analyses of variance on mean percentage crop cover for Matanya, Thome and Aguthi respectively 70 days after planting.

Fig. 11: Crop Cover (Matanya)

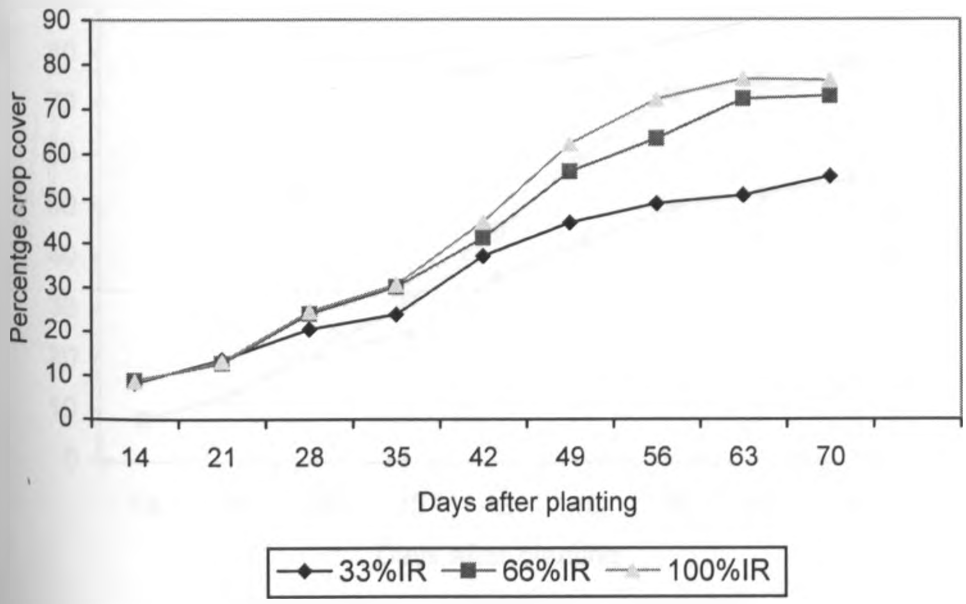


Fig. 12: Percentage Crop cover (Thome)

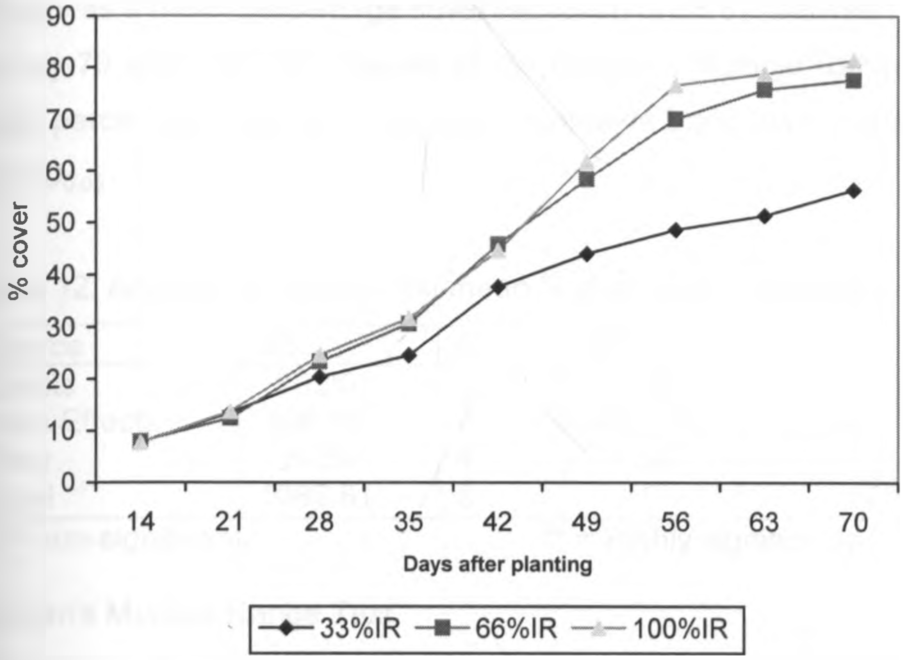
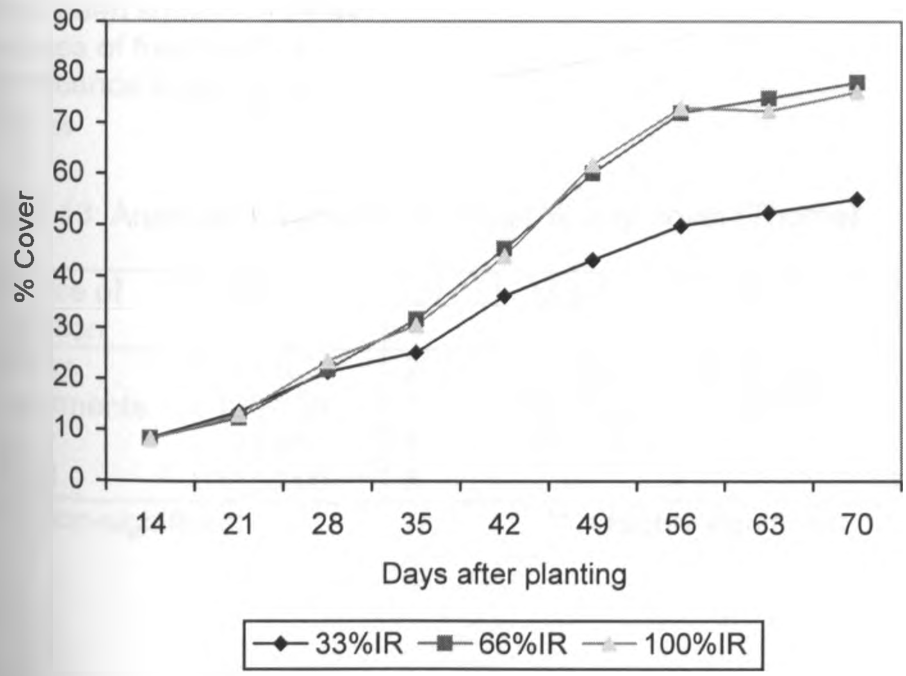


Fig. 13: Percentage crop cover (Aguthi)



The mean percentage crop cover was significantly different at 5% level of significance showing that the three levels of irrigation water had an effect on percentage crop cover. There was a mean percentage cover reduction of 28.8% between treatments 1 and 3 on day 70 after planting. Results of the Duncan's Multiple Range Test showed that mean percentage crop cover between treatments 2 and 3 was not significantly different at $LSD_{0.05}$

Table 12: Analysis of variance on mean % crop cover (Matanya).

Source	SS	df	MS	F	P	Result
Blocks	70.20	2	35.101	1.4126	0.3435	ns
Main Effects	896.22	2	448.111	18.034	0.0100	**
Error	99.39	4	24.847			
Total	1065.81	8				

ns = non-significant ** = Highly significant

Duncan's Multiple Range Test

Rank	Treatment No.	Mean	n non-significant ranges
1	3	76.3	3 a
2	2	75.966	3 a
3	1	54.966	3 b

Error mean square = 24.847
Degrees of freedom = 4
Significance level = 5 %
$LSD_{0.05}$ = 11.3

Table 13: Analysis of variance on mean % crop cover (Thome)

Source of variation	SS	Df	MS	F	P	Result
Blocks	12.67	2	6.333	0.32129	0.7423	ns
Treatments	1097.39	2	548.693	27.83597	0.0045	**
Error	78.85	4	19.712			
Total	1188.90	8				

ns = non-significant ** = Highly significant

Table 14: Analysis of variance on mean % crop cover (Aguthi)

Source of variation	SS	Df	MS	F	P	
Blocks	69.7088	2	34.8544	1.8414	0.2711	ns
Treatments	965.0155	2	482.5077	25.4920	0.0053	**
Error	75.7111	4	18.9277			
Total	1110.435	8				

ns = non-significant ** = Highly significant

A regression analysis on mean crop height and percentage crop cover for the three experimental sites shows that crop height and percentage crop cover are positively correlated with correlation coefficient (r) values of 0.965, 0.975 and 0.973 for treatments 1, 2 and 3 respectively (See Table 15). The respective regression curves are shown in Figures 14 a, b and c.

Table 15: Regression analysis table of crop cover on crop height

Treatment	Constant Term (A)	Regression coefficient (B)	Correlation coefficient (r)
1	8.437	0.566	0.965
2	11.955	0.543	0.975
3	7.169	0.612	0.973

Fig. 14a: Regression of % cover onheight(Treatment 1)

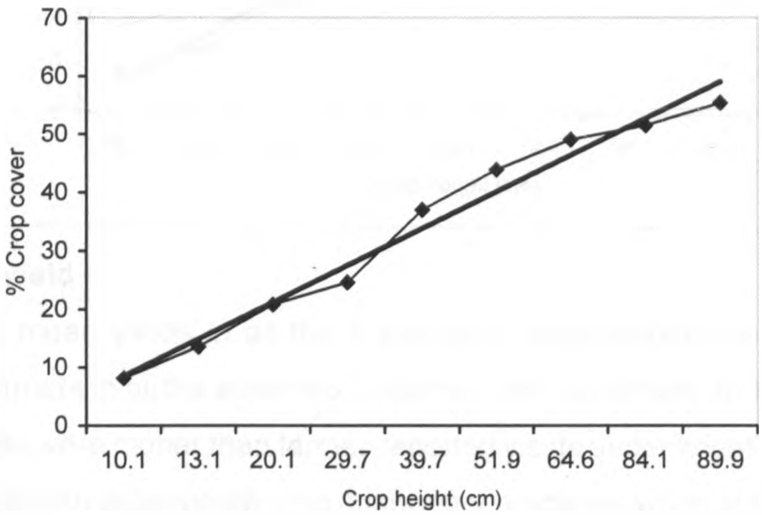


Fig. 14b:Regression of % cover on Height(Treatment 2)

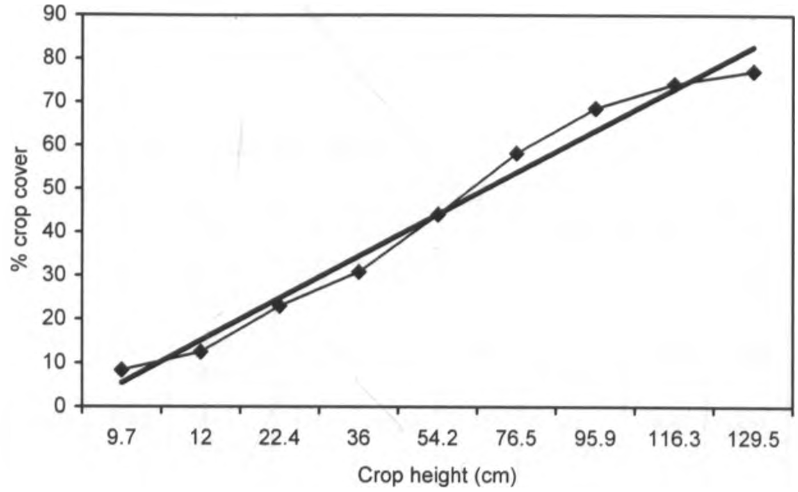
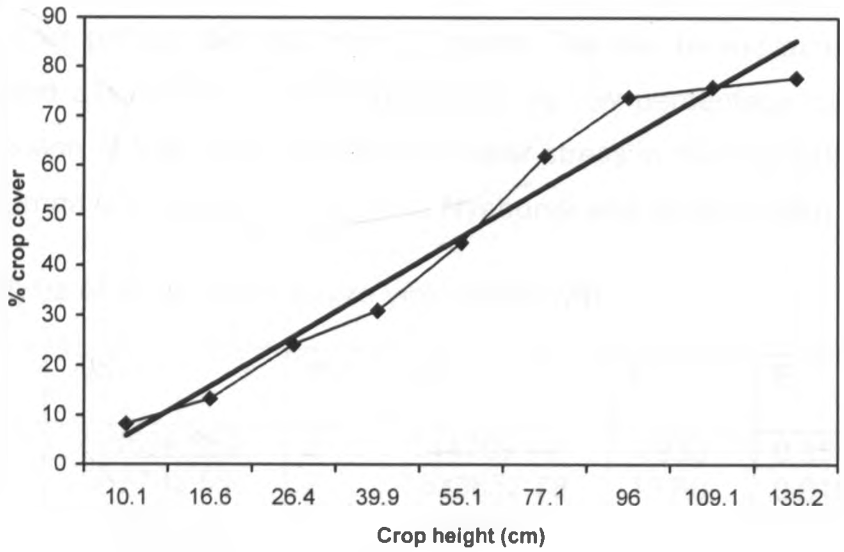


Fig 14c: Regression of % cover on height (Treatment 3)



4.5 Maize yield

The recorded mean yields in all the Treatments were higher than the mean yields reported by farmers in all the schemes under rain-fed conditions. In Treatments 2 and 3 the mean yields were higher than farmer-reported yields under irrigation (See Table 16). This shows that with appropriate crop husbandry practices, when at least 33% and 66%

of the irrigation water requirements are met during the vegetative phase and thereafter adequate water is supplied in the yield formation and ripening stages, higher yields than the farmer-reported yields can be realised under rain-fed and irrigation respectively (See Table 22).

Table 16: Recorded maize yields (g) per plot

Scheme	Matanya				Thome				Aguthi				3 sites
Treatment	A	B	c	Mean	a	B	c	Mean	a	b	c	Mean	Meean
33IR	810	830	765	801.7 (1336)*	875	850	795	840 (1400)*	675	830	865	790 (1317)*	810.6 (1351)*
66IR	1375	1790	2135	1767 (2945)*	110	1475	1645	1645 (2742)*	1850	1635	1965	1817 (3028)*	1743 (29050*
100IR	1490	2260	1840	1863 (3105)*	1760	1535	1945	1747 (2912)*	1630	1575	2045	1750 (2917)*	1786.7 (2978)*

* (kg/ha)

The mean Treatment yields were significantly different at the 5% level of significance in all the three schemes (See Tables 17, 18 and 19). Duncan's Multiple Range Test ranked yields from plots under treatment 1 lowest. This can be explained to be as a result of reduced assimilatory surface (indicated by low percentage canopy cover) through depression of leaf area index due to water stress in the vegetative phase as explained by Lenga and Stewart (1982) and Nyabundi and Hsiao (1989).

Table 17: Analysis of variance on maize yield (Matanya)

Source	SS	df	MS	F	P	Result
Blocks	289538.889	2	144769.44	1.933	0.359	ns
Main Effects	2067705.556	2	1033852.78	13.80	0.016	*
Error	299561.111	4	74890.27			
Total	2656805.556	8				

ns = non significant * = Significant

<u>Duncan's Multiple Range Test</u>

Error mean square = 74890.278

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 620.377

Rank	Treatment No.	Mean	n Non-significant ranges
1	3	1863.33	3a
2	2	1766.67	3a
3	1	801.67	3b

Table 18: Analysis of variance on maize yield (Thome)

Source	SS	df	MS	F	P	Results
Blocks	132050	2	66025	1.537	0.353	ns
Main Effects	1638066.67	2	819033.33	19.077	8	**
Error	171733.33	4	42933.33	8	0.009	
Total		8			0	

ns = non-significant ** = Highly significant

Duncan's multiple Range Test

Error mean square = 42933.33

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 469.72

Rank	Treatment No.	Mean	n Non-significant ranges
1	3	1746.67	3a
2	2	1743.33	3a
3	1	840	3b

Table 19: Analysis of variance on maize yield (Aguthi)

Source	SS	df	MS	F	P	Result
Blocks	136538.89	2	68269.44	3.788	0.1194	ns
Main Effects	1980088.89	2	990044.44	54.943	0.0012	**
Error	72077.78	4	18019.44			
Total		8				

ns = non-significant ** = Highly significant

Duncan's multiple Range Test

Error mean square = 18019.54

Degrees of freedom = 4

Significance level = 5%

$LSD_{0.05}$ = 314.31

Rank	Treatment No.	Mean	n Non-significant ranges
1	3	1816.67	3a
2	2	1750	3a
3	1	790	3b

Yield response factors (K_y) for the three Treatments were computed (See Appendix 8) using Equation 1 and presented in Table 20.

Table 20: Yield Response Factor (K_y)

Scheme	Yield response factor (Ky)	
	Treatment 1 (33% IR)	Treatment 2 (66% IR)
Matanya	0.85	0.15
Thome	0.77	0.17
Aguthi	0.84	0.11
Mean	0.82	0.14

The K_y values in Treatment 1 relative to treatment 3 were high and ranged from 0.77 to 0.85. This shows that in Treatment 1 the maize crop was severely water-stressed resulting in high yield depression. In treatment 2 the stress was mild with negligible effect on yields relative to Treatment 3 (See Table 20). The computation assumes that evapotranspiration during the vegetative phase and yields at 100IR were maximum i.e. ET_m and Y_m respectively.

4.6 Agronomic performance

The size of the sample holdings varies among the sample households and also between the schemes. The mean size of the total holdings were 1.68 ha, 1.26 ha and 1.22 ha for Aguthi, Matanya and Thome respectively (See Appendices 9, 10 and 11) with low standard deviations of 0.75, 1.6 and 1.22. This is an indication that the plot sizes within individual schemes are almost equal. This is the case as the schemes are located in settlement areas where households were allocated equal plots of land and the small differences can be attributed to subdivision of land by some farmers. In general the head sections of the furrow systems have the highest percentage of land under irrigation whereas the tail sections have the lowest. This is a reflection of the extent of inequitable distribution of irrigation water within the schemes (See Table 21). The percentage of land under rain-fed agriculture generally increases from the head-section to the tail-section of the furrows. This means that rain-fed agriculture plays an increasingly bigger role downstream of the furrows as irrigation water becomes increasingly scarcer. Therefore availability of irrigation water is one of the factors that determine the proportion of the total holding under irrigation. Inspite of these differences the data indicate that irrigation plays a big role in terms of total land under cultivation.

Table 21:Percentage of total holding under irrigation and rain-fed agriculture (1994/95).

Scheme	Head section		Middle section		Tail section	
	Irrigated (%)	rainfed (%)	irrigated (%)	rainfed (%)	irrigated (%)	rainfed (%)
Aguthi	34.75	35.6	33.1	39.8	26.9	36.0
Thome	48.9	23.9	46.7	20.0	36.6	39.4
Matanya	50.4	16.4	54.5	27.6	39.3	26.9

4.6.1 Cropping Patterns

Cropping patterns, especially the composition of the cropping patterns, can be used as indicators of agronomic performance of irrigation systems (Meinzen-Dick et al, 1993). The type of crops that can be successfully grown under rainfed conditions and under irrigation gives an indication of the contribution of irrigation towards crop diversification and hence improvement of agricultural production in the schemes.

In Matanya the crops grown under rain-fed condition are maize, beans, sweet potatoes and Irish potatoes (Appendix 12). Under irrigation, in addition to the above crops, tomatoes, onions and cabbage are also grown (Appendix 13). In Thome the crops grown under rain-fed conditions are maize, beans and Irish potatoes whereas under irrigation tomatoes, onions and cabbage are grown in addition (Appendix 14). In Aguthi the crops grown under rainfed conditions are wheat, maize, beans and potatoes whereas under irrigation the crops grown are maize, beans, tomatoes, carrots, onions, snow peas and cabbage (Appendix 15)

Among the rain-fed crops Irish potatoes is the dominant crop in all the furrow sections with a mean of 0.15 ha, 0.18 ha and 0.18 ha per household in the head, middle and tail sections respectively. Under irrigation maize is the dominant crop with a mean of 0.45 ha, 0.5 ha and 0.34 ha per household in the head, middle and tail sections of the furrow respectively.

The cropping patterns in the three schemes show that irrigation has contributed to improvement of cropping patterns by enabling crop diversification. In particular irrigation has enabled production of horticultural crops that could not be grown under rain-fed conditions due to low rainfall and short rainy seasons experienced in the scheme areas. Although irrigation has resulted in crop diversification, this is more pronounced in the head and middle sections of the schemes in Matanya and Thome. In the tail sections of these schemes only a small percentage of the sample farmers grew horticultural crops due to scarcity of irrigation water. In Thome only 14.3%, 21.4% and 7.1% of the sample households in the tail section grew tomato, onion and cabbage respectively. In Matanya 10%, 0% and 0% grew tomato, onion and cabbage respectively in the tail section of the scheme. In Aguthi majority of the sample farmers in all the sections grew horticultural crops thereby spreading the benefits of irrigation more evenly in the whole scheme than either Matanya or Thome.

4.6.2 Crop yields

Table 22 shows the yield levels reported by farmers for the various crops under irrigation and rain-fed farming. These yields vary widely from household to household within the schemes and also between the schemes as indicated by the standard deviations and coefficients of variability (CV) of the computed mean yields (See Appendices 12, 13, 14 and 15). These yields reflect the varying levels of crop husbandry practices on individual household plots.

Table 22: Farmer-reported mean crop yields (kg/ha) under irrigation and rain-fed farming (1994/95).

Scheme	Maize		Beans		Potato		Tomato	Cabbage	Onion	Snow Peas
Matanya	Irri.	Rainfed	Rainfed.	Irri	Irri.	Rainfed	Irr.	Irr.	Irr.	Irr.
Head	1341	994	375	794	3505	2663	18704	5875	1300	–
middle	1292	594	571	845	4639	3454	5871	7000	7500	–
Tail	1137	1159	613	673	4131	5464	8875	–	–	–
Mean	1257	916	520	771	4092	3860	11150	6438	4400	–
Thome	Irr.	Rainfed	Rainfed	Irr.	Irr.	Rainfed	Irr.	Irr.	Irr.	Irr.
Head	1783	1175	853	1638	3122	3875	3135	3869	874	–
Middle	1398	1215	1908	3150	3986	2978	2169	5033	1228	–
Tail	1331	841	1237	1375	4917	4180	3200	2000	1328	–
Mean	1504	1077	1333	2054	4008	3677	2837	3634	1443	–
Aguthi	Irr.	Rainfed	Rainfed	Irr.	Irr.	Rainfed	Irr.	Irr.	Irr.	Irr.
Head	1483	1002	1125	1190	3597	3875	9936	9366	2400	2481
Middle	1259	806	993	1040	2736	2673	7955	6089	1272	2237
Tail	1371	1159	1130	1434	3604	3150	8887	8986	3340	2353
Mean	1371	989	1083	1221	3312	3233	8926	8147	2337	2357

Source: Field survey, 1995

The Irrigated maize yields were highest in the head and lowest in the tail sections of the schemes whereas rain-fed maize had the lowest yields as shown by the Duncan's Multiple Range Test. The yields were significantly different at the 5% level of significance between scheme sections and between irrigation and rain-fed conditions (See Table 23). This shows that the unequitable allocation of irrigation water between scheme sections affects maize performance.

Bean yields were highest under irrigation than under rain-fed farming but lowest in the head section under irrigation. However, these differences are not significantly different at the 5 % level of significance except between the schemes (See Table 24). This shows that water is not the main constraint for bean production in "normal" seasons and that irrigation may not be necessary. The lower reported yields in the head scheme sections under irrigation could be explained to be a result of over-irrigation with the attendant poor root zone aeration. This conforms to findings by Carruthers and Clark (1983) that where water is unpriced, farmers tend to apply water frequently and wastefully.

Table 23: ANOVA table on farmer-reported maize yield

Source	SS	Df	MS	F_{cal}	$F_{0.05}$
Block	1242273.17	2	62136.58	7.034	0.0027*
Treatments	501664.25	3	167221.42	18.93	0.0018**
Error	53001.5	6	8838.58		
Total	678938.92	11			

* = Significant ** = Highly Significant

Duncan's Multiple Range Test

Rank	Treatment #	Mean	Non-significant ranges
1	1	1535.667	3a
2	2	1316.333	3b
3	3	1279.667	3b
4	4	962.667	3c

Error mean square = 8833.853
df = 6
Significance level = 5%
$LSD_{0.05}$ = 187.78

Table 24: ANOVA table on farmer-reported bean yield

Source	SS	df	MS	F_{cal}	$F_{0.05}$
Block	174454.17	2	872270.58	9.546	0.0137*
Treatments	518286.25	3	172762.08	1.891	0.232 ns
Error	548271.5	6	91378.58		
Total	2811098.92	11			

ns = non-significant * = Significant

Duncan's Multiple Range Test

Rank	Treatment #	Mean	Non-significant ranges
1	4	1349	3a
2	2	1157	3a
3	3	993	3a
4	1	784	3a

Error mean square = 91378.58
Df = 6
Significance level = 5%
$LSD_{0.05}$ = 603.94

Potato yields were not significantly different at 5 % level of significance between schemes, scheme sections or between irrigated and rain-fed farming (See Table 25). This implies that in normal seasons, rainfall is adequate for potatoes and that, factors other than water, especially poor husbandry practices, constrain potato production.

Table 25: ANOVA for farmer-reported potato yield

Source	SS	df	MS	F_{cal}	$F_{0.05}$
Block	1328128.67	2	664064.33	2.229	0.1887 ns
Treatments	1102988.25	3	367662.75	1.235	0.3764 ns
Error	1786780	6	297796.67		
Total	4217896.92	11			

ns = non-significant * = Significant

Duncan's Multiple Range Test

Rank	Treatment #	Mean	Non-significant ranges
21	3	4217	3a
2	2	3787	3a
3	4	3574	3a
4	1	3408	3a

Error mean square = 297796.67
df = 6
Significance level =5%
$LSD_{0.05}$ =1090.27

As Meizen-Dick *et al* (1993) point out, because farmers cannot recall cropped areas and yields of multiple crops accurately, these errors are magnified when yields are extrapolated to a per hectare basis. The potential error in the reported yields is therefore high and considerable caution is necessary in interpreting them. As such these yields should be regarded as being indicative rather than absolute values as indicators of agronomic performance.

4.6.3 Cropping Intensities

Cropping intensities are an indication of the level of productivity to land. The cropping intensities are based on the total mean area cultivated annually under irrigation or rainfed farming to the total holding size available for irrigation or rainfed farming. Higher cropping intensities were realised under irrigation than under rainfed conditions in all the schemes and furrow sections (See Table 26). These higher cropping intensities are attributed to the larger number of cropping seasons that are realised annually under irrigation. Most farmers reported two or three crops for the horticultural crops and beans and two crops of maize annually under irrigation. Under rainfed conditions the number of crops realised annually were zero for horticultural crops (except in exceptionally wet years when a crop could be realised), one or two for beans and one or none for maize.

As shown in Table 26, cropping intensity varies widely along the scheme sections. In Matanya cropping intensity decreases from head tail section of the furrow. This is expected because farmers in the head section have better access to irrigation water throughout the year than farmers in other sections enabling them to cultivate more area annually.

Table 26: Computed cropping intensities (%) on irrigated and rain-fed plots 1994).

Scheme	Head section		Middle section		Tail section	
	irrigated	rainfed	irrigated	rainfed	irrigated	rainfed
Matanya	228.7	181.0	209.0	210.3	177.8	169.6
Thome	246.7	130.7	294.4	266.7	301.1	209.6
Aguthi	265.0	119.0	249.0	70.4	326.1	82.9

4.7 Economic Performance

4.7.1 Primary sources of food

Results indicate that 44.6, 40.7 and 38.3 percent of the sample households are primarily dependent on irrigation for food in Matanya, Thome and Aguthi respectively (See Figures 15, 16 and 17). This is explained by the fact that Aguthi has higher rainfall than Matanya and Thome hence farmers depend significantly on rainfall for food production. In all the schemes irrigation accounts for the largest share of the primary sources of food for the households. This shows that as far as food production is concerned irrigation plays a big role in the economy of the schemes although it is carried out to supplement rainfall in the production of maize, beans and Irish potatoes which are the major food crops.

When the furrow sections are considered, in all the schemes a higher percentage of farmers in the head sections are dependent on irrigation for food. However, in Matanya and Thome majority of the sample households are dependent on rainfed agriculture for food in the tail-end sections. This is an indication that farmers nearest to the intake benefit more from irrigation than the farmers further downstream because they have better access to irrigation water than those downstream. In Aguthi the trend is slightly different in that in all the sections almost equal percentages of households are dependent on irrigation for food production. This is an indication of a more equitable distribution of irrigation water in the scheme than in Matanya and Thome.

Fig. 15: Primary Source of food (Matanya, 1994/5)

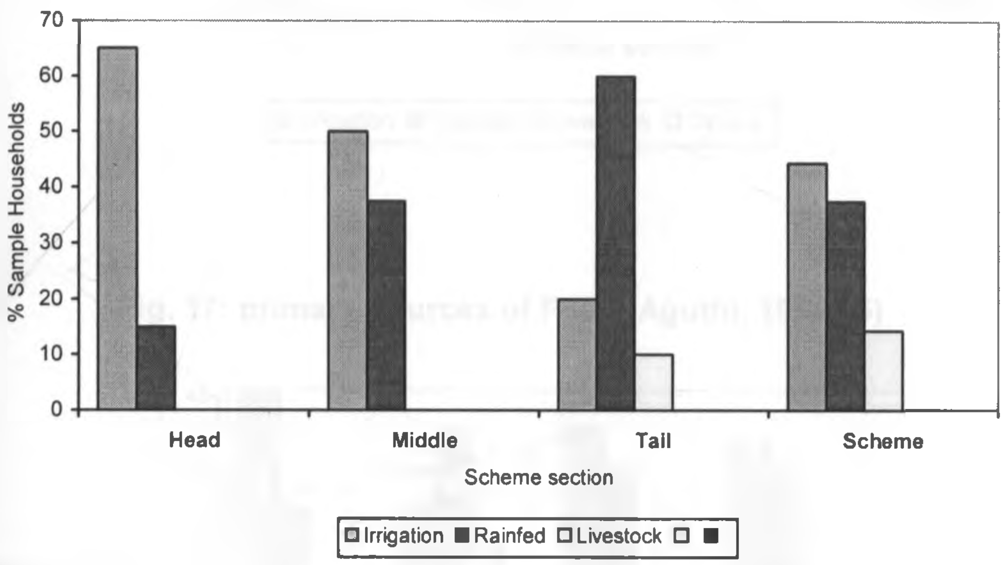


Fig. 16:Primary sources of Food(Thome, 1994/95)

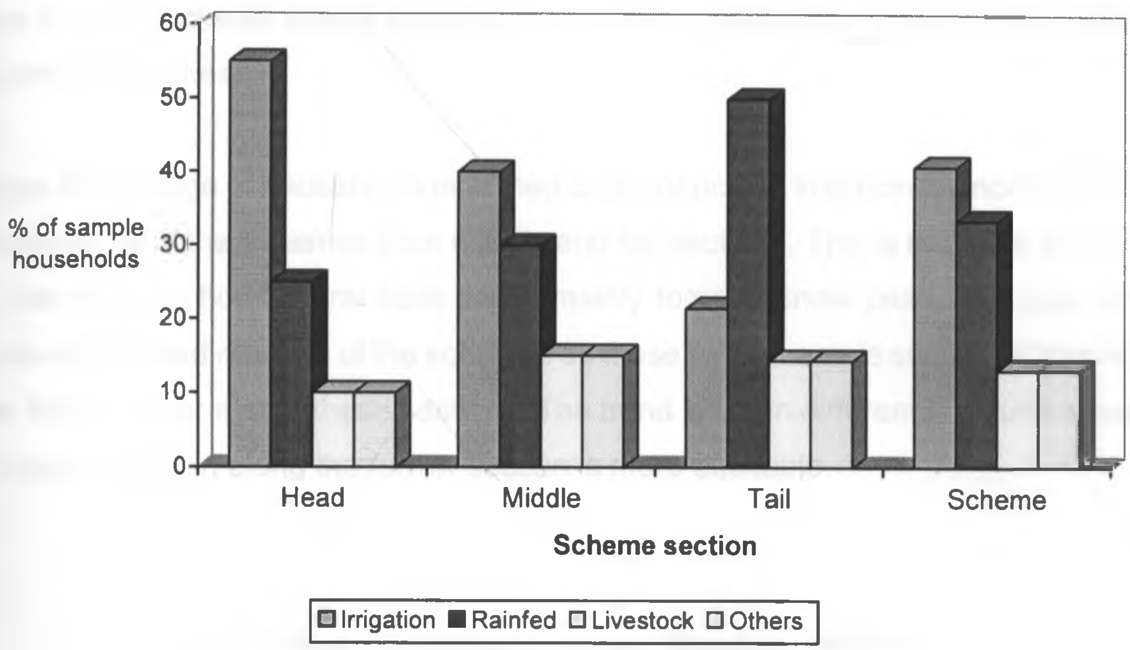
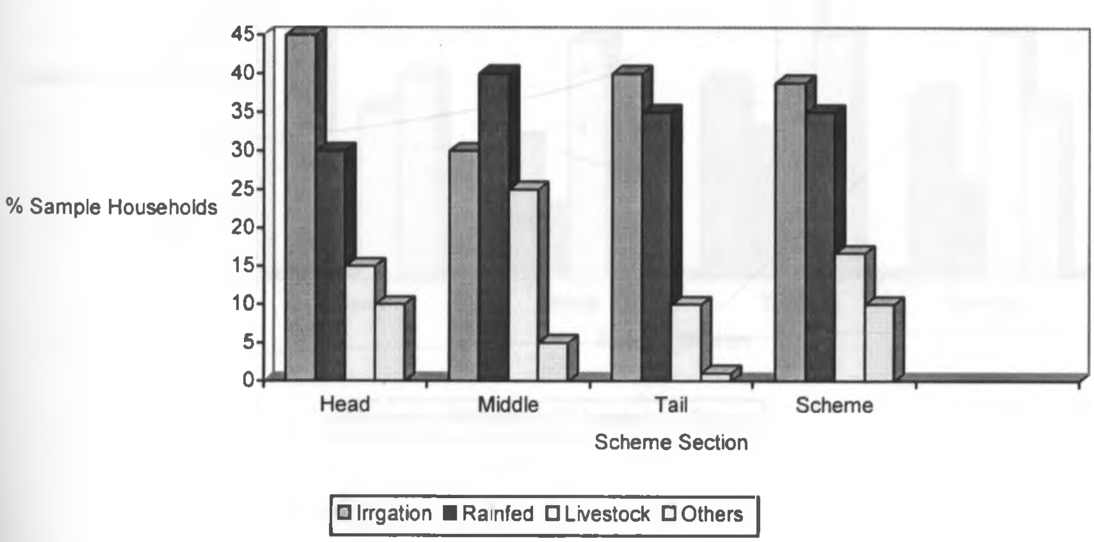


Fig. 17: primary Sources of Food (Aguthi, 1994/95)



4.7.2 Primary sources of income

Livestock enterprises are the major sources of income in all the three schemes although there are variations in individual sections (See Appendix 17 and Figures 18, 19 and 20).

As a primary source of income, irrigation ranks second in all the schemes. As mentioned in the introduction, the schemes are located in a traditionally ranching zone where livestock namely sheep, goats, dairy and beef cattle feature prominently in the economy of the area.

A larger percentage of households indicated dependence on irrigation for income in the head sections of the schemes than middle and tail sections. This is because farmers are able to grow horticultural cash crops mainly tomato, snow peas, cabbage and carrots in the Head reaches of the schemes as these require ample supply of irrigation water that is better met in these sections. The trend is again different in Aguthi where the water allocation along the furrow section is more equitable.

Fig. 18:Primary Sources of income (Matanya, 1994/95)

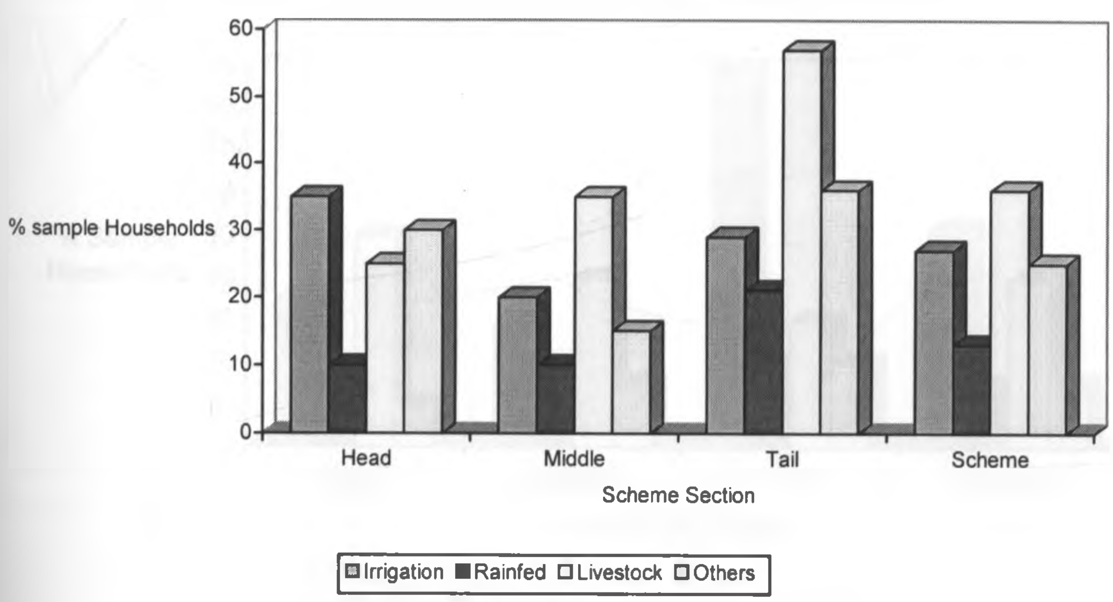


Fig. 19: Primary Sources of Income(Thome, 1994/95)

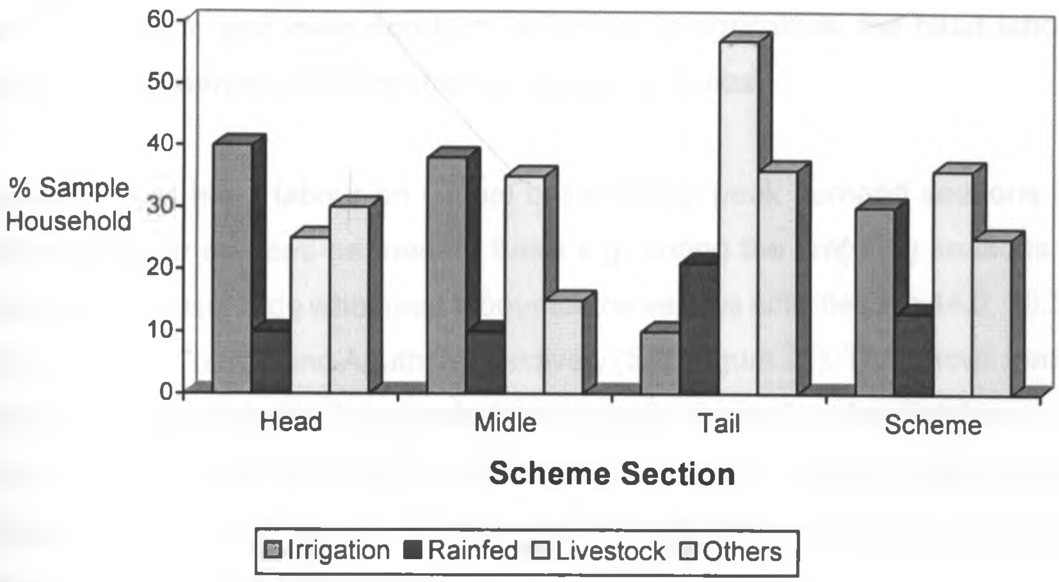
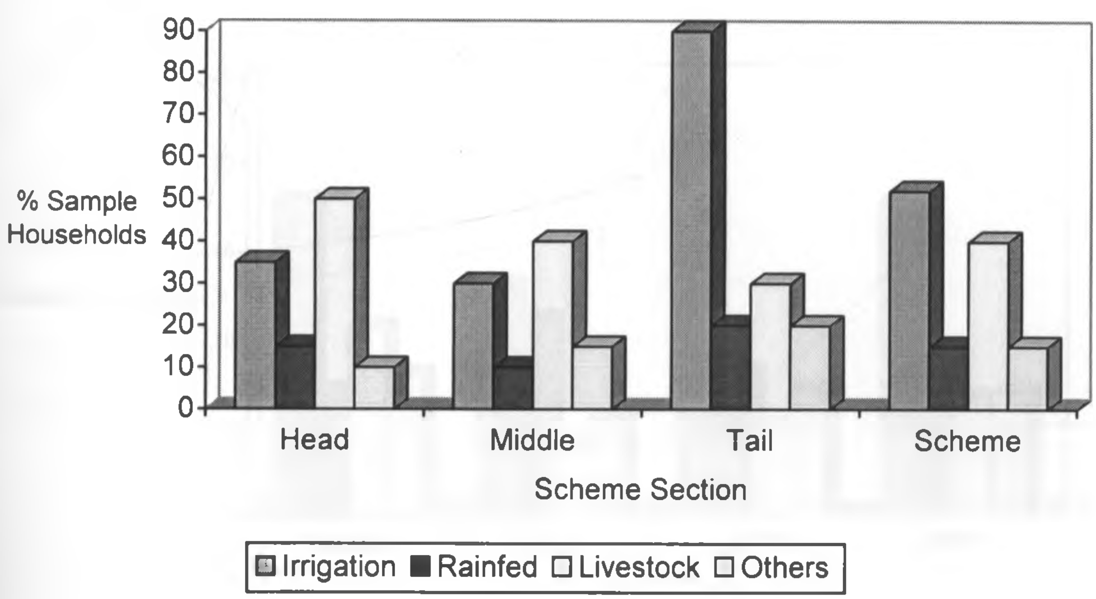


Fig. 20: Primary Sources of Income (Aguthi, 1994/95)

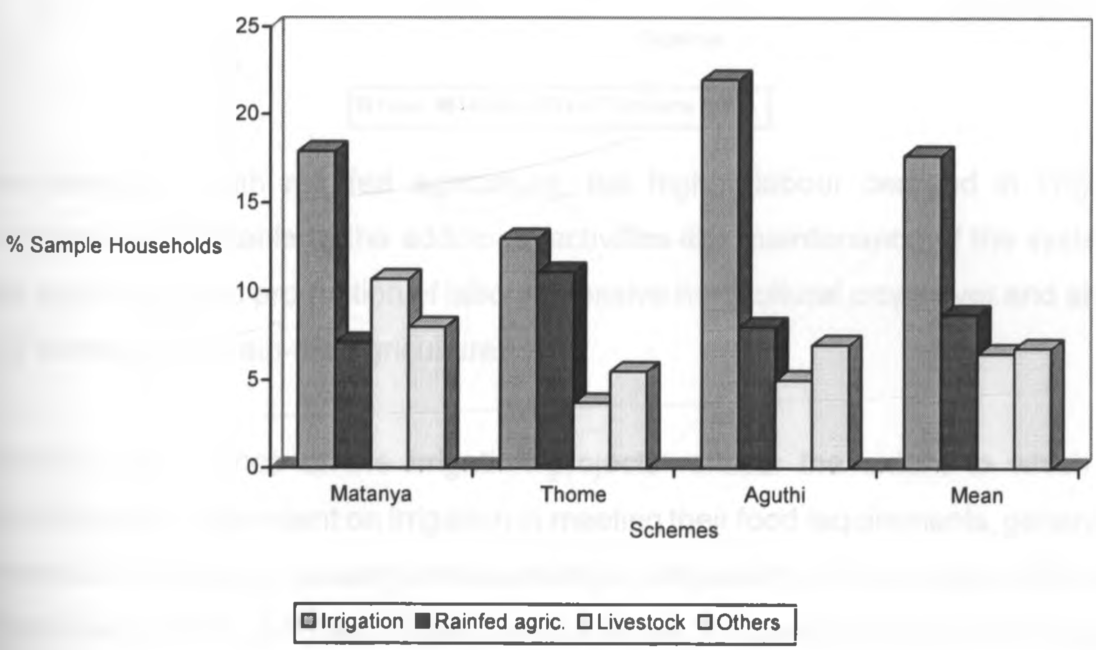


4.7.3 Employment Generation

Agriculture is the major source of employment in rural communities. Although the size of labour does not give a measure of labour productivity, the proportion of households that hire labour to supplement the family labour can be used as an indicator of the extent to which irrigated agriculture contributes to employment generation in these rural communities. Households that hired labour used it in various activities like tending livestock, cultivation and even non-farm activities. In agriculture the hired labour is mainly used for watering, weeding and harvesting activities.

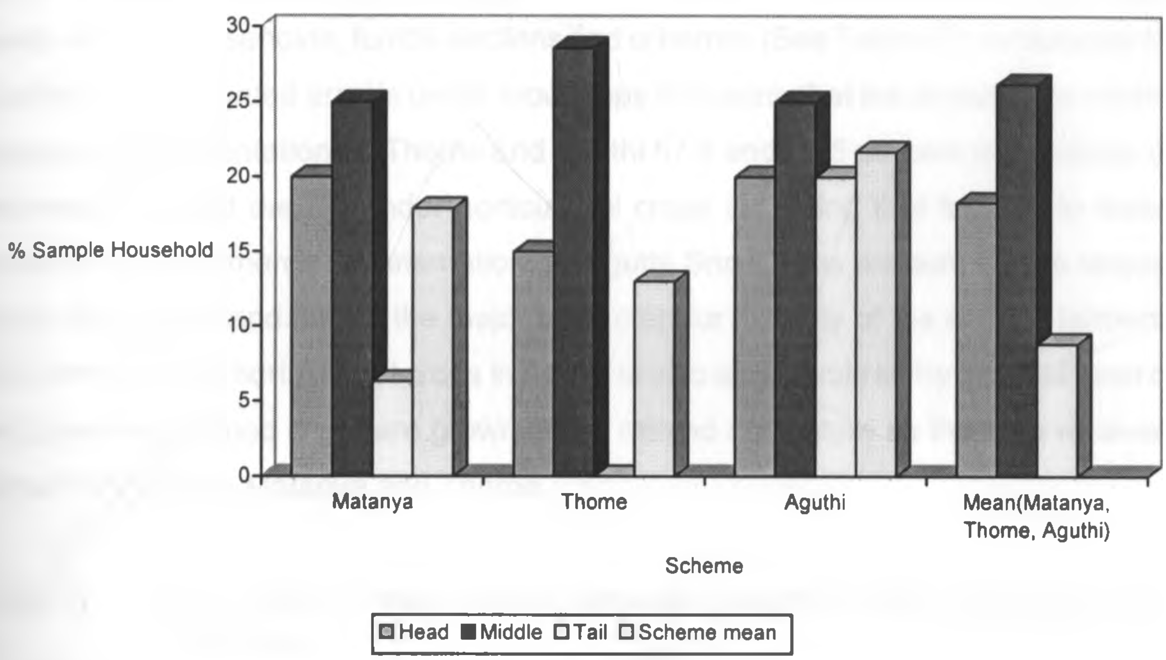
Some households hired labour on casual basis during peak demand seasons while others hired labour on semi-permanent basis e.g. during the cropping seasons. The percentages of households who hired labour for the various activities are 44.6, 35.3 and 41.7 for Matanya, Thome and Aguthi respectively (See Figure 21). This shows that in all the three schemes majority of the households usually depend on family labour for the various activities. Most of the hired labour is used in irrigation related activities meaning that irrigation is the major source of employment in the three systems when the major activities are considered (See Figure 21).

Fig. 21: Percentage of sample Households Who Hirred labour for various activities (1994/95)



When the individual furrow sections are considered, most labour under irrigation is used in the head and middle sections in Matanya and Thome where irrigation activities are concentrated. In Aguthi the proportions of households that utilise hired labour for irrigated agriculture are almost equal in all the sections of the furrow (See Figure 22). A larger proportion of sample households allocated hired labour to irrigation in Aguthi than either Matanya or Thome because in Aguthi majority of the sample farmers grew snow peas which is a more labour intensive horticultural crop than the other crops.

Fig. 22: Percentage of sample Households Who allocated hired labour under irrigation



When compared with rain-fed agriculture, the higher labour demand in irrigated agriculture is attributable to the additional activities like maintenance of the systems, water application and production of labour intensive horticultural crops over and above those carried out in rain-fed agriculture.

Economic performance of the irrigation projects reflects the extent to which the beneficiaries are dependent on irrigation in meeting their food requirements, generating household incomes and creating employment as compared to other sources. Although self-reported primary sources of food and income are not ideal indicators of the level of dependence because they do not measure actual incomes and food production, they provide an indication of farmers' orientation and the importance they attach to irrigation (Meinzen-Dick *et al*, 1993).

4.7.4 Production orientation

The composition of the cropping pattern is an indication of the orientation of production to either subsistence or commercial. The proportion of irrigated area under high-value horticultural crops is an important determinant of the economic performance of the irrigation projects.

The percentage of mean irrigated area per household under horticultural crops varies widely among households, furrow sections and schemes (See Table 27). In Matanya 59 % of the mean irrigated area is under food crops indicating that the farmers are mainly subsistence in orientation. In Thome and Aguthi 57.8 and 65.5 percent respectively of the mean irrigated area is under horticultural crops indicating that farmers in these schemes are commercial in orientation. In Aguthi Snow peas account for the largest share of irrigated land as it is the major cash crop for majority of the sample farmers. The dominance of horticultural crops in Aguthi is also attributable to the fact that most of the conventional food crops are grown under rainfed agriculture as the area receives higher rainfall than Matanya and Thome.

Table 27: Percentage of mean irrigated area per household under horticultural and food crops.

Scheme	Head section		Middle section		Tail section		Scheme Mean	
	Hort. crops	Food crops	Hort. crops	Food crops	Hort. crops	Food crops	Hort. crops	Food crops
Matanya	37.7	62.3	54.6	45.4	30.8	69.2	41.0	59.0
Thome	68.0	32.0	48.4	51.6	62.9	37.1	59.8	40.2
Aguthi	69.3	30.7	60.4	39.6	66.7	33.3	65.5	34.5

4.8 Constraints to Agroeconomic performance

4.8.1 Level of Agronomic practices

The level of crop husbandry practices practised by the farmers varies from farmer to farmer and crop to crop. Table 28 shows the percentage of sample farmers who practised the various husbandry practices in each crop for the three schemes. Majority of the sample farmers used certified seed except for maize and beans where farmers tended to use seed from the previous seasons' crops. In the three schemes, use of certified seed and weed control were practised by 65% of the sample farmers whereas less than 50% of the sample farmers practised the other husbandry practices ie 34.8%, 27.0%, 30.9% and 33.2% for use of commercial fertilizer, manure, crop protection chemicals, and crop rotation respectively. Majority of the sample farmers weeded their crops except for cabbage and onion probably because these were not considered as priority crops. Only a minority of the sample farmers used commercial fertilizer, manure and pest and diseases control chemicals. The level of agronomic practices was high in tomato, potato and Snow peas which are high-value cash crops for the farmers. From the data it is apparent that the level of agronomic practices in the irrigation projects is low to moderate.

Table 28: Percentage of sample farmers who practised the various husbandry practices in different crops (1994/95)

Crop	Certified seed	Fertilizer	Manure	Crop protection chemicals	Weed control
Maize	39.0	49.1	21.1	29.0	59.6
Beans	32.1	6.3	6.7	8.8	59.9
Tomato	69.1	41.6	39.6	49.4	59.3
Potato	53.2	40.1	46.0	58.3	55.8
Onion	81.0	31.5	14.4	10.6	47.7
Cabbage	100.0	36.6	37.3	23.8	47.5
Carrots	100.0	25.0	50.0	25.0	75.0
S.peas	76.7	67.4	8.8	52.9	70.6

Although the percentage of sample farmers carrying out the various husbandry practises does not give a quantitative measure of the effectiveness and economic rationale of these practices, it gives an indication of the level of agronomic practices and its influence on the realised crop yields.

4.8.2 Irrigation Infrastructure.

The three irrigation schemes are gravity-fed furrow systems and farmers use them for domestic, livestock and irrigation purposes.

In Aguthi and Thome diversion of water from the river is by use of permanent weirs whereas in Matanya a temporary weir is used. Water conveyance from the river to the scheme areas and fields is by unlined furrows and canals. The entire furrow system is fairly well maintained. The main furrow is subdivided into three sub-mains A, B and C from which farmers abstract water. The scheme regulations require farmers to abstract water using 2-inch pipes in order to reduce loss through seepage and to ensure a more or less equitable distribution to all the members.

Thome scheme consists of one main furrow that conveys water from the intake to the tail section of the scheme. Farmers abstract water directly from the main furrow to their fields via unlined field canals. The main furrow is well maintained except at some foot path and cattle track crossings where the furrow is damaged by human and animal traffic (See Plate 4).

Plate 4: A damaged section of main furrow in Thome scheme

The success of the maintenance is attributed to the participation by majority of the members in communal work that is carried out on Saturdays. Those using water for irrigation purposes are required to participate in the communal maintenance work. Those using water only for domestic and livestock watering purposes are not obliged to participate in maintenance work.

In Matanya scheme the main furrow is divided into two sub-mains A and B from which farmers abstract water using unlined field canals. The entire furrow system is poorly maintained and is overgrown with weeds (See Plate 5). This results in excessive water losses through consumptive use by water weeds (Phreatophytes), seepage and leakage.

Plate 5: A section of Matanya sub-main furrow overgrown with weeds

4.8.3 Irrigation Methods and Technologies

In Matanya and Thome farmers predominantly practise furrow irrigation (75.% and 72.2% respectively) whereas in Aguthi sprinkler irrigation dominates (60%) as shown in Table 29. The high percentage of sample farmers using sprinkler irrigation in Aguthi is due to scheme regulations that forbid farmers to use surface irrigation methods as these are seen to be wasteful of the scarce water resource. As much as practicable farmers are encouraged to use sprinklers to ensure efficient use of water thereby enabling households downstream have access to water.

Table 29: Percentage of sample households using various irrigation methods (1994/95)

Scheme	Section	Sprinkler	Furrow	Basin	Combination of methods
Matanya	Head	1.8	28.6	0.0	3.6
	Middle	3.6	32.1	1.8	5.4
	Tail	1.8	14.3	3.6	3.6
	Scheme	7.2	75.0	5.4	12.6
Thome	Head	7.4	22.2	0.0	0.0
	Middle	5.6	18.5	1.9	5.6
	Tail	3.7	31.5	1.9	1.9
	Scheme	16.7	72.2	3.8	7.5
Aguthi	Head	28.3	10.0	0.0	5.0
	Middle	16.7	6.7	0.0	6.7
	Tail	15.0	3.3	3.3	5.0
	Scheme	60.0	20.0	3.3	16.7

Source: Field survey

4.8.4 Irrigation Scheduling

The irrigation scheduling adopted by the farmers in Matanya and Thome is opportunistic in that farmers tend to apply as much water as possible especially in the drier seasons when the stream flow is low and demand for water highest. In Aguthi the situation is different because water allocation among the three sub-mains is on a rotational basis during the drier parts of the year. This ensures that most if not all households have access to irrigation water at least two days in a week.

As shown in table 30 farmers upstream of the furrows in Matanya and Thome tend to use shorter irrigation intervals than those further downstream. Therefore in Matanya and Thome the major determinant of depth and frequency of irrigation is availability of irrigation water but not the crop water requirements. Serious inefficiency of water utilization in these schemes results and farmers downstream experience water shortage. In Aguthi the irrigation interval is more or less uniform along the furrow as water distribution is regulated.

Table 30: Percentage of sample farmers who reported various irrigation intervals in various crops

Scheme	Crop	Irrigation Interval (days)								
		Head			Middle			Tail		
		< 5	5-10	> 10	< 5	5-10	> 10	< 5	5-10	> 10
Matanya	Maize	60.0	40.0	0.0	25.0	25.0	50.0	33.3	11.0	55.6
	Beans	62.5	37.5	0.0	50.0	12.5	37.5	11.2	33.3	55.5
	Potato	46.1	38.5	15.4	41.7	33.3	25.0	0.0	14.3	85.7
	Tomato	71.4	28.6	0.0	57.1	42.9	0.0	0.0	50.0	50.0
	Onion	100.0	0.0	0.0	50.0	50.0	0.0	-	-	-
	Cabbage	100.0	0.0	0.0	0.0	100.0	0.0	-	-	-
Thome	Maize	45.4	27.3	27.3	40.0	30.0	30.0	20.0	20.0	60.0
	Beans	54.5	36.4	9.1	36.4	45.5	18.1	25.0	12.5	62.5
	Potato	50.0	37.5	12.5	33.3	50.0	16.7	0.0	33.3	66.7
	Tomato	61.5	30.8	7.7	37.5	12.5	50.0	0.0	50.0	50.0
	Onion	40.0	30.0	30.0	36.4	27.2	36.4	33.3	33.3	33.4
	Cabbage	53.3	33.3	8.4	33.3	22.2	44.5	0.0	100.0	0.0
Aguthi	Maize	33.3	55.6	11.1	36.4	54.5	9.1	22.2	55.6	22.2
	Beans	40.0	60.0	0.0	16.7	66.7	16.6	40.0	40.0	20.0
	Potato	33.3	50.0	16.7	40.0	60.0	0.0	16.7	66.7	16.6
	Tomato	36.4	54.5	0.0	10.0	70.0	20.0	25.0	62.5	12.5
	Onion	33.3	66.2	9.1	33.3	55.6	11.1	20.0	60.0	20.0
	Cabbage	27.3	63.6	9.1	15.4	69.2	15.4	16.7	66.7	16.6
	S.peas	21.5	71.4	7.1	11.1	77.8	11.1	18.2	72.2	9.1
	Carrots	0.0	100.0	0.0	0.0	100.0	0.0	-	-	-

Source: Field Survey

4.8.5 Market Infrastructure

The three schemes are linked to Nanyuki, Naro Moru, Karatina and Nyeri partly by dry weather roads that are virtually impassable during the wet seasons. Because of the poor road conditions transportation costs for farm inputs and produce are high hence individual farmers are unable to transport their produce to the market centres.

4.8.6 Market Outlets

Horticultural produce is mainly sold at the farm level to middlemen who then resell it at the main markets at Karatina Nanyuki, Naro Moru and Nyeri. Maize and beans are normally consumed at the household level although a few farmers sell the surplus locally. Green maize is marketed as a vegetable by a few farmers because it fetches a higher price than grain maize. According to the sample farmers interviewed only Snow peas from Aguthi gets into the export market through middlemen, the principal one being an export company called Everest. Local-commercial is the major market outlet especially for horticultural produce (See Table 31).

Table 31: Percentage of sample farmers who reported various market outlets for their produce (1994/95)

Scheme	Crop	Domestic consumption	Domestic consumption+ Local commercial	Local commercial	Export commercial
Matanya	Maize	71.1	17.8	11.1	0.0
	Beans	51.2	14.6	34.2	0.0
	Tomato	12.5	18.8	68.7	0.0
	Potato	21.9	40.6	37.5	0.0
	Onion	33.3	66.7	0.0	0.0
	Cabbage	0	66.7	33.3	0.0
Thome	Maize	61.3	19.4	19.3	0.0
	beans	46.7	16.7	36.6	0.0
	Tomato	11.8	23.6	64.6	0.0
	Potato	30.4	43.5	26.1	0.0
	Onion	25.0	33.3	41.7	0.0
	Cabbage	18.2	27.3	55.5	0.0
Aguthi	Maize	65.5	20.7	13.8	0.0
	Beans	56.3	31.3	12.4	0.0
	Tomato	6.9	44.8	48.3	0.0
	Potato	29.4	47.1	23.5	0.0
	Onion	11.8	41.2	47.0	0.0
	Cabbage	12.9	22.5	64.6	0.0
	S.peas	0.0	0.0	5.9	94.1
	Carrots	0.0	25.0	75.0	0.0

Source: field Survey

4.8.7 Marketing Constraints

Majority of the farmers reported low farm-gate produce prices which they attributed to exploitation by middlemen who purchase the produce for resale in the major local towns. The poor condition of the roads during the rainy seasons when most of the horticultural products are ready for the market results in high losses and raises the cost of transportation. Individual farmers find it costly to transport their produce to the markets as they have to depend on the scarce and costly public transport. Among the marketing problems facing the schemes, majority of the sample farmers reported exploitation by middlemen as the most important (See Table 32)

Table 32: Percentage of sample households who reported various factors as the major market constraints (1994/95)

Market constraint	Matanya	Thome	Aguthi	Average
Low prices	19.6	24.1	16.7	20.0
Price fluctuations	16.1	18.5	20.0	18.2
Lack of markets	14.3	7.4	11.7	11.2
Poor communication network	10.7	14.8	18.3	14.7
Exploitation by middlemen	39.3	35.2	33.3	35.9

Source: field Survey

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The research findings are that irrigation plays a big role in the economy of the scheme areas. However, the benefits of irrigation are not equitably distributed among the scheme members because the water distribution favours farmers upstream of the furrows in Thome and Matanya who abstract excessive amounts thereby denying those downstream their rightful share.

5.1.1 Yield Response to Water

Crop height, percentage cover and yield in maize are affected by the amount of irrigation water applied during the vegetative stage of development. In treatment 1 where 33% of irrigation water requirement was applied the stress due to water deficit was severe resulting in stunted plants with low canopy cover. The depressed assimilatory surface led to the low yields realised in this treatment. In treatment 2 the water stress was negligible during the vegetative stage as indicated by insignificant depression in crop height, percentage cover and yield relative to treatment 3.

5.1.3 Agronomic Performance

Irrigation has resulted in improved crop production through improved cropping patterns that have enabled production of horticultural crops which could not be successfully grown under rainfed agriculture. Multiple cropping has also resulted in higher annual crop yields per unit of land. However, this performance varies between the scheme sections with the farmers upstream of the furrows generally performing better than those downstream. Although irrigation resulted in increased maize yield per hectare as compared to non-irrigated farming, the mean yield was low when compared to potential and actual yields reported elsewhere even under rainfed conditions. This was attributed to the low level of crop husbandry practices in the schemes. The same case applies to vegetable crops where the reported yields are low when compared to potential yields reported in other areas under tropical condition

5.1.3 Economic Performance

Irrigation has led to improved living standards of people within the scheme areas by creating jobs especially in horticultural crops which are labour-intensive, enabling successful production of maize which is the staple food crop and providing a source of income to the farmers who engage in horticulture. This income has a foreign exchange earnings component from the Snow peas grown in Aguthi for the export market.

5.1.4 Performance Constraints

Poor irrigation water management, low levels of agronomic practices and poor marketing organisation are the major problems that affect the agroeconomic performance of the irrigation schemes.

5.2 Recommendations

5.2.1 Improvement in efficiency of water use

The results show that the irrigation water applied to a maize crop can be reduced to 66% of the irrigation requirement during the vegetative phase without compromising maize yields. Given that maize is the most widely grown food crop in the schemes and that water is the major constraint to crop production, substantial amount of water could be saved if just 66% of the irrigation requirement was applied in maize. A production programme can then be adopted to incorporate crops with short growing seasons e.g. vegetables during this period (which is about 55 days) to make use of this water. This would lead to higher scheme productivity to water and higher incomes to the farmers. It would also offer an opportunity to release the unused water to downstream farmers thereby spreading the benefits of irrigation to more members.

5.2.3 Improved crop husbandry

Production can be greatly improved by improving on the level of agronomic practices especially use of certified high-yielding seed for maize and beans, fertilizer and manure use and pests and disease management. This would result in higher crop yields per unit of land and unit of water. This calls for improved agricultural extension and farmer training on agronomy and water management.

5.2.3 Improvement in water management

To improve the performance of the schemes requires the beneficiaries to address the water management problem. There is need to carry out proper maintenance of the irrigation infrastructure by clearing the furrows and canals of weeds and silt load to reduce the conveyance and distribution loses. Rotational method of water distribution is recommended in the schemes to ensure that all members have access to irrigation water. This will spread the benefits of irrigation to all the members thereby increasing the chances for the long-term sustainability of the schemes.

In Matanya and Thome conveyance losses can also be reduced if farmers abstracted and conveyed water to their fields using pipes as is the case in Aguthi. However, this investment is economically justifiable only if irrigation is concentrated on high-value horticultural crops.

The amount of irrigation water abstracted by individual farmers should be controlled by limiting the irrigation duration and net irrigated area per household. This requires redesigning schemes to determine the net irrigable area per household for an "average" crop during the periods of peak water demand .

To achieve improved water management, effective scheme organisations with elaborate by-laws and effective management should be established to ensure optimum participation of all members in maintenance work.

5.2.4 Improvement in marketing organisations

Farmers should form marketing organisations to market their horticultural produce in order to benefit from the economies of scale in transportation and also alleviate the problem of exploitation by middlemen. This would fetch farmers higher prices for their produce and therefore increase the household incomes. Formation of marketing organisations would not be difficult because most farmers already belong to dairy marketing organisations.

5.2.5 Further Research

There is a need to undertake research on the yield response to water by the other crops commonly grown in the schemes to facilitate formulation of a comprehensive strategy for water management.

REFERENCES

Acland, J. D., 1977. East Africa crops, Longman Group, United Kingdom.

Ahn, P. M. and Geiger, L. C., 1987. Soils of Laikipia of District, Reconnaissance Survey Report, Kenya Soil Survey, Government of Kenya.

Barret, J. W. H. and Skogerboe, G. V., 1978. Effect of Irrigation Regime on Maize Yields, In: Journal of the Irrigation and Drainage Division Vol. 104 No.IR2, Amer.Soc. of Civil Engineers.

Biswas, A. K., 1990. Monitoring and Evaluation of Irrigation Projects. In: Journal of Irrigation and Drainage Engineering Vol.116 No.2

Bos, M. G. and Nugteren,J., 1978. On Irrigation Efficiencies, ILRI, Wageningen, Netherlands.

Bouwer, H., 1986. Intake Rate: Cylinder Infiltrometer, In: Methods of Soil Analysis, Part 1.Agr.No.9. Amer Soc. Agr. Madison, Wisconsin.

Carruthers and Clark,1981. Economics of Irrigation, 3rd edition, Liverpool University Press.

Casey, M., 1991. Ground Water Development on Madura, Indonesia: Gender Issues in an Irrigation Project, Irrigation Network Paper 1, Overseas Development Institute, London.

Casley, D. J., and Lury, D. A., 1987. Data collection in developing countries, 2nd edition, Clarendon Press, Oxford.

Chancellor, F., 1990. Socio-economic Parameters in Designing Small Irrigation schemes, The exchange Case Study, Report ODI 121.

CoHort Softwares, 1986. COSTAT Statistical Program.

Doorenbos, J.,1976. Agro-Meteorological Field Stations, Irrigation and Drainage Paper 27, FAO, Rome.

Doorenbos, J. and Kassam, A. H., 1979. Yield Response to Water. Irrigation and Drainage Paper No.33. FAO, Rome.

Doorenbos, J. and Pruit, W. O., 1977. Crop Water Requirements, Irrigation and Drainage Paper No.24. FAO, Rome.

Eicher et al, 1970. Employment Generation in African Agriculture, Institute of International Agriculture, Research Report No. 9, Michigan State University.

FAO, 1981. Agriculture: Toward 2000, FAO, Rome.

FAO, 1986. Irrigation in Africa South of the Sahara, FAO, Rome.

FAO, 1987. Consultation on Irrigation in Africa: Proceedings on the Consultation on Irrigation in Africa held in Lome', Togo, FAO, Rome.

Fisher, K. S and Palmer, A. F. E., 1983. Maize, In: Symposium on Potential Productivity of Field Crops under different environments, IRRI, Philippines.

Fuchaka, P. W.,1993. Evaluation and Calibration of Field Techniques to Quantify Crop Cover, Unpublished Msc. Thesis, University of Nairobi.

Gates, T. K. and Ahmed, S. I.,1995. Sensitivity of Predicted Irrigation-Delivery Performance to Hydraulic and Hydrological Uncertainty, In: Agricultural Water Management Journal Vol. 27 Nos. 3, 4.

Gee, G. W. and Bauder, J. W., 1986. Particle-Size Analysis, In: Methods of Soil Analysis Part 1, Agr. Journal No. 9, Amer.Soc. Agr., Madison, Wisconsin.

Goldsworthy, P. R. and Fisher, N. M.(ed), 1984. The Physiology of Tropical Field Crops, John Wiley & Sons.

Hillel, D., 1980. Applications of Soil Physics, Academic Press.

Hillel, D., 1987. The efficient use of water in irrigation:, Principles and practices for improving irrigation in Arid and Semiarid Regions, World Bank Technical Paper No.64.

Hoetch, A., 1990. Management Information System (MIS) for Scheme and Sector Management in Irrigation: A Modular Approach. OD/TN 54. Hydraulic Research, Wallingford.

Hoffman, G. J., Howell, T. A. and Solomon, K. H.,(ed) 1990. Management of farm irrigation systems, American Society of Agricultural Engineers.

Holy, M., 1971. Water and the Environment, Irrigation and Drainage Paper 8. FAO, Rome.

Hubbard, K. R., 1982. Agronomic Requirements of Cereal Crops and their Effect on Soil Management Strategy, In: Journal and Proceedings of the Institution of Agricultural Engineers Vol. 37 (1)

Irrigation and Drainage Branch, Ministry of Agriculture, 1990, Profitability of Smallholder Irrigation in Kenya, Part I, Government of Kenya, Nairobi.

Irrigation and Drainage Branch, Ministry of Agriculture, 1990, Atlas of Irrigation and Drainage in Kenya, Government of Kenya, Nairobi

Jaetzold, R. and Schmidt, H., 1983. Farm Management Handbook of Kenya, Vol. II B, Ministry of Agriculture, Kenya.

Joblin, W. R., 1978. Tropical Disease Bilharzia and Irrigation Systems in Puerto Rico, In: Journal of Irrigation and Drainage Division Vol. 104 No. IR3, Amer. Soc. of Civil Engineers.

Joshi, M. B.; Murphy, J. S. R. and Shar, M. M., 1995. CROSOWAT: A Decision Tool for Irrigation Schedule, In: Agricultural Water Management Journal vol. 27 Nos. 3,4.

Kay, M., 1986. Surface Irrigation: Systems and Practice, Cranfield Press, UK.

Labye et al, 1988. Design and Optimization of Irrigation Distribution Networks, Irrigation and Drainage Paper No. 44. FAO, Rome.

Lenga, F. K. and Stewart, J. I., 1982. Water-Yield Response of Maize and Bean Intercrop, In: East African Agricultural and Forestry Journal. Vol. 45 (1)

Lockhart, J. A. R and Wiseman, A. J. L, 1983. Introduction to Crop Husbandry, 5th edition, Pergamon Press, Oxford.

Kamau, B. C. L., 1990. Financial Evaluation of Private Smallholder Pumped Irrigation Projects in Kiambu District, - Kenya, Unpublished Msc. Thesis, University of Nairobi.

Mbogoh, S. G,. 1989. Economic aspects of Smallholder Irrigated Rice Production in Kisumu District of Nyanza Province in Kenya: Results of 1987/88 Monitoring Survey, IDB, MoA, Nairobi.

Mbogoh,S.G and Nyameino, D.M., 1988. Results of a Performance Monitoring Survey of Eldon, Eldume and Sandai Smallholder Irrigation Schemes by Ministry of Agriculture in 1987, IDB, MoA, Nairobi.

Meinzen-Dick, R Makombe, G. and Sullins,M., 1993. Agro-economic Performance of Smallholder Irrigation in Zimbabwe, Paper presented at UZ/IFPRI/AGRITEX conference on Irrigation Performance in Zimbabwe, Aug. 1993.

Ministry of Planning and National Development, 1989, Sixth Development Plan of 1989 – 1993, Government of Kenya, Nairobi.

Mugah, J. O. and Stewart, J. I., 1982. Water Use of Katumani Composite B Maize as Determined from Climatic Data, In: East African Agricultural and Forestry Journal, Vol. 45(1).

Mukhebi, A. W.,1981. Income and Employment Generation in Kenyan Small-scale Agriculture, Ph.D Thesis, Washington State University.

Nyabundi, J. O. and Hsiao. T. C., 1989. Effect of Water Stress on Growth and Development of Field-grown Tomato (1), Canopy Development and Biomass Accumulation, In: East African Agricultural and forestry Journal Vol. 55 (1).

Osoro, C. M., 1982. Small-scale Irrigation and Drainage Development Programme in Kenya, In: Farm Water Management, Proc. of the Expert Consultation on Farm Water Management in Islamabad, Sept. - Oct. 1981, FAO, Rome

Otwera, A. O., 1984. Evaluation of Causes of Problems and Failures in Kibirigwi irrigation Scheme with special reference to Socio-economic factors, Post-Graduate Diploma in Irrigation Thesis, University of Nairobi.

Pike, J. G., 1995. Some aspects of Irrigation System Management in India, In: Agricultural Water Management Journal vol. 27 No.2.

Prewitt K., 1980. Introductory Research Methodology: East African Application, Occasional Papers No.101, first Print, Institute of Development Studies, University of Nairobi.

Sagardoy, J. A.; Bottral, A.and Uittenbogaard, G. O., 1982. Organization, Operation and Maintenance of Irrigation Schemes, Irrigation and Drainage Paper No. 40. FAO, Rome.

Schilfgoarde, J.,1994. Irrigation: A Blessing or a Curse, In: Journal of Agricultural Water Management. Vol. 25/3.

Steel, R. G. and Torrie, J. H., 1980. Principles and Procedures of Statistics: A Biometric Approach, 2nd edition, Mcgraw-Hill International Editions, Statistics Series.

Teare, I. D.and Peet, M. M.(ed), 1983. Crop-Water relations, John Wiley & Sons.

Tiffen, M., 1987. The Dominance of the Internal Rate of Return (EIRR) as a Planning Criterion and the Treatment of O & M Cost in Feasibility Studies, Irrigation Management Network Paper 87\b, ODI\IIMI.

Tindall, H. D., 1983. Vegetables in the Tropics, Macmillan Education, London.

Todorov, A.V., 1977. Guide Book for Agro-meteorological Observations, East African Meteorological Department, Nairobi.

Water Management Research Project Staff, 1980. Problem Identification Manual, Water Management Technical Report No.65 B, Engineering Research Centre, Colorado State University.

World Bank, 1986. Kenya Agricultural Sectors Report, Vol. I and II.

Worthington, E. B. (ed), 1977. Arid Land Irrigation In Developing Countries: Environmental Problems and Effects, Pergamon Press.

Yates, F., 1971. Sampling Methods for Census and Surveys, Griffin, London.

Yoder, R. and Martin, E., 1985. Identification and Utilization of Farmer Resources in Irrigation Development: A guide for Rapid Appraisal, Irrigation Management Network Paper 12 c, Overseas Development Institute, London.

Zalla, T.M., 1987. Irrigation as a Privileged Solution, In: African Irrigation Overview Main Report, Water Management Synthesis II Project (WMS), Report 37.

APPENDICES

APPENDIX 1: Sensitive Growth Periods to Water Deficit for various Crops

Alfalfa	just after cutting (and for seed production at flowering)
Banana	throughout but particularly during first part of vegetative period, flowering and yield formation
Bean	flowering and pod filling; vegetative period not sensitive when followed by ample water supply
Cabbage	during head enlargement and ripening
Citrus	
grapefruit	flowering and fruit set >fruit enlargement
lemon	flowering and fruit set >fruit enlargement; heavy flowering may be induced by withholding irrigation just before flowering
orange	flowering and fruit set >fruit enlargement
Cotton	flowering and boll formation
Grape	vegetative period, particularly during shoot elongation and flowering >fruit filling
Groundnut	flowering and yield formation, particularly during pod setting
Maize	flowering > grain filling; flowering very sensitive if no prior water deficit
Olive	just prior flowering and yield formation, particularly during the period of stone hardening
Onion	bulb enlargement, particularly during rapid bulb growth >vegetative period (and for seed production at flowering)
Pea	flowering and yield formation >vegetative, ripening for dry peas
Pepper	throughout but particularly just prior and at start of flowering
Pineapple	during period of vegetative growth
Potato	period of stolonization and tuber initiation, yield formation > early vegetative period and ripening
Rice	during period of head development and flowering >vegetative period and ripening
Safflower	seed filling and flowering >vegetative
Sorghum	flowering yield formation >vegetative; vegetative period less sensitive when followed by ample water supply
Soybean	yield formation and flowering; particularly during pod development
Sugarbeet	particularly first month after emergence
Sugarcane	vegetative period, particularly during period of tillering and stem elongation > yield formation
Sunflower	flowering > yield formation > late vegetative, particularly period of bud development
Tobacco	period of rapid growth > yield formation and ripening
Tomato	flowering > yield formation > vegetative period, particularly during and just after transplanting
Watermelon	flowering, fruit filling > vegetative period, particularly during vine development
Wheat	flowering > yield formation > vegetative period; winter wheat less sensitive than spring wheat

Source: Doorenbos and Kassam, 1979

APPENDIX 2: Agro-economic Survey Questionnaire.

1. General Information

Name of Enumerator ....
Name of Farmer ....
Name of Scheme ....
Total holding size ________ (acres/ha)
Section of furrow ________ (Head, Middle, Tail)
Date of interview ________

2. Crop Production Data

(a) What is the size of your total irrigated holding?

Last season ________ (acres/ha)
Current season ________ (acres/ha)

(b) What is the size of your rain-fed (non-irrigated holding)?

Last season ________ (acres/ha)
Current season ________ (acres/ha)

(c) (i) Which crops did you grow last season under irrigation and what were their areas and yield ?

Area (acres/ha)	Harvested Yield	Unit of measurement	Yield(kg/ha)

(ii) What crops are you currently growing under irrigation and what are their acreage and yield?

Crop	Area (acres/ha)	Harvested yield(kg/bags)	Unit of measurement	Yield(kg/ha)

(d) (i) Which crops did you grow last season on rain-fed plots and what were their areas and yield?.

Crop	Area (acres/ha)	Harvested yield	Unit of measurement	Yield (kg/ha)

(ii) Which crops are you currently growing on rain-fed plots and what are their areas and yields?

Crop	Area (acres/ha)	Harvested yield	Unit of measurement	Yield (kg/ha)

3. Agronomic Practices

(a) Do you use certified hybrid seed on your farm? Yes/No. If yes, in which crops?
1.
2.
3.
4.

(b) Do you use commercial fertilizer on your farm? Yes/No. If Yes, in which crops?
1.
2.
3.
4.

(c) Do you use manure on your farm? Yes/No. If yes, on which crops?
1.
2.
3.
4.

(d) Do you use any pest or disease control chemicals on your farm? Yes/No. If yes, which chemicals?

Crop	Chemicals

(e) Do you practice crop rotation on your farm? Yes/No. If yes, in what sequence?

Plot no.	Current crop	Last season crop	Last year's crop

f. Do you practice weed control on your farm? Yes / No. If yes, How many times per season?

Crop	No. of weedings

4. Marketing

(a) How do you dispose produce from your farm ?

Mode of Disposal	Code
Domestic consumption	A
Domestic consumption and local commercials	B
Local commercial	C
Export Commercial	E.

Crop	Mode of Disposal

(d) Do you sell any produce to middle men? Yes/No. If yes, which produce?

1.
2.
3.

(e) Do you belong to any marketing organization? If yes, which produce do you sell through the respective organizations ?

Type of market organization	Produce sold

(f) Which among the following marketing problems do you face in order of importance?

Importance of Problem	Code
Very importance	A
Fairly important	B
Unimportant	C

Problem	**Code**
1.Low prices	
2.Price fluctuations	
3.Lack of markets	
4.Poor communication network	
5.Exploitation by middlemen	

(g) On what do you primarily depend for your food and income?

Primary source of food	Code
Irrigated Agriculture	A
Rainfed Agriculture	B
Livestock	C
Others	D

Primary source of food	Primary source of Income

5. Irrigation Water Management

(a) What irrigation method(s) do you use on your farm?

Irrigation Method	Code
Sprinkler	A
Basin	B
Furrow	C
Combination	D

(b) How do you determine the irrigation frequency and depth that you use on the various crops?

Irrigation frequency	Code
Constant interval and duration	A
Dependence on water availability	B
Degree of soil wetness	C

Crop	Irrigation Interval	Criterion

APPENDIX 3: Soil Infiltration Rate Data at Experimental Sites

Matanya

Time(Hr)	0	0.08	0.17	0.25	0.33	0.5	0.67	0.83	1	1.33	1.67	2	2.5	3	3.5	4
Infiltration (mm)		14.6	13.8	11	12.4	7.8	7.4	7.8	7	7.6	6.8	6.6	6.4	6.4	6.5	6.4

Thome

Time(Hr)	0	0.08	0.17	0.25	0.33	0.5	0.67	0.83	1	1.33	1.67	2	2.5	3	3.5	4	4.5
Infiltration (mm)		16.8	14.8	10.7	12	8.2	8	7.6	7	7.8	7.2	6.8	6.6	6.8	7	6.8	6.9

Aguthi

Time (hr)	0	0.08	0.17	0.25	0.33	0.5	0.67	0.83	1	1.33	1.67	2	2.5	3	3.5	4	4.5
Infiltration (mm)		16	13.8	11.6	12	8	8.8	8	7.6	7	6.8	7.4	5.6	5.2	5.4	5.2	5.2

APPENDIX 4: Computed Irrigation Water Requirements

Date(1995)	RH (%)*	Wind*(Km/d)	K_{pan}	E_{pan}*(mm/d)	ET_o(mm/d)	K_c	ET_c	R*(mm)	IR(mm/d)
2/1	-	-	-	-	-	-	-	0.0	10.0
5/1	55.5	111.9	0.75	26.1	19.6	0.35	6.9	0.0	6.9
9/1	60.4	98.5	0.75	21.3	16.0	0.35	5.6	0.0	5.6
13/1	63.9	119.2	0.75	18.7	14.0	0.35	4.9	0.0	4.9
17/1	57.6	101.6	0.75	21.2	16.0	0.35	5.6	0.0	5.6
21/1	58.9	106.1	0.75	23.1	17.3	0.35	6.1	0.0	6.1
25/1	58.6	86.10	0.75	13.2	10.0	0.35	3.5	0.0	3.5
29/1	56.0	105.0	0.75	26.7	20.0	0.35	7.0	0.0	7.0
2/2	60.4	113.5	0.75	24.5	18.4	0.35	6.4	0.0	6.4
6/2	52.0	145.8	0.75	26.5	19.9	0.78	15.5	0.0	15.0
10/2	57.9	109.8	0.75	27.8	20.9	0.78	16.3	23.5	0.0
14/2	63.8	103.6	0.75	15.0	11.3	0.78	8.8	8.0	0.0
18/2	63.0	101.3	0.75	16.5	12.4	0.78	9.7	6.5	0.0
22/2	54.3	114.6	0.75	22.0	16.5	0.78	12.9	0.0	0.0
26/2	57.4	141.9	0.75	20.4	15.3	0.78	11.9	17.8	9.6
2/3	54.3	141.2	0.75	24.5	18.4	0.78	14.4	60.5	0.0
6/3	67.0	106.6	0.75	16.3	12.2	1.10	13.4	12.8	0.0
10/3	65.5	151.0	0.75	13.6	10.2	1.10	11.2	0.8	0.0
14/3	67.6	173.4	0.70	18.4	12.9	1.10	14.2	10.3	0.0

* Source: Matanya Agrometeorological station - LRP

APPENDIX 5: Crop coefficients

Crop Coefficient (Kc) for Field and Vegetable Crops for Different stages of crop Growth and Prevailing Climatic Conditions

Crop	Humidity	Rhminn	>70%	Rhmin.	< 20%
	Wind m/sesc.	0 – 5	5 - 6		
	Crop stage				
Artichokes	Mid-Season 3	0.95	0.95	1.0	1.05
	Maturity 4	0.90	0.9	0.95	1.0
Barley	3	1.05	1.1	1.15	1.2
	4	0.25	0.25	0.2	0.2
Beans (green)	3	0.95	0.95	1.0	1.05
	4	0.85	0.85	0.9	0.9
Beans (dry)	3	1.05	1.1	1.15	1.2
	4	0.3	0.3	0.25	0.25
Beets (table)	3	1.00	1.0	1.05	1.1
	4	0.9	0.9	0.95	1.0
Carrots	3	1.0	1.05	1.1	1.15
	4	0.7	0.75	0.8	0.85
Castor beans	3	1.05	1.1	1.15	1.2
	4	0.5	0.5	0.5	0.5
Celery	3	1.0	1.05	1.1	1.15
	4	0.9	0.95	1.0	1.05
Corn (sweet)	3	1.05	1.1	1.15	1.2
	4	0.95	1.0	1.05	1.1
Corn (Grain)	3	1.05	1.1	1.15	1.2
	4	0.55	0.5	0.6	0.6
Cotton	3	1.065	1.15	1.2	1.25
	4	0.95	0.65	0.65	0.7
Crucifers	3	0.80	1.0	1.05	1.1
	4	0.9	0.85	0.9	0.95
Cucumber	3	0.7	0.9	.095	1.0
	4	0.85	0.7	0.75	0.8
Egg Plant	3	0.95	0.85	0.95	1.1
	4	0.8	1.0	1.05	0.9
Flax	3	1.0	0.85	0.85	1.15
	4	0.25	1.05	1.1	0.2
Gram	3	10.5	0.25	0.2	1.2
	4	0.3	1.1	1.15	0.25
Lentel	3	1.05	0.3	0.25	1.2
	4	0.3	1.1	1.15	0.25
Lettuce	3	0.95	0.3	0.25	1.05
	4	0.9	1.1	1.0	1.0
Melons	3	0.95	0.3	0.9	1.05
	4	0.65	0.95	0.75	0.75
Millet	3	1.0	0.9	1.1	1.15
	4	0.3	0.95	0.25	0.25

Source: Doorenbos and Pruit, 1984.

APPENDIX 6: Recorded Mean Crop Height (cm) on Experimental plots

Matanya

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment 3 (100IR)
15/1	14	10.9	11.0	11.4
22/1	21	15.3	16.7	19.2
29/1	28	21.4	25.7	29.0
5/2	35	36.8	43.9	49.6
12/2	42	48.1	57.2	57.0
19/2	49	58.8	80.6	85.7
26/2	56	71.2	101.7	105.1
5/3	63	89.6	122.5	123.0
10/3	70	93.0	126.7	129.3

Aguthi

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment 3 (100IR)
13/1	14	8.6	8.5	9.4
20/1	21	10.5	11.7	10.7
27/1	28	14.8	18.8	19.7
3/2	35	18.6	25.1	29.4
10/2	42	25.7	44.8	52.5
17/2	49	36.1	62.4	61.6
24/2	56	51.7	86.2	85.8
3/3	63	74.8	118.8	99.9
10/3	70	87.4	131.8	148.1

Thome

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment 3 (100IR)
30/1	14	10.4	9.6	9.4
6/2	21	13.5	17.5	20.0
13/2	28	24.4	22.7	30.5
20/2	35	33.8	39.1	40.6
27/2	42	45.4	60.7	55.7
6/3	49	60.9	86.4	84.1
13/3	56	71.0	99.9	97.1
20/3	63	87.9	107.5	104.4
27/3	70	89.4	130.0	128.2

APPENDIX 7: Recorded Mean Crop Cover (%m) on Experimental plots

Matanya

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66 IR)	Treatment 3 (100IR)
15/1	14	8.3	8.9	8.6
22/1	21	13.6	12.7	13.2
29/1	28	20.5	24.0	24.5
5/2	35	23.9	30.1	30.6
12/2	42	37.1	41.2	44.8
19/2	49	44.6	56.0	62.2
26/2	56	48.9	63.4	72.1
5/3	63	50.7	72.2	76.7
10/3	70	54.9	72.8	76.3

Thome

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment 3 (33IR)
30/1	14	7.8	7.9	7.7
6/2	21	13.5	12.4	13.7
13/2	28	20.4	23.3	24.6
20/2	35	24.6	30.6	31.6
27/2	42	37.7	45.8	44.9
6/3	49	44.0	58.4	61.8
13/3	56	48.6	70.5	76.5
20/3	63	51.3	75.7	78.8
27/3	70	56.3	77.6	81.4

Aguthi

Date (1995)	Days after planting	Treatment 1 (33IR)	Treatment 2 (66IR)	Treatment 3 (100IR)
13/1	14	8.5	8.4	8.2
20/1	21	13.6	12.4	13.1
27/1	28	21.4	21.8	23.5
3/2	35	25.2	31.6	30.5
10/2	42	36.2	45.4	43.9
17/2	49	43.2	60.1	61.8
24/2	56	49.9	71.9	72.9
3/3	63	52.4	74.8	72.3
10/3	70	55.1	78.0	76.1

APPENDIX 8: Example of Computed K_y using Treatment 1 Data (Matanya Scheme)

Treatment 1(33%Irrigation Requirement)

$(ET_a = .33)$

$(Y_a) = 801.7g)$

Ky $= [1 - Y_a/Y_m]/ [1 - ET_a /ET_m]$

$= [1- 801.7/1863] / [1 - .33)$

$= [1 - 0.43]/0.67$

$= 0.57/0.67$

$= 0.85$

APPENDIX 9: Total Sample Holding sizes, Rain-fed and Irrigated areas in Matanya Scheme (1994/95)

	Head section			Middle section			Tail section		
	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated
	1.28	0.2	0.6	1.28	0.8	1.0	1.28	0.2	1.2
	1.28	0.2	1.0	1.28	0.4	0.8	1.28	0.3	0.3
	1.28	0.1	0.6	1.28	0.5	0.6	1.28	0.4	0.6
	1.28	0.3	0.5	1.28	0.2	0.8	1.28	0.5	0.78
	1.28	0.2	0.6	1.28	0.3	0.5	0.8	0.1	0.7
	1.28	0.0	1.0	1.28	0.1	1.0	1.28	0.1	1.0
	1.28	0.2	0.4	0.4	0.1	0.5	1.6	0.2	0.8
	1.28	0.2	0.6	1.28	0.2	0.4	0.8	0.2	0.6
	1.28	0.2	0.8	1.28	0.4	0.6	1.28	0.4	0.6
	1.28	0.4	0.6	1.28	0.2	0.6	1.28	0.1	0.6
	1.28	0.1	0.7	1.28	0.6	1.0	1.0	0.4	0.0
	1.28	0.2	0.8	1.28	0.2	0.8	1.28	0.0	0.4
	1.28	0.1	0.5	1.28	0.6	0.1	1.28	0.3	0.8
	1.28	0.3	0.8	1.28	0.3	0.6	1.28	0.6	0.0
	1.28	0.0	0.2	1.28	0.3	0.6	0.4	0.1	0.2
	1.28	0.4	0.6	1.28	0.2	0.8	0.8	0.0	0.0
	1.28	0.2	0.8				1.28	1.0	0.0
	1.28	0.4	0.6				1.28	0.2	0.6
	1.28	0.1	0.8				1.28	0.8	0.0
	1.28	0.3	0.4				1.28	0.4	0.0
Mean	1.28	0.21	0.65	1.23	0.34	0.67	1.17	0.32	0.46
Std.dev.	0.0	0.14	0.2	0.22	0.2	0.24	0.27	0.26	0.38

Source: Field Survey

APPENDIX 10: Total Sample Holding sizes, Rain-fed and Irrigated areas in Thome Scheme (1994/95)

	Head section			Middle section			Tail section		
	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated
	1.6	0.2	0.8	1.2	0.0	0.8	2.0	0.2	0.8
	0.4	0.2	0.0	2.0	1.2	0.6	0.4	0.0	0.4
	0.8	0.0	0.8	0.4	0.0	0.2	2.4	0.6	0.8
	0.4	0.4	0.0	0.8	0.4	0.2	1.6	0.4	0.8
	0.8	0.2	0.4	3.8	2.0	0.2	8.0	3.2	3.6
	0.4	0.2	0.0	0.8	0.4	0.4	0.8	0.1	0.6
	2.0	0.6	0.6	1.2	1.2	0.0	0.8	0.0	0.6
	0.4	0.2	0.4	1.6	0.8	0.0	0.4	0.0	0.4
	0.4	0.4	0.0	0.4	0.4	0.0	0.8	0.0	0.8
	0.4	0.3	0.4	0.4	0.4	0.0	0.8	0.1	0.4
	0.4	0.4	0.0	0.8	0.4	0.2	8.0	2.8	0.4
	0.8	0.4	0.0	0.4	0.2	0.2	5.2	0.6	3.2
	0.4	0.1	0.2	0.8	0.4	0.0	0.4	0.0	0.4
	0.8	0.0	0.4	0.4	0.2	0.0	1.6	0.2	0.8
				1.2	0.8	0.2	0.8	0.1	0.6
				0.8	0.6	0.2	0.4	0.0	0.2
				0.8	0.8	0.0	0.2	0.0	0.1
				1.2	0.4	0.4	0.4	0.1	0.1
				0.4	0.0	0.2	0.8	0.2	0.54
				1.6	0.2	0.4	1.0	0.2	0.6
Mean	0.71	0.26	0.28	1.05	0.54	0.21	1.84	0.44	0.90
Std.dev.	0.50	0.17	0.30	0.79	0.49	0.22	2.38	0.089	0.98

Source: Field Survey

APPENDIX 11: Total Sample Holding sizes, Rain-fed and Irrigated areas in Aguthi Scheme (1994/95)

	Head section			Middle section			Tail section		
	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated	Total	Rainfed	Irrigated
	2.0	0.6	1.3	1.6	1.8	0.5	2.0	0.8	0.5
	2.8	1.6	0.9	2.4	0.7	0.7	0.8	0.4	0.2
	1.6	0.6	0.5	1.6	0.8	0.4	1.2	0.2	0.6
	1.4	0.1	0.2	1.4	0.7	0.5	1.4	1.0	0.3
	1.2	0.4	0.8	2.1	0.8	1.2	1.2	0.7	0.4
	1.2	0.6	0.6	1.6	0.4	0.3	1.2	0.7	0.3
	2.0	0.8	1.1	1.2	0.4	0.8	1.6	0.8	0.8
	2.4	1.6	0.7	3.0	1.2	0.6	1.4	0.7	0.1
	2.0	0.0	0.4	0.8	0.0	0.0	2.0	0.5	0.6
	0.8	0.4	0.1	0.8	0.0	0.0	1.6	0.6	0.6
	1.8	0.9	0.4	1.0	0.3	0.4	1.1	0.3	0.4
	4.0	1.4	0.5	1.6	0.6	0.7	0.8	0.4	0.2
	2.0	0.7	1.0	1.6	0.9	0.7	1.2	0.7	0.4
	1.6	0.5	0.4	1.2	0.6	0.3	2.0	0.8	0.5
	2.0	0.8	0.7	1.6	0.7	0.4	1.6	0.8	0.8
	1.6	0.5	0.7	1.4	0.5	0.2	1.4	0.7	0.1
	1.2	0.0	0.7	1.6	0.3	0.9	1.2	0.7	0.3
	1.2	0.6	0.1	1.2	0.7	0.3	3.0	0.4	0.6
	1.4	0.3	0.4	2.4	0.7	0.7	2.5	0.3	0.4
	1.2	0.2	0.8	1.2	0.4	0.8	5.0	0.8	1.0
Mean	1.77	0.63	0.615	1.57	0.625	0.52	1.71	0.615	0.46
Std.dev.	0.71	0.47	0.32	0.55	0.4	0.3	0.95	0.22	0.24

Source: Field survey

APPENDIX 12: Reported Cropped area and Crop yields under Rain-fed (1994/95)

Section	Maize			Beans			Potato		
	Area(ha)	Yield(kg)	kg/ha	Area(ha)	Yield(kg)	kg/ha	Area(ha)	Yield(kg)	kg/ha
Head	0.6	810	1350	0.1	90	900	0.1	400	4000
	0.2	315	1575	0.05	50	1000	0.2	800	4000
	0.3	270	900	0.1	60	600	0.1	300	3000
	0.6	765	1275	0.2	135	675	0.1	500	5000
	0.8	1080	1350	0.3	230	767	0.2	600	3000
	0.6	810	1350	0.4	190	475	0.4	300	750
	0.6	1080	1600	0.2	135	675	0.1	900	9000
	0.8	1400	1750	0.1	135	1350	0.2	200	1000
	0.5	585	1170	0.1	160	1600	0.15	600	4000
	0.2	360	1800	0.15	90	600	0.8	1750	2188
	0.8	450	562	0.2	90	450	0.1	600	6000
	0.6	630	1050	0.1	90	900	0.2	325	1625
	0.5	720	1440	0.3	225	750	0.1	200	2000
	0.6	810	1350	0.1	90	900			
	1.0	1350	1350	0.05	45	900			
	0.6	900	1500	0.2	90	450			
	0.2	315	1575	0.2	135	675			
	0.3	450	1500						
	0.6	990	1650						
	0.5	360	720						
Mean	0.55		1341	0.2		804	0.21		3505
Std.dev	0.22		325.7	0.1		307	0.19		2260
Middle	0.5	630	1260	0.2	135	675	0.1	200	2000
	0.6	810	1350	0.5	270	540	0.1	1000	10000
	0.8	900	1125	0.3	90	300	0.2	400	2000
	0.6	810	1350	0.6	225	375	0.1	400	4000
	0.5	540	1080	0.5	180	360	0.1	300	3000
	0.6	1080	1800	0.6	135	225	0.6	1600	2667
	0.1	180	1800	0.1	20	200	0.1	200	2000
	0.4	585	1462	0.4	360	900	0.1	1200	12000
	0.4	315	787	0.2	90	450	0.3	300	3000
	0.2	135	675	0.1	160	1600	0.4	1400	3500
	0.3	360	1200	0.3	225	750	0.2	300	1500
	0.4	600	1500	0.4	180	450	0.1	1000	10000
	0.8	1305	1631	0.4	315	788			
	0.4	540	1350	0.4	68	170			
	0.6	675	1125	0.6	360	600			
	1.0	1170	1170	0.	450	750			
Mean	0.51		1292	0.39		570.8	0.2		4638.9
Std dev.	0.23		313.5	0.17		355.4	0.16		3734
CV	10.42		76.1	7.82		221.3	12.7		3005.6

Appendix 12 cont.

Section	Maize			Bean			Potato		
	Area (ha)	Yield (kg)	kg/ha	Area(ha)	Yield (kg)	kg/ha	Area (ha)	Yield (kg)	(kg/ha)
Tail									
	0.4	405	1012	2.0	135	675	0.1	800	8000
	0.3	315	1050	0.2	156	788	0.1	800	8000
	0.2	270	1350	0.4	180	450	0.2	750	3750
	0.5	450	900	0.2	105	525	0.2	500	2500
	0.6	450	750	0.3	90	300	0.1	300	3000
	0.3	495	1650	0.1	68	680	0.1	67	667
	0.3	315	1050	0.2	135	675	0.2	600	3000
	0.3	405	1350	0.1	75	750			
	0.2	225	1125	0.2	135	675			
Mean	0.34		1137	0.2		613.1	0.14		4131
std dev.	0.13		271.7	0.09		157.2	0.05		2807.8
CV	5.23		64.9	4.1		40.3	2.04		1908.4
	Tomato			Onion			Cabbage		
Head	0.3	7030	23433	0.1	130	1300	0.2		6750
	0.4	11000	27500				0.1	350	5000
	0.1	1200	12000					500	
	0.2	2600	13000						
	0.1	1800	18000						
	0.1	2500	25000						
	0.1	1200	12000						
Mean	0.19		18704	0.1		1300	0.15		5875
Std dev.	0.12		6611.8	0.0		0	0.07		1237.4
CV	7.77		2337.2	0		0	3.27		260.6
	0.1	160	1600	0.1	300	3000	0.1	700	7000
Middle	0.1	200	2000	0.1	1200	12000			
	0.1	400	4000						
	0.1	1500	15000						
	0.1	1600	16000						
	0.1	1000	10000						
	0.1	600	6000						
Mean	0.1		5871	0.1		7500	0.1		7000
Std dev	0.0		5408	0.0		6363.7	0.0		0
CV	0		4981.5	0.0		5399.6	0.0		0
Tail		275	2750						
	0.1	1500	15000						
	0.1								
Mean	0.11		8875						
Std.dev	0.0		8662						
CV	0.0		8454.2						

APPENDIX 13: Reported Crop area and Harvested yields in Matanya Scheme (1994/95)

Section	Maize			Beans			Potato		
	Area (ha)	Yield (kg)	Kg/ha	area (ha)	Yield (kg)	kg/ha	Area (ha)	Yield (kg)	kg/ha
Head	0.2	765	3825	0.2	360	1800	0.1	600	6000
	0.1	360	3600	0.2	90	450	0.2	800	4000
	0.2	90	450	0.3	180	600	0.2	900	4500
	0.2	135	675	0.1	90	900	0.4	1600	4000
	0.2	270	1350	0.2	450	2250	0.8	2400	3000
	0.3	180	600	0.4	60	150	0.1	200	2000
	0.4	540	1350	0.8	300	375	0.3	600	2000
	0.8	810	1013	0.6	135	225	0.4	750	1875
	1.0	450	4500	0.3	225	750			
	0.1	90	900	0.1	160	1600			
	0.6	810	1350	0.5	140	280			
Mean	0.4		1783	0.3		584	0.3		3421
Std dev	0.3		1456	0.2		714	0.2		1468
CV	24		1185	143		875	17		630
Middle	1.2	720	600	0.2	1350	6750	0.1	700	7000
	0.4	225	563	0.1	135	1350	0.2	800	4000
	0.2	270	1350	0.1	315	3150	0.1	600	6000
	0.4	450	1125	0.2	540	2700	0.2	450	2250
	0.8	540	675	0.2	270	1350	0.1	300	3000
	0.4	675	1563	0.4	720	1800	0.3	500	1667
	0.2	630	3150	1.2	1080	900			
	0.1	180	1800	0.1	180	1800			
	0.3	675	2250	0.6	248	413			
	0.4	360	900	0.75	360	480			
	-			0.3	90	300			
Mean	0.4		1398	0.4		1908	0.2		3986
Std.dev	0.3		828	0.4		1848	0.1		2122
CV	25		490	32		1789	3.8		1129
Tail	0.13	180	1385	0.2	180	900	0.1	600	6000
	0.2	225	1125	0.1	135	1350	0.1	500	5000
	0.2	315	1575	0.1	90	900	0.2	750	3750
	0.1	90	900	0.1	100	1000			
	0.2	180	900	0.3	315	1050			
	0.1	180	1800	0.1	135	1350			
	0.3	405	1350	0.2	270	1350			
	0.1	135	1350	0.1	200	2000			
	0.1	180	1800						
	0.2	225	1125						
Mean	0.1		1331	0.2		1237	0.1		4917
Std.dev	0.1		326	0.14.3		366	0.1		11272595
CV	3.0		80.1			108	2.8		

Appendix 13 Cont.

Section	Tomato			Onion			Cabbage		
	Area(ha)	Reported yield(Kg)	Yield (Kg/ha)	Area (ha)	Reported Yield(kg)	Yield (kg/ha)	Area (ha)	Reported yield(kg)	Yield (kg/ha)
Head	1.6	4000	2500	0.2	200	1000	0.4	1600	4000
	0.4	300	750	0.2	150	750	0.4	2000	5000
	0.4	350	875	0.4	200	500	0.2	1350	6750
	0.2	200	1000	0.8	650	812	0.4	2500	6250
	0.4	400	1000	0.4	235	588	0.2	500	2500
	0.4	300	750	0.4	400	1000	0.4	650	1625
	0.8	6000	7500	0.4	450	1125	0.8	1000	1250
	0.2	2500	12500	0.1	130	1300	0.4	2600	6500
	0.8	4500	5625	0.3	300	1000	0.1	600	6000
	0.4	600	1500	0.6	400	667	0.3	900	3000
	0.1	300	3000				0.6	750	1250
	0.2	350	1750				0.1	230	2300
	0.1	200	2000						
Mean	0.46		3135	0.38		874	0.36		3869
std.dev	0.4		3474.7	0.201		252.9	0.2		2144.2
CV	34.8		385121	1.0		7476	11.1		118832
Middle	0.2	600	3000	0.2	500	2500	0.2	1000	5000
	0.2	250	1250	0.1	50	500	0.4	2500	6250
	0.1	700	7000	0.4	200	500	0.2	1800	9000
	0.2	400	2000	0.2	500	2500	0.1	700	7000
	0.3	480	1600	0.2	300	1500	0.1	650	6500
	0.2	1200	6000	0.1	150	1500	0.3	750	2500
	0.1	200	2000	0.3	250	1250	0.2	1000	5000
	0.2	2000	1000	0.2	120	600	0.1	180	1800
				0.2	160	800	0.2	480	2250
				0.1	140	1400			
				0.3	137	457			
Mean	0.19		2169	0.21		1228	0.2		5033
Std.dev	0.06		1674	0.1		751.3	0.1		2445
CV	2.16		129197	4.76		45965	5.0		118777
Tail	0.2	360	3600	0.3	340	1133	0.1	200	2000
	0.2	280	2800	0.2	230	1150			
				0.1	170	1700			
Mean	0.2		3200	0.2		1328	0.1		2000
Std.dev	0.0		565.7	0.1		322.6	0.0		0.0
CV	0.0		10000	5.0		7836.7	0.0		0.0

APPENDIX 14: Reported Crop area and Harvested yields in Thome Scheme (1994/95)

Section	Maize			Beans			Potato		
	Area (ha)	Yield (kg)	Kg/ha	area (ha)	Yield (kg)	kg/ha	Area (ha)	Yield (kg)	kg/ha
Head	0.2	765	3825	0.2	360	1800	0.1	600	6000
	0.1	360	3600	0.2	90	450	0.2	800	4000
	0.2	90	450	0.3	180	600	0.2	900	4500
	0.2	135	675	0.1	90	900	0.4	1600	4000
	0.2	270	1350	0.2	450	2250	0.8	2400	3000
	0.3	180	600	0.4	60	150	0.1	200	2000
	0.4	540	1350	0.8	300	375	0.3	600	2000
	0.8	810	1013	0.6	135	225	0.4	750	1875
	1.0	450	4500	0.3	225	750			
	0.1	90	900	0.1	160	1600			
	0.6	810	1350	0.5	140	280			
Mean	0.4		1783	0.3		584	0.3		3421
Std dev	0.3		1456	0.2		714	0.2		1468
CV	24		1185	143		875	17		630
Middle	1.2	720	600	0.2	1350	6750	0.1	700	7000
	0.4	225	563	0.1	135	1350	0.2	800	4000
	0.2	270	1350	0.1	315	3150	0.1	600	6000
	0.4	450	1125	0.2	540	2700	0.2	450	2250
	0.8	540	675	0.2	270	1350	0.1	300	3000
	0.4	675	1563	0.4	720	1800	0.3	500	1667
	0.2	630	3150	1.2	1080	900			
	0.1	180	1800	0.1	180	1800			
	0.3	675	2250	0.6	248	413			
	0.4	360	900	0.75	360	480			
				0.3	90	300			
Mean	0.4		1398	0.4		1908	0.2		3986
Std.dev	0.3		828	0.4		1848	0.1		2122
CV	25		490	32		1789	3.8		1129
Tail	0.13	180	1385	0.2	180	900	0.1	600	6000
	0.2	225	1125	0.1	135	1350	0.1	500	5000
	0.2	315	1575	0.1	90	900	0.2	750	3750
	0.1	90	900	0.1	100	1000			
	0.2	180	900	0.3	315	1050			
	0.1	180	1800	0.1	135	1350			
	0.3	405	1350	0.2	270	1350			
	0.1	135	1350	0.1	200	2000			
	0.1	180	1800						
	0.2	225	1125						
Mean	0.1		1331	0.2		1237	0.1		4917
Std.dev	0.1		326	0.14.3		366	0.1		11272595
CV	3.0		80.1			108	2.8		

Appendix 14 Cont.

Section	Tomato			Onion			Cabbage		
	Area(ha)	Reported yield(Kg)	Yield (Kg/ha)	Area (ha)	Reported Yield(kg)	Yield (kg/ha)	Area (ha)	Reported yield(kg)	Yield (kg/ha)
Head	1.6	4000	2500	0.2	200	1000	0.4	1600	4000
	0.4	300	750	0.2	150	750	0.4	2000	5000
	0.4	350	875	0.4	200	500	0.2	1350	6750
	0.2	200	1000	0.8	650	812	0.4	2500	6250
	0.4	400	1000	0.4	235	588	0.2	500	2500
	0.4	300	750	0.4	400	1000	0.4	650	1625
	0.8	6000	7500	0.4	450	1125	0.8	1000	1250
	0.2	2500	12500	0.1	130	1300	0.4	2600	6500
	0.8	4500	5625	0.3	300	1000	0.1	600	6000
	0.4	600	1500	0.6	400	667	0.3	900	3000
	0.1	300	3000				0.6	750	1250
	0.2	350	1750				0.1	230	2300
	0.1	200	2000						
Mean	0.46		3135	0.38		874	0.36		3869
std.dev	0.4		3474.7	0.201		252.9	0.2		2144.2
CV	34.8		385121	1.0		7476	11.1		118832
Middle	0.2	600	3000	0.2	500	2500	0.2	1000	5000
	0.2	250	1250	0.1	50	500	0.4	2500	6250
	0.1	700	7000	0.4	200	500	0.2	1800	9000
	0.2	400	2000	0.2	500	2500	0.1	700	7000
	0.3	480	1600	0.2	300	1500	0.1	650	6500
	0.2	1200	6000	0.1	150	1500	0.3	750	2500
	0.1	200	2000	0.3	250	1250	0.2	1000	5000
	0.2	2000	1000	0.2	120	600	0.1	180	1800
				0.2	160	800	0.2	480	2250
				0.1	140	1400			
				0.3	137	457			
Mean	0.19		2169	0.21		1228	0.2		5033
Std.dev	0.06		1674	0.1		751.3	0.1		2445
CV	2.16		129197	4.76		45965	5.0		118777
Tail	0.2	360	3600	0.3	340	1133	0.1	200	2000
	0.2	280	2800	0.2	230	1150			
				0.1	170	1700			
Mean	0.2		3200	0.2		1328	0.1		2000
Std.dev	0.0		565.7	0.1		322.6	0.0		0.0
CV	0.0		10000	5.0		7836.7	0.0		0.0

APPENDIX 15: Reported Crop area and Harvested yields in Aguthi Scheme (1994/95)

Section	Maize			Beans			Potato		
	Area (ha)	Reported yield(Kg)	Yield (Kg/ha)	Area (ha)	Reported Yield(kg)	Yield (kg/ha)	Area (ha)	Reported yield(kg)	Yield (kg/ha)
Head	0.6	990	1650	0.1	180	1800	0.1	400	4000
	0.4	450	1125	0.02	90	450	0.6	1400	2333
	0.2	450	2250	0.1	90	900	0.1	300	3000
	0.4	630	1575	0.1	180	1800	0.05	400	8000
	0.2	225	1125	0.2	135	675	0.2	300	1500
	0.4	675	1688				0.4	1100	2750
	0.4	495	1238						
	0.2	450	2250						
	0.4	180	450						
Mean	0.36		1483	0.14		1125	0.24		3597
Std.dev	0.13		574.3	0.05		636.6	0.21		2307.3
CV	4.69		222.4	1.79		3523.9	18.4		148002
Middle	0.8	1215	1519	0.1	180	1800	0.2	800	4000
	0.4	180	450	0.1	45	450	0.6	950	1583
	0.2	450	2250	0.2	160	800	0.5	1300	2600
	0.1	180	1800	0.6	720	1200	0.4	1400	3500
	0.3	630	2100	0.4	380	950	0.1	200	2000
	0.4	720	1800	0.5	380	760			
	0.5	360	720						
	0.6	900	1500						
	0.6	315	525						
	0.4	270	675						
	0.8	405	5065						
Mean	0.46		1259	0.32		993	0.36		2737
Std.dev	0.22		692.3	0.21		465.3	0.21		1008.8
CV	11.0		380.1	13.78		218.0	11.94		371.8
Tail	0.6	945	1575	0.1	170	1700	0.1	500	5000
	0.4	450	1125	0.2	110	550	0.2	420	2100
	0.2	450	2250	0.3	300	1000	0.2	560	2800
	0.4	630	1575	0.2	380	1900	0.4	3000	7500
	0.2	360	1200	0.2	100	500	0.4	1050	2625
	0.4	270	1350				0.2	320	1600
	0.3	405	1350						
	0.4	585	1463						
	0.1	45	450						
mean	0.33		1371	0.20		1130	0.25		3604
Std.dev	0.15		474.8	0.07		645.8	0.12		2236
CV	6.82		164.4	2.5		369.1	6.0		1387.3

Appendix 15 Cont.

Section	Tomato			Onion			Cabbage		
	Area(ha)	Reported yield(Kg)	Yield (Kg/ha)	Area (ha)	Reported Yield(kg)	Yield (kg/ha)	Area (ha)	Reported yield(kg)	Yield (kg/ha)
Head	0.2	1800	9000	0.1	300	3000	0.3	1700	5667
	0.2	960	4800	0.05	200	4000	0.3	2500	8333
	0.05	360	7200	0.1	20	200	0.2	2000	20000
	0.1	1500	1500				0.05	400	8000
	0.1	1800	18000				0.1	1200	12000
	0.3	1620	5400				0.1	1300	13000
	0.1	690	6900				0.2	2200	11000
	0.4	4800	12000				0.05	700	1400
	0.4	5400	13500				0.2	1300	6500
	0.2	2500	12500				0.2	2800	14000
	0.1	500	5000				0.8	2500	3125
Mean	0.2		9936	0.08		2400	0.23		9366
Std.dev	0.12		4507	0.03		1967.7	0.2		5335
CV	7.2		2044.4	1.13		1613.3	17.4		3038.9
Tail	0.2	1700	8500	0.2	1200	6000	0.2	1200	6000
	0.1	1400	14000	0.1	450	4500	0.3	2400	8000
	0.2	920	4600	0.3	90	300	0.1	3800	19000
	0.3	1560	5200	0.1	250	2500	0.1	800	8000
	0.4	5200	13000	0.05	170	3400	0.1	1700	17000
	0.1	480	4800				0.2	1000	10000
	0.2	2520	12600					2400	12000
	0.5	4200	8400						
Mean	0.25		8887	0.15		3340	0.17		8986
Std.dev	0.14		3889.8	0.1		2143.1	0.08		4750.6
CV	8.0		1702.5	6.67		1375.1	3.92		2511.5
Middle	0.3	1950	6500	0.1	130	1300	0.4	1600	4000
	0.2	840	4200	0.1	300	3000	0.2	1500	7500
	0.1	1200	12000	0.2	200	1000	0.1	1000	10000
	0.4	1920	4800	0.1	170	1700	0.13	950	7407
	0.1	1050	10500	0.2	150	750	0.3	1800	6000
	0.1	900	9000	0.1	130	1300	0.5	2500	5000
	0.2	1660	8300	0.3	300	1000	0.1	600	6000
	0.2	1040	5200	0.2	180	900	0.2	1200	6000
	0.3	2235	7450	0.1	50	500	0.1	750	7500
	0.1	1160	11600			1272	0.1	900	9000
						735.3	0.05	250	5000
						425.1	0.2	350	1750
							0.1	400	4000
Mean	0.2		7955	0.16			0.19		6089
Std.dev	0.11		2815.7	0.07			0.13		2225.6
Cv	5.56		996.6	3.06			9.49		813.5

Appendix 15 cont.

Section	Snow Peas			Carrots		
	Area(ha)	Reported yield(Kg)	Yield (Kg/ha)	Area (ha)	Reported Yield(kg)	Yield (kg/ha)
Head	0.1	350	3500	0.26	300	1154
	0.1	120	1200	0.1	600	6000
	0.1	300	3000			
	0.05	50	1000			
	0.1	700	7000			
	0.3	650	2167			
	0.1	750	7500			
	0.2	700	3500			
	0.05	70	1400			
	0.4	210	525			
	0.4	250	625			
	0.1	125	1250			
	0.3	375	1250			
	0.5	405	810			
Mean	0.2		2481	0.18		3577
Std.dev	0.15		2255.8	0.11		3426.6
CV	11.25		2051.2	6.72		3282.5
Middle	0.4	200	500	0.1	230	2300
	0.3	400	1333	0.1	190	1900
	0.2	650	3250			
	0.2	550	2750			
	0.1	150	1500			
	0.1	250	2500			
	0.1	180	1800			
	0.2	600	3000			
	0.1	350	3500			
Mean	0.19		2237	0.1		2100
Std.dev	0.11		1006.5	0.0		282.8
Tail	0.1	340	3400			
	0.1	130	1300			
	0.2	600	3000			
	0.1	85	850			
	0.3	670	2233			
	0.4	3000	7500			
	0.2	700	3500			
	0.2	270	1350			
	0.1	60	600			
	0.1	55	550			
	0.2	320	1600			
Mean	0.18		2353			
Std.dev	0.10		2014.97			

Appendix 16: Primarily Sources of Food for Sample Households (1994/95)

Scheme	Furrow section	Sample size	Irrigated agriculture		Rainfed agriculture		Livestock		Others	
				%		%		%		%
Matanya	Head	20	13	65	3	15	0	0	4	20
	Middle	16	8	50	6	37.5	0	0	2	33.3
	Tail	20	4	20	12	60	2	10	2	10
	Scheme	56	25	44.6	21	37.5	2	3.6	8	14.3
Thome	Head	20	11	55	5	25	2	10	2	10
	Middle	20	8	40	6	30	3	15	3	15
	Tail	14	3	21.4	7	50	2	14.3	2	14.3
	Scheme	54	22	40.7	18	33.3	7	13	7	13
Aguthi	Head	20	9	45	6	30	3	15	2	10
	middle	20	6	30	8	40	5	25	1	5
	Tail	20	8	40	7	35	2	10	3	15
	Scheme	60	23	38.3	21	35	10	16.7	6	10

APPENDIX 17: Primarily Sources of Income for Sample Households (1994/95)

Scheme	Section	Sample size	Irrigated agriculture		Rainfed agricultur e		Livestock enterprise		Others	
				%		%		%		%
Matanya	Head	20	7	35	2	10	5	25	6	30
	Middle	16	4	20	2	10	7	35	3	15
	Tail	20	4	29	3	21	8	57	5	36
	Scheme	56	15	27	7	13	20	36	14	25
Thome	Head	20	8	40	2	10	7	35	3	15
	Middle	20	6	38	5	31	7	44	2	13
	Tail	14	2	10	6	30	5	25	1	5
	Scheme	54	16	30	13	24	19	35	6	11
Aguthi	Head	20	7	35	3	15	10	50	2	10
	Middle	20	6	30	2	10	8	40	3	15
	Tail	20	18	90	4	20	6	30	4	20
	Scheme	60	31	52	9	15	24	40	9	15

APPENDIX 18: Hired Labour by Sample Households (1994/95)

Scheme	Activity	Head section		Middle section		Tail section		Total	
		(n=20)	%	(n=20)	%	(n=16)	%	(n=56)	%
Matanya	Irrigation	4	20	5	25	1	6.3	10	17.9
	Rainfed agric.	2	10	1	5	1	6.3	4	7.1
	Livestock	2	10	2	10	2	12.5	6	10.7
	Others	1	5	2	10	2	12.5	5	8
Thome	Irrigation	3	15	4	28.6	0	0	7	13
	Rainfed agric.	3	15	2	14.3	2	10	6	11.1
	Livestock	1	5	0	0	1	5	2	3.7
	Others	1	5	1	7.1	1	5	3	5.5
Aguthi	Irrigation	4	20	5	25	4	20	13	21.7
	Rainfed agric.	2	10	1	5	2	10	5	8.3
	Livestock	2	10	1	5	0	0	3	5
	Others	1	5	1	5	2	5	4	6.7

APPENDIX 19: Crop Husbandry Practices by Sample Farmers (1994/95)

Scheme	Certified seed	Fertilizer	Manure	Crop protection chemicals	Crop rotation (whole scheme)	Weed control
Matanya						
maize	40	44.4	4.4	26.7	32.1	66.6
beans	38.2	0	0	7.3		68.3
tomato	56.3	37.5	50	43.8		62.5
potato	50	31.3	37.5	66.7		59.4
onion	100	33.3	0	0		33.3
cabbage	100	33.3	33.3	0		33.3
Mean	64.1	30.0	20.9	24.1		53.9
Thome						
maize	35.5	58.1	45.2	22.3	25.9	71
beans	26.7	0	6.7	6.7		61.3
tomato	64.7	52.9	41.2	35.3		70.6
potato	39.1	47.8	65.2	43.5		60.9
onion	70.8	33.3	37.5	20.8		54.2
cabbage	100	40.9	59.1	45.5		54.5
Mean	47.4	32.8	42.5	22.1		62.1
Aguthi						
maize	41.4	44.8	13.8	37.9	41.7	41.4
beans	31.3	6.3	0	12.5		50
tomato	86.2	34.5	27.6	69		44.8
potato	70.6	41.2	35.3	64.7		47.1
onion	72.2	27.8	5.6	11.1		55.6
cabbage	100	35.5	19.4	25.8		54.8
carrots	100	25.0	50	25		75.0
snow peas	76.7	67.4	8.8	52.9		70.6
Mean	72.3	35.3	20.1	37.4		54.9
All Schemes mean	65.0	34.8	27.0	30.9	33.2	56.8

APPENDIX 20: Farmer Reported Market Outlets

Scheme	Sample size	Domestic consumption	Domestic consumption +Local commercial	Local commercial	Export commercial
Matanya					
Maize	45	32	8	5	0
Beans	41	21	6	14	0
Tomato	16	2	3	11	0
Potato	32	7	13	12	0
Onion	3	1	2	0	0
Cabbage	3	0	2	1	0
Thome					
Maize	31	19	6	6	0
Beans	30	14	5	11	0
Tomato	17	2	4	11	0
Potato	23	7	10	6	0
Onion	24	6	8	10	0
Cabbage	22	4	6	12	0
Aguthi					
Maize	29	19	6	4	0
Beans	16	9	5	2	0
Tomato	29	2	13	14	0
Potato	17	5	8	4	0
Onion	17	2	7	8	0
Cabbage	31	4	7	20	3
S. peas	34	0	0	2	2
Carrots	4	0	1	3	0

APPENDIX 21: Farmer-reported Market Constraints

Market Constraint	Matanya	Thome	Aguthi	All schemes
Low prices	11	13	10	34
Price fluctuations	9	10	12	31
Poor communication network	6	8	11	25
Lack of markets	8	4	7	19
Exploitation by middlemen	22	19	20	61

APPENDIX 22: Farmer-reported Irrigation Methods

Scheme	Sprinkler irrigation	Furrow irrigation	Basin irrigation	Combination of methods
Matanya				
Head	1	16	0	2
Middle	2	18	1	3
Tail	1	8	2	2
Thome				
Head	4	12	0	0
Middle	3	10	1	3
Tail	2	17	1	1
Aguthi				
Head	17	6	0	3
Middle	10	4	0	4
Tail	9	2	2	3