AGROECONOMIC PERFORMANCE OF
AGUTHI, MATANYA AND THOME SMALLHOLDER IRRIGATION SCHEMES

BY

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

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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.

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Date: 21/11/02

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

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Date: 21/11/02
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.
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<td>AEZ</td>
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<td>df</td>
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<td>EDF</td>
<td>European Development Fund</td>
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<td>EIRR</td>
<td>Economic Internal Rate of Return</td>
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<td>Hort.</td>
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<td>IDB</td>
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<td>IIMI</td>
<td>International Irrigation Management Institute</td>
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<td>IR</td>
<td>Irrigation Requirement</td>
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<td>K&lt;sub&gt;y&lt;/sub&gt;</td>
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<td>LH</td>
<td>Lower Highland</td>
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<td>LRP</td>
<td>Laikipia Research Programme</td>
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<td>MAZ</td>
<td>Moisture Availability Zone</td>
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<td>MoA</td>
<td>Ministry of Agriculture</td>
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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/Eo  Rainfall-Evapotranspiration ratio
SS    Sum of Squares
Std.dev. Standard deviation
Ya    Actual Yield
Yp    Potential Yield
Ym    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.
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

<table>
<thead>
<tr>
<th>Region</th>
<th>1980</th>
<th>2000 (Projections)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area equipped for irrigation (million ha)</td>
<td>Share of irrigated area in total arable area (%)</td>
</tr>
<tr>
<td>90 countries</td>
<td>105.3</td>
<td>14</td>
</tr>
<tr>
<td>Africa</td>
<td>3.7</td>
<td>2</td>
</tr>
<tr>
<td>Far East</td>
<td>67.5</td>
<td>25</td>
</tr>
<tr>
<td>Latin America</td>
<td>13.4</td>
<td>7</td>
</tr>
<tr>
<td>Near East</td>
<td>20.7</td>
<td>23</td>
</tr>
<tr>
<td>Middle-income</td>
<td>34.8</td>
<td>9</td>
</tr>
<tr>
<td>Low-income</td>
<td>70.5</td>
<td>18</td>
</tr>
</tbody>
</table>

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, Schilfgaarde (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..."
2.1.5 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 Ottera (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 anthropogenic 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 (ETa)
Actual evapotranspiration refers to the rate of evapo-transpiration of a crop that is equal to or less than the predicted ET\textsubscript{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\textsubscript{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 short 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.

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

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 Pruitt, 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 Pruitt, 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).
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 relative yield decrease and relative evapotranspiration. Source: FAO 1979
relationship between $Y_a/Y_p$ and $ET_a/ET_p$ when growth factors other than water are not limiting (Doorenbos and Pruitt, 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.

\[ [1 - Y_a / Y_m] = K_v [1 - ET_a / ET_m] \]

\[ K_v = [1 - Y_a / Y_m] / [1 - ET_a / ET_m] \] (1)

The $K_v$ 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.
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 (ETc)

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 comparisons 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:

$$ET_c (\text{mm/day}) = K_c \times K_{\text{pan}} \times E_{\text{pan}}$$  \hspace{1cm} (2)

Where:

$E_{\text{pan}}$ = Evaporation from unscreened class A pan (mm/day)
$K_{\text{pan}}$ = 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).

$$ET_c = K_c \times C \left[ W \times R_n + (1-W) \times f(u) \times (e_a - e_d) \right]$$  \hspace{1cm} (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 $U_{\text{day}} / U_{\text{night}}$

2.7.3 Radiation Method

The Radiation Method is applied using equation 4 as given by Doorenbos and Pruit (1977).
\[ ET_c = K_c \cdot C (W \cdot R_s) \]  

Where:

\( R_s \) = Measured mean incoming shortwave radiation (mm/day)
\( W \) = Temperature and altitude dependent weighting factor
\( c \) = Adjustment factor on \( W \cdot 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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield (Tons/ha)</th>
<th>Crop</th>
<th>Yield (Tons/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato</td>
<td>25 - 60</td>
<td>Onion</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Maize</td>
<td>4 - 6</td>
<td>Beans</td>
<td>2 - 4</td>
</tr>
<tr>
<td>Cabbage</td>
<td>15 - 20</td>
<td>Peas</td>
<td>3 - 8</td>
</tr>
<tr>
<td>Carrots</td>
<td>30</td>
<td>Tomato</td>
<td>*5 - 15</td>
</tr>
</tbody>
</table>

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/E₀) 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/E₀) 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°C. 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
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 \( R_h \) and temperature \( T_h \) recorded 40 seconds after stirring ceased. 2 hours after stirring ceased a second hydrometer reading \( R_{h2} \) and temperature \( T_{h2} \) were recorded for the soil suspensions and blank. The percentage sand, clay and silt were then calculated using the equations:

\[
\begin{align*}
\text{% Sand} &= 100 - [H_1 + 0.2(T_1 - 60) - 2]^2 \\
\text{% Clay} &= [H_2 + 0.2(T_2 - 60) - 2]^2 \\
\text{% Silt} &= 100 - (\text{% sand} + \text{% clay})
\end{align*}
\]

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 \( E_{\text{pan}} \), Pan Coefficient \( K_{\text{pan}} \) and Crop coefficient \( K_c \). \( E_{\text{pan}} \) 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 \( K_{\text{pan}} \) 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:

\[
\begin{align*}
ET_0 &= K_p \cdot E_{\text{pan}} \\
ET_c &= ET_0 \cdot K_c
\end{align*}
\]
IR = ET_c − R \hspace{1cm} (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:

\[ V = 6 \times IR \hspace{1cm} (11) \]

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 511 was 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.
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.
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.
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.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>No.of households</th>
<th>Sample size</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thome</td>
<td>180</td>
<td>54</td>
<td>30</td>
</tr>
<tr>
<td>Matanya</td>
<td>185</td>
<td>56</td>
<td>30</td>
</tr>
<tr>
<td>Aguthi</td>
<td>500</td>
<td>60</td>
<td>12</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Unit of measurement</th>
<th>Equivalent in Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 bag of Irish potato</td>
<td>130 kg</td>
</tr>
<tr>
<td>1 bag of shelled maize</td>
<td>90 kg</td>
</tr>
<tr>
<td>1 crate of tomato</td>
<td>60 kg</td>
</tr>
<tr>
<td>1 bag of beans</td>
<td>90 kg</td>
</tr>
</tbody>
</table>

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 indicators 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. 5: Soil infiltration rate - Matanya scheme](image)
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

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

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 Kc 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)

<table>
<thead>
<tr>
<th>Date</th>
<th>Days after planting</th>
<th>4-day rainfall total (mm)</th>
<th>IR (mm)</th>
<th>Applied irrigation water (litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(33IR)</td>
</tr>
<tr>
<td>2/1/95</td>
<td>0</td>
<td>0.0</td>
<td>10.0</td>
<td>60.0</td>
</tr>
<tr>
<td>6/1/95</td>
<td>4</td>
<td>0.0</td>
<td>6.9</td>
<td>41.0</td>
</tr>
<tr>
<td>10/1/95</td>
<td>8</td>
<td>0.0</td>
<td>5.6</td>
<td>34.0</td>
</tr>
<tr>
<td>14/1/95</td>
<td>12</td>
<td>0.0</td>
<td>4.9</td>
<td>29.0</td>
</tr>
<tr>
<td>18/1/95</td>
<td>16</td>
<td>0.0</td>
<td>5.6</td>
<td>11.0</td>
</tr>
<tr>
<td>22/1/95</td>
<td>20</td>
<td>0.0</td>
<td>6.1</td>
<td>12.0</td>
</tr>
<tr>
<td>26/1/95</td>
<td>24</td>
<td>0.0</td>
<td>3.5</td>
<td>7.0</td>
</tr>
<tr>
<td>30/1/95</td>
<td>28</td>
<td>0.0</td>
<td>7.0</td>
<td>14.0</td>
</tr>
<tr>
<td>3/2/95</td>
<td>32</td>
<td>0.0</td>
<td>6.4</td>
<td>13.0</td>
</tr>
<tr>
<td>7/2/95</td>
<td>36</td>
<td>0.0</td>
<td>15.5</td>
<td>31.0</td>
</tr>
<tr>
<td>11/2/95</td>
<td>40</td>
<td>23.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>15/2/95</td>
<td>44</td>
<td>8.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>19/2/95</td>
<td>48</td>
<td>6.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>23/2/95</td>
<td>52</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>27/2/95</td>
<td>56</td>
<td>17.8</td>
<td>9.7</td>
<td>19.0</td>
</tr>
<tr>
<td>3/3/95</td>
<td>60</td>
<td>60.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>7/3/95</td>
<td>64</td>
<td>12.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>11/3/95</td>
<td>68</td>
<td>0.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>15/3/95</td>
<td>72</td>
<td>10.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 7: Applied irrigation water (Thome)

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

Table 8: Applied Irrigation Water (Aguthi)

<table>
<thead>
<tr>
<th>Date</th>
<th>Days after planting</th>
<th>4-day rainfall total(mm)</th>
<th>IR (mm)</th>
<th>Applied Irrigation Water (Litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Treatment 1 (33IR)</td>
</tr>
<tr>
<td>31/12/95</td>
<td>0</td>
<td>0.0</td>
<td>10.0</td>
<td>60.0</td>
</tr>
<tr>
<td>6/1/95</td>
<td>5</td>
<td>0.0</td>
<td>7.8</td>
<td>46.8</td>
</tr>
<tr>
<td>11/1/95</td>
<td>10</td>
<td>0.0</td>
<td>6.4</td>
<td>38.4</td>
</tr>
<tr>
<td>16/1/95</td>
<td>15</td>
<td>0.0</td>
<td>7.9</td>
<td>47.4</td>
</tr>
<tr>
<td>21/1/95</td>
<td>20</td>
<td>0.0</td>
<td>8.0</td>
<td>16.0</td>
</tr>
<tr>
<td>26/1/95</td>
<td>25</td>
<td>0.0</td>
<td>10.0</td>
<td>20.0</td>
</tr>
<tr>
<td>31/1/95</td>
<td>30</td>
<td>0.0</td>
<td>10.4</td>
<td>20.5</td>
</tr>
<tr>
<td>5/2/95</td>
<td>35</td>
<td>0.0</td>
<td>19.7</td>
<td>39.0</td>
</tr>
<tr>
<td>10/2/95</td>
<td>40</td>
<td>25.0</td>
<td>10.6</td>
<td>21.0</td>
</tr>
<tr>
<td>15/2/95</td>
<td>45</td>
<td>14.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>20/2/95</td>
<td>50</td>
<td>8.5</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>25/2/95</td>
<td>55</td>
<td>16.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2/3/95</td>
<td>60</td>
<td>10.8</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td>7/3/95</td>
<td>65</td>
<td>80.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>12/3/95</td>
<td>70</td>
<td>14.8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
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)
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)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>10.22</td>
<td>2</td>
<td>5.11</td>
<td>0.03685</td>
<td>.9641</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>2460.14</td>
<td>2</td>
<td>1230.07</td>
<td>8.871</td>
<td>.0338</td>
<td>★</td>
</tr>
<tr>
<td>Error</td>
<td>554.6</td>
<td>4</td>
<td>138.65</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>3024.96</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = not significant. ★ = significant.

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>129.333</td>
<td>3 a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>126.733</td>
<td>3 a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>93.033</td>
<td>3 b</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>44.846</td>
<td>2</td>
<td>22.42</td>
<td>1.16</td>
<td>0.4004</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>622.726</td>
<td>2</td>
<td>331.36</td>
<td>17.15</td>
<td>0.0109</td>
<td>*</td>
</tr>
<tr>
<td>Error</td>
<td>77.286</td>
<td>4</td>
<td>19.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>784.86</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = not significant.  * = significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>107.5</td>
<td>3 a</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>104.37</td>
<td>3 a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>87.93</td>
<td>3 b</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>143.08</td>
<td>2</td>
<td>71.54</td>
<td>3.099</td>
<td>0.1538</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>5935.56</td>
<td>2</td>
<td>2967.78</td>
<td>128.589</td>
<td>0.0002</td>
<td>***</td>
</tr>
<tr>
<td>Error</td>
<td>92.32</td>
<td>4</td>
<td>23.08</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>6170.96</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = not significant.  *** = Highly significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>148.13</td>
<td>3 a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>131.83</td>
<td>3 b</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>87.37</td>
<td>3 c</td>
</tr>
</tbody>
</table>

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)

Days after planting

% cover

33%IR  66%IR  100%IR

Fig. 13: Percentage crop cover (Aguthi)

Days after planting

% Cover

33%IR  66%IR  100%IR
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).

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>70.20</td>
<td>2</td>
<td>35.101</td>
<td>1.4126</td>
<td>0.3435</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>896.22</td>
<td>2</td>
<td>448.111</td>
<td>18.034</td>
<td>0.0100</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>99.39</td>
<td>4</td>
<td>24.847</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1065.81</td>
<td>8</td>
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</tr>
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</table>

ns = non-significant ** = Highly significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>76.3</td>
<td>3 a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>75.966</td>
<td>3 a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>54.966</td>
<td>3 b</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>12.67</td>
<td>2</td>
<td>6.333</td>
<td>0.32129</td>
<td>0.7423</td>
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</tr>
<tr>
<td>Treatments</td>
<td>1097.39</td>
<td>2</td>
<td>548.693</td>
<td>27.83597</td>
<td>0.0045</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>78.85</td>
<td>4</td>
<td>19.712</td>
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<td></td>
</tr>
<tr>
<td>Total</td>
<td>1188.90</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

ns = non-significant ** = Highly significant
Table 14: Analysis of variance on mean % crop cover (Aguthi)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>69.7088</td>
<td>2</td>
<td>34.8544</td>
<td>1.8414</td>
<td>0.2711</td>
</tr>
<tr>
<td>Treatments</td>
<td>965.0155</td>
<td>2</td>
<td>482.5077</td>
<td>25.4920</td>
<td>0.0053</td>
</tr>
<tr>
<td>Error</td>
<td>75.7111</td>
<td>4</td>
<td>18.9277</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1110.435</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Constant Term (A)</th>
<th>Regression coefficient (B)</th>
<th>Correlation coefficient (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.437</td>
<td>0.566</td>
<td>0.965</td>
</tr>
<tr>
<td>2</td>
<td>11.955</td>
<td>0.543</td>
<td>0.975</td>
</tr>
<tr>
<td>3</td>
<td>7.169</td>
<td>0.612</td>
<td>0.973</td>
</tr>
</tbody>
</table>

**Fig. 14a: Regression of % cover on height (Treatment 1)**
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

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Matanya</th>
<th>Thome</th>
<th>Aguthi</th>
<th>3 sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>a</td>
<td>b</td>
<td>c Mean</td>
<td>a</td>
</tr>
<tr>
<td>33IR</td>
<td>810</td>
<td>830</td>
<td>765</td>
<td>817.7</td>
</tr>
<tr>
<td>66IR</td>
<td>1375</td>
<td>1790</td>
<td>2135</td>
<td>1767</td>
</tr>
<tr>
<td>100IR</td>
<td>1490</td>
<td>2260</td>
<td>1840</td>
<td>1863</td>
</tr>
</tbody>
</table>

* (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)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>289538.889</td>
<td>2</td>
<td>144769.44</td>
<td>1.933</td>
<td>0.359</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>2067705.556</td>
<td>2</td>
<td>1033852.78</td>
<td>13.80</td>
<td>0.016</td>
<td>*</td>
</tr>
<tr>
<td>Error</td>
<td>299561.111</td>
<td>4</td>
<td>74890.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2656805.556</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = non significant

Duncan's Multiple Range Test

Error mean square = 74890.278

Degrees of freedom = 4

Significance level = 5%

LSD₀.05 = 620.377
<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1863.33</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1766.67</td>
<td>3a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>801.67</td>
<td>3b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>132050</td>
<td>2</td>
<td>66025</td>
<td>1.537</td>
<td>0.353</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>1638066.67</td>
<td>2</td>
<td>819033.33</td>
<td>19.077</td>
<td>8</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>171733.33</td>
<td>4</td>
<td>42933.33</td>
<td>8</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = non-significant
** = Highly significant

Duncan's multiple Range Test

Error mean square = 42933.33
Degrees of freedom = 4
Significance level = 5%
LSD<sub>0.05</sub> = 469.72

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1746.67</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1743.33</td>
<td>3a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>840</td>
<td>3b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>136538.89</td>
<td>2</td>
<td>68269.44</td>
<td>3.788</td>
<td>0.1194</td>
<td>ns</td>
</tr>
<tr>
<td>Main Effects</td>
<td>1980088.89</td>
<td>2</td>
<td>990044.44</td>
<td>54.943</td>
<td>0.0012</td>
<td>**</td>
</tr>
<tr>
<td>Error</td>
<td>72077.78</td>
<td>4</td>
<td>18019.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = non-significant
** = Highly significant

Duncan's multiple Range Test

Error mean square = 18019.54
Degrees of freedom = 4
Significance level = 5%
LSD<sub>0.05</sub> = 314.31
<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment No.</th>
<th>Mean</th>
<th>n Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>1816.67</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1750</td>
<td>3a</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>790</td>
<td>3b</td>
</tr>
</tbody>
</table>

Yield response factors (K\textsubscript{y}) for the three Treatments were computed (See Appendix 8) using Equation 1 and presented in Table 20.

### Table 20: Yield Response Factor (K\textsubscript{y})

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Yield response factor (K\textsubscript{y})</th>
<th>Treatment 1 (33% IR)</th>
<th>Treatment 2 (66% IR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matanya</td>
<td>0.85</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Thome</td>
<td>0.77</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Aguthi</td>
<td>0.84</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.82</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>

The K\textsubscript{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\textsubscript{m} and Y\textsubscript{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)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Head section</th>
<th>Middle section</th>
<th>Tail section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigated (%)</td>
<td>Rainfed (%)</td>
<td>Irrigated (%)</td>
</tr>
<tr>
<td>Aguthi</td>
<td>34.75</td>
<td>35.6</td>
<td>33.1</td>
</tr>
<tr>
<td>Thome</td>
<td>48.9</td>
<td>23.9</td>
<td>46.7</td>
</tr>
<tr>
<td>Matanya</td>
<td>50.4</td>
<td>16.4</td>
<td>54.5</td>
</tr>
</tbody>
</table>

#### 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).

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Maize</th>
<th>Beans</th>
<th>Potato</th>
<th>Tomato</th>
<th>Cabbage</th>
<th>Onion</th>
<th>Snow Peas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matanya</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>1341</td>
<td>994</td>
<td>375</td>
<td>794</td>
<td>3505</td>
<td>2663</td>
<td>18704</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>1292</td>
<td>594</td>
<td>571</td>
<td>845</td>
<td>4639</td>
<td>3454</td>
<td>5871</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tail</td>
<td>1137</td>
<td>1159</td>
<td>613</td>
<td>673</td>
<td>4131</td>
<td>5464</td>
<td>8875</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1257</td>
<td>916</td>
<td>520</td>
<td>771</td>
<td>4092</td>
<td>3860</td>
<td>11150</td>
</tr>
<tr>
<td>Thome</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>1783</td>
<td>1175</td>
<td>853</td>
<td>1638</td>
<td>3122</td>
<td>3875</td>
<td>3135</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>1398</td>
<td>1215</td>
<td>1908</td>
<td>3150</td>
<td>3986</td>
<td>2978</td>
<td>2169</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tail</td>
<td>1331</td>
<td>841</td>
<td>1237</td>
<td>1375</td>
<td>4917</td>
<td>4180</td>
<td>3200</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1504</td>
<td>1077</td>
<td>1333</td>
<td>2054</td>
<td>4008</td>
<td>3677</td>
<td>2837</td>
</tr>
<tr>
<td>Aguthi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>1483</td>
<td>1002</td>
<td>1125</td>
<td>1190</td>
<td>3597</td>
<td>3875</td>
<td>9936</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td>1259</td>
<td>806</td>
<td>993</td>
<td>1040</td>
<td>2736</td>
<td>2673</td>
<td>7955</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tail</td>
<td>1371</td>
<td>1159</td>
<td>1130</td>
<td>1434</td>
<td>3604</td>
<td>3150</td>
<td>8887</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1371</td>
<td>989</td>
<td>1083</td>
<td>1221</td>
<td>3312</td>
<td>3233</td>
<td>8926</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>Df</th>
<th>MS</th>
<th>(F_{\text{cal}})</th>
<th>(F_{0.05})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>1242273.17</td>
<td>2</td>
<td>62136.58</td>
<td>7.034</td>
<td>0.0027**</td>
</tr>
<tr>
<td>Treatments</td>
<td>501664.25</td>
<td>3</td>
<td>167221.42</td>
<td>18.93</td>
<td>0.0018**</td>
</tr>
<tr>
<td>Error</td>
<td>53001.5</td>
<td>6</td>
<td>8838.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>678938.92</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = Significant  ** = Highly Significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment #</th>
<th>Mean</th>
<th>Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1535.667</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1316.333</td>
<td>3b</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1279.667</td>
<td>3b</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>962.667</td>
<td>3c</td>
</tr>
</tbody>
</table>

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

Table 24: ANOVA table on farmer-reported bean yield

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>(F_{\text{cal}})</th>
<th>(F_{0.05})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>174454.17</td>
<td>2</td>
<td>872270.58</td>
<td>9.546</td>
<td>0.0137**</td>
</tr>
<tr>
<td>Treatments</td>
<td>518286.25</td>
<td>3</td>
<td>172762.08</td>
<td>1.891</td>
<td>0.232 ns</td>
</tr>
<tr>
<td>Error</td>
<td>548271.5</td>
<td>6</td>
<td>91378.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2811098.92</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = non-significant  * = Significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment #</th>
<th>Mean</th>
<th>Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1349</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1157</td>
<td>3a</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>993</td>
<td>3a</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>784</td>
<td>3a</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F_cal</th>
<th>F_0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block</td>
<td>1328128.67</td>
<td>2</td>
<td>664064.33</td>
<td>2.229</td>
<td>0.1887 ns</td>
</tr>
<tr>
<td>Treatments</td>
<td>1102988.25</td>
<td>3</td>
<td>367662.75</td>
<td>1.235</td>
<td>0.3764 ns</td>
</tr>
<tr>
<td>Error</td>
<td>1786780</td>
<td>6</td>
<td>297796.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4217896.92</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns = non-significant  * = Significant

Duncan's Multiple Range Test

<table>
<thead>
<tr>
<th>Rank</th>
<th>Treatment #</th>
<th>Mean</th>
<th>Non-significant ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>3</td>
<td>4217</td>
<td>3a</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3787</td>
<td>3a</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3574</td>
<td>3a</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>3408</td>
<td>3a</td>
</tr>
</tbody>
</table>

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).

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Head section</th>
<th>Middle section</th>
<th>Tail section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>irrigated</td>
<td>irrigated</td>
<td>irrigated</td>
</tr>
<tr>
<td></td>
<td>rainfed</td>
<td>rainfed</td>
<td>rainfed</td>
</tr>
<tr>
<td>Matanya</td>
<td>228.7</td>
<td>209.0</td>
<td>177.8</td>
</tr>
<tr>
<td>Thome</td>
<td>246.7</td>
<td>294.4</td>
<td>301.1</td>
</tr>
<tr>
<td>Aguthi</td>
<td>265.0</td>
<td>249.0</td>
<td>326.1</td>
</tr>
</tbody>
</table>

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)
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)
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.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Head section</th>
<th>Middle section</th>
<th>Tail section</th>
<th>Scheme Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hort. crops</td>
<td>Food crops</td>
<td>Hort. crops</td>
<td>Food crops</td>
</tr>
<tr>
<td>Matanya</td>
<td>37.7</td>
<td>62.3</td>
<td>54.6</td>
<td>45.4</td>
</tr>
<tr>
<td></td>
<td>68.0</td>
<td>32.0</td>
<td>48.4</td>
<td>51.6</td>
</tr>
<tr>
<td>Thome</td>
<td>30.7</td>
<td>60.4</td>
<td>39.6</td>
<td>66.7</td>
</tr>
<tr>
<td>Aguthi</td>
<td>69.3</td>
<td>320.0</td>
<td>48.4</td>
<td>51.6</td>
</tr>
</tbody>
</table>

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)

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

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 (75.0% 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)

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

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

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Crop</th>
<th>Head</th>
<th>Irrigation Interval (days)</th>
<th>Middle</th>
<th>Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 5</td>
<td>5-10</td>
<td>&gt; 10</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Matanya</td>
<td>Maize</td>
<td>60.0</td>
<td>40.0</td>
<td>0.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>Beans</td>
<td>62.5</td>
<td>37.5</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>Potato</td>
<td>46.1</td>
<td>38.5</td>
<td>15.4</td>
<td>41.7</td>
</tr>
<tr>
<td></td>
<td>Tomato</td>
<td>71.4</td>
<td>28.6</td>
<td>0.0</td>
<td>57.1</td>
</tr>
<tr>
<td></td>
<td>Onion</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>Cabbage</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Thome</td>
<td>Maize</td>
<td>45.4</td>
<td>27.3</td>
<td>27.3</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>Beans</td>
<td>54.5</td>
<td>36.4</td>
<td>9.1</td>
<td>36.4</td>
</tr>
<tr>
<td></td>
<td>Potato</td>
<td>50.0</td>
<td>37.5</td>
<td>12.5</td>
<td>33.3</td>
</tr>
<tr>
<td></td>
<td>Tomato</td>
<td>61.5</td>
<td>30.8</td>
<td>7.7</td>
<td>37.5</td>
</tr>
<tr>
<td></td>
<td>Onion</td>
<td>40.0</td>
<td>30.0</td>
<td>0.0</td>
<td>36.4</td>
</tr>
<tr>
<td></td>
<td>Cabbage</td>
<td>53.3</td>
<td>33.3</td>
<td>8.4</td>
<td>33.3</td>
</tr>
<tr>
<td>Aguthi</td>
<td>Maize</td>
<td>33.3</td>
<td>55.6</td>
<td>11.1</td>
<td>36.4</td>
</tr>
<tr>
<td></td>
<td>Beans</td>
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<td>60.0</td>
<td>0.0</td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td>Potato</td>
<td>33.3</td>
<td>50.0</td>
<td>16.7</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>Tomato</td>
<td>36.4</td>
<td>54.5</td>
<td>0.0</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Onion</td>
<td>33.3</td>
<td>66.2</td>
<td>9.1</td>
<td>33.3</td>
</tr>
<tr>
<td></td>
<td>Cabbage</td>
<td>27.3</td>
<td>63.6</td>
<td>9.1</td>
<td>15.4</td>
</tr>
<tr>
<td></td>
<td>S.peas</td>
<td>21.5</td>
<td>71.4</td>
<td>7.1</td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td>Carrots</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

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)

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

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)

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

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


CoHort Softwares, 1986. COSTAT Statistical Program.


## APPENDICES

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

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

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?

<table>
<thead>
<tr>
<th>Area (acres/ha)</th>
<th>Harvested Yield</th>
<th>Unit of measurement</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (acres/ha)</th>
<th>Harvested yield (kg/bags)</th>
<th>Unit of measurement</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (acres/ha)</th>
<th>Harvested yield</th>
<th>Unit of measurement</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(ii) Which crops are you currently growing on rain-fed plots and what are their areas and yields?

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (acres/ha)</th>
<th>Harvested yield</th>
<th>Unit of measurement</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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?

<table>
<thead>
<tr>
<th>Crop</th>
<th>Chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Plot no.</th>
<th>Current crop</th>
<th>Last season crop</th>
<th>Last year's crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


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

<table>
<thead>
<tr>
<th>Crop</th>
<th>No. of weedings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Marketing

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

<table>
<thead>
<tr>
<th>Mode of Disposal</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic consumption</td>
<td>A</td>
</tr>
<tr>
<td>Domestic consumption and local commercials</td>
<td>B</td>
</tr>
<tr>
<td>Local commercial</td>
<td>C</td>
</tr>
<tr>
<td>Export Commercial</td>
<td>E</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop</th>
<th>Mode of Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(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?

<table>
<thead>
<tr>
<th>Type of market organization</th>
<th>Produce sold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Importance of Problem</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very important</td>
<td>A</td>
</tr>
<tr>
<td>Fairly important</td>
<td>B</td>
</tr>
<tr>
<td>Unimportant</td>
<td>C</td>
</tr>
</tbody>
</table>
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?

<table>
<thead>
<tr>
<th>Primary source of food</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated Agriculture</td>
<td>A</td>
</tr>
<tr>
<td>Rainfed Agriculture</td>
<td>B</td>
</tr>
<tr>
<td>Livestock</td>
<td>C</td>
</tr>
<tr>
<td>Others</td>
<td>D</td>
</tr>
</tbody>
</table>

Primary source of food
Primary source of Income

5. Irrigation Water Management

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

<table>
<thead>
<tr>
<th>Irrigation Method</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinkler</td>
<td>A</td>
</tr>
<tr>
<td>Basin</td>
<td>B</td>
</tr>
<tr>
<td>Furrow</td>
<td>C</td>
</tr>
<tr>
<td>Combination</td>
<td>D</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant interval and duration</td>
<td>A</td>
</tr>
<tr>
<td>Dependence on water availability</td>
<td>B</td>
</tr>
<tr>
<td>Degree of soil wetness</td>
<td>C</td>
</tr>
</tbody>
</table>

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    | 6.8  | 6.6  | 6.4  | 6.4  | 6.5  | 6.4  |      |

### Thome

<table>
<thead>
<tr>
<th>Time (Hr)</th>
<th>0</th>
<th>0.08</th>
<th>0.17</th>
<th>0.25</th>
<th>0.33</th>
<th>0.5</th>
<th>0.67</th>
<th>0.83</th>
<th>1</th>
<th>1.33</th>
<th>1.67</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration (mm)</td>
<td>16.8</td>
<td>14.8</td>
<td>10.7</td>
<td>12</td>
<td>8.2</td>
<td>8</td>
<td>7.6</td>
<td>7</td>
<td>6.8</td>
<td>6.6</td>
<td>6.8</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Aguthi

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>0</th>
<th>0.08</th>
<th>0.17</th>
<th>0.25</th>
<th>0.33</th>
<th>0.5</th>
<th>0.67</th>
<th>0.83</th>
<th>1</th>
<th>1.33</th>
<th>1.67</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
<th>3.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration (mm)</td>
<td>16</td>
<td>13.8</td>
<td>11.6</td>
<td>12</td>
<td>8</td>
<td>8.8</td>
<td>8</td>
<td>7.6</td>
<td>6.8</td>
<td>6.4</td>
<td>5.2</td>
<td>5.4</td>
<td>5.2</td>
<td>5.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX 4: Computed Irrigation Water Requirements

<table>
<thead>
<tr>
<th>Date (1995)</th>
<th>RH (%)</th>
<th>Wind (Km/d)</th>
<th>(K_{cin})</th>
<th>(E_{cin}) (mm/d)</th>
<th>(ET_0) (mm/d)</th>
<th>(K_c)</th>
<th>(ET_c)</th>
<th>(R^*) (mm)</th>
<th>IR (mm/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0</td>
<td>10.0</td>
</tr>
<tr>
<td>5/1</td>
<td>55.5</td>
<td>111.9</td>
<td>0.75</td>
<td>26.1</td>
<td>19.6</td>
<td>0.35</td>
<td>6.9</td>
<td>0.0</td>
<td>6.9</td>
</tr>
<tr>
<td>9/1</td>
<td>60.4</td>
<td>98.5</td>
<td>0.75</td>
<td>21.3</td>
<td>16.0</td>
<td>0.35</td>
<td>5.6</td>
<td>0.0</td>
<td>5.6</td>
</tr>
<tr>
<td>13/1</td>
<td>63.9</td>
<td>119.2</td>
<td>0.75</td>
<td>18.7</td>
<td>14.0</td>
<td>0.35</td>
<td>4.9</td>
<td>0.0</td>
<td>4.9</td>
</tr>
<tr>
<td>17/1</td>
<td>57.6</td>
<td>101.6</td>
<td>0.75</td>
<td>21.2</td>
<td>16.0</td>
<td>0.35</td>
<td>5.6</td>
<td>0.0</td>
<td>5.6</td>
</tr>
<tr>
<td>21/1</td>
<td>58.9</td>
<td>106.1</td>
<td>0.75</td>
<td>23.1</td>
<td>17.3</td>
<td>0.35</td>
<td>6.1</td>
<td>0.0</td>
<td>6.1</td>
</tr>
<tr>
<td>25/1</td>
<td>58.6</td>
<td>86.10</td>
<td>0.75</td>
<td>13.2</td>
<td>10.0</td>
<td>0.35</td>
<td>3.5</td>
<td>0.0</td>
<td>3.5</td>
</tr>
<tr>
<td>29/1</td>
<td>56.0</td>
<td>105.0</td>
<td>0.75</td>
<td>26.7</td>
<td>20.0</td>
<td>0.35</td>
<td>7.0</td>
<td>0.0</td>
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* 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

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

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Aguthi

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

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

Treatment 1 (33% Irrigation Requirement)

($ET_a = .33$)

($Y_a = 801.7g$)

$K_Y = \frac{[1 - \frac{Y_a}{Y_m}] / [1 - \frac{ET_a}{ET_m}]}{[1 - .33]}$

$= \frac{[1 - \frac{801.7}{1863}] / [1 - .33]}{[1 - 0.43]} / 0.67$

$= 0.57 / 0.67$

$= 0.85$
### APPENDIX 9: Total Sample Holding sizes, Rain-fed and Irrigated areas in Matanya Scheme (1994/95)

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| 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)

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

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

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All Schemes mean
### APPENDIX 20: Farmer Reported Market Outlets

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### APPENDIX 21: Farmer-reported Market Constraints

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