Factors Influencing Shift from Pastoralism to Irrigated Agriculture and its Impact on Soil Quality in Kajiado

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A Thesis submitted in partial fulfilment of the degree of Master of Science in Agricultural Resource Management

University of Nairobi, Kenya

2009

DECLARATION OF ORIGINALITY

I certify that, to the best of my knowledge, the material contained in this thesis has never been submitted for a degree in any university, and contains no material previously published or written by another person, except where due reference to such published works have been acknowledged.

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APPROVAL

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DEDICATION

This thesis is a special dedication to my late father for his care and tireless effort in educating me. He was a source of inspiration and instilled in me morals of hard work and honesty.

Special dedication also to my son Reuben Okari.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisors, Dr. G. Kironchi and Dr. Julius Okello for the effective guidance they provided throughout the duration of this study.

Secondly am very grateful to the Ministry of Agriculture for awarding me study leave and the staff at Mashuru division for assisting me in data collection and providing the necessary information for this work.

I am also very grateful to the soil science laboratory staff U.O.N especially Mr. Ndambuki, Mr. Anyika and Mr.Tirop for analysing the soil and water samples and technical guidance.

I am very thankful to Winrock International for financing the research.

I am grateful to my fellow students and friends for providing great company both in and outside lecture rooms which made student life fun.

Last but not least gratitude to God who endowed me with ability and good health throughout the study. To this end I thank my son Reuben for his patience while I was studying.

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LIST OF ABBREVIATIONS

ASALs	Arid and Semiarid Lands
C	Clay
Ca	Calcium
CL	Clay Loam
Cmol/ kg	Centimols per kilogram
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
HVC	High Value Crops
Ksat	Saturated Hydraulic Conductivity
Ksh	Kenyan Shillings
L	Litre
Log	Logarithm
LS	Loamy Sand
m.e	Milliequevalent
mmhos/cm	Millimhos per centimeter
Na	Sodium
Pb	Bulk density
Pp	Particle density
$PH^{*}c$	Calculated value based on total cations, Ca+ Mg and CO_3 + HCO_3 in the water.
RSC	Residual Sodium Carbonate
SARadj	Adjusted Sodium Adsorption Ratio
SAR	Sodium Adsorption Ratio
SAS	Salt Affected Soils
SCL	Sandy Clay Loam
SL	Sand loam
SSP	Soluble Sodium Percentage
U.O.N	University of Nairobi.
USDA	United States Department of Agriculture
USSL	United States Salinity Laboratory

ABSTRACT

Crop cultivation in the arid and semiarid ecosystems is mainly constrained by inadequate and unreliable rainfall. Smallholder irrigation in such areas is therefore necessary to supplement rainfall to meet crop water requirements. As cultivated agriculture encroaches into marginal ecosystems that are fragile and delicate, there is need to understand the drivers of the transition from pastoral to irrigated agriculture and the effects of irrigation on soil quality for better management of the smallholder irrigation systems towards increased and sustainable crop production. A study was therefore carried out to investigate the factors influencing the transition to irrigation farming and the effects of the transition on soil quality and subsequently the soil conservation management practices adopted under the new farming regime. The study objectives were to: (1) Investigate the social-economic factors that influence transition from pastoral grazing to irrigated smallholder crop production. (2) Assess existing soil management practices and the socioeconomic factors that influence the farmers' decision on whether to or not to conserve soil. (3) Assess the quality of irrigation water at different times/seasons in the year. (4) Asses the effect of smallholder irrigated crop production on sele cted soil ph ysical and chemical properties along the Olkeriae River basin. Primary data on socioeconomics was collected through personal interviews using a semi-structured questionnaire.Probit regression was used to analyse the factors driving the transition to irrigated-crop farming and factors determining soil management practices. Water samples were collected from the shallow wells used for irrigation and analysed. To examine the effect of change in land use on the soil quality, surface soil (0-10cm) was sampled from randomly selected fields under irrigation and under natural vegetation along the river. Both chemical and physical properties of the soils were analysed. The socio-economic factors that influenced the shift to irrigation included education and age of the household head, household size, distance to the agricultural agent, access to information, distance to market and access to hired labour. The factors that influenced the use of soil management practices included age and education of household head, household size, access to information, access to hired labour, irrigation experience and involvement of the farmer in promotion of soil conservation activities. Irrigation water had medium salinity with a mean electrical conductivity of 0.94 dSm^{-1} during the dry season and 0.85 dSm^{-1} during wet season. The sodium level was high and ranged between 4.50 me/l to 2.48 me/l for dry and wet season, respectively. The water was found to be of marginal quality for irrigation and therefore there is a likelihood of the soils becoming saline over time. Bulk density, available water capacity and saturated hydraulic conductivity were higher in the grazed sites compared to the cultivated sites, while total porosity was lower. Soil texture was silty clay loam for all sites. The soils were non-saline and non-sodic with very low organic matter in the cultivated areas and high electrical conductivity in the grazing sites. There is therefore need for adoption of appropriate soil management practices such as application of organic fertilizers, adequate water application and deep tillage to prevent build-up of salts in the cultivated areas.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The world population is projected to double to 11 billion by the year 2100. About 800 million people in the developing countries, 200 million of them children, are chronically undernourished (Republic of Kenya, 2006). Both the world food summit in 1996 and the millennium summit in 2000 set goals for reducing hunger between baseline period 1990 and the year 2015. The target date is drawing near, but the goals are far from being achieved by the target countries.

Kenya's agricultural sector is comprised of small scale, large scale and pastoralist sectors. Of the total area of 582,646 km^2, only 17% is suitable for rain fed agriculture. About 2.2% of the arable land is covered by forest reserves. Arid and semi-arid lands (ASALs) comprising grassland and savannah rangelands cover the remaining 82%. The rangelands are home to 85% of total wildlife population, and 14 million people practising dry-land farming and pastoralism (Mwichabe, 1996). The agricultural sector accounts directly for about 26 percent of the country's GDP and 27 percent indirectly through manufacturing, distribution and service-related sectors. It provides about 80 percent of the employment, accounts for 60 percent of exports and generates 57 percent of national income both directly and indirectly. The sector provides raw materials for agro-based industries which account for over 70 percent of all industries (Ministry of Agriculture, 2006).

To support the rapidly increasing population that is estimated to grow at 2.2 percent annually and ensure the country's economic growth, there is need to open new lands in the ASAL areas in order to expand agricultural production (Republic of Kenya, 2004). This will require the use of irrigation technologies which will support intensification of production in these marginal areas.Currently only about 4-14% of Kenya's irrigation potential has been harnessed. Irrigation can play an important role in increasing Kenya's agricultural productivity per unit land, expand arable land and stabilize agricultural production in times of adverse weather conditions (Republic of Kenya, 2004).Vision 2030 has also prioritized agriculture as a major driver of economic development and it is estimated that intensified irrigation can increase agricultural productivity four-fold and depending on the crops, incomes can be multiplied ten-times. Irrigation doubles land productivity, improves economic returns and can boost production by up to 400% (Ministry of Water and Irrigation, 2006). The Kenya Government also promotes smallholder irrigation projects owing to their low operational costs and contribution to food security, higher levels of rural development and higher rural incomes. In the Government policy, Strategy for Revitalizing Agriculture (2004-2014) identifies food security and poverty alleviation as the main development goals. Irrigation development has been identified as one of the avenues for achieving these objectives Irrigation has a positive direct impact on household income and agricultural employment because it increases productivity of land. (Republic of Kenya, 2004).

In the recent past, conversion of forests and pastures to arable lands and exploitation of natural resources has contributed to a variety of environmental problems including desertification, soil erosion, flooding, sedimentation, as well as chemical and physical degradation of soils (Brady, 1999)

Irrigation can affect the quality of land overtime and, ultimately, the sustainability of production. About one-third of the world's irrigated lands have reduced productivity as a consequence of poorly managed irrigation that has caused water logging and salinity (FAO, 1998). In Kenya the total salt affected area is about 4.86 million hectares. About 75 % of Kenya receives less than 500 mm of rainfall annually and the potential evapotranspiration is between 1500 and 2000 mm. This naturally occurring salinity at time results in salt-affect soils once put under irrigation. Several cases of salt-affected soils due to irrigation have been reported in Kenya (Radiro et al., 2003).

People in the arid and semi-arid areas, especially those close to urban centres have switched from the traditional pastoralism to high value crop (HVC) production. Since the rainfall is low and unreliable, most of these HVC producers use irrigation, especially during dry seasons. One of the areas witnessing the change in land use is the Kajiado District. Where soils are favourable and water is available such as along the Olkeriae River, smallholder irrigated farming activities have increased in the past few years. The area was originally used for dry season grazing. However, currently the river has changed role serving instead as a source of irrigation water. Farmers dig shallow wells along the river bank which they use for irrigation during dry season. The farmers grow horticultural crops as a copping strategy to drought. The produce is used for subsistence and as a source of income. During the rain season little or no irrigation is carried out. Despite the widespread irrigation practices in the area, to date no evaluation has been carried out to ascertain the suitability of the soil and water for irrigation. Therefore there is need to assess the impact of the spontaneous smallholder irrigation practices in Mashuru, Kajiado District to determine intervention measures that can ensure sustainability of crop production.

1.2 Justification of the Study

Future growth and development of the agricultural sector will rely on intensification of land use in the high and medium potential areas and innovative use of the ASALs taking into account the limited water resources available in the country. Approximately 59% of the soils in Kenya have moderate to high natural fertility making them suitable for growing a large variety of crops. Productivity is curtailed because only 17% of the country receives average annual rainfall of more than 800 mm which is the minimum requirement for rain fed agriculture (Sombroek et al., 1982).

The high population growth rate in Kenya has resulted in increased population pressure on the land. As opportunities for expansion diminish, agriculture has encroached into fragile ecosystems that are marginal for rain fed farming. An increasing number of pastoralists are incorporating cultivation and commercial farming into a traditional livestock economy. For example in Kajiado District, during the year 2002, the area under irrigation for various horticultural crops was about 1500 ha as compared to 1000 ha in the year 2000. This increment was mainly due to opening up of new farms by individuals who had drilled boreholes and dug shallow wells for irrigation purposes. A total of about 14,500 metric tonnes of horticultural produce worth about ksh.180 million was produced during the year as compared to 11,500 metric tonnes valued at about ksh.130 million in the year 2000 (Ministry of Agriculture, 2001).

Encouraging smallholder irrigated agriculture is vital to enhance production and attainment of food self sufficiency in Kenya. However, this requires not only high investments, but also appropriate technologies to avoid soil degradation and subsequent reduction of productivity. Monitoring the impacts of irrigation on soil properties is crucial for sustainable crop production. The success of soil management to maintain soil quality depends on the understanding of how soils respond to agricultural use and practices over time (Negassa and Gebrekidan, 2004). Poorly managed irrigation can have adverse effect on soil properties and thereby on sustainable productivity. Timely monitoring, especially for spontaneously established irrigation projects is therefore necessary to avoid negative effects on the soil and the environment (Henry and Hogg, 2003). Irrigation of marginal areas of Kajiado such as in Mashuru along the Olkeriae seasonal river is a practical example where the suitability of soils and water for irrigation have not been carried out. The farmers in the area currently growing horticultural crops under furrow irrigation without any prior design of the projects.

To date, there is limited information on the effects of transitioning from pastoralism to irrigated crop production. The study therefore investigated the socioeconomic drivers of the transition to irrigated crop production, the management practices the farmers were employing to counteract soil degradation and the socioeconomic factors influencing the use of soil management practices, determined the water quality used for irrigation at different seasons and the changes in soil quality indicators associated with irrigation after conversion of the dry season grazing area to arable land. The results obtained would therefore be used in planning of irrigation projects in the arid and semi-arid areas while incorporating soil and water management practices that would ensure sustainability of the irrigation projects and prevent land degradation.

1.3 Objectives

1.3.1 Broad Objective

To investigate the socioeconomic factors influencing transition from pastoralism to smallholder irrigated crop production and its effect on soil quality along the Olkeriae River in Kajiado district.

1.3.2 Specific Objectives

The specific objectives were to:

1. Investigate the social-economic factors that influence transition from pastoral grazing to irrigated smallholder crop production.
2. Assess existing soil management practices and the socioeconomic factors that influence the farmers' decision on whether to or not to conserve soil.

3. Assess the quality of irrigation water at different times/seasons in the year.
4. Asses the effect of smallholder irrigated crop production on selected soil physical and chemical properties along the Olkeriae River basin.

CHAPTER TWO

LITERATURE REVIEW

2.1 Irrigation Development in Pastoral Areas

Pastoral ecosystems are dynamic and resilient, with plant cover, productivity and bio-diversity dependent on the amount and distribution of rainfall. The stability of the ecosystems also depends on the quality of its soils and with soils being eroded and lost, range stability and productivity have declined (Brady and Will, 1999).

To secure their livelihoods, the strategies pursued by pastoralists are changing as pastoral populations respond to development inputs, political and administrative pressure and to changing aspirations. In many areas, there have been attempts to offer alternative means of subsistence by developing a multi-resource economy. (Scoones, 1994).

Many donor-assisted projects have been introduced into the drylands on the presumption that pastoralism is no longer a viable way of life. Before the 1970's irrigation schemes were viewed as highly effective means of transforming traditional agricultural systems into commercially oriented and scientifically based production enterprises (Sijali et al., 2003). However, irrigation projects are facing increasing challenges from environment conservation lobby groups due to potential degradation of the agricultural systems (Ministry of water and irrigation, 2006).

2.2 Factors Influencing Soil and Water Management

Much of the current soil nutrient debate ignores the role farmers play in shaping processes of environmental change. Yet farmers are key actors in the cycling of nutrients within agricultural areas, and are also an important source of information and knowledge regarding local soils and crop performance. Farmers have a range of economic opportunities for investment of labour and capital, of which agriculture is one. Within agriculture, soil fertility is only one constraint among many. Social and economic factors therefore are critical in understanding patterns of soil fertility management in different contexts, over time and from one farmer to another.

2. 2.1 Socio-economic Factors

The variables associated with sustainable conservation use fall into different subcategories i.e. individual level characteristics of the farmers, farm structural variables and institutional variables.

2.2.1.1 Individual level characteristics

Age, a commonly used independent variable in research on adoption of innovations has been used to try to explain conservation behaviour, but with ambiguous success. Research results show a varied relationship between age and conservation behaviour. Hoover and Wiitala (1980) and found that older farmers were more likely to be co-operators and adopters of no-tillage techniques but Carlson et al. (1981) found no relationship between age and use of conservation practices. Lasley and Nolan (1981) showed that younger farmers were more likely to adopt reduced tillage technologies, while older farmers were more likely to adopt structural practices and other cultural practices such as grass waterways and strip cropping.

Abd-Ella (1981) indicated that farming experience had a positive and significant relationship with the use of conservation practices, at least in the early years while Miranowski (1981) showed that experienced farmers were more likely to rely on traditional tillage practices.

Carlson et al. (1981) and Ervin and David (1982) found a positive association between education and the use of conservation practices. Education also affects adoption and adaptation of conservation practices by enhancing the likelihood of farmers perceiving land degradation as a problem. This in turn increases their likelihood of receiving and processing information about a technology that can solve the problem by increasing their managerial ability. On the other hand, higher levels of education under certain conditions may raise the opportunity cost of family labour in agriculture and direct its allocation into other activities that offer higher returns such as non-agricultural wage employment (Shiferaw et al., 2008). Social capital in form of membership in local organizations has a positive relationship with the use of conservation practices as reported by Abd-Ella et al. (1981). Lovejoy and Parent (1981) found that farmers who are local opinion leaders are more likely than other farmers to adopt conservation practices. This is probably related to the fact that local leaders tend to be better educated, manage larger farms, and have a good understanding of soil erosion problems.

2.2.1.2 Farm structural variables

Farm structural variables related to the adoption of conservation practices include: size of operation, net income/farm sales, debt levels, tenure and specialization/diversification. Most studies indicate the larger the farm size and the more income produced by the farm enterprise, the greater the use of conservation practices. The relative value of land, labour and capital endowments over time, among different farmers and between areas, may have important implications for the form and efficiency of any farm-level nutrient cycle. For example, rising prices for land and crops provide both an incentive and a means for investment in improving land. As land becomes scarcer, its implicit price rises, and it becomes more worthwhile to invest in it, thereby raising its value further. Similarly, as land becomes scarcer, farmers become more aware of the need to make best use of what they have.

Early studies on adoption of conservation practices have shown a positive relationship between a farmer's use of credit and use of conservation practices. It can be expected that farmers with high debt levels will be more concerned about profit maximization. Practices that can be shown to maintain or increase profits (such as conservation tillage) will be more likely adopted than more costly conservation practices. High debt loads will further impact soil and water conservation efforts due to the inability of farmers to maintain existing practices. Shiferaw et al. (2004) tested the effect of access to input credit (seed and fertilizer inputs) on adoption of sustainable soil and water management strategies in Ethiopia. They observed that increased access to input credit for fertilizer may reduce farmer conservation investments in terms of traditional soil and water conservation works on farmers' fields.

Security of tenure and access to land is also a critical factor in the ways farmers manage soil fertility. Farmers invest in improving a particular asset where they have some assurance they will benefit and are not likely to invest in sustainable resource management of rented private property if the length of use right does not allow them to recoup their investments (Ahuja, 1998; Barrett et al., 2002; Shiferaw and Bantilan, 2004).

Related to ownership is family participation in the farm operation. Abd-Ella et al. (1981) and Carlson and Dillman (1983) found that when families have common aspirations regarding the future of the farm, use of conservation practices is significantly higher. Family size is also positively related to the number of practices used, as is the degree to which married couples share in farm decisions and the degree to which the family is involved in gathering farm-related information (Abd-Ella et al., 1981)

2.2.1.3 Institutional variables

Institutional variables related to farm conservation include commodity prices, agricultural inputs, access to markets, access to the road and farmer organizations. Farmers will likely adopt practices that improve the fertility of their soils if the produce price is considered high enough to compensate for the short-term costs of the practices. In addition, the use of inputs needed to maintain soil fertility will be influenced by the price of such inputs. High input prices will generally discourage the use of such input. Some studies find a positive relation between increase in commodity price and adoption of conservation technologies. Shiferaw and Holden (2000) showed that when conservation offers short-term productivity gains, an increase in commodity prices enhances the adoption of soil and water conservation technologies among highland smallholder farmers in Ethiopia.

Market access for agricultural products often facilitates commercialization of production and adoption of commercial inputs like fertilizer and pesticides. The positive role of market access in promoting land and water conservation is best demonstrated by the often-cited example of Machakos District in Kenya (Barbier, 2000).The district suffered serious soil erosion problems in the 1930s due to failed colonial government soil conservation policies. By the mid-1980s, the district had not only brought soil erosion largely under control but also realized increased per capita income, even after a six fold population growth during the period. This tremendous success has been in part attributed to good access to markets for local produce, which was facilitated by proximity to Nairobi. This has accelerated commercialization of agriculture, which raised the profitability of farmer investments, raised incomes and facilitated adoption and maintenance of conservation practices in this largely semi-arid area. Pender et al. (2004) found that physical distance to the nearest market was not significantly correlated with production or erosion levels, but distance to nearest all-weather road had a negative effect on production and soil erosion.

Existence of farmers organizations such as merry-go-round, self-help groups, catchments/farmer clubs through and by which farmers can get information, technical advice on soil conservation and sometimes facilitation of the conservation activities are also key in adoption of conservation practices. Farmer participation in the design of conservation technologies and availability of information about the potential benefits and risks associated with new methods has an important role to play in influencing farmers' attitudes and perceptions. Involvement of farmers enables them to be able to test, try or experiment with and adopt various practices at their own pace and preferred sequence.

2.2.2 Biophysical Factors

Investment in soil and water management technologies will depend on the agro ecological and biophysical conditions. Factors like the natural fertility of soils, topography, climate and the length of the growing period influence the success of the investments and the type of technologies needed to sustain livelihoods and conserve the resource base (Shiferaw et al., 2008). In drought-prone semi-arid areas with infertile soils and erratic rainfall patterns, emphasis is on water management to reduce vulnerabilities to drought and to increase crop yields. In such areas suffering from moisture stress and seasonal drought, water conservation is important hence, the need to focus on enhancing in-situ conservation and productivity of water. Technologies for water harvesting and supplementary irrigation provide higher incentives for farmers (Joshi et al., 2005). Similarly, in higher rainfall areas, soil and water conservation may emphasize mitigating soil erosion through cost-effective methods, which reduce overland flow and improve safe drainage of excess water.

2.3 Soil Management Practices in Irrigated Agriculture

Most small-scale farmers have adopted different soil management practices. In most cases, the practices adopted are integrated involving the application of leguminous mulches, agro forestry, crop rotations, direct application of organic matter, farmyard manure and inorganic fertilizers as well as composting. These technologies are often geared towards improving soil fertility and productivity as well as reduce erosion and loss of water.

2. 3 .1 Addition of Inorganic and Organic Fertilizers

The response of crops to fertilizers has generally been good, showing great potential for increasing crop production. However the cost of fertilizers is beyond the reach of poor farmers. Eyasu (2002) conducted a study in 1995, which revealed that 78% of the farmers interviewed used mineral fertilizers and virtually all the nonusers were poorer farmers. The quantity of fertilizer used depended on the socio-economic level of the farmers, with richer farmers using more fertilizers. In Kenya most smallholder farmers do not use fertilizers because they are not available locally and lack information on the differences and uses of the various fertilizers, appropriate timing of application and the rates of application.

Many small-scale farmers use different organic fertilizers that range from animal manure to crop residues. Levels of organic carbon have been shown to be the overriding factor affecting soil fertility. Murage et al. (2000) in their study indicated that among soil organic pools and fractions, total organic carbon was the most sensitive soil quality indicator. Irungu et al. (1996) reported that soil organic matter fraction may offer an insight into soil fertility changes and the sustainability of past management systems. The use of manure has been growing as a result of farmers getting more sensitized, especially with conservation technologies. The main problem however has been the decline in the quality and quantity of manure, which is attributed to substandard storage facilities and irresponsible handling.

2.3.2 Agroforestry

The role of agro forestry in maintenance of soil fertility is the fundamental proposition that trees improve soils. Soils that develop under natural woodland or forests are fertile, well structured, have good moisture-holding capacity, are resistant to erosion and possess a store of fertility in the nutrients bound up in organic molecules. In semiarid climates it is common to find higher soil organic matter and nutrient content under tree canopies than in adjacent open land. In Nigeria, maize in pot samples from soils under trees grew 2-3 times faster than in soils with no trees (Verinumbe, 1987). Majority of the smallholder farmers practicing agro forestry prefer to grow multipurpose trees. Agro forestry trees maintain or improve soils in different forms which include processes which augment additions to the soil such as increase in organic matter, nutrient uptake, atmospheric input Parker (1983) and exudation of growth promoting substances .Other processes are those that reduce losses from the soil by promoting recycling and checking erosion and improving soil physical properties including water-holding capacity. Biamah and Rockstrom (2000) reported that trees enhance nutrient cycling through conversion of soil organic matter into available nutrients. It is therefore possible to recycle nutrients through leaf-fall, root decay and green manure. Afforestation has been successfully employed as a means of reclaiming saline and alkaline soils (Gill and Abrol, 1986; Grewal and Abrol, 1986). Agro forestry also benefits farmers directly through the provision of poles for building, fruits for sale and consumption, fuel wood and fodder for livestock.

Agro forestry trees can also have direct adverse effects on soil properties. The main soil related problems include loss of organic matter and nutrients in tree harvest, nutrient and moisture competition between trees and crops and production of substances which inhibit germination or growth.

2. 4 Water Quality for Irrigated Agriculture

Wells, ponds, streams, and waste treatment plants are common water sources for irrigation. The introduction of irrigation in arid and semi-arid environments may elevate the water table and subsequently lead to problems of water-logging and soil salinisation (Hoffman and Durnford, 1999). According to Ghassemi et al. (1995) about 230 million ha of the arable land is under irrigation globally whereby about 45million ha (20%) suffer from severe irrigation induced salinity problems partly due to poor irrigation water quality.

Soil may be maintained in good condition (non-saline, non-sodic) by the use of high quality irrigation water and adequate leaching. Such water can potentially allow maximum crop yield under optimal soil and water management practices. The criteria of quality are low salinity, a low ratio of Na^+ to Ca^{2+} + Mg^{2+} to prevent the development of sodicity, and small concentrations of those ions which may have specific toxic effects. However with poor quality water, soil and cropping problems can be expected to develop which will reduce yields unless special management practices are adopted to maintain or restore maximum production capability under the given set of conditions (Ayers and Wescot, 1985).

Problem levels of salinity, sodium, carbonates, and pH can occur in any of the water sources. The continued application of poor quality irrigation water and its detrimental effects on soil properties can reduce the quality and growth of crops grown. However, with proper precautions and altered management practices, poor quality irrigation water may be used to produce high quality crops

Water quality is determined by analysis of the chemical properties of a water sample such as pH, electrical conductivity, soluble bicarbonates, carbonates, chlorides and hydroxides in the laboratory.

2.4.1 Classification of Irrigation Water

A number of criteria have been devised for the classification of irrigation water into different levels of quality. The water quality classification schemes vary from general to detailed for a particular crop or region. In addition to the chemical analysis of the water, many other factors require evaluation such as soil properties, irrigation management, climate and crops before determining the water suitability for irrigation. An example of the guidelines for interpretation of water quality for irrigation by Wescott (1980) are given in appendix 8.

The water quality tests for the Kibwezi River in the neighboring Kibwezi District of the study area indicated water of high salinity and sodicity hazard in the absence of leaching and adequate drainage (Sijali et al., 2003). They classified the Kibwezi river water as class 1 (the concentration of Mg^{2+} and Ca^{2+} cations is less than that of $-HCO_3^-$ and $-CO_3^{2-}$ anions) and when they used the water for irrigation, Mg^{2+} and Ca^{2+} cations precipitated as carbonates while all the Na^+ and K^+ salts remained in solution. The wide difference of $-CO_3^{2-}$ and $-HCO_3^-$ to Ca^{2+} and Mg^{2+} indicate an increase in sodium hazard

2.4.2 Problems Associated with Poor Irrigation Water Quality

Irrigation may trigger changes in all the major ecosystem regimes which may have undesirable consequences unless appropriate countermeasures are incorporated into the system. Irrigation interferes with the prevalent soil regime by introducing moisture in a quantity and sometimes quality which modifies the arid and semi-arid ecosystems (Marshall et al., 1996)

The poor water quality problems generally occur in four categories namely salinity, permeability, toxicity and miscellaneous. Each may affect the crop singly or in a combination of two or more (Doneen, 1975).When soils are inadequately leached and poorly drained, excess evaporation and transpiration results in salinization of soils. This is particularly a problem where artificially raised water tables, water logging and capillary rise or pollution from salinized outflow effluent prevent proper leaching of salts.Salinization also occurs when irrigation water has a high salt concentration. The salts accumulate in the crop root zone thus affecting water uptake by the plant resulting in slow or reduced growth.

Poor soil permeability occurs when the rate of water infiltration into the soil is reduced due to the concentration of soluble salts. Permeability is measured by use of the sodium adsorption ratio which is based on the interaction between total salt concentration and sodium concentration. Soil permeability is affected by long term irrigation which will be influenced by the total salt concentration of the water and by the sodium and bicarbonate content.

Toxicity occurs when certain constituents in the water are taken up by the crop and accumulate in amounts that result in reduced yield. This refers to one or specific ions in the water namely boron, chloride and sodium.

Miscellaneous problems related to irrigation water quality include excessive vegetative growth, lodging and delayed crop maturity resulting from excessive nitrogen in the water supply, white deposits on fruits or leaves due to sprinkler irrigation with high bicarbonate water and suspected abnormalities indicated by an unusual pH of the water.

2.5 Effect of Irrigation on Soil Properties

The expansion of arable agriculture into marginal forested and pasturelands where there is inadequate water for crop production. Crop production in such areas requires water supplementation from irrigation. Irrigated agriculture has led to degradation of the soil due to over-irrigation and poor land management practices (Rhoades et al., 1999). Such degradation has suppressed productivity under irrigation and sustainability of irrigated agriculture is threatened due to sub-optimal soil conditions (physical, chemical and biological).

Employment of sustainable management practices is necessary for improved soil quality to sustain plant and animal productivity for food security (Doran et al., 1996). Indicators of soil quality are the soil properties that are sensitive to changes in soil function Andrews et al. (2004) and selected soil indicators are used to assess soil quality. Selected chemical indicators include, soil organic matter, and organic N, C/N ratio, soil pH, extractable available N, P and K, CEC, salinity or alkalinity, and extractable available trace elements (Cu, Zn, Cd, and Pb) (Doran and Parkin, 1994). Physical indicators of soil quality include soil texture, depth of topsoil or rooting depth, infiltration rate, soil bulk density, water-holding capacity, available water content, aggregate stability, drainage and slope (Eswaran et al., 1998)

2.5.2 Effect of Irrigation on Soil pH

In soils of arid and semi-arid regions, human induced application of water and its subsequent evaporation leads to limited extensive leaching of base forming cations such as Ca 2+ and Mg2+ and the pH of such soils is 7 or above. Soil profiles in such areas usually have a calcic C horizon and the lower the rainfall, the nearer the surface this layer will be and these soils may have alkaline subsoils and alkaline or neutral surface layers. When enough leaching occurs to free the salts, a mild acidity may develop in the surface horizons. (Adams, 1984)

Soil pH for arable tropical soils generally ranges from 4 to 8.5, but can be as low as 2 in soils associated with pyrite oxidation and acid mine drainage. L ong-term, experiments on tillage indicate that soil inversion lead to low soil organic matter and consequently low microbial activity that ultimately increases soil pH (Dick, 1982).

PH varies with neutral salt concentrations and increases during the hot dry season when soluble salts accumulate in the soil. These are subject to leaching during the relatively cool rainy season when pH decreases again. In arid and semi-arid areas, nutrient imbalances occur naturally due to high soil pH and deficiency in micro-nutrients such as iron and Zinc is common.

2.5.3 Effect of Irrigation on Electrical Conductivity

EC (Electrical conductivity) is a measure of soil salinity (total soluble salt concentration) Rhoades et al. (1999) and salt affected soils can be classified as either saline, saline-sodic or sodic (Table 1).

Golchin and Asgari (2008) observed lower EC values in cultivated soils compared to the virgin soils, but when the soil water table was elevated, the EC values were higher in cultivated sites. The results indicated that where the water table is deep, the soluble salt contents of the virgin soils can be reduced by cultivation and leaching of excess salts to deeper layers.

The quality of salt affected virgin soils can be improved by cultivation when soil drainage is adequate and irrigation water of good quality is used for crops (Rhoades, 1984). However, cultivation enhances the salinisation process in soils with a shallow water table, as irrigation raises ground water table over time and enhances evaporation from the soil surface.

Table 1. Properties of Normal Soils Compared to Acid, Saline, Sodic and Saline-Sodic Soils

Soil	Common pH	Electrical Conductivity (EC) (dS/m)	Sodium adsorption ratio (SAR)
Normal	6.5-7.2	< 4	< 13-15
Acid	<6.5	< 4	< 13-15
Saline	<8.5	> 4	< 13-15
Saline-sodic	<8.5	> 4	> 13-15
Sodic	>8.5	< 4	> 13-15

Source: Brady (1990)

2.5.4 Effect of Texture on Irrigation

Soil texture influences irrigated agriculture through effects on the water holding capacity, infiltration and the ability of sodium to bind to the soil (Marshall et al., 1996). Clay soils hold more water and are slower to drain than course textured soils. In soils with low soil organic matter content , texture can more significantly contribute to bulk density, because soil texture is often cited as a critical property affecting the responses to machine traffic, tillage, and other forms of mechanical soil disturbance (Bulmer, 1998).

Under normal irrigation practices, sandy soils flush more water through the root zone than clay soils. Sandy soils can therefore withstand low quality irrigation water because more dissolved salts will be removed from the root zone by leaching. A given volume of clay particles has a higher surface area than an equal volume of a larger sized particle and are more likely to be bound by excess sodium causing dispersion. (Pearson, 2003).

2.6.1 Land Use Change and Effect on Soil Organic Matter

Soil conditions are usually best under permanent grasslands/forests and deteriorate at a rate dependent on climate, soil texture and management as the soil is cultivated. Changes in land use influence the amount, quality and turnover (Tiessen and Stewart, 1983). When land is ploughed, previously inaccessible organic matter from lower soil layers is exposed to attack by micro-organisms.

Studies have been carried out to investigate the influence of land use changes on soil organic matter in the tropical Guggenberger et al. (1995) and temperate soils (Tiessen and Stewart, 1983). The soil organic matter turnover is higher in the tropics due to higher temperatures.Guggenberger et al. (1994) and Bruno Glaser et al. (1999) found that change in land use from forest to pasture establishment led to a loss of about 30% of the total soil organic matter content. Cultivation replaces deep-rooted perennial plants with shallow-rooted annual plants, and thus reduces organic carbon inputs to the subsoil. On the other hand, Lanbin and Gifford (2007) found that soil carbon decreased following land use change from pasture to conifer plantation. Golchin and Asgari (2008) indicated that tillage practices reduced organic carbon content of the topsoil while tillage of grassland resulted in the loss of one-third to one-half of the native soil organic matter in the first 40–60 years (Rasmussen and Collins, 1991).

Exposure of soil due to vegetation removal reduces organic carbon .The decline is attributed to two causes. First, clea ring and cultivation results to reduced rate of addition of vegetation organic material Greenland and Nye (1959) and secondly the rate of decomposition of the soils organic carbon is accelerated as a result of a combination of factors favouring increased mineralization after clearing and cultivation.

2.6.2 Effect of Cultivation on Bulk Density

Bulk density is defined as the ratio of mass of oven-dry soil to its total volume. Bulk density is an indication of the physical condition of the soil. It is usually related to soil porosity, texture, hydraulic conductivity, infiltration rate, aggregation, compaction and organic matter content.

Bulk density is a good index for soil porosity (Wood et al., 1983). For any given soil, the higher the bulk density, the more compacted the soil and the lower the pore space. Bulk density of cultivated land tends to increase as the season progresses, the effects of tillage being mostly transient.

Golchin and Asgari (2008) reported that the bulk densities of conventionally tilled sites to be 4–33% higher compared to untilled sites indicating higher compaction of cultivated soils due to tillage practices, lower organic matter content, and lower activity of soil fauna. However, Henry (2003) reported no significant difference in the bulk density and pH of irrigated soil and non-irrigated fields Bulk density was found to correlate strongly with organic matter and soil texture (Salifu et al., 1999). Increasing organic matter decreases soil bulk density (Bhushan and Sharma, 2005). In virgin and uncultivated soils, such as forest and pasture soils, organic matter has a dominating effect on bulk density and acts as its main predictor (Krzie et al., 2004). McCalla II et al., (1984) reported that bulk density of the soil surface under heavy continuous grazing was higher than from either controlled grazing sites or those excluded from grazing. Similar results were obtained by Cheruiyot (1984) and Mbakaya (1985) in Kenya at Kiboko and Buchuma respectively. Cultivation of soil for arable production has been shown to cause soils bulk densities to rise in tropical soils (Mwonga, 1986)

Bulk density measures are therefore used as indicators of problems of root penetration and soil aeration in soils and for the calculation of available water capacity in a soil profile. It is an important soil parameter since it is related to soil structure and is a good index for soil porosity. Stevene et al. (2007) reported livestock grazing as having changed the soil infiltration rates and soil bulk density. Soils in the areas that had been grazed by livestock had 13% higher bulk density and 7% lower total porosity than those in adjacent forests. Soil bulk density, for forests and pastures were the same after 2 years without livestock grazing.

2.6.3 Effect of Cultivation on Soil Porosity and Water Availability

Good soil management should create optimum conditions for plant growth as shown by among others adequate available water. Adequate available water depend on soil pore size distribution, the key indices being air capacity (air filled porosity (C_a) at the soil field capacity and AWC). Soils with < 10% AWC are droughty and those with air field capacity < 5% are likely to be waterlogged while total soil porosity decline most rapidly in the first year after grassland is ploughed and deteriorate gradually as cultivation is prolonged (White, 1997).

Many previous studies have indicated that the conversion of forest and pasture soils into agricultural soils is accompanied by a loss of soil organic matter and structural stability and, under some conditions, an increase in soil compaction (Martel and MacKenzie, 1980). Compaction disrupts soil physical integrity by modifying porosity and impeding gas, water, nutrient, and root movement in the soil profile leading to a decline or cessation of plant growth. Livestock grazing changed soil porosity (Stevene, 2007). Soils in the areas that had been grazed by livestock had 7% lower total porosity than those in adjacent forests. Total porosity, was similar for forests and pastures after 2 years without livestock grazing.

AWC can be used for determination of the quantity and frequency of irrigation required in mm per m (mm m^{-1}) of soil (Bernard et al., 2005). The values may be given for the actual or potential rooting depth of the soil profile. It is important to note that not all the calculated 'Available Water' is necessarily accessible to plants since the accessibility depends on the rooting depth and root concentrations at different horizon depths, root dimensions and conductive properties and hydraulic conductivity of the soil as a function of depth and water content. Other factors include plant species, stage of growth, season and drainage characteristics of the profile. Reduction of soil organic matter in the soils is likely to lead to higher percent of micro pores which do not favour rapid water flow (Mwonga, 1986). Cultivation of grasslands leads to a decrease of organic matter in the soil which in turn leads to an increase of micro pores thus reducing the available water capacity. (Golchin et al., 2008).

2.6.4 Effect of Cultivation on Saturated Hydraulic Conductivity

The saturated hydraulic conductivity (K_S) of a soil, defines the volume of water, which will pass through a unit cross-sectional area of a soil in unit time given a unit difference in water potential (hydraulic head). It is therefore a constant referring to the flow of a fluid through a saturated conducting medium. In practice the saturated hydraulic conductivity is the parameter of most interest, measurements being made mainly for comparison of hydraulic conducting rates of different soil horizons, particularly as a guide to water movement and possible drainage problems within soil profiles. It is of considerable importance since it gives an indication of the rate of movement of water to plant roots, the flow of water to drains and wells and the evaporation of water from the soil surface.

Kopittke et al. (2004) found that K_S tended to be greater in non-cultivated than cultivated soils. The decrease was attributable to a loss of structure associated with cultivation. In addition, as the sodium adsorption ratio increased, the reduction in relative K_S tended to be significantly greater in cultivated than non-cultivated soils. The relatively rapid saturated hydraulic conductivity in the non-cultivated soils at large sodium adsorption ratio was due to a greater aggregate stability due to greater soil carbon content. Cultivation, especially that which is continuous causes deterioration in soil structure (Greenland, 1981). This leads to a reduction in the percent composition of transmission pores in the soil. Organic carbon improves hydraulic conductivity of soils as a result of balancing the macro and micro pores distribution. Therefore the reduction of organic carbon in the soils is likely to lead to a higher percent of microspores which do not favor rapid water flow especially in continuous cultivation (Mwonga, 1986).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Area

3.1.1 Location

Mashuru Division is situated in the south-eastern part of Kajiado District and extends between latitudes $1^0 44'$S to $2^o 26'$S and longitude 36^0 $50'$E to 37^0 $45'$E. The division was curved out of Central and Oloitokitok Divisions in 1989 (Figure 1).It occupies an area of approximately 22,500km^2. The general altitude ranges between 1200m to over 2000m above sea level (ASL). The other divisions in Kajiado district are Oloitokitok, Namanga, Central, Isinya, Magadi and Ngong. Administratively, the Division has 9 locations and 17 sub-locations with a population of approximately 47,000 persons and 9,600 households.

3.1.2 Vegetation

Vegetation consists of trees, shrubs, herbs, and grasses that are adapted to the arid and semi-arid environment. The dominant plant species in the division are acacia trees mainly along major river courses. Dominant grass species include *Themeda thiandra* and *Pennisetum mezianum.* The vegetation of the area has traditionally supported livestock production, which remains the primary agricultural activity and occupation of the people in Mashuru Division

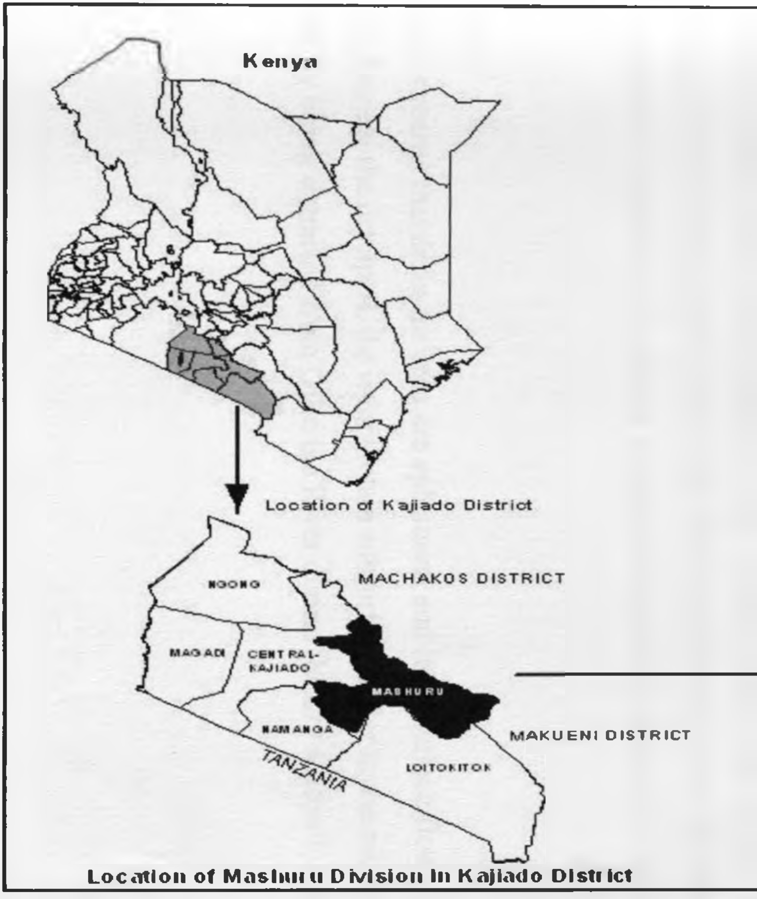

Fig 1.Location of the Study Area

STUDY AREA

Mashuru Sub_Locations

3.2 Socio-economic Study

A reconnaissance survey was conducted in the study area .This was done by randomly identifying the farmers that were to be interviewed and administering/ pre-testing the questionnaire.

3.2.1 Collection of Socio-economic Data

Primary data on socio-economics was collected through personal interviews using a semi-structured questionnaire. Stratified random sampling was used and a total of 70 farmers were interviewed. The farmers were stratified by farming practice into irrigation farmers or livestock farmers. All farmers practicing irrigation and those not practicing were listed. Random numbers were used to select the farmers for interviews. A total of 35 irrigation and 35 livestock farmers were interviewed in the cropping season of March to October 2006.

Secondary data on socio-economics was collected from reports in the relevant government departments, non-governmental organizations and community-based organizations involved in crop development activities in Mashuru division.

3.2.2 Socio-economic Data Analysis

3.2.2.1 Factors affecting shift from pastoralism to irrigation

To examine the social and economic factors causing/conditioning the transition from pastoralism to crop production in Mashuru, probit regression model was used (equation 3.1). Probit regression is a major method used for analyzing binary response data. The model uses the cumulative normal probability distribution.

Transition was conceptualised as a function of farmer, farm and institutional characteristics. A correlation matrix was used to select the variables for analysis in the model. (Appendix 1). Some 12 variables were hypothesized to have various forms of influence on the decision to transit from pastoralism to irrigation. In the model, if there was a probability of the farmer shifting to irrigation the dependent variable took the value of 1 and if not it took the value of 0 as shown below;

Crop = f (Individual farmer characteristics, Farm Structural characteristics, Institutional characteristics) + e ....(3.1)

Where;

Crop is a dependent variable with;

1=farmer shifts to irrigated crop production

0=otherwise.

e = stochastic term (aspects attributed to error)

The independent variables considered are shown in the table below:

Table 2. Independent variables influencing shift to irrigation

Farmer characteristics	Farm structural characteristics	Institutional characteristics
age =Natural log of age of household head in years	hhdsize= Family size in number	acccinf= Access to information. 1= yes, 0= otherwise
educ=Education of household head in years of schooling	Accehl = Access to hired labour	distagent= Natural Log of distance to extension agent in walking minutes
memborg= Membership to organizations 1= yes, 0 = otherwise	Vcows=Natural Log of Value of cows owned by the farmer in Kenyan shillings	distmark = Natural Log of distance to the nearest market in walking minutes
Iexp=Irrigation experience in years	Inc=Amount from other sources of income in Kenyan shillings	distwroad =Natural Log of distance to nearest weather road in walking minutes

3.2.2.2 Factors affecting soil and water conservation

To examine the factors driving farmers' decision to conserve soil and water, a probit regression model was estimated. The dependent variable use is binary variable which is 1 if farmer decided to use soil fertility management practices and 0 if otherwise. The explanatory variables are as below;

Table 3. Explanatory variables influencing decision to conserve soil and water

Farmer characteristics	Farm structural characteristics	Institutional characteristics
age= Age of household head in years	hhsize= Family size in number	accinf= Access to information. 1= yes, 0= otherwise
educ= Education of household head in years of schooling	Inc=Amount from other sources of income in Kenyan shillings	cons= Involvement in conservation activities; 1=yes, 0= otherwise
Iexp=Irrigation experience in years	ten= Type of tenure, 1= Individual, 0= Rented	ninf =Number of information sources
memborg= Membership to organizations 1= yes, 0= otherwise	accel= Access to hired labour; 1= yes, 0 = otherwise	
persf =Perceived soil fertility	Lfarm=Farmer lives on the farm	

The data were analysed using computer package SPSS.

3.3 Irrigation Water Sampling

Water samples were taken from the shallow wells that were used to irrigate each of the sampled farms. Two wells were sampled in two of the clusters that had relatively many farms and one well for each of the two clusters totalling 6 samples. Two replicate water samples from each well at two different times of the year were taken. The times were at the end of the dry season in October 2006, and at the end of the wet season/beginning of the dry season in January 2007. Sampling was done by skipping two wells and collecting water from the third. Using a 5 litre bucket, water was scooped 50cm from the water surface. A sub-sample of one litre was taken in clean plastic bottles. The water samples were delivered to the soil science laboratory in Faculty of Agriculture within 24 hours after sampling where they were stored in the refrigerator at 4^0c awaiting analysis.

3. 4 Experimental Layout and Treatments

After a survey conducted during the socioeconomic study, farms under different years of irrigation were identified and listed. Two sites under different years of irrigation were chosen to represent treatments and one control under grazing in four replicates. These were sites that had been cultivated for less than five years, sites that had been cultivated for more than five years and the uncultivated sites of natural vegetation under grazing. The sites were selected from farms along the riverine zone with one soil type (vertisols) within a stretch of 3 km along the river, there were four clusters of about 70 farmers irrigating small plots ranging from 0.25-3.0 ha. The main crops grown were vegetables such as tomatoes, kales, onions and capsicums. In each cluster, a farm that had plots of different lengths periods of cultivation was identified and sampling from plots of below 5 years and those at least over 5 years done. The uncultivated sites were adjacent to those cultivated about 200 to 300 meters on similar gradient along the river mostly covered by bush and used for grazing. Sampling was carried out in dry and wet seasons.

3.5 Soil Sampling

The selection of treatments was geared towards finding out if any significant difference existed between three different sites which included fields that had been irrigated for less than five years, more than five years and non-irrigated soils in terms of soil physical and chemical properties. Twelve composite soil samples from 0-10cm depth were collected from the cultivated and non-cultivated sites by auguring to the required depth. Undisturbed soil samples were obtained using metal core rings measuring 8 cm and 5cm (in length and diameter respectively) on the top horizon (0-15cm) by driving the core ring vertically using a hammer. Four core samples from the surface horizon were collected per site.

3.6 Laboratory Analysis

3.5.1 Soil Texture

Soil texture was determined using the hydrometer method as described by Gee and Bauder (1998). The soil texture class was determined from the standard USDA textural triangle (USDA 1975).

3.6.2 Bulk Density

The undisturbed soil samples collected were oven dried at 105^0c for 24 hours to obtain the oven dry weight. Bulk density was calculated as given by Blake (1986). The volume was that of the samples as taken from the field (i.e. volume was calculated from the core-ring dimensions).Bulk density was then calculated as follows,

$$\rho_b = \frac{M_s}{V_t} \qquad (3.2)$$

Where

ρ_b = Bulk density,

M_S = Weight in grams of the oven dry soil sample,

V_t= Total volume of sample as determined y the volume of core ring in cm^3.

3.6.3 Total Porosity (f)

Total porosity was derived from values of bulk density and taking the particle density as 2.65 g/cm^3 The calculation was done as follows:

$$f(\%) - [1 - \frac{\rho_b}{\rho s}] * 100 \qquad (3.3)$$

Where

ρ_s = particle density in g/cm^3

ρ_b is as defined above.

3.6.4 Saturated Hydraulic Conductivity (K_S)

Saturated hydraulic conductivity was determined by the constant head method using a manifold connected to a constant head supply as outlined by Klute and Dirksen (1986). After a constant hydraulic head was obtained for each sample, the setup was allowed to equilibrate for about 15 minutes. The volume of water percolating through the soil sample in a pre-determined time of 30 minutes was measured using a measuring cylinder. The time allowed for each percolation was chosen so as to obtain measurable quantities of the percolating water. The calculation of K_S was done as follows:

$$K_S - \frac{QL}{A\,t\,H} \quad \text{.......(3.4)}$$

Where

K_S = saturated hydraulic conductivity in cm/hr

Q = volume of water collected in cm^3,

t = time taken to collect water in minutes

A = cross-sectional area of the ring in cm^2,

L = length of soil column in cm, and

H =Δh + L where Δh is the hydraulic head in cm.

3.6.5 Available Water Capacity

The gravimetric method Gardener (1986) was used to determine the amount of water in the soils sampled. The aluminium cans were opened, weighed and then placed in the oven at a temperature of 105^0C for 24 hours. The oven dry weight was taken and the percent water content computed as:

$$\theta_w = 100\ (\ W_{wg} - W_{dg} / W_{dg} \quad \text{.......(3.5)}$$

Where

θ_w =gravimetric water content (%)

W_{wg} = weight of moist soil (g)

W_{dg} = weight of oven dry soil (g)

Then the volume –basis water content was obtained from the mass- basis values by use of the formula;

$$\theta_w = (\rho_b/\rho_{bw})\theta_w \quad \text{.......(3.6)}$$

Where

θv = Volumetric water content (%)

ρ_b = bulk density (g/cm^3)

ρ_w = density of water (g/cm^3)

3.6 .6 Soil Reaction

For each sample, soil reaction or pH was determined both in water and in Calcium chloride solution. The pH in water was determined in distilled water at a soil to water ratio of 1:2.5. The pH in potassium chloride was determined in 1N potassium chloride solution in a soil to water ratio of 1:2.5. The mixture was shaken mechanically for 30 minutes and then left to stand for 30 minutes before introducing the electrode into the solution. For both, pH in water and pH in potassium chloride determinations were done using an electronic pH meter with a glass electrode. The shallow well water aliquot was taken for the same determination.

3.6.7 Electric Conductivity

5 grams of soil and water at a ratio of 1:2.5 were placed in plastic containers. The containers were shaken for one hour with a reciprocal shaker to equilibrate. The mixture was left to settle for 15 minutes and the readings taken with an EC meter. The EC readings were corrected to give the EC values at 25^0C. Similar determination of the EC was also conducted for the shallow well water.

3.6.8 Organic Carbon

The Warkley and Black method (1934) was used in the determination of organic carbon. Soil samples sieved through 2mm sieves were passed through 0.5mm sieves and used for organic carbon determination. One gram of each of these fine samples was oxidized with potassium dichromate and unreacted dichromate titrated against 0.5N ferrous sulphate. The organic carbon was then calculated as given by Nelson and Sommers (1982).

3.6.9 Soluble Salts

A 1: 2.5 soil/ water mixture was shaken for one hour and then filtered. The filtrate was used for the determination of soluble K, Na, Ca, Mg, OH, HCO_3, and Cl.

The cations were determined as follows;

Table 4.Cation determination

Cation	Method	Reference
Potassium and Sodium	The EEL flame photometer	Dewis and Freitas (1970).
Calcium	titrating with EDTA as titre and using calcon as indicator	(Black 1965).
Magnesium	titrating with EDTA as titre and using EBT as calcium plus magnesium indicator	(Black 1965).

The carbonates, bicarbonates and chlorides wer e dete rmined as follows while adopting the method given by Rhodes (1982).

A 50 ml aliquot was used for all the anions determined. It involved titrating the water quality sample portion with sulphuric acid using phenolphthalein indicator. To the same sample, Methyl orange indicator was added and titration with sulphuric acid continued upto end point. To the same sample, 1 ml of 2% potassium dichromate was added and the mixture titrated with 0.05N Silver Nitrate.

Hydroxides and carbonates present were obtained from the first titration with sulphuric acid and phenolphthalein as indicator, whereas bicarbonates were determined by the same titration but with methyl orange indicator and final titration with silver nitrate gives the chloride content. The water aliquots were determined using the same way for the ions.

3.6.10 Statistical Analysis

The soil and water data was analysed using arithmetic and geometric means to describe the central tendency and variation of the data. All statistical analyses were performed using the computer package, GENSTAT. Completely randomized design was used for ANOVA to test the level of significance. All data were tested for normality before carrying out analysis of variance or regression. Differences among treatments were determined by analysis of variance and means separated by Student-Newman-Keuls.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Socio-economic Factors Influencing Transition to Irrigation

The monetary value of livestock by the respondent farmers was the main indicator of the socio-economic status and varied from 0 (farmers without cows) to a maximum of 1.7 million Kenyan shillings. The average age of the respondent farmers was 45 years with a standard deviation of 14 years. The youngest and oldest respondents were 25 and 70 years old respectively.

Farm families in the sample area have an average of 9 persons per household with the largest household having 23 persons. The average distance to the nearest extension agent was 4 hours in walking minutes with a standard deviation 3 walking hours. The closest farmer to the extension agent was 30 walking minutes while the farthest was 9 walking hours. The maximum number of organizations a farmer belonged was 2. (Table 5)

Table 5. Descriptive statistics of the key variables for the respondent farmers

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Value of livestock owned (KSh.)	70	0	1,700,000	111,429	285,205
Age of the household head (years)	70	25	70	45	14
Household size (persons)	70	1	23	9	5
Formal education level (years)	70	0	15	5.2	5
Distance to the nearest market (walking minutes)	70	30	600	172	111
Distance to the nearest all-weather road (walking minutes)	70	30	360	1230	840
Distance to the nearest extension agent (walking minutes)	70	30	540	270	210
Income from other sources (KSh)	70	1,234	624,000	99,572	139,738
Irrigation experience (years)	35	4	17	5	4
No. of organizations farmer belongs	70	0	2	1	0.5

Table 6 & 7indicate great variation in the value of cows owned by the irrigation and pastoralist farmers with a minimum of Ksh.0 for irrigators and Ksh. 450, 000 for pastoralists and a maximum of Ksh.350, 000 and Ksh.1.6m for irrigators and pastoralists respectively. The average age for the irrigation farmers was 44 years while the average age for pastoralists was 51 years. The youngest irrigation and pastoralist farmer was 15 and 18 years, respectively while the oldest was 60 and 104 years, respectively. Irrigation farmers took an average one hour to reach the nearest extension agent while the pastoralist farmers took an average of two hours. The closest irrigation farmer to the extension agent would take 2 minutes to reach him while the farthest could take three hours.

Table 6.Descriptive statistics for irrigators

Parameter	N	Minimum	Maximum	Mean	Std.deviation
Value of livestock owned	35	0	350,000	75,000	68,765
Age of household head (years)	35	15	60		
Household size (persons)	35	3	23		
Dist.to the nearest market (walking minutes)	35	5	180		
Dist.to the nearest weather road (walking minutes)	35	3	120		
Distance to the nearest agriculture extension agent (walking minutes)	35	2	180		
Other sources of income (Ksh.)	35	0	624,000.00	99,376.0	
Irrigation experience (years)	35	1	17	5	
N0. of organizations farmer belongs	25	2	2	2	

Table 7. Descriptive statistics of pastoralists

Parameter	N	Minimum	Maximum	Mean	Std.deviation
Value of cows owned	35	450,000	1,600,000	232,000	167,502
Age of household head (years)	35	18	104	51	18.43
Household size (persons)	35	4	31	10	5.39
Dist.to the nearest market (walking minutes)	35	3	180	47	30.67
Dist.to the nearest weather road (walking minutes)	35	0	180	28	36.48
Distance to the nearest agriculture extension agent (walking minutes)	35	5	240	119	52.82
Other sources of income (Ksh.)	35	0	100,000	33,137.00	32,994.50
Irrigation experience (years)	35	0	0	0	0
No.of organizations farmer belongs	35	0	2	1	0.5

From the probit model, 7 of the 12 variables were found to be statistically significant at $P \leq 0.05$ (Table 8).The farmer characteristics that were statistically significant were age at $P \leq 0.05$ and formal education of household head at $P \leq 0.01$. Age of household head had a negative relationship with the outcome binary variable. The implication was that younger farmers were most likely to shift to irrigation compared to older ones as confirmed by the age difference between pastoralists and irrigators (Table 6 & 7).The farmers in the study area are traditionally pastoralists and hence the older ones are deeply rooted in pastoralism and are unlikely to adopt irrigation farming. Increase in number of years in school of the farmer will increase the probability of the farmer shifting to irrigated farming. Farmers who are educated are more likely to practice irrigation unlike those who are not educated. Similar results were reported by Jha et al. (1991) where he reported a positive and significant effect between farmers' level of formal education and technology adoption in Eastern Zambia. Better-educated farmers are more likely to acquire, interpret and use technical advice from research enabling them to assess the relative benefits and risks of irrigation. They are also able to compare different enterprises and make an informed decision.

Household size and access to hired labour were the farm structural characteristics that were statistically significant at $P \leq 0.05$. Increase in household size by one increased the probability of a farmer shifting to irrigation. This may be attributed to the fact that if a household has more people, it is likely to adopt irrigation for food production in order to generate income to support the large family. Large families are also able to provide labour needed for the labour intensive irrigation activities. Increase in accessibility to hired labour would influence the farmer to shift to irrigation for similar reasons and hired labour may supplement family labour during peak periods.

Distance to market, distance to extension agent and access to information were the institutional characteristics that were statistically significant at $P \leq 0.05$. Farmers closer to markets were likely to shift to irrigation than those that were far away. Irrigators were closer to the market centre as compared to pastoralists (Table 6 & 7). Closeness to markets offered opportunities to access inputs and readiness of market for the farm produce. Decrease in distance to the extension agent by one walking minute would increase the probability of a farmer shifting to irrigation. This is validated in table 6 & 7 where irrigators spent averagely one hour walking to reach the extension agent while the pastoralists spent two hours. Farmers close to the extension agent are likely to get technical advice on irrigation and thus practice it. Majority of the farmers indicated that extension agents had visited them in the year 2006. The most important source of extension service was the public sector.

Table 8.Probit regressions results of factors driving the change in land use

Dependent Variable: Shift to irrigated crop production

Parameter	Estimate	P-Value
House hold head age	-0.16	0.036*
Formal education years	0.314	0.001**
Household size persons	0.029	0.043*
Distance to market	-0.149	0.046*
Distance to road	-0.052	0.073
Distance to Agent	-0.152	0.047*
Access to information	0.531	0.026*
Other sources income	-0.074	0.059
Belong to organization	0.232	0.065
Irrigation experience	0.054	0.160
Value of cows owned	-0.122	0.107
Access to hired labour	0.152	0.048*
Intercept	1.882	0.001**

**, * = Significance at 1% and 5%, levels respectively

Number of observations	70
Log pseudo Likelihood	-623.1004
Chi squared	54.7012**
Prob > chi-square	0.001031256

4.2 Soil Management

4.2.1 Soil and Water Management Practices

The irrigation farmers employed various soil management practices. The major soil management practices that were used by irrigation farmers included application of crop residues (85.5%), crop rotation (65.7%), fallowing (51.4%) and animal manure application (45.7%). These may be attributed to the easy availability of the materials on the farms. The least common soil management practices were contour bunding, conservation tillage and mulching (Table 9). Majority of the farmers used crop residues (85.5%), crop rotation 65.7%), fallowing (51.4%) and animal manure (45.7%) to conserve soil and water.

Table 9. Descriptive Statistics of Soil Management Practices

Management practice	Frequency	Percent
Crop residues	30	85.7
Crop rotation	23	65.7
Fallowing	18	51.4
Animal manure	16	45.7
Terraces	14	40.0
Trash lines	11	31.4
Artificial fertilizers	11	31.4
Agro forestry	7	20
Grass strips	1	2.8
Contour bands	1	2.8
Conservation tillage	1	2.8
Mulching	1	2.8

4.2.2 Factors Influencing Soil and Water Conservation Practices

Several socio-economic factors influenced the use of the soil and water management practices (Table 10). Four factors (whether the farmer lives on the farm or not, other sources of income, number of information sources and membership to social organizations) had a negative relationship with the outcome binary variable. The farmer characteristics (age, education and irrigation experience of the household head), farm structural characteristics (household size, and access to hired labour) and the institutional characteristics (access to information and farmer involvement in soil conservation activities by Ministry of Agriculture) had a positive statistically significant ($P \leq 0.05$) relationship with the outcome binary variable.

Increasing the age of the household head by one more year increased the probability of using soil and water management practices. Older farmers could have preferential access to new information or technologies through extension services or rural development projects that existed in the area (Adesina et al., 1993). Increase of irrigation experience by one year would increase the probability of implementing soil and water management practices. This is attributed to the fact that farmers who have been irrigating for a while know the value of conserving land. It may also imply that farmers who have been irrigating for longer periods have been exposed to information on appropriate soil management technologies. Abd-Ella (1981) also found that farming experience had a positive and significant relationship with the use of conservation practices while Miranowski (1981) reported that experienced farmers were more likely to rely on traditional tillage practices.

Increasing the level of education of a farmer by one year in schooling would increase the probability of using soil and water management practices. This indicates that farmers with more education tend to adopt new technologies in soil and water management. A positive relationship between level of education and technology adoption was also reported by Jha et al. (1991) in the Eastern province of Zambia. Carlson et al (1981) and Ervin (1982) reported a positive association between education and the use of conservation practices.

Increasing the size of household by one person would increase the probability of using soil and water conservation practices. This is attributed to the fact that the size of the family effectively determines the available labour and reduces the labour constraints faced on the farm. Increase in accessibility to hired labour will increase the probability of a farmer adoption of soil and water management activities. About 85% of the farmers interviewed used hired labour. Majority of the permanent labourers were paid by sharing of produce after harvest. The casual workers were hired during peak periods to assist the permanent labourers. Soil improvement technologies require a high labour input. Moreover, additional labour is also needed to harvest and process output and thus labour has a greater likelihood to influence adoption of improved soil management technologies.

Farmers' access to information increased the adoption of soil management practices. Farmers involved in conservation activities get their information from public extension and from neighbours. About 80% of the respondents had access to information. Some 91% of the farmers who were implementing conservation activities indicated that they had previously been involved in promotion of soil conservation activities such as field days and farmers' tours organized by the Ministry of Agriculture. Such farmers were exposed to different conservation practices. This finding suggests that exposure of farmers to conservation practices positively affects their adoption.

Table 10. Probit regression results for farmers' decision to use conservation practices
Outcome Variable: farmer uses soil and water conservation practices

Variable	Coefficient	P-Value
Age of Household head	0.140	0.050*
Irrigation experience	0.029	0.035*
Household size	0.144	0.047*
Does farmer live on the farm	-0.316	0.971
Other sources of income	-0.117	0.099
Perceived status of fertility	0.536	0.657
Education of House head	0.148	0.035*
Land tenure	0.481	0.592
Access to information	0.026	0.032*
Number of information sources	-0.126	0.801
Access to hired labour	0.613	0.033*
Involved in soil conservation activities by MoA	0.831	0.004
Membership to social Organizations	-1.490	0.670
Intercept	1.456	0.037*

* = Significance at 5% level

Number of observations	70
Log pseudo Likelihood	-62.4718
Chi squared	40.608*
Prob > chi-square	0.002 013

4.3 Irrigation Water Quality

The mean EC of the irrigation water was 0.94 dSm^{-1} at 25^{o} C and 0.85 dSm^{-1} at 25^{o} C for dry and wet seasons, respectively (Table 11) with significant difference at $P \leq 0.05$. According to Wescott (1980) guidelines for irrigation water quality, the water is marginal for irrigation and therefore there is a likelihood of the soils becoming saline in the long term under irrigation. The difference in water quality between seasons would be attributed to elevation in concentration of the total soluble salts probably due to high rates of water evaporation. The sodium content of the irrigation water was significantly different at $P \leq 0.05$ between the two seasons (Table 11). The carbonates of calcium and magnesium may have been precipitated in the dry season and sodium became the dominant cation, increasing the exchangeable sodium percentage in the irrigation water. Irrigation waters with high Na^+ would result in higher accumulation of Na^+ in the soil exchange complex with respect to other cations. This consequently results in reduced porosity, aeration and impeded water movement within the soil matrix as a result of soil structure destruction and blockage of pores (Radiro et al., 2003). Crops grown on such soils suffer adversely from poor aeration and water logging conditions which cause poor root development and consequently poor uptake of water and nutrients.These problems are pronounced on fine textured soils such as clays and loams that were predominant in the study area.

There were trace amounts of carbonates in irrigation water during the dry season as opposed to bicarbonates (Table 11) because bicarbonates have higher solubility in water. In the wet season however, there is enough water to solublize both the carbonates and bicarbonates.

Residual sodium carbonate was marginal in the dry season. Marginal water in residual sodium carbonate will precipitate calcium and magnesium thus increasing sodium concentration. With increased sodium the soil particles disperse thus loosing structure and this will affect the infiltration of water into the soil.

Table 11. Means of measured parameters for irrigation water

Parameter	**Units**	**Dry season**	**Wet season**
pH	-	7.59^a	7.45^b
$EC_{25}{}^0C$	dSm^{-1}	0.94^a	0.85^b
Na	me/l	4.50^a	2.48^b
Ca	me/l	0.31^a	0.20^b
Mg	me/l	2.78^a	2.17^b
CO_3	me/l	Trace	1.27
HCO_3	me/l	4.78^a	1.82^b
Cl	me/l	3.90^a	3.48^b
SAR	me/l	3.62^a	2.28^b
adj.SAR	me/l	7.24^a	1.82^b
RSC	me/l	1.69^a	0.72^b

4.4 Soil Physical Properties

4.4.1 Organic Carbon

The percentage soil organic carbon was significantly different at $P \leq 0.05$ between the grazed sites and sites that had been cultivated for less than five years. The value obtained for sites that had been cultivated for less than five years was 1.54 %, for more than five years was 1.44 % while the grazing sites had 1.72 %. The grazing sites had the highest amount of organic carbon while in the cultivated sites the amounts decreased with increase in the number of years of cultivation. Lanbin and Gifford (2007) observed a decrease in soil carbon following land use change from pasture to conifer plantation. Rasmussen et al. (1991) also reported that tillage of grassland resulted in the loss of utmost 50% of the native soil organic matter in the first 40–60 years.

The lower values of organic carbon in the cultivated sites can be attributed to the continuous cultivation throughout the year resulting in higher rates of decomposition and utilization by crops. Moreover, limited above ground crop residues remained on the land for decomposition as compared to the adjacent lands used for pastures.

4.4.2 Bulk Density

The mean bulk densities ranged from $1.21 g/cm^3$ to $1.35 g/cm^3$ for sites that had been cultivated for more than five years and the grazed sites, respectively. There was a significant difference at $P \leq 0.05$ between sites that had been cultivated for more than five years and the grazed sites. The estimated means for the grazing areas were higher than for the cultivated attributable to compaction from trampling by grazing livestock. Similar results were obtained by Stevene (2007) where he reported soil infiltration rates and soil bulk density in areas that had been grazed by livestock having 13% higher bulk density and 7% lower total porosity than those in adjacent forests. He further found that soil bulk density, for forests and pastures were the same after 2 years without livestock grazing. However, Golchin et al. (2008) reported conflicting results with bulk densities of conventionally tilled sites 4–33% higher compared to untilled sites indicating higher compaction of cultivated soils due to tillage practices, lower organic matter content, and lower activity of soil fauna

Bulk densities above 1.75 g/cm^3 for sand textures or 1.46 to 1.63 g/cm^3 for silt and clay textures will cause hindrance to root penetration (Landon, 1984). There are usually great differences in bulk density values depending on organic matter levels, land use and soil texture. Increase in soil bulk density imposes stress on plants root system. The mechanical resistance to root penetration increases, so reducing plants ability to its environment. The air- filled porosity of the soil decreases thus restricting the air supply to plant roots and facilitating the build-up of toxic products such as carbon dioxide and ethylene. The bulk densities obtained in the study indicate no anticipated hindrances to crop growth.

4.4.3 Total Porosity

The soil porosity values generally ranged from 47% to 58% (Appendix 2). Total porosity was significantly different at $P \leq 0.05$ between sites that had been cultivated for more than five years and the grazing sites. The grazing sites had the lowest total porosity. This may be attributed to the grazing of animals which may have compacted the soil over time due to trampling thereby increasing bulk density and lowering total porosity. Martel and Mackenzie (1980) however reported that conversion of forest and pasture soils into agricultural soils is accompanied by a decrease in total soil porosity due to a loss of soil organic matter and structural stability and, under some conditions, an increase in soil compaction. The difference would be attributed to tillage systems used and specific pasture management practices.

4.4.4 Saturated Hydraulic Conductivity (K_S)

The results obtained for K_S ranged from 0.93 cm/h to 3.76 cm/h, classified as slow to moderate respectively (Table 12) This wide variation corresponds to the prevailing diverse land uses in the study area, (cultivation and grazing). High percent clay values and moderate percent silt values account for moderate to slow values of hydraulic conductivity. This is ideal for the surface irrigation practiced by farmers in the area.

From the data in Table 12, there is significant difference between areas that had been cultivated for more than five years, those cultivated for less than five years and the grazed areas at $P \leq 0.05$. The saturated hydraulic conductivity ranged from 0.93 cm/h for the areas cultivated for more than 5 years (slow) to 3.76 cm/h for the grazed areas (moderate). Despite the uncultivated areas having the lowest total porosity, the hydraulic conductivity was highest. This is attributed to higher distribution of the macropores in the soil structure resulting from higher organic matter and higher microbial activity such as the termites' activity that are predominant in the study area. Similar results were reported by Kopittke et al. (2004). Ksat tended to be higher in non-cultivated areas compared to the cultivated soils. The difference was attributable to loss of structure associated with cultivation and reduction of organic carbon which lead to a higher percent of micropores which do not favour rapid water flow. Hydraulic conductivity values are related to textural and structural characteristics of a soil (Golchin and Asgari, 2008)

4.4.6 Available Water Capacity

The values obtained in this study ranged from 179 mm/m to 210.6 mm/m (Table 12). The soils have medium to high irrigation suitability. There was significant difference in available water capacity between areas that had been cultivated for more than five years and the grazed areas at $P \leq 0.05$. Bulk density and organic carbon content are the variables that have been found to influence available water content (Kironchi, 1992). The grazing sites had the highest water holding capacity followed by the cultivated sites whose capacity declined with increase in years of cultivation. The available water capacity may have been dependent on the soil organic matter content that was lowest in the cultivated areas due to continuous cultivation throughout the year resulting in higher turnover of organic matter. In addition, crop residues on cultivated lands are burned hence limiting organic matter input compared to the adjacent lands used for grazing that have additional inputs from animal wastes.

Table 12. Physical properties under irrigated and non-irrigated sites at 0-10 cm soil depth

Property	Units	Land Use		
		>5 years	< 5 years	Grazing
Organic carbon	%	1.44ab	1.54b	1.72[a]
Bulk density	g/cm^3	1.21[b]	1.25[ab]	1.35[a]
Total porosity	%	54.3[a]	52.5[ab]	49.1[b]
Saturated hydraulic conductivity	K_s (cm/hr.)	0.93[c]	2.55[b]	3.76[a]
	K_s class	Slow	Moderate	Moderate
Texture				
Sand	%	57[ab]	60[a]	53[b]
Silt	%	12[b]	14[a]	14[a]
Clay	%	31[a]	26[b]	33[a]
Textural class	-	SCL	SCL	SCL
Available water Capacity	mm/m	179[b]	184[ab]	210.6[a]

Means followed by the same letter superscript are not significant at $p \leq 0.05$.

4.5 Soil Chemical Properties

4.5.1 Electrical Conductivity and Soil pH

The values for EC ranged between 0.24 dS/m and 0.29 dS/m and all sites were non-saline. The values obtained were higher during the dry season. This is attributed to the high evaporation rate, which left the salts on the surface layer. For both seasons, the grazed areas had the highest mean EC of 0.36 dS/m and 0.29 dS/m for dry and wet season respectively. Similar results were observed by Golchin et al. (2008) where he observed higher EC values in virgin soils compared to the cultivated soils, but when the soil water table was elevated, the EC values were higher in cultivated sites. In the dry season, the grazed areas EC is significantly higher than the cultivated areas at $P \leq 0.05$. This would be attributed to accumulation of salts on the surface as the water evaporates. In the cultivated areas, irrigation leaches the salts. This is also indicated in both seasons where the EC has remained higher for gazed areas compared to the cultivated areas. Rhoades (1984) reported that the quality of salt affected virgin soils could be improved by cultivation when soil drainage is adequate and irrigation water of good quality is used. From the values obtained, the soils are normal (Brady and Weil, 1999). The soluble salt concentration in the soil is low and within safe limits.

The pH values obtained for sites that had been cultivated for less than five years ranged from 6.70-7.48 and 5.69-7.15, while sites that had been cultivated for more than five years had pH ranges between 6.34-7.47and 6.74-7.28 and those for grazed sites ranged from 6.36-7.24 and 6.20-7.20 for the dry and wet seasons respectively. (Appendix 3). From the data obtained, pH was relatively higher in the dry season. This may be attributed to limited leaching in the area which leads to accumulation of the base forming cations in the soil surface thus raising the soil pH (Adams, 1984). The pH is significantly higher at $P \leq 0.05$ for sites that had been cultivated for more than five years for both seasons. This may be attributed to the higher organic matter in the grazed and areas that had been cultivated for less than five years which buffers the soil pH.The soils under study range from neutral, mildly alkaline to moderately alkaline.
Soil pH greatly influences the soil quality. Most crops perform best in slightly acid soils (pH 6.5 - 6.8). For pH values above 8.0, some of the micronutrients (iron and manganese) and phosphorus become unavailable to the plants. Biological activity is also reduced as soil becomes sodic.

4.5.2 Exchangeable Cations

The exchangeable cations measured included sodium, calcium and magnesium. All the cations were higher in the dry season as shown in Tables 13.During the dry season the bicarbonates were also higher compared to the wet season. This would precipitate calcium and magnesium. The high evaporation during the dry season would also concentrate the cations on the surface. In all the treatments sodium was generally higher in proportion to other cations.This may be attributed to carbonates precipitating calcium and magnesium thus rendering sodium more available. There is significant difference between the cultivated and the grazed areas for all the cations at $P \leq 0.05$ during the dry season. In both seasons, all cations are higher in the grazed areas compared to the cultivated areas. This may be attributed to the leaching of the salts during irrigation in the cultivated sites.

4.5.3 Sodium Adsorption Ratio and Residual Sodium Carbonate

The Sodium Adsorption Ratio (SAR) ranged between 3.83-7.65 (dry season) and 3.16-7.65 (wet season).The SAR was significantly different at $P \leq 0.05$ for the cultivated and the grazing sites in the dry season. The soils were classified as slight to moderate restriction for irrigation.

Residual sodium carbonate (RSC) was significant at $P \leq 0.05$ for all the land uses during the dry season. From the results obtained for both seasons, the soils will have a tendency to precipitate calcium and magnesium cations and thus consequently increase the concentration of sodium in the soil. Irrigation of these soils will require good management practices to be put in place. This will include manure application deep tillage and application of adequate amounts of water to allow leaching of excess salts.

Table 13. Surface soil (0-10cm) chemical properties in irrigated and non-irrigated sites during the dry and wet seasons

Parameter	Units	Dry season			Wet season		
		Land use					
		> 5 years	< 5 years	Grazing	> 5 years	< 5 years	Grazing
EC_{25^0C}	dS/m	0.29^b	0.24^b	0.36^a	0.24^a	0.25^a	0.29^a
pH	-	7.90^a	7.14^b	6.67^b	7.04^a	6.66^b	6.78^{ab}
Na	cmol/ kg	1.12^b	1.24^b	3.90^a	0.63^a	0.57^a	0.70^a
Ca	cmol/ kg	0.09^b	0.12^b	0.28^a	0.04^a	0.05^a	0.09^a
Mg	cmol/ kg	0.08^b	0.09^b	0.24^a	0.04^a	0.03^a	0.06^a
CO_3	cmol/ kg	Trace	Trace	Trace	Trace	Trace	Trace
HCO_3	cmol/ kg	5.25^b	4.98^b	8.00^a	5.23^b	5.67^{ab}	6.75^a
Cl	cmol/ kg	13.90^a	11.60^b	13.70^a	9.00^b	10.20^{ab}	12.40^a
SAR	cmol/ kg	3.84^b	3.83^b	7.65a	3.15^a	3.83^b	7.65a
RSC	cmol/ kg	5.08^b	4.77^c	7.48^a	5.15^b	5.59^{ab}	6.60^a

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Irrigation is beneficial in that it provides for the production of food. Encouraging smallholder irrigated agriculture is vital to enhance production and attainment of food self sufficiency especially in regions where rainfall cannot meet the crop water requirements. Pastoralist farmers in Mashuru division, Kajiado district were found to have shifted to crop production and practiced irrigation as a coping mechanism during the dry seasons. Education and age of the household head, household size, distance to the agricultural agent, access to information, distance to market and access to hired labour influenced transition from pastoralism to irrigation positively and significantly.

Irrigating farmers used different soil and water conservation practices such as use of crop residues, crop rotation, fallowing and animal manure. The socio-economic factors that influenced their decision to conserve included the age and education of the household head, household size, access to information, access to hired labour, irrigation experience and involvement in promotion of soil conservation activities.

Irrigation water had moderate values of EC and SAR indicating that the irrigation water was of moderate quality. The irrigation water used was marginally suitable for irrigation and therefore it was likely to make the soils become saline over time unless appropriate measures were imposed.

Organic carbon, available water holding capacity (AWC) and saturated hydraulic conductivity were higher in the grazed sites but lower in the cultivated areas, decreasing with period under cultivation. Cultivation has therefore reduced the water storage and lowered organic carbon in the surface soils as compared to the uncultivated grazing areas.

The EC was higher in the dry season compared to the wet season. The EC was higher in the grazing areas compared to the cultivated areas and decreased with number of years of cultivation, indicating the effect of irrigation in lowering build-up of salts through leaching.

Exchangeable cations and the bicarbonates were higher in the dry season for all the land use types. The high concentration of bicarbonates would precipitate calcium and magnesium and thus increase the concentration of sodium in the soil over time. The high sodium level would then lead to increased exchangeable sodium percentage thus result in destruction of the soil structure. These soils therefore need proper management practices such as application of animal manure and adequate amounts of irrigation water, and therefore avoid any gradual buildup of excessive salts.

5.2 Recommendations

- Extension personnel and other development agencies such as NGOs that promote smallholder irrigation farming should target young farmers, most of who have relatively more formal education compared to the elderly, for faster adoption and imposition of appropriate conservation farming practices for improved and sustainable productivity.

- The farmers in Mashuru division should continue to use the irrigation water but since the irrigation water is of marginal quality, there is need to carry out a further study on the irrigation water leaching requirements to avoid salinity problems. There is also need to study the long term implications of smallholder irrigation agriculture as more pastoralist farmers shift to irrigation in terms of the water quantity and land degradation.

- Due to the declining soil organic carbon, farmers practicing irrigation should increase the use of organic fertilizers. This can be in form of the animal manure which is readily available in the area.

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LIST OF APPENDICES

Appendix 1: Correlation Matrix for Dependent Variables

	Age of the household head	Years of schooling of HH	HH size	Distance to the nearest mkt in kms	Distance to the nearest weather road in kms	Distance to the nearst agriculture extension agent in kms	Irrigation experience	Value of cows owned	No of organizations farmer belongs.	Number of information sources for farmer
Age of the household head	1	-0.543**	0.589**	0.107	-0.136	-0.101	0.011	0.004	0.129	-0.295
Years of schooling of HH	-0.543**	1	0.018	0.114	0.226	-0.021	-0.297	-0.08	0.049	0.381*
HH size	0.589**	0.018	1	0.17	-0.162	-0.014	0.327*	0.1	0.091	-.391*
Distance to the nearest mkt in kms	0.107	0.114	0.17	1	0.143	0.055	-.346*	-0.144	-0.098	-0.3
Distance to the nearest weather road in kms	-0.136	0.226	-0.162	0.143	1	0.387**	-0.191	-0.068	0.277	-0.199
Distance to the nearest agriculture extension agent	-0.101	-0.021	-0.014	0.055	0.387**	1	-0.195	0.127	0.308	0.189

in kms										
Irrigation experience(years)	0.011	-0.297	0.327*	-.346*	-0.191	-0.195	1	-0.081	0.406**	0.416*
Value of cows owned	0.004	-0.08	0.1	-0.144	-0.068	0.127	-0.081	1	-0.178	0.128
No of organizations farmer belongs.	0.129	0.049	0.091	-0.098	0.277	0.308	0.406**	-0.178	1	-0.086
Number of information sources for farmer	-0.295	0.381*	-.391*	-0.3	-0.199	0.189	0.416*	0.128	-0.086	1

* Significant at 0.1 level of significance

** Significant at 0.05 level of significance

*** Significant at 0.01 level of significance

Appendix 2: Soil Physical Properties

Trt 1=cultivated < 5 yrs.										
				Texture						
Replicates	**%C**	**B.D g/cm^3**	**Porosity(%)**	**% sand**	**% silt**	**% clay**	**Textural class**	**K_s (cm/hr)**	**Class**	**AWC (mm/m**
R1	1.60	1.3	51	80.0	10.0	10.0	SL	1.20	Slow	214
R2	1.28	1.2	47	76.0	8.0	16.0	SL	1.00	V.Slow	208
R3	2.79	1.2	58	46.0	14.0	40.0	SC	0.52	V.Slow	118
R4	1.03	1.3	55	72.0	8.0	20.0	SL	1.00	V.Slow	204
Trt 2=cultivated >5 yrs.										
R1	1.76	1.1	58	26.4	20.0	53.6	C	0.60	V.Slow	168
R2	1.23	1.2	51	72.0	8.0	20.0	SL	4.90	Moderate	187
R3	1.66	1.2	51	78.4	6.0	15.6	SL	3.20	Moderate	221
R4	1.15	1.3	55	52.0	14.0	34.0	SCL	1.50	Slow	132
Trt 3=Uncultivated										
R1	1.13	1.5	47	76.0	6.0	10.0	SL	5.72	Moderate	238
R2	2.62	1.3	47	28.4	16.0	55.6	C	5.00	Moderate	238
R3	1.36	1.4	51	72.4	6.0	21.6	SCL	2.32	Slow	162
R4	1.78	1.4	55	32.4	26.0	41.6	C	2.00	Slow	204

KEY: SL= Sand loam SCL = Sandy Clay Loam
SC = Sandy Loam

Appendix 3: Soil Chemical Properties

(i)Dry Season

Land Use	$EC_{25}{}^0C$	PH	Na	Ca	Mg	CO_3	H CO_3	Cl	SAR	SARadj	RSC
Trt.1=cultivated < 5 yrs.											
R1	0.20	7.08	1.30	0.12	0.10	Trace	5.00	12.00	3.28	3.06	5.00
R2	0.20	7.29	1.30	0.14	0.10	Trace	5.00	12.00	4.00	3.05	5.00
R3	0.40	6.70	1.30	0.10	0.06	Trace	4.92	12.00	4.00	3.10	4.08
R4	0.20	7.48	1.06	0.12	0.10	Trace	5.00	10.40	4.00	3.03	5.00
Trt.2=cultivated >5 years											
R1	0.30	6.34	1.22	0.10	0.10	Trace	5.00	15.20	4.00	3.22	5.10
R2	0.30	7.47	1.12	0.10	0.10	Trace	5.00	15.20	4.00	3.22	5.02
R3	0.35	7.07	1.12	0.06	0.02	Trace	6.00	14.10	4.00	3.22	5.10
R4	0.30	7.20	1.02	0.10	0.10	Trace	5.00	13.10	3.36	4.20	5.10
Trt.3=Uncultivated											
R1	0.20	6.74	3.60	0.28	0.24	Trace	8.50	13.40	7.20	3.16	8.00
R2	0.35	6.36	4.00	0.28	0.24	Trace	9.00	14.40	7.20	3.16	7.30
R3	0.20	7.24	4.00	0.28	0.24	Trace	6.50	14.00	8.10	4.00	7.32
R4	0.40	6.79	4.00	0.28	0.24	Trace	8.00	13.00	8.10	5.00	7.30

(ii) Wet Season

Land Use	$EC_{25}{}^0C$	PH	Na	Ca	Mg	CO_3	H CO_3	Cl	SAR	adj. SAR	RSC
Trt.1=Cultivated < 5 yrs.											
R1	0.20	6.84	0.09	0.06	0.03	Trace	5.57	10.20	3.20	2.00	5.18
R2	0.20	7.15	1.05	0.07	0.04	Trace	5.64	10.40	3.20	2.70	6.00
R3	0.40	5.69	0.07	0.03	0.02	Trace	5.67	11.00	3.00	2.80	5.18
R4	0.20	6.96	0.07	0.04	0.03	Trace	5.80	9.20	2.00	1.62	6.00
Trt.2=Cultivated >5 years											
R1	0.25	6.74	0.50	0.04	0.03	Trace	5.30	9.00	3.20	2.32	5.20
R2	0.20	7.28	1.00	0.03	0.05	Trace	5.28	11.0	3.20	2.30	5.18
R3	0.20	7.07	0.50	0.05	0.04	Trace	5.16	8.00	3.10	2.34	5.12
R4	0.20	7.05	0.52	0.04	0.04	Trace	5.18	8.00	3.10	2.00	5.10
Trt.3=Uncultivated											
R1	0.20	6.92	0.7	0.10	0.04	Trace	7.00	12.30	2.20	2.04	6.20
R2	0.30	6.20	0.6	0.10	0.05	Trace	6.00	12.10	2.04	3.00	5.00
R3	0.20	7.20	0.8	0.10	0.06	Trace	7.00	12.20	3.00	3.00	7.20
R4	0.25	6.89	0.7	0.06	0.06	Trace	7.00	13.00	3.00	2.20	8.00

Appendix 4. 1rrigation Water Quality

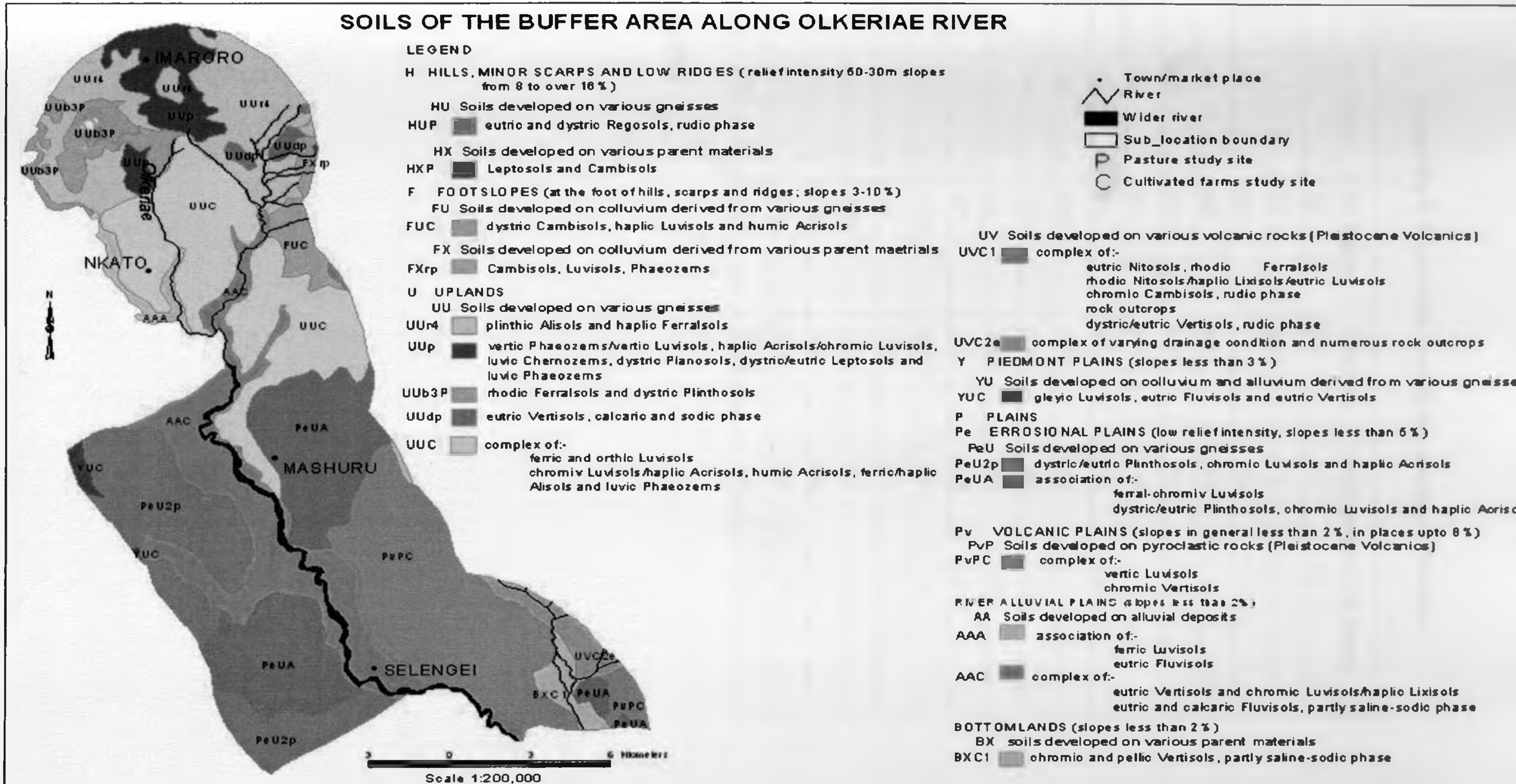
(i) Dry season

	Me/l												
Replicates	**PH**	**EC**	**K**	**Na**	**Ca**	**Mg**	**OH**	**HCO_3**	**CO_3**	**CL**	**SAR**	**SARadj.**	**RSC**
R1	7.92	0.02	0.55	8.10	0.51	4.10	Trace	6.90	Trace	11.20	5.34	12.18	2.29
R2	7.84	0.90	0.65	2.50	0.11	2.50	Trace	3.20	Trace	3.10	2.19	3.90	0.59
R3	7.87	0.90	0.33	1.70	0.21	2.80	Trace	4.70	Trace	2.50	1.39	2.87	1.69
R4	7.78	0.80	0.33	2.70	0.32	2.10	Trace	5.10	Trace	3.90	2.45	4.90	2.68
R5	7.76	1.00	0.33	2.70	0.55	1.70	Trace	3.70	Trace	1.30	2.55	4.59	1.45
R6	7.92	2.00	0.30	9.30	0.16	3.50	Trace	5.10	Trace	1.40	6.87	14.43	1.44
Average	**7.85**	**0.94**	**0.42**	**4.50**	**0.31**	**2.78**	**Trace**	**4.78**	**Trace**	**3.9**	**3.47**	**7.15**	**1.69**

(ii) Wet season

	Me/l												
Replicates	**Ph**	**EC**	**K**	**Na**	**Ca**	**Mg**	**OH**	**HCO_3**	**CO_3**	**CL**	**SAR**	**SARadj.**	**RSC**
R1	8.75	1.60	0.40	6.50	0.05	3.70	Trace	2.70	2.00	7.70	4.75	9.98	0.95
R2	8.60	0.50	0.15	0.40	0.06	1.40	Trace	0.90	0.80	1.70	0.47	0.47	0.66
R3	8.71	0.50	0.30	0.40	0.16	2.30	Trace	1.50	2.00	0.90	0.36	0.68	1.04
R4	8.53	0.50	0.30	1.70	0.10	1.30	Trace	2.50	1.40	1.10	2.03	3.40	2.50
R5	8.50	0.80	0.30	1.70	0.25	1.50	Trace	1.70	0.80	3.10	1.82	2.90	0.75
R6	8.42	1.20	0.26	4.20	0.55	2.80	Trace	2.50	0.60	6.40	3.25	5.90	0.25
Average	**8.59**	**0.85**	**0.29**	**2.48**	**0.20**	**2.17**	**Trace**	**1.82**	**1.27**	**3.48**	**2.11**	**3.88**	**1.03**

Appendix 5. Soils along the Olkeriae river



Appendix 6: Population Density for Mashuru Division

Sub location	No. males	No. females	Total Pop.	No.H_holds	Pop. density
Arroi	476	484	960	157	6
Emali	617	601	1218	241	10
Emarti	585	590	1175	200	8
Emotoroki	854	982	1836	419	6
Erankau	2159	2005	4164	737	20
Imbilini	296	313	609	140	3
Imbuko	473	459	932	172	4
Kiboko	1226	1070	2296	549	13
Kilo	1244	1203	2447	430	15
Lesonkoyo	574	521	1095	204	25
Mashuru	796	797	1593	319	12
Masimba	1334	1284	2618	660	21
Merueshi	580	656	1236	254	13
Nkama	1127	1008	2135	397	13
Olkeriai	984	1179	2163	461	13
Olmolelian	1175	1282	2457	537	8
Sultan hamud	3382	3350	6732	1456	27

Source: CBS 2001

Appendix 7. Kibwezi River Water Quality Analysis

Analysis	Kibwezi town	TARDA	KARI Sub-Centre
Ph	9.53	7.7	9.93
Ec mS/cm	0.6	1.10	1.15
Calcium meq/l	0.12	0.23	0.23
Magnesium me/l	0.15	0.28	0.31
Potassium me/l	1.44	1.15	1.95
Sodium me/l	3.48	6.78	7.30
Chlorides me/l	2.26	9.09	10.40
Sulphates me/l	0.31	0.24	0.07
Carbonates me/l	0.49	0.76	0.69
Bicarbonates me/l	4.92	7.20	7.09
SAR	9.47	13.42	14.00
ESP %	11.28	15.64	16.24

Source: Ministry of Water 1983/84.

Appendix 8: Guidelines for interpretation of water quality for irrigation

IRRIGATION PROBLEM	DEGREE OF PROBLEM		
	No problem	Increasing Problem	Severe Problem
SALINITY (affects crop water availability)			
ECw (mmhos/cm)	<0.75	0.75 - 3.0	<3.0
PERMEABILITY (affects infiltration rate into soil)			
ECw (mmho/cm)	>0.5	0.5 - 0.2	<0.2
Adj. SAR 1/2/			
Montmorillonite (2:1 crystal lattice)	<6	6 - 9 3/	>9
Illite-vermiculite (2:1 crystal lattice)	<8	8 - 16 3/	<16
Kaolinite-sesquioxides (1:1 crystal lattice)	<16	16 - 24 3/	>24
SPECIFICATION TOXICITY (affects sensitive crops)			
Sodium 4/ 5/ (adj. SAR)	<3	3 - 9	>9
Chloride 4/ 5/ (meg/l)	<4	4 - 10	>10
Boron (mg/l)	<0.75	0.75 - 2.0	>2.0
MISCELLANEOUS EFFECTS (affects susceptible crops)			
NO_3-N (or) NH_4-N (mg/l)	<5	5-30	>30
HCO_3 (meg/l) [overhead sprinkling]	<1.5	1.5-8.5	>8.5
pH	[Normal Range 6.5 - 8.4]		

Source: Wescot (1980).

1/ Adj. SAR - means adjusted sodium adsorption ratio, calculated as:
$SAR = Na^+/(\sqrt{([Ca^{++}+Mg^{++}]/2)}[1 + (8.4 - pHc]$

2/ Problems are less likely to develop if water salinity is high; more likely to develop if water salinity is low.

3/ Use the lower range if ECw < .4-1.6 mmhos/cm (1 mmhos/cm = 1 dS/m)
Use upper limit if ECw > 1.6 mmhos/cm

4/ Most tree crops are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive.

5/ With sprinkler irrigation on sensitive crops, sodium or chloride in excess of 3 meg/ l under certain conditions has resulted in excessive leaf absorption and crop damage.
<means less than
>means more than

Appendix 9 Questionnaire for Socio-economic Information

A. Identification

1. Name of the Interviewer..

2 Date of interview......................

3. Study Site.

Division .... Location ....

Sub location ....Village ....

4. Household Identification

a). Name of respondent.............................. ....

b). Relationship to household head (Tick appropriately)

1=Spouse 2=Daughter 3=Son 4=Employee 5= Relative

5. What is the household type (Tick appropriate)

1=Male headed

2=Female headed widowed/divorced/Single

3=Male headed, widowed/divorced/single

6. Distance to the nearest local market in walking minutes ....

7. Distance from the nearest all weather road ....

8. Distance to the nearest agricultural extension agent ....

9. Ethnic group to which the respondent belongs ....

10. Where do you live?...

B. Crop Farming/Livestock farming

1. When did you start irrigation farming? ....

2. What made you start irrigation activities? (Please circle all that apply)

1= Lost animals due to drought 2= Poor and never had animal 3= Proximity of Land to water source 4= Need to supplement family income 5=High earnings from irrigated vegetable production. 6= Others (specify)..

....

3. What is the total land under irrigated crop production in acres?................ ...

4. What is the distance of your irrigated farm from the water source in walking minutes? ....

5. What is the total size of your farm (own) in acres? ....

6. Did you rent any other land for irrigation activities last season of 2006?

1=Yes 0=No

7. If YES, please specify the:

i) Size .... ii) Cost (Kshs)..........................

8. If you rented the land you are using, how long have you been doing so? ....

9a). What crops did you grow before the short rains of 2006?

Crop	Acreage	Land rented	Output /acre	Quantity sold	Price/kg	Total revenue
Onions						
Kales						
Spinach						
Capsicums(pilipili hoho)						
Tomatoes						
Maize						
Others (Specify)						

9b) Where did you sell your irrigated crops?

1=in the farm 2=local market 3=send to Kajiado 4=send to Nairobi

5=through the group

9c). If you didnt sell your irrigated crops at the farm, how much did it cost you to transport it to the other markets (2,3,4, and 5 above) and the price you got there?

Crop	Costs to mrkts.				Prices			
	Mrkt.2	Mrkt.3	Mrkt.4	Mrkt.5	Mrkt.2	Mrkt.3	Mrkt.4	Mrkt.5
Onions								
Kales								
Spinach								
Hoho								
Tomatoes								
Maize								
Others								

10.) Crop production 2006

Crop grown	Total area planted (acres)	Land rented in (acres)	Variety (codes)	Manure (dry equivalent)[B]			Fertilizer		Seed				Field pest chemical		Storage pest chemical		Soil fertility (codes)	Oxen hiring (ksh)	Irrigation water(pumping)	Labour (labour days)						Production (kg)
				Own (tons)	Bought		Amount	Value (ksh)	Own saved (kg)		Bought		Litres/kg	Ksh/litre	Amount (kg)	Ksh/kg				Total hired Ploughing,	harrowing &	Weeding (1st and	Chemical application	Harvesting	Threshing/shelling	
					tons	Value (ksh)					Amount	Ksh/kg														
1.Onions																										
2.Kales																										
3.Spinach																										
4.Capsicums(pilipili hoho)																										
5.Tomatoes																										
6.Maize																										
Others (Specify)																										
1.																										
2.																										
3.																										
4.																										
5.																										

Variety	Soil fertility	B: Manure estimates
1 Local	1. Poor	Dry equivalent
2 Improved	2. Good	Small ox-cart = 300 kg
	3. Very good	Big ox-cart = 500 kg
		Standard wheel barrow = 50 kg

11. Have you ever experienced drought since you started irrigation?
1=Yes 0=No.
12. If YES, did it affect the supply of water to your farm?
1=Yes 0= No
13. Did you seek information about production of irrigated crops during last season of 2006? 1=Yes 0=No
14. If YES, please specify the sources you sought information from (Circle all that apply and rank them from most important to least important)
1=Govt. extension agent ....2=Neighbor........... 3=Group leaders.....
4=Input dealer 5=Other (please specify)......................................
15. Do you hire labour?
1=Yes 2 = No
16. If Yes, how many?...................................
17. Are you able to get labour when you need it?
1=Yes 0=No
18. If NO, when is the labour problem most pressing?
1=Planting 2= Weeding 3= Harvesting 4=Marketing.
19. Did you apply for credit for irrigated crop production?
1=Yes 2= No
20. If YES did you get credit?
1=Yes 0=No
21. If you got credit, what was your credit source(s) in the production season before the short rains in 2006? 1 =farmer self-help group 2=SACCO 3=Farmer cooperative Society 4=Church 5= NGO 6= Bank 7= Other (please specify).....................
....
....

22. Other sources of income.

Sources	Earning family member (use codes)	Where earned? (specify if out of village)	Actual amount	Price per unit (cash & in-kind)		Total income (cash & in-kind)	
				Cash payment (Ksh/day)	Payment in kind (Cash equivalent)	Cash payment (Ksh)	Payment in kind (Cash equivalent)
Rented out land							
Rented out oxen/donkey for ploughing							
Permanent nonfarm labour							
Casual nonfarm labour							
Long-term farm labour							
Casual farm labor							
Migration income							
Pension income							
Drought relief							
Remittances (sent from family and relatives)							
Sales from common property resources (firewood, brick making, charcoal making etc)							
Business net income (shops, trade, tailor, etc)							
Other short term employment							

Earning family member: Codes (e.g., 1=Household head, 2=Spouse, 3=Son 4=Daughter 5=Other (specify

23: Livestock production activities

Animal type	Current stock	Value (ksh.)						
		Died (ksh.)	Consumed (ksh.)	Bought	Gifts in	Gifts out	Sold	Milk yield earnings
Cattle								
Indigenous milking cows								
Crossbred milking cows								
Other non milking cows (mature)								
Oxen for ploughing								
Heifers/steers								
Calves								
Goats								
Milking she goats								
Other mature she goats								
Mature he goats								
Young goats								
Sheep								
Mature female sheep								
Mature male sheep								
Young sheep								
Other livestock								
Mature donkeys								
Young donkeys								
Mature pigs								
Mature chicken								
Mature ducks								

24: Livestock maintenance costs

Description	Targeted animal group **codes**	Total quantity bought	Units	Per unit price (ksh)	Sales tax or charges (ksh)	Market name if outside the village	Distance to market **(km)**	**Total cost (ksh)**
Green fodder								
Dry fodder								
Concentrates								
Veterinary services								
Vaccinations								
Acaricides (tick control)								
Dewormers								
AI services								
Herds boy (animal tending)								
Other costs (specify)								
1.								
2.								
3.								
4.								
5.								

Codes

1. Milking cows
2. Other cows
3. Oxen
4. Other cattle (heifer, bulls, calves)
5. Sheep
6. Goats
7. Poultry
8. Pigs
9. Donkeys
10. Bees

C. Household Food security indicators

	First harvest 2006	
	Maize	Beans
1. Was the grain produced enough to meet your home consumption requirements? **(Codes 1)**		
2. If **YES** to **Q 1** how much did you give to relatives, friends , Church neighbours as gifts, tithe, donations		
3. If **NO** to **Q 1** above, for how many months was the harvest enough to meet the household demand?		
4. How much (kg) did you buy to meet the remaining balance?		
5. Cost of purchased grain in **Ksh** (if known)		
6. How much (kg) did you borrow or receive as gifts?		
7. Give 3 main sources of money used to buy the food grains **(Codes 2)**		
6. How much food aid (kg) did you receive during the year (including food for work)?		

Codes 1

1. Yes

0. No

Codes 2

1. Sale of other crops
2. Sale of livestock
3. Remittances
4. Salary from regular employment
5. Income from other non-farm employment
6. Income from agricultural wages
7. Other, specify.......

D). Soil fertility and water conservation

1a). How do you perceive the status of soil fertility in your plots you use for irrigated farming? (Tick)

1=Not a problem 2=A minor problem 3=A severe problem

1b) How do you perceive the water quality you use for irrigation? (Circle where applicable)

1=Saline 2= slightly saline 3= Not saline

Give reasons for your choice above

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....

....

2. How does the soil fertility of the irrigated plots compare with non-irrigated?

1=Same 2= Worse 3=Better 4=Don't know

3. Since you started irrigation, have you ever experienced any of the following soil related problems? (Circle where applicable).

1=Salinization 2=Water logging 3=Nutrient depletion 4= Others

(Specify)..

....

4. Do you use any soil and water conservation techniques? 1=Yes 0=No

5. If YES, please select the techniques you are currently using (Circle all that apply)

1=Terracing 2=Grass strips 3=Contour bands 4=Trash lines 5=Conservation tillage 6=Animal manure 7= Crop residues 8=Crop Rotation

9= Fallowing 10=Others (please specify).......................................

6. Do you use any soil nutrient improvement techniques? 1= Yes 0=No

7. If yes which one? (Circle all that apply) 1=Artificial fertilizers 2= Animal manure

3=Green manure/crop residues 4=Compost 5=Crop rotation 6=Fallowing

7 =Double digging 8=Mulching 9 =Agroforestry 10=Intercropping

11=Others

(Specify)..

....

....

8. For each of the practices used, where did you first learn about it? (Tick where applicable)

Practice code	MOA extn.staff	NGO extn. Staff	Neighbour	Research station	Other (specify)	Yrs. Of Use.
1						
2						
3						
Practice code	MOA extn.staff	NGO extn. Staff	Neighbour	Research station	Other (specify)	Yrs. Of Use.
4						
5						
6						
7						
8						
9						
10						

Codes

1=Terracing 2=Grass strips 3=Contour bands 4=Trash lines 5=Conservation tillage 6=Animal manure 7= Crop residues 8=Crop Rotation 9= Fallowing 10=Artificial fertilizers 11 = Animal manure 12=Green manure/crop residues 13=Compost 14=Crop rotation 15=Fallowing 16 =Double digging 17=Mulching 18=Agro forestry 19=Intercropping 20=Others (Specify)

9. Have you ever been in direct contact with any organization involved in soil Conservation technologies promotion? 1=Yes 0=No

10. If YES, which organization and what were the activities you were involved in?

Organization	Activities
1.	
2.	
3.	
4.	

13. What are the main constraints in farming? (Circle all that apply and rank)

1=Lack of Inputs 2= Pests 3= Lack of technical know- how 4=Low soil fertility 5=Poor quality irrigation water 6=Lack of labour 7= lack of rkets8=others(specify)..

E. Farmer's Social Networks

1. Do you belong to any organisation that supports farming activities? (Circle all that apply)

1=Merry-go-round 2=farmer self-help groups 3=SACCO 4=Farmer Cooperative society 5=Church 6=Other (please specify)...

2. How long have you been a member of the group?...........yrs.

3. What services does the group offer to members? 1=Extension services 2=Promotion of Soil conservation technologies 3=Avail farm Credit 4=Marketing of produce 5= Others (specify)...

4. Did you receive any support from the public or private sector in establishing your Irrigation system? 1=Yes 0=No

5. If YES, please circle all the sources you have received help from.

1=Area politician 2=NGO 3=Govt. agric office 4= donor 5=local Church

6=Others (please specify)...............................

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F. Household information

1a). Family members information. (All members of the household)

Household member (use nos.)	Age (yrs)	Gender (M/F)	Relation to HHD	Years of schooling	Highest education attained (codes)
H/head					
Household member (Name)	Age (yrs)	Gender (M/F)	Relation to HHD	Years of schooling	Highest education attained (codes)

Codes: 1=None 2=Primary 3=Secondary 4=University 5=Other college

2. How many of the family members lived on the farm throughout the year 2006? ....