EVALUATION OF LIVELIHOOD, SOIL AND WATER RESOURCES IN SMALLHOLDER IRRIGATION SCHEMES ALONG THE TANA RIVER IN GARISSA DISTRICT

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DECLARATION

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

24.07.2009

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University Supervisors

This thesis has been submitted for examination with my approval as University supervisor.

24.07.09

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DEDICATION

This thesis is dedicated to my loving parents. wife and children

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LIST OF ABBREVIATIONS AND SYMBOLS

ASAL	-	Arid and Semi-Arid Lands
S-N-K	-	Student Neuman Keuls
EC	-	Electrical Conductivity
CEC	-	Cation Exchange Capacity
BSP	-	Base Saturation Percentage
FAO	-	Food and Agriculture Organization
UNESCO	-	United Nations Education Scientific and Cultural Organisation
IDB	-	Irrigation and Drainage Branch
DDC	-	District Development Committee
GoK	-	Government of Kenya.
MoA	-	Ministry of Agriculture
ET	-	Evapotranspiration
ETm	-	Potential Evapotranspiration
OC	-	Organic Carbon
WHC	-	Water Holding Capacity
TDS	-	Total Dissolved Solids
ESP	-	Exchangeable Sodium Percentage
SAR	-	Sodium Adsorption Ratio
SAR_{adj}	-	SAR Adjusted
FYM	-	Farm Yard Manure
cm	-	Centimetre
g	-	gram
g/cm^3	-	gram per cubic centimeter
hr	-	hour
Ks	-	Saturated hydraulic conductivity
kg	-	Kilogram
L	-	litre
m.e.	-	milliequivalent
mm	-	millimeter

dS/m	-	decisiemen / metre
mmhos/cm	-	millimhos per centimeter
r	-	correlation coefficient
RSC	-	Residual Sodium Carbonate
SSP	-	Soluble Sodium Carbonate
USDA	-	United States Department of Agriculture
P_b	-	Bulk density
P	-	Porosity
μS/m	-	microsiemen per metre
μmhos/cm	-	Micro millimhos per centimeter
pH_c*	-	The theoretical pH of an irrigation water.
UNDP	-	United Nations Development Programme
RDF	-	Rural Development Fund
PINEP	-	Pastoral Information Network Programme
FHI	-	Food for Hungry International
ALRMP	-	Arid Lands Resource Management Programme
ACC&S	-	African Christian Churches and School
KSS	-	Kenya Soil Survey
HH	-	Household
C	-	Clay
SCL	-	Sandy Clay Loam
SL	-	Sandy Loam
CL	-	Clay Loam
Sd	-	Standard Deviation

ABSTRACT

One of the major problems, facing the world today is that of meeting the food security needs of an ever-increasing population over a limited arable land. To overcome this problem, one option has been opening up more land for crop production through irrigation in the arid and semi-arid lands (ASAL). In Kenya over 83% of the land mass is in the marginal ASAL. Despite improving the livelihoods of farmers, irrigation often contributes to environmental degradation.

The objectives of the study were; first, to evaluate the impact of smallholder irrigation on the livelihoods of agro-pastoralists, soils and water resources along the Tana River in Central division of Garissa District, secondly to determine the state of the soil quality in the irrigated fields, and thirdly to assess the quality of irrigation water during the dry and wet seasons. For livelihood survey, open and close ended questionnaire was administered on 45 farming households. The information collected were household characteristics, crop production and marketing, soil and water management, farm inputs, household food security and wealth status. Soil samples were collected from randomly selected existing irrigation schemes during the end of a dry season (October 2006) and end of a rainy season (January 2007). Treatments consisted of three types of irrigation schemes randomly selected based on number of years of irrigation and one non-irrigated site. Similarly, water samples were collected from the same irrigation schemes along a canal at distances of 0 m, 500 m and 1000 m away from the river. Descriptive and quantitative statistics were used to analyze the data.

Results show that 98% of the farmers interviewed were male, of who 89% were married. On average, a family had 10 members, while the education level of the farmers was low with 38% of households interviewed having no formal education, 20% had adult literacy, 22% had primary education and 13% with secondary education.

Most of the farmers (78%) who grew crops owned livestock, mainly cattle, goats and camels. About (93%) of the farmers grow crops both for home consumption and sale with majority of the farmers using hired labour (71%). The area under crop production had significantly increased ($P \leq 0.021$) over the years, leading to increased household income, which 62% of farmers had used to acquire a variety of assets. Most of the farmers (79%) in the irrigation scheme were food secure most of the time.

Soil bulk density and total porosity differed significantly ($P>0.05$) between the number of years of irrigation and also between surface and sub-surface soils. Organic carbon varied from 1.01 to 2.18 and 10.60 to 1.02 for surface and sub-surface soils after dry season, while it varied from 1.40 to 1.90 and 1.02 to 1.43, after the rainy season for both surface and sub-surface soils. Significant differences ($P>0.05$) were observed within and between the two seasons with organic carbon increasing at the end of the rainy season compared to end of dry season. The soil pH decreased at the end of rainy season compared to the end of dry season, while it increased in sub-surface soils compared to surface soils both at end of dry and rainy seasons.

For EC, significant differences were observed ($P>0.05$) within and between the seasons. The dry season increased irrigation water salinity while the rainy season increased the leaching levels, both cases having an effect on EC.

CEC varied within and between the two seasons with CEC significantly ($P>0.05$) increasing at the end of rainy season. Calcium and magnesium significantly increased ($P>0.05$) at the end of the rainy season in both surface and sub-surface soils compared to end of dry season.

The pH of irrigation water fall within the normal range of 6.5 – 8.4 indicating the water in the canal was safe for irrigation. Similarly the EC was o.25 dS/m, hence it had no salinity problem. However, significant differences ($P>0.05$) were observed between the dry and rainy season where K^+ and Cl^- ions increased after rainy season, but the chloride levels were also within the accepted range (<4me/l). From the results, irrigation water quality varied with season, but on average the water quality fall in the low salinity and low sodium hazard class.

It is recommended that to boost the farmers efforts and to ensure higher incomes, a marketing system for the high value horticultural crops be improved especially, for tomatoes and mangoes whose prices fluctuate widely. It is also recommended that the scheme management committees be strengthened through capacity building. The continuous use of traditional farming implements like plain jembes at shallow depth ha resulted in increased surface soil compaction, resulting in decreased water flow, therefore farmers should be advised to frequently practice deep ploughing, such as ripping and sub-soiling to break hardpans and compacted soils to improve soil structure which will translate into improved crop water performance, thus increased yields. Finally, it's recommended that further studies be carried out to determine the causes of irrigation water quality variations with season, and variation of soil physical and chemical properties with depth

CHAPTER 1: INTRODUCTION

1.1 Background Information

Irrigation which compensates for the deficiency of climate has been practiced in agriculture for many years in many parts of the world. Although it is estimated that 15 - 20% of the worlds crop land is under irrigation, the production from this land amounts to 30 – 40% of the worlds agricultural output. The area of lands suitable for irrigation in the world is estimated at 1 billion hectares, of which the area currently irrigated in estimated at 277 million hectares (Li, 2008).

In sub-Saharan Africa, only 5% of the area in production is under irrigation, compared with 39% in South Asia and 29% in East Asia 17% in America, 9% in Europe and 1% in Oceania with climate change leading to rising uncertainties in rainfed agricultural, there are many opportunities to enhance productivity by revamping existing irrigation schemes and expanding smallholder irrigation schemes (World Bank, 2007)

Improving, the productivity, profitability and sustainability of smallholder irrigation farming is the main pathway out of poverty in using agriculture for development (World Bank, 2007).

Irrigation is an important factor in raising living standards of farming communities and eliminating unemployment. Irrigation system do not always produce agricultural crops without causing adverse effects on the soil, including erosion, salinization, alkalinization, and water logging. According to estimates by FAO/ UNESCO (1990) more than 50% of all irrigated lands have been damaged by those processes (secondary salinization and alkalinization) and as a consequences, many millions of hectares of irrigation systems have been abandoned (Worthington, 1977). The reasons for these harmful processes include use of poor quality irrigation water, inadequate water and soil management, seepage from the canals, uneven distribution of irrigation water and improper irrigation techniques. In many cases too much water is used, in others too little.

It is very difficult to reverse some of the soil deterioration processes by mere leaching and draining. Increasing salinity in irrigated soils of arid and semi arid lands is practically universal. There are salt affected soils occurring widely all over the world like in western Australia, the great plains regions of U.S. America, the Canadian Prairies, Russia, Iran, Syria, Afghanistan, Thailand, India, South Africa, Tunisia, Egypt and Morocco (Omulubi, 1996). According to FAO (2006) soils in the arid and semi arid land are characterized by sodicity and salinity, low fertility and vulnerability to erosion.

The land area of Kenya is 582,646km^2, 17% of which is classified as medium to high potential land with more than 700mm of rainfall per year, which is suitable for rain-fed agriculture. The remaining land (483,596.18km^2) is classified as arid and semi arid lands (ASAL) and cannot reliably support rain fed agriculture unless other technologies such as irrigation are used to augment water for crop production (Blank, et al., 2002).

The arid and semi-arid lands (ASALs) experience frequent crop failures and hence food insecurity. The incidence of household poverty in ASALs in higher (68%) than the National average of 51% (GoK, 1997). Thus the priority concern in this areas is food security through the development of technologies relevant to dry land farming with strong component of water management (Lagat et al., 2003). Adoption of irrigation technology for crop production by the local population is one way that significant areas of the semi-arid lands can be made productive on a sustainable basis. Farmers will adopt irrigated agriculture when they see that its benefits will outweigh the costs.

Farmers view irrigation as a means of achieving crop production, increasing household food security from both higher productivity and crop diversification. When farmers find incentives exceed disincentives, adoption begins and it is assumed that farmers made adoption decision based upon an objective of utility maximization (Lagat, et al., 2003).

The increasing demand for food and fibre as a consequence of the rapid rate of population growth necessitates that the country's agricultural potential be fully developed in order to address this challenge (GoK, 2007). In the medium and high potential areas, the option to pursue is the intensification of agricultural production (such as high yielding crop varieties and use of fertilizers) since there is limited scope for increasing the cropped area due to scarcity of suitable arable land.

Past studies have estimated irrigation potential in Kenya at 539,000 ha and out of this, only 119,200 ha have been developed (Anon, 2008).

Water used for irrigation always contains measurable quantities of dissolved salts. The suitability of water for irrigation will be determined by the amount and the kind of salts present. With poor water quality, various soils and cropping problems can be expected to develop. With good water quality there should be very infrequent or no problems affecting productivity (Ayers and Wescot, 1976).

According to Chhabra (1996), the impact of salt affected soil, not only decrease the agricultural production of most crops, but also adversely affect the associated ecological balance of the area. Some of the harmful impacts of salt (as a result of their effect on soil physiochemical properties) are; low agricultural production, soil erosion by both water and wind due to high dispensability of soil and decrease in shear stress; increase in floods due to higher run off as a result of decreased permeability of soil and low economic returns due to high cost of cultivation, decreased yields and poor quality.

In Kenya, widespread soil salinity, which had adversely influenced irrigation development, is found in isolated pockets around the lake Baringo basin in the rift valley and in the Taveta Area in coast province (Kundell, 2008).

Irrigation is a very expensive enterprise and care must be taken in it's planning and implementation. According to Tum (1996), such planning and implementation must take into consideration the chemical and physical properties of the irrigated soils so that the soils can be productive both in the present and in the future.

1.2 Problem Statement

Kenya is predominantly an agricultural country with quite limited areas of high potential land. It is therefore vital that investment be undertaken that will result in an addition to the area of productive land. Particular attention need to be directed towards developing the arid and semi arid lands which comprise about 80% of the countries total land mass and whose agricultural potential is largely unexploited because of lack of adequate rainfall (GoK, 2008).

This is why irrigation has gained greater importance as one of the few policy options of expanding food production, providing employment, absorbing the landless, achieving food self-sufficiency and raising the levels of income. The ability of irrigation farming to offer environmentally –based sustainable alternative source of livelihood to pastoralists is critical (Ahmed, 1999).

In Garissa District, like many other arid and semi arid areas of the country, small-scale irrigation farming started in the late 1970's and the area under smallholder irrigation development has gradually increased, and was estimated at about 2000 ha in 1995 (GoK, 1995). This is far less than the potential area estimated to be 28000 ha. Farmers use Tana River as the source of water to irrigate small plots for mainly horticultural crops such as vegetables and fruits for commercial purposes. They use pump-fed furrow irrigation system. Most smallholder irrigation farms are group-based with average land holding of between 0.5 to 5 acres (GoK, 2002).

Irrigation schemes are at different stages of development, with those which are much older showing decline in yield as compared to those, were started recently. Various reasons could be attributed to this scenario, high temperatures that increase the rate of evaporation from the surface, under irrigation or over irrigation, and poor land and water management resulting in soil quality degradation.

The smallholder irrigation schemes are characterized by various socio-economic problems including lack of financing, poor maintenance, absence of functioning farmer support services and low-income level of farmers (Blank et al., 2002).

This study evaluated the socio economic and environmental aspects of small holder irrigation schemes in Garissa with a view to finding out whether the irrigation schemes are sustainable. Environmental considerations are becoming increasingly important due to the heavy bearing they have on economic development. Sustained economic development can only be realized if environmentally sound development policies are pursued. The major environmental issues that are identified with marginal areas are the soil and water quality degradation. A dilemma therefore arises when irrigation is being considered, since on one hand it makes possible the use of the arid and semi arid land for crop production while on the other hand, the environment is adversely affected such as salinization of soils. Concern has been raised about the impact of irrigation on soil quality in Garissa (Ahmed, 1999).

Soil salinity causes land degradation and affects food production (Sharma and Rao, 1998). This problem is not only reducing the agriculture productivity, but is also putting far reaching impacts on the livelihood strategies of smallholder farmers (Tanwir et al., 2003).

Such information will contribute to the database for smallholder irrigation farmers, development planners, aid agencies, government extension workers, other stakeholders and in general help in understanding the impact of changing resource management and also improve adaptive management capacity (Stern, et al., 2004). It will also identify the gaps that currently exist amongst irrigation farmers as far as sustainable natural management of soil natural resources for socio-economic development are concerned.

1.3 Justification

Recurrent drought in the arid and semi arid parts of Kenya is responsible for the toll on pastoralists and their livestock, rendering many of them destitute. This led to various interventions to be instituted to free pastoralists from their predicament. Irrigation development was one of the strategies, introduced with a view to providing hope for the disposed pastoralists (Ahmed, 1999).

Improved irrigation is critical to increasing agricultural productivity (GoK, 2007). It changes low priced grazing land into expensive cropland (Troech, 1980). Land that formerly supported only grazing animals can be converted to high production of a wide variety of crops.

Irrigation projects are some of the most expensive agricultural investments, and therefore to pay for such investment, there is need for careful soil, water and the environmental management in general in order to achieve sustainable development. Soil quality degradation is one problem that has been the cause of failure of many irrigation projects. Some irrigation schemes in Garissa have already been abandoned due to soil quality degradation and others are on the verge of collapse.

The soils in arid and semi-arid lands (ASAL) are characterized with pockets of sodicity and salinity low fertility and vulnerability to erosion (Kundell, 2008).

Whereas compulsions to expand crop areas have brought arable farming to lands otherwise unsuitable for crop cultivation, irrigated agriculture has rendered many productive soils infertile (Chhabra, 1996). Continuous depletion of nutrients from soils, water logging, and secondary salinization are some of the problems threatening sustainability of crops in irrigated areas. Owing to this degradation processes, large areas of otherwise productive land have already gone out of production or are producing sub-optimal yields. In many areas the problem could assume serious proportions if proper care is not taken to control the build up of salts upon the introduction of irrigation.

This study will provide a data base on the status of irrigation schemes and give recommendations on how to improve on it. Also data collected from this study will be used as a source of information by policy makers, development planners, and farmers in assessing the impact of small-scale irrigation in a dry land environment in planning future irrigation schemes. The study is also necessary because not much has been done in terms of research yet there has been continuous expansion of irrigation projects. The study will provide critical data for such projects and it's impact on natural resources. Despite the planning and implementation, no information on socio-economic or environmental exists on the present and future impact of smallholder irrigation development.

1.4 Objectives of the Study

1.4.1 Broad Objective

To evaluate the impact of smallholder irrigation on the livelihoods of agro-pastoralists, soils and water resources along the Tana River in Central division of Garissa District.

1.4.2 Specific Objectives

1. To evaluate the impact of irrigation on the livelihoods of agro-pastoralists.
2. To determine the state of soil quality in the irrigated fields.
3. To assess the quality of irrigation water in wet and dry seasons.

1.5 Research Questions

1. To what extent does irrigation farming affects the socio-economics of smallholder households?
2. What are the major constraints to irrigated crop production?
3. What is the effect of smallholder irrigation on soil quality?
4. Does irrigation water quality vary with season and what is its effect on soil quality?

CHAPTER 2: LITERATURE REVIEW

2.1 The impact of irrigation on livelihoods

The full impact of irrigation upon water, soil and human extend through the social and economic fabric of local and national societies. Depending upon national resources and aspirations, irrigation may be viewed not so much as a means of increasing net production per hectare or person or amount of water but as a means of enabling an agricultural livelihood to maintain itself in harmony with the environment (Worthington, 1977).

According to Ministry of Water and Irrigation (2006), the national aims of irrigation development include; national economic efficiency, gaining of foreign exchange through cultivation of export cash crops, sedentarization of nomadic people, drought damage prevention, stabilization of agricultural systems and modernization of rural economy.

Irrigation can have substantial impacts on livelihoods that stem from increased demands for agricultural inputs: labour, fertilizer, seeds, pesticides, equipment and fuels, and from foods and fibres that are stored, transported and processed in adjacent communities. Irrigation also stimulates the growth of permanent settlements (towns) leading to increase in the density of rural population. Moreover, the majority of people moving from pastoralism to irrigated agriculture in dry-land environment are likely to be relatively young adults who will establish households and raise families (Worthington 1977). Irrigation will enhance food supplies, increase employment opportunities, improve amenities, reduce flood hazards and improve utilities like schools and sanitation facilities.

2.1.1 Irrigation and agro-pastoral livelihood

Irrigation farming is an external interference in nomadic pastoral areas that ultimately lead to sedentarization (Kariuki, 1995). Sedentarization through irrigation schemes has many adverse impacts on pastoral communities. It displaces true pastoralism, causes loss of good and critical grazing areas, usually dry seasons grazing areas (PINEP, 1996). This sudden and drastic transformation may affect the social, cultural and economic foundations of pastoral life as it introduces new values in relation to land tenure, income through wages employment, labour for livestock herding and farming Irrigation requires the adoption of drastically different skills and ideas about land preparation, drainage, watering, rate of planting fertilization, harvesting and many other cultural practices. It may mean a complete change in the lifestyle of farming populations. The successes of irrigation depend, greatly on the adaptability of populations practicing irrigated agriculture (Batisse, 1969).

Cases of pastoralists' involvement in irrigation schemes have been reported all over Africa with varying degrees of success and failure. But general pastoral communities have readily settled to irrigation farming, particularly following heavy losses of livestock due to drought and other catastrophes. Following the Sahelian drought of 1968-1974, there was a general increase in land under irrigation in the whole of West Africa (Delgado, 1979).

In the Sudan, agricultural development schemes, mainly the Gezira and the White Nile pump schemes resulted in spontaneous settlement of nomads (Khogali, 1981). In Kenya the Turkana have been settled in irrigation schemes (Kariuki, 1995). Sedentarization of nomads through irrigation has also taken place along the Daua and Tana rivers (PINEP, 1999).

Sedentarization resulting from irrigation schemes may lead to the introduction of formal education in pastoral areas, interrupts the technical learning of pastoral skills (Mwaniki 1981) and may lead to the irretrievable loss of pastoral know-how (Konczacki, 1978). In the Sudan where children are part of the labour force, nomads feel that formal education makes children rebellious because they often reject values common to nomadic communities. As a result, education has little practical appeal to pastoralist because it does not focus on nomadism.

The cultivation of flood recession lands and the use of lands that retain moisture into the dry season are common all over pastoral Africa (Kariuki, 1995). Conflicts and tensions are growing between different resources users over the shared exploitation of land, often pitting pastoral groups against sedentary farming communities. Cultivation of pastoral lands not only reduce the availability of key grazing areas, but also access to watering points along the rivers. In Morocco, like other Madreb countries, the extension of the area under irrigation prevents semi-nomadic pastoralists from using their tradition winter pastures (Dresch, 1975).

The elbow of the river Niger in Mali which provides seasonal flood retreat agriculture is an area of sharpest conflict between the nomadic and sedentary population (Kariuki 1995). In the Sudan and Senegal, herders have been deprived of dry season range by installation of irrigated perimeters along the rivers (Horowitz, 1980). In Kenya the introduction and expansion of irrigation in the lower Tana delta is likely to lead to the conflict between agriculturists and pastoralists (Ahmed, 1999).

2.1.2 History of Irrigation in Garissa district

Irrigation in the district started in the early 1970's following the drought in the same period that led to loss of livestock rendering the majority of pastoralists of the district destitute. This led to intervention of United Nations Development Programme (UNDP) and Food and Agriculture Organization (FAO) by introducing irrigated agriculture as an alternative to livestock for the destitute. Four schemes were started under this programme, one gravity scheme- Jarajara, and three sprinkler schemes – Bura, Masalani and First Farm Irrigation Schemes (GoK, 1995). All these schemes however developed problems and collapsed due to lack of technical and management know how by farmers, poor farmers' organization, poor extension services, market far away from schemes, poor farmers selection and participation, insecurity, transport problems, poor institutional support and poor soil and water management (GoK, 1995).

Later the government joined in irrigation development efforts in Garissa with assistance from the Rural Development Fund (RDF) through the North Eastern Provisional Irrigation Unit. Assistance consisted mainly of bush clearing, canal construction and the provision of diesel pumping sets. Most schemes hardly survived after initial aid was withdrawn (PINEP, 1999).

In 1984 an agreement was signed between the Government of Kenya (GoK) and Danish Government for financial and technical support to rehabilitate selected small-scale irrigation schemes in Garissa district. The objective of the programme included provision of adequate and balanced diet, by making the district self reliant on basic food items, conserving and upgrading the natural resource status in the area, particularly soil, water and vegetation; provision of higher and less risky sources of cash income from agriculture and related resources, and increasing employment in the rural sector of the district, and integrating the economies of the area more closely with mainstream national economic activities (PINEP, 1999). The Danish supported programme came to an end in 1993 after supporting fifteen (15) irrigation schemes with a total area of 226.5ha and 490 farm families (GoK, 1995).

In addition to efforts made by Danish government to support smallholder irrigation programme in Garissa there were other irrigation schemes which were developed with the assistance from, RDF, Food and Agriculture Organization (FAO), African Christian Churches and School (ACC&S), Food for Hungry International (FHI), Ministry of Agriculture (MoA) and Arid Lands Resource Management Project (ALRMP). To date there are about 120 irrigation schemes in Garissa District with a total cropped area of about 2000 ha. The major crops grown are horticultural crops mainly for commercial purposes. Irrigation is carried out throughout the year.

In an irrigation scheme plots are managed on individual or household basis. Communal responsibilities are confined to such essentials as joint action for repair or maintenance of canals and pumping sets. The size of plots allocated to individuals or households in most schemes in primarily limited by either the total number of people to be settled, water availability and topography or by combination of the above. Therefore major characteristics of smallholder irrigation schemes are intensive irrigation, small areas, and poor irrigation infrastructure.

The government initially provided irrigation facilities to farmers at no cost; but this is no longer the case. Farmers now assume a greater, if not the full investment cost of providing water for their crops. In order to meet this cost, farmers need to produce crops that can repay this investment and provide livelihood for their families (GoK. 1995). Increasingly, farmers have moved from the production of staple crops to market-oriented crops that can provide the needed cash incomes like growing of horticultural crops. However, the introduction of this crops means farmers have to be knowledgeable in a whole range of issues including improved agronomic practices, the benefits of fertilizer and pest control, sources of credit and the knowledge of the markets (Blank, et al., 2002).

In order to achieve higher yields and hence optimize their returns by harvesting their crops when the market prices is highest, farmers need to adopt a cropping pattern based on maximum harvested yield and water utilization (Sifuma, 1997). This means that the irrigated crops receive timely application of good quality irrigation water. However in most cases poor soil and water management are affecting crop yield.

2.2 Linkages between livelihoods and soil quality degradation

Existing natural capital of geological and biological resources is needed for agricultural, industrial and other productions (Ahmed, 1999). Depletion of natural resources can have serious indirect effects because a reduction in the stocks or populations of plants and animals may in turn reduce the sustainable flow of resource inputs and ecosystem services (Bonham 1989; Van Dyne, 1969). Only careful husbandry of environmental capacities can ensure sustainable and potentially larger income flows in the future.

Sustainable livelihood is not independent of the growth of the renewable resource base. As the ultimate support of much of livelihood activities, the environmental resource base makes a critical contribution to the cause of sustainable development (Hughes, 1987; Tadingar, 1994). Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Livelihood analysis is critically important in determining appropriate investment areas (Murdoch, 1975; Sanford, 1983). On the bases of a broad assessment of natural resources, socio-economic tools play a vital role in determining the desirability of environmentally related-projects, their design and location (Behnke and Scoones, 1992). Socio economic indicators are therefore crucial in pin pointing the need for introducing new incentives and removing misguided ones. Used properly, socio-economic parameters can identify the policy instruments necessary for sustainable development (Ahmed,1999).

To maintain future viability of irrigated agriculture farmers must be able to demonstrate that they are farming in a sustainable manner, that they are making informed and responsible management decisions, and that they understand and take responsibility for those decisions. Irrigation impacts on the overall sustainability of a farm because it affects many aspects of farming including economics, labour and energy requirements, crop production, soil quality and agrochemical and fertilizer use. Good environmental management practices ensure farmers are able to provide a continuing livelihood and way of life for themselves and future generations. By protecting environmental quality, and staying profitable, the impact on the farming community is far-reaching in terms of employment, economics and community dynamics (Ahmed, 1999).

2.3 Irrigation development

James and Hanks (1970) pointed out that the real drama in irrigation is in its tremendous potential for increased agricultural production and that in many instances irrigation farmers have been so preoccupied with the initial benefits obtained from irrigating new lands that they have failed to recognize the real potential of irrigated agriculture when all aspects of irrigation management are considered. Some of those issues that farmers ignore or neglect quite often are the drainage, soil, salts and the correct management. Soil quality degradation means a significant deterioration in the physical and chemical properties of the soil particularly salinization due to inadequate irrigation and drainage and acidification (Steiner, 1996). The challenge now facing irrigation farmers is the sustainable use of soil and water resources to secure food supply, conserve the environment and alleviate poverty.

2.3.1 Impact of irrigation on the environment

Although smallholder irrigation schemes have performed better than centrally managed schemes they are faced with the various constrains, among them being soil and water management, degradation of environment, and low production per acreage. Water management has a direct bearing on the long-term viability of an irrigation scheme. The way irrigation water is distributed among different farmers and within a single farm can make a difference between successful crop production or crop failure (Sifuma, 1997). The low crop yields in the smallholder irrigation schemes is due to limited knowledge on proper use of water and other inputs. Furthermore, over irrigation or under irrigation leads to problem of water logging and salinity.

Salinization occurs due to insufficient drainage where salts contained in the irrigation water remain in the soil and increase in concentration. Water logging results from a rising water table to the point where plant roots are permanently saturated (Ayers and Wescot, 1976). Human impacts on natural or quasi-natural dry land ecosystems include habitat fragmentation and loss, introduction of alien and invasive species, air, soil and water pollution and climate change. Activities that affect these ecosystems include agro-pastoral and firewood collection (Kariuki, 1995).

2.3.2 Human activities and their impact

There are proximate causes and indirect drivers of land degradation. The proximate causes include factors such as cropland expansion, intensification of agriculture and livestock grazing. Wood extraction and infrastructure extension such as the spread of irrigation technologies also play a significant role. The indirect drivers of land degradation include population density and growth, migration and policies that encourage or subsidize unsustainable practices such as over stocking of livestock and irrigation with saline water.

There are three principal soil degradation processes; physical, chemical and biological The first involves a decline in soil structure; leading to reduction in infiltration, increase in run off and exacerbation in erosion by water and wind. Chemical degradation involves processes such as salinization, alkalinization, leaching and acidification. The cost of these includes reduction in humus quality and quantity or declines in soil biodiversity. The overall result of these processes is reduction in biomass productivity, and soil and water quality deterioration (Brady and Weil, 2002).

2.3.3 Causes of land degradation

In the context of land degradation, researchers speak of "fast" and "slow" variables. In terms of biophysical variables, crop yield, for example, would be a fast (or quickly changing) variable whereas soil fertility, which affects yield is a slow (slowly changing) variable. In terms of socio-economic variables, household dept would be a fast variable whereas market accesses, which affect dept, are a slowly changing variable. Importantly, these biophysical and socio-economic variables are closely linked and constantly changing, both in short and long term. Land degradation has natural and human induced components, and therefore sometimes difficult to determine where the biophysical component leaves off and the socio-economic drivers begin (Chhabra, 1996).

2.4 Soil quality degradation

2.4.1 Soil quality as affected by human activities

Soils are integral components of agro-ecosystems, forest ecosystems and grassland ecosystems. Likewise, they influence downstream freshwater and coastal ecosystems as well as urban ecosystems. The ecosystem approach continually reminds us of the interaction among physical and biological entities in our environment. Soil quality is defined as the capacity of a soil to function within (and sometimes outside) its ecosystem boundaries to sustain biological productivity and diversity, maintain environmental quality and promote plant health (Brady and Weil, 2002).

Soil quality can be thought of as a stock of capital, which provides goods and services to farmers in the form of agricultural production outcomes through biological and chemical processes that are affected by the quality of the soil (Osgood and Lipper, 2000). Through their agricultural production decisions, farmers can deplete, maintain or augment the stock of soil quality. Land degradation is defined as the depletion of soil quality. At the same time, the quality of the soil present on a farmer's field in any one production period is a determinant of the yield outcomes. Generally, more highly degraded lands result in lower productivity, although the impacts vary across production conditions and the production technologies employed. Lower productivity can be due either to decreasing yields or increased production costs associated with decreased input efficiency.

Farm profits will be based upon yield outcomes, which in turn will be related to the level of soil quality. The income (or poverty) of the farmer is thus affected by the soil degradation through its impact on yields. Income is also affected by a multitude of other economic, social and natural factors such as prices, management practices, plot characteristics, other income sources, institutional arrangements and weather. These constitute a mix of exogenous and endogenous factors.

Soil quality is therefore a function of the farmers' response to a multitude of exogenous factors as well as the grower's socio-economic situation. Likewise the grower's socio-economic situation is a function of a series of exogenous factors and soil degradation. (Osgood and Lipper, 2000).

2.4.2 Irrigation induced salinity and alkalinity

Irrigation not only alters the water balance by bringing in more water, it also brings in more salts whether taken from a river or pumped from the ground water, even the best quality fresh water contains some dissolved salts. The amount of salt brought in with the water may be negligible but the amount of salt applied over the course of time are huge. The effect is accentuated in arid regions for two reasons (Ayers and Wescot, 1976):

(a) The water available from rivers or from underground is relatively high in salts because it has flow through dry region soils which typically contain large amounts of easily weatherable minerals

(b) The dry climates create a relatively high evaporative demand, so large amounts of water are needed for irrigation.

Salts not only decrease the agricultural production of most crops, but also, as a result of their effect on soil physico-chemical properties, adversely affect the associated ecological balance of the area (Chhabra, 1996). Some of the harmful impacts of salts are:

(a) Low agricultural production.

(b) Soil erosion by both water and wind due to high dispensability of soil and decrease in shear stress.

(c) Increase in floods due to higher run off as a result of decreased permeability of soil.

(d) Low ground water recharge.

(e) Poor human health due to toxic effects of elements such as F, B and Se and frequent outbreak of malaria and other diseases.

(f) Low economic return due to high cost of cultivation decreased yields and poor quality.

(g) Higher maintenance cost and short life of irrigation structures farm machinery and pumping sets which get corroded by high salts and the specific effect of sodium and certain other elements.

Salt-affected soils adversely affect plants because of the total concentration of salts (salinity) in the soil solution and because of concentration of specific ions, especially sodium (sodicity) (Richards,1954). In order to assist in characterizing and managing salt-affected soils, it is important to measure and quantify the degree of soil salinity and sodicity Salinity in measured primarily as the total dissolved solids (TDS) or more conveniently, as electrical conductivity (EC). Sodicity is characterized primarily, by exchangeable sodium percentage (ESP); and sodium adsorption ration (SAR). Table 1 shows the classification of salt-affected soils according to USDA salinity system of classification

Table 1: Classification of salt affected soils according to USDA salinity system of classification.

Type of soil	EC dS/m	ESP	pH
Saline	>4.0	>15	<8.5
Sodic	<4.0	<15	>8.5
Saline sodic	>4.0	>4.0	>8.5

Source: Richards (1954).

As Table 2 shows, exchangeable sodium percentage (ESP) tends to increase with soil pH, and therefore the sodicity hazard to plants (Abrol et al., 1980).

Table 2: Exchangeable sodium percentage of soil and sodicity hazards to plants.

Approximate ESP	Ph	Sodicity hazards
<15	8.0 – 8.2	Non to slight
15 – 35	8.2 – 8.4	Slight to moderate
35 – 50	8.4 – 8.6	Moderate to high
50 – 65	8.6 – 8.8	High to very high
>65	> 8.8	Extremely high

Source: Abrol et al., 1980

2.5 Irrigation water quality

Irrigation water quality refers to its suitability for use. Good quality water has the potential to allow maximum yield under good soil and water maintenance practices. 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.

Water quality, problems though often complex, generally occur in the four categories: salinity, permeability, toxicity and miscellaneous. Each may affect the crop singly or in a combination of two or more (Ayers and Westcot, 1976). Significant changes in the quality of irrigation water may occur during or as a result of its storage, conveyance and distribution, application, drainage away from areas of application and withdrawal from ground water aquifers (Worthington, 1977)

The table in Appendix 10 shows guidelines for interpretation of water quality analysis. These guidelines are a management tool and as with all laboratory methods and interpretation tools in agriculture, they are developed to help the trained fieldsmen or the scientists to better understand, characterize, interpret and hopefully improve the soil or plant response under a given set of conditions (Ayers and Westcot, 1976).

Almost all irrigation waters contain dissolved salts and suspended materials in varying amounts (James et al., 1982). Water has no inherent quality except in the context of the purpose for which it is used. According to Richards (1954), the requirements of irrigated agriculture are focused on three water qualities:

(a) Salinity, expressed as the total salt content of the water.

(b) Sodicity, expressed as the ratio of Na to Ca", Mg concentrations.

(c) Toxicity, caused by the presence of boron or other toxic elements and under some conditions the bicarbonate concentration as related to the concentration of calcium plus magnesium.

Kovda et al. (1973), recommended the use of SAR index as a measure of sodicity because of it is a good correlation with exchangeable sodium percentage (ESP). The sodicity of irrigation water is mainly affected by the levels of exchangeable sodium in soils.

2.5.1 Classification of Irrigation waters

According to Richards (1954), irrigation waters were divided into four saline and four sodic classes. Water suitable for irrigation could be chosen by combining the two hazards one affecting crop yields and the other exchangeable sodium levels; the higher the salinity class, the lower the sodicity class of the water be used. In general, waters with conductivity values below 0.75 dS/m are satisfactory for irrigation in so far as salt content is concerned, although salt sensitive crops may be adversely affected. Waters in the range of 0.75–2.25 dS/m are widely used and satisfactory crop growth is obtained under good management and favourable drainage conditions. For conductivity values above 2.25 dS/m, the waters are not suitable for successful crop growth. Van Hoorn (1970) stated that each of these classifications may be utilized as a guide, but should not be used as a generalization.

2.5.2 Factors affecting the suitability of irrigation water

Some of the factors considered when determining the suitability of water for irrigation include; chemical composition of the water, soils to be irrigated, crops to be irrigated, climate, and irrigation and drainage management. The quality of the water is determined by the total salt content, ionic composition and the presence of minor elements (FAO, 1971). The soils affect irrigation water suitability on accounts of its physical and chemical properties. The interaction of these factors can modify the limits otherwise imposed by the composition of irrigation water for their successful exploitation.

Chemical composition of water is a major factor in determining its quality. The total concentration and the important constituents determine the quality of water The ions analysed to determine the suitability of water for irrigation include calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Sulphates SO_4, Chloride (Cl), Carbonate (CO_3) and bicarbonate (HCO_3) as well as total salinity as measured by electrical conductivity (EC) and pH (Rhoades, 1972). If the pH exceeds 8.3, carbonate concentration becomes significant (Shainberg and Oster, 1978).

2.5.3 Seasonal variation in the composition of irrigation water

According to Kovda (1960), the salt composition of irrigation water is not static, but is continuously changing. Thus the evaluation of quality of irrigation water must be based on knowledge of seasonal variation in the salt content. The composition of flowing water changes under the influence precipitation or dissolution. The lack of rainfall and a high evaporation rate during dry seasons contribute to the rise in salt concentration (Kovda, 1960). The contact between the soil and irrigation water can bring about a sharp increase in the salt concentration especially under conditions of gravity irrigation (Shainberg and Oster, 1978).

2.6. Water quality associated hazards

Most of the waters in the arid and semi-arid areas have high salinity hazard but usually have low sodium hazards (Bhumbla, 1977). The hazards to be considered when evaluating suitability of water for irrigation purposes are salinity, sodium, carbonate alkalinisation, chloride and boron.

2.6.1 Salinity hazard

Total salt content, expressed in electrical conductivity in mmhos/cm or dS/m gives an indication of the waters quality with regard to the salinity hazard. Yaron et al (1973) cautions that the salinity ranges chosen to characterize irrigation water in a given area must be modified according to the local environmental conditions and that its total salt content only serves as a general qualitative assessment of its quality water. Badhe and Kadwe (1977) reported that waters having EC values below 0.25 dS/m are suitable for crops, those having values between 0.25-0.75dS/m are less suitable while those with values above 0.75 dS/m should be used cautiously.

Carter (1975) reviewed the development of salinity in the plant root zone. Evaporation removes water in the pure state leaving behind salts and other substances. This results in greater concentration of salts in the remaining solution unless leaching occurs. The introduction of salts into the soil from irrigation water or other sources, results in chemical reactions, especially the exchange of bases. Shalhevet and Kambulov (1976) described a number of processes, which occur as irrigation water percolates into the soil and gets lost through evapotranspiration and deep seepage. The important ones of these processes are the accumulation of salts in the plants root zone and the exchange of cations between irrigation water and soil exchange complex.

2.6.2 Sodium hazard

Due to its effect on the soil and plant, sodium is considered to be one of the major factors governing water quality. Kovda (1960) indicated that sodium sensitive plants may suffer injury as a result of sodium accumulation in the leaves, but in general sodium exerts a primary effect on the soil and a secondary effect on plant growth through deterioration of the physical condition of the soil (Van Hoorn, 1970). Several methods were proposed for expressing the sodium hazard. However, the most commonly used is the Sodium Adsorption Ratio (SAR) (Richards, 1954). SAR is defined as the ratio for soil extracts and irrigation waters used to express the relative activity of Na, Ca and Mg ions in a soil or water sample (see Appendix 10).

The most important soil physical property affected by high levels of soluble salts and / or sodicity is permeability of the soil to water. Ayers and Westcot (1976) noted that a permeability problem occurs if the irrigation water does not enter the soil rapidly enough to replenish the soil with water needed by the crop before the next irrigation and / or precipitation

2.6.3 Bicarbonate hazard

One of the characteristics of many ground and river waters is the presence of bicarbonates. The bicarbonate ion is important in irrigation water as regards precipitation of calcium and, to a lesser degree magnesium in the soil. Evidently, the depletion of bivalent ions is the soil solution leads to an increase in situ of the SAR and consequently ESP values larger than those that could be anticipated on the basis of SAR values of the irrigation waters (Eaton. 1950).

Various formulations have been proposed to account for the effect of bicarbonates on sodicity hazards of irrigation water. Eaton (1950) proposed the concept of residual sodium carbonate (RSC) for the assessment of high carbonate waters as follows:

$RSC = (CO_3^{2-} + HCO^{3-}) - (Ca^{2+} + Mg^{2+})$ 2.1

Where all ionic concentrations are expressed in me/l. RSC > 2.50 the water is hazardous for irrigation. If 1.25 < RSC < 2.5 it is marginal and if RSC < 1.25 it is safe. Good management practices and proper use of amendments, particularly gypsum, might make it possible for marginal waters to be used for irrigation.

The pH values of irrigation water and soil solution are governed, to a large extent, by the amount and proportion of CO^{2-}_3 and HCO_3 ions. The soil pH has been shown to correlate well with the contents of soil soluble CO^{2-}_3 and HCO^-_3 (Maliwal, 1968). High CO^{2-}_3 and HCO^-_3 content in irrigation water reduce the levels of Ca^{2+} and Mg^{2+} through precipitation and tend to increase the relative proportion of Na^+ in the water (Eaton, 1950), thus contributing to reduction in the soil permeability resulting in low soil moisture and hence reduced water availability to plants.

2.6.4 Chlorides and sulphates

Gullot (1954) stated that chloride ion appears as a factor in some regional water classifications, but it has no effect on the physical properties of a soil and is not absorbed on the soil complex. Fireman and Kraus (1965) recommended that water be divided into four groups to chloride with limits at 2.5 and 8 me/l.

According to Chhabra (1996) waters high in SO_4^{2-}, commonly having $Cl:SO_4^{2-}$ ratio of 1:3 or higher, are known as SO_4^{2-} waters, and more delirious than Cl^- waters because high concentration of SO_4^{2-} is more injurious to roots and disturbs the internal metabolism of the plants. At the same time, continuous use of such waters leads to precipitation of Ca^{++} as $CaSO_4$ causing rise in pH and ESP of the soil concentration (ILACO, 1981).

2.7 Effects of irrigation on soil properties

2.7.1 Soil physical properties

The key soil physical properties include; texture, structure, bulk density, porosity, colour and hydraulic conductivity. These determine the availability of oxygen in soils, the mobility of water into or through soils, and the ease of root penetration. Some of these properties are immutable, e.g. texture cannot be modified by cultural practices, but bulk density and hydraulic conductivity can be improved using appropriate soil management techniques (Evanylo and McGuinn, 2000). Most studies conclude that agriculture induced salinity and sodicity influences the chemical and physical characteristics of soils. (Rietz and Hayness, 2003), tillage, specially has been shown to increase bulk density and reduce hydraulic conductivity and organic carbon.

Irrigation induced salinity affect soil physical properties by causing fine particles to bind together to form aggregates and is beneficial in terms of aeration, penetration and root growth at low levels.

Irrigation induced sodicity has opposite effect of salinity on soils. The primary physical processes associated with high sodium concentrations are soil dispersion and clay platelet and aggregate swelling (Pearson et al., 2003).

2.7.1.1 Hydraulic conductivity

The hydraulic conductivity of a soil, symbolically represented as K in cm/h or m/day is a property of soil, that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Saturated hydraulic conductivity (K_s) describes water movement through saturated media, defines the volume of water which will pass through unit cross-sectional area of a soil in unit time, given a unit difference in water potential (Landon, 1984).
The knowledge of K_s is necessary for modeling the water flow in the soil, both in the saturated and unsaturated zone, transportation of water-soluble pollutants in the soil, and in designing of the drainage of an area (Spychalski et al., 2007).

It's generally recognized that extensive degradation of soil structure occurs at SAR values greater than 15 mmol/l (Shainberg and Letey, 1984). Several studies have been done relating the decrease of soil Hydraulic conductivity with high SAR (>15). (Quirk and Schofield, 1955; Frenkel et al., 1978, Shainberg et al., 1981 and Abu-sharer et al. 1987). Irrigation induced sodium causes dispersion of clay which leads to reduced soil permeability and increased run-off and soil erosion (Pearson et al., 2003).

The main concern related to the relationship between (EC) and SAR of irrigation water are the effects on soil infiltration rates and hydraulic conductivity. The ratio of salinity (EC) and sodicity (SAR) determines the effect of salts and sodium on soils (Pearson et al., 2003).

2.7.1.2 Bulk density

Soil bulk density is the mass of soil per unit volume in its natural field state and includes air space and mineral plus organic materials. Bulk density gives useful information in assessing the potential for leaching of nutrients, erosion, crop productivity and soil aeration in different soil horizons and water intake (Gachene and Kimaru, 2003). Run off and erosion losses of soil and nutrients can be caused by high bulk density when surface water is restricted from moving through the soil. Bulk density provides an estimate of total water storage capacity when the soil moisture content is known. Bulk densities are influenced by management factors. Continuous tillage and removing or burning crop residue can result in an increase in soil bulk density while rotational cropping and adding organic amendments on wet soils decreases bulk density. Vehicle traffic also compacts the soil and reduces aeration (Czyz, 2004).

Bulk densities that limit plant growth vary for soils of different textural classes (Arshad et al., 1996). Sandy soils typically have a higher bulk density than soils high in clay or loam because sandy soils have few tiny pores associated with fine textured soils that have clay and organic matter. Additionally, sandy soils that contain sand in a range of sizes already tightly packed, as smaller sand grains fit in between larger ones (Landon, 1984). Generally soil bulk density decreases with increasing levels of irrigation (Bhattacharyaya et al., 2006).

Irrigation induced sodium causes reduced infiltration and surface run off (increased bulk density) and reduced soil permeability. Generally soil bulk density decreases with increasing levels of irrigation (Bhattacharyaya et al., 2006). According to Al-Zu'bi (2007), damages to soil physical properties were produced by salt concentration in irrigation water. Increased amount of calcium (Ca) and Magnesium can reduce the amount of Sodium induced dispersion.

2.7.1.3 Total Porosity

Porosity is a measure of the void spaces (void space may contain air or water), in a material, and is measured as a fraction between 0 – 1, or as a percent between 0 – 100%. Knowledge of the soil bulk density and particle density allows the porosity and void ratio to be calculated; the void ratio being of more interest to crop production and consolidation of soils respectively (Dekkev, 1991). Adequate supply of soil solution and soil aeration especially oxygen to plant roots is essential for plant growth. Harrod (1975) found out that sandy soils with a total pore space less than 40% are liable to restrict root growth Thus porosity of surface soils typically decreases as particle size increases. This is due to soil aggregate formation in finer textured surface soils when subjected to soil biological processes.

Porosity of sub-surface soil is lower than in surface soil due to compaction by gravity. It is desirable for a root zone to have approximately half of its volume solid and half pore space (Ferro, 2006). The amount of air-filled and water-filled pore spaces ought to be present in roughly equal amounts. This should provide advantageous conditions for root growth, proper oxygen levels, and good mineral and water holding.

Gachene and Kimaru (2003) state that the compaction of soils through tillage or other operations increases the micropores and decreases the macropores and this reduces the total pore space, thus increasing bulk density. Compacted soils (with high bulk density) are less aerated, and root penetration is restricted. Surface water infiltration is also hindered, thus reducing the moisture available to crops. Total porosity generally increases with decreasing level of irrigation. Increases in sand and silt content in soil, decreases total porosity. Irrigated soils generally have low porosity.

2.7.1.4 Soil texture

Hillel (1998) defines soil texture as the measured distribution of particle sizes or the proportions of the various size ranges of particles that occur in a given soil. As such soil texture is a permanent, natural attribute of the soil and the one most often used to characterize its physical make up. The textural class provides an indication of a soils stability or potential for compaction and tendency to drain or retain moisture (Ferro, 2006). High infiltration rate is associated with medium to coarse textured soils while low infiltration is associated with fine textured soils (Julander and Jackson, 1983), but soils with a wide range in texture can have similar water movement properties (Lal, 1979). Subsurface soils high in clay content retain relatively high amounts of water than the surface soils for cultivated sites (Kironchi, 1992).

Under normal irrigation practices sandy soils, will naturally be able to flash more water through the root zone than clay soils. The end result is that sandy soils can stand higher salinity irrigation water because more dissolved salts will be removed from the root zone by leaching. Clay particles have a larger surface area because of their tiny size and hence have a larger risk than course textured soils for excess sodium to bind to them and cause dispersion (Pearson et al., 2003).

Hydraulic conductivity generally decreases according to soil textural class as follows: sandy soil > loamy soil > clay soil (Ozdemir, 1998). Increases in sand and silt content in soil texture generally increases soil bulk density and decreases total porosity. Hydraulic conductivity increases with decreasing clay content and increasing bulk density clay swelling and dispersion are unavoidable after irrigation with water of low quality (Kamphorst and Bolt, 1978).

2.7.2 Soil chemical properties

Chemical properties of soils, just like the physical properties, can be used as indicators of soil quality. Various properties can be considered, but those fundamental include soil reaction (pH), electrical conductivity, cation exchange capacity (CEC), exchangeable cations and organic carbon content.

Under irrigation, soil and water compatibility is very important, if they are not compatible, the applied irrigation could have an adverse effect on the chemical and physical properties of the soil. A basic understanding of soil / water / plant interactions will help irrigators efficiently manage their crops, soils and irrigation systems. (Scherer et al., 1996)

2.7.2.1 Soil reaction (pH)

Soil pH indicates how acid (pH < 7, high H^+ concentration) or basic (pH > 7, high OH^- concentration) is the soil solution. Soil pH is influenced by parent soil minerals and tends to decrease with time (Evanylo and McGuinn, 2000). pH values are very important because pH influences many chemical elements and biological processes in the soil (Tum, 1996). Although organic additions may not directly affect soil pH, soils that receive significant amounts of organic materials tend to maintain (buffer) soil pH values for long periods of time. Soils with pH values greater than 8.5 are classified as alkali, with values between 7.0 – 8.5 are rated as high, those with pH between 5.5 to 7.0 are rated medium and are in the preferred range for most crops, and with pH less than 5.5 are acid soils with possibly alluminium toxicity (Landon, 1984).

pH varies with neutral salt concentration. It decreases during the hot dry season when soluble salts accumulate in the soil (Tum, 1996). To offset the influence of seasonal variation in soluble salt concentration, Scofield and Taylor (1955) proposed a method for the determination of pH in 0.01 m $CaCl_2$. The pH measured in the salt reflects better the intrinsic characteristics of the soil and the value obtained is virtually independent of the initial soil: water ratio.

Irrigation leads to increased pH and it increases the sodium content in the soil (Rodolfo et al., 2007)

2.7.2.2 Electrical conductivity

Electrical conductivity (EC) measurements are used as indications of total quantities of soluble salts in soils. This is expressed in milliohms cm^{-1} (mmhos cm^{-1}) or decisiemens per metre (dS/m) (Ayers and Wescot, 1976). The quantities of salts which pass into solution depend on the relative amount of soil and water.

Many interpretations of EC values have been devised (Landon, 1984), but no universal, precise interpretation is possible because the effects of salinity are modified greatly by other factors such as quality of irrigation waters, soil texture, salt types present, crop varieties and species, soil drainability, stage of crop growth and climate. Michael (1978) stated that a high degree of correlation exists between EC, the total cations and osmotic pressure of soil-water extract.

Irrigation with saline water decreases soil salinity as long as the salt concentration in the water is less than that of the soil. On the other hand using the same water quality in soils with salt concentration less than 4 mmhos, the salt will accumulate (El-Guindy et al., 1987). Low salinity water will cause clay dispersion, soil swelling and plugging of the soil. This could lead to poor leaching, runoff and erosion (Zahow M.F. and Amrhein C. 1992). As irrigation water salinity increases soil salinity (EC) and soil SAR increases and the effect is greater for surface compared to sub-surface soils (Mustafazadeh-Fard et al., 2007).

2.7.2.3 Cation exchange capacity

Most cations, that is, positively charged ions are nutrients such as Ca^{+}, Mg^{2+} and K. These cations are in the soil solution and are in dynamic equilibrium with the cations adsorbed on the surface of clay and organic matter. Cation exchange capacity (CEC) is a measure of the quantity of cations that can be adsorbed and held by a soil. CEC is dependent upon the amount of organic matter and clay in soils and on the type of clay. Generally, the higher the organic matter and clay content, the higher the CEC. Cation exchange capacity is the sum total of exchangeable cations that a soil can absorb (Gachene and Kimaru, 2003). Cation exchange capacity (CEC) measurements are commonly made as part of the overall assessment of the potential fertility of a soil (Landon, 1984). Cation exchange in irrigated field occurs during percolation of water through the soil and the most important reaction in these soils is Na^{+}-Ca^{2+} exchange (Levy, 1984).

2.7.2.4 Exchangeable cations

The cations displaced during a cation exchange reaction are termed 'exchangeable bases' (Richards, 1954). The main common exchangeable bases are Ca, Mg, K and Na and are the primary soil nutrients (Tum, 1996). The main exchangeable bases are the divalent cations Ca and Mg, comprising about 90% of the exchange capacity of the soils (Levy, 1984), with Ca exceeding that of Mg. The remaining 10% of exchangeable bases are Na and K.

Cation exchange in irrigated fields occur during percolation of water through the soil profile. Determinations of the amounts and proportions of the various exchangeable cations present in soils markedly influences the physical and chemical properties of soils and nutrients uptake by crops (Landon, 1984). In irrigated soils, the main reaction of concern is the Na^{+}-Ca^{2+} exchange. Increased amount of calcium and magnesium can reduce the amount of sodium induced dispersion (Pearson et al., 2003). In normal soils, the range of soil solution concentration varies from 5 to 100 meq/l and the levels of exchangeable sodium do not usually exceed 20 to 30% (Poonia and Talibudeen, 1977).

2.7.2.5 Organic carbon

The amount of organic carbon in the soil is very variable. The factors which mostly affect the soil organic carbon under natural conditions are climate and vegetation (Kironchi, 1992). Sanchez (1976), stated that organic carbon in soils is a major factor contributing to soil aggregation of soil particles. This favours soil structure by increasing total porosity and percent of macropores, decreases crust formation and reduces susceptibility to erosion. A decrease in soil organic carbon content is indicator of a lowered soil quality (Gachene and Kimaru, 2003). The organic matter builds and improves soil structure thereby improving soil drainage, infiltration of water into the soil, aeration and water holding capacity. The rate of organic carbon decline is higher in semi-arid environment due to high rate of decomposition and mineralization.

Soil organic carbon increases the cation exchange capacity of a soil and provides a neutralizing or buffering effect on soil pH. Organic carbon improves the hydraulic conductivity of soil as a result of balancing the macro and micro pores distribution (Sanchez, 1976). A higher percentage of micro pores in the soil is as a result of reduction in organic carbon and this may not favour rapid water flow (Kironchi, 1992). On average, soil organic matter contains 58% organic carbon giving a conversion factor of 1.72 (Tum, 1996). The importance of organic carbon determination, therefore, lies in its indication of carbon content of the soil which is generally used as an index of soil fertility.

Increased level of irrigation increases the amount of organic carbon due to higher root biomass and crop residue addition. But, increased salinity and sodicity of irrigation water will result in progressively smaller, more stressed microbial community which is less metabolically efficient (Rietz and Haynes, 2003).

Sodium induced dispersion causes loss of soil structure. This results in anaerobic soils which can reduce or prevent plant growth or decrease organic matter decomposition.

CHAPTER 3: MATERIALS AND METHODS

3.1 The study area

3.1.1 Location

The irrigation schemes under study area are located in central division of Garissa District (Fig 1). The district borders the republic of Somalia to the east, Wajir district to the North, Isiolo district to the North-West, Tana River district to the west and Ijara district to the South. The district serves the provincial headquarters.

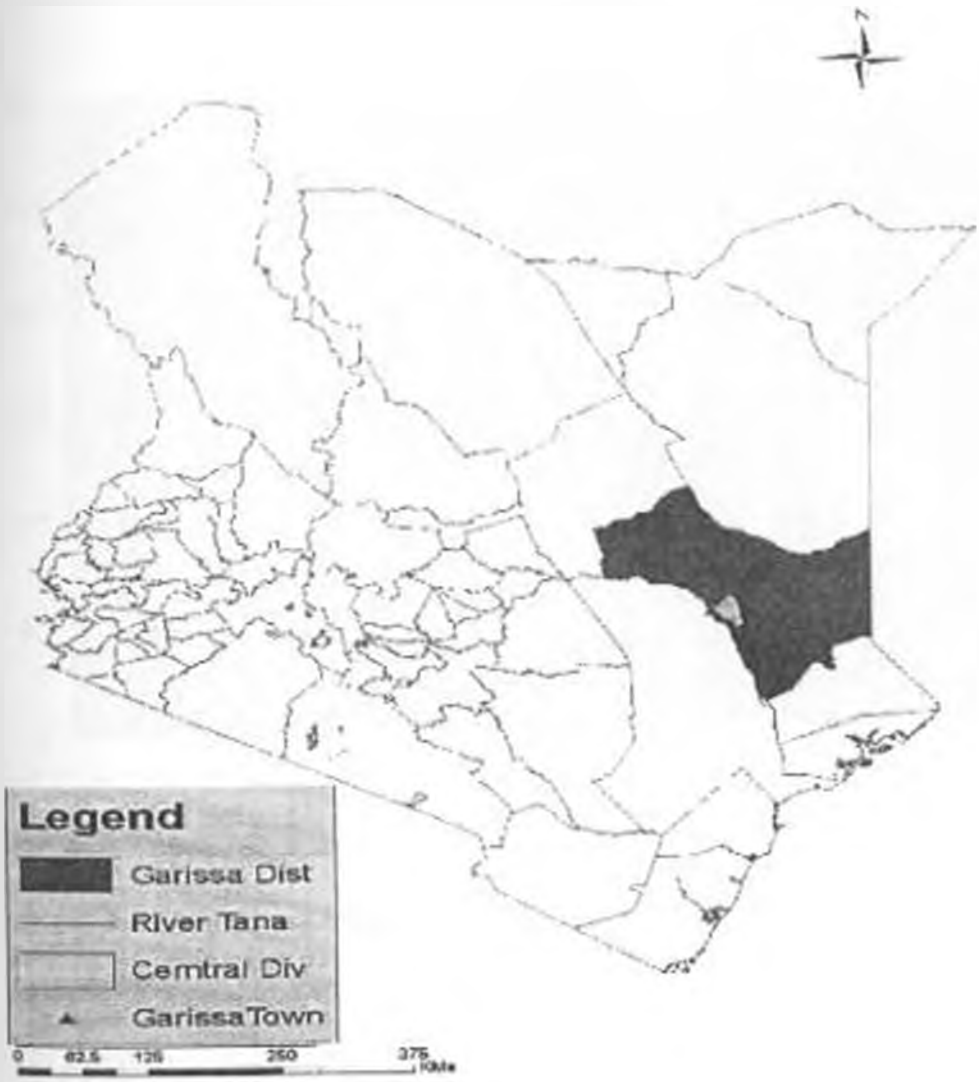

Figure 1: Location of the study area.

The area lies between latitude 0° 58'N and 1° 30' S and longitudes 38° 34'E and 41° 32'E. The area is generally flat with altitude of 70 m- 400 m above sea level (GoK, 2002).

3.1.2 Climate

The area is normally hot and dry for most part of the year. Rainfall is erratic and poorly distributed. The mean annual rainfall is about 350mm per annum, while mean pan evaporation is 26.80mm per annum (Fig 2). Temperatures are normally very high ranging between 33°C and 39°C (MoA, 2003).

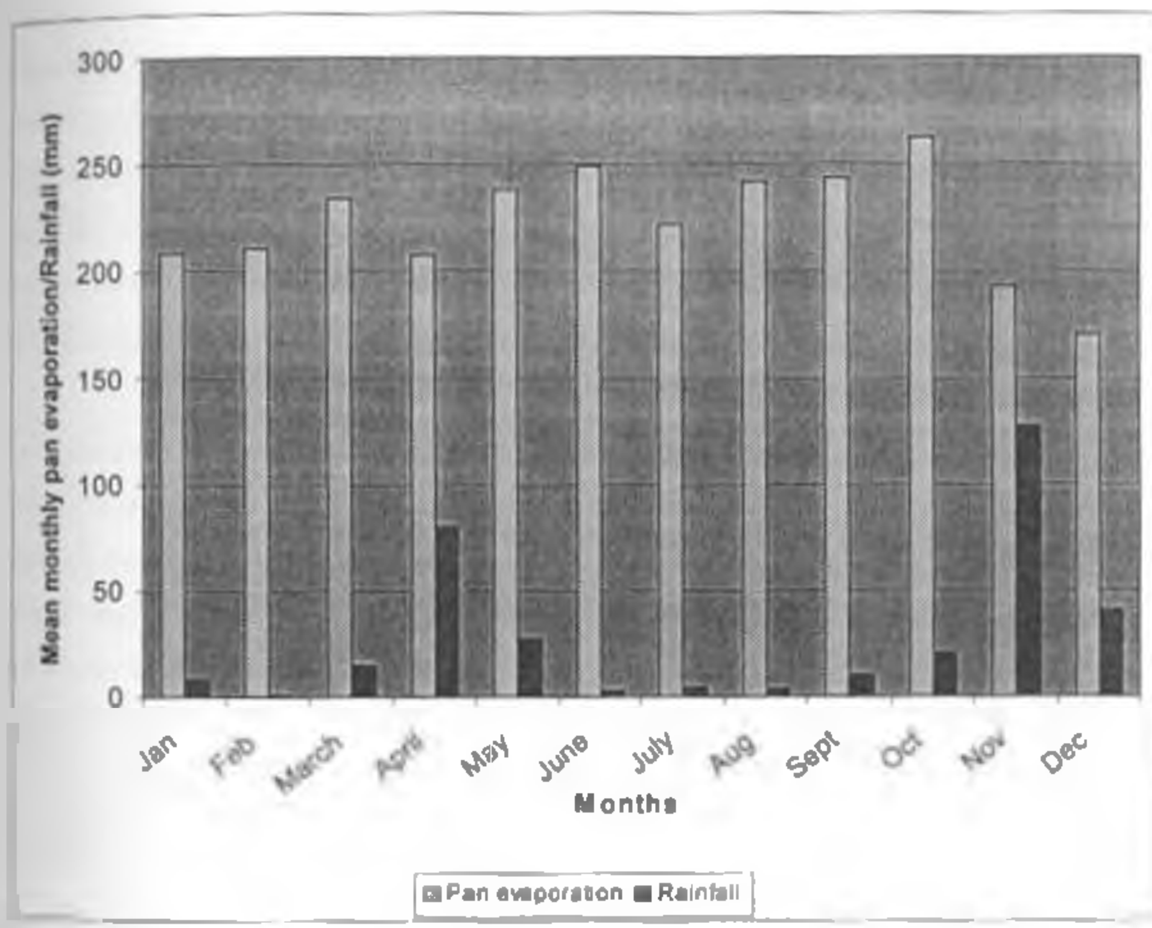

Figure 2: Monthly average pan evaporation and rainfall (mm) for Garissa Station (2002 – 2006).

3.1.3 Geology and geomorphology

The Kenya soil survey (1974) report indicates that the area consists geologically of quaternary sediments that are smoothly capped by a veneer of Pleistocene sediments of different ages and composition. Geomorphologically, the area outside the flood plains consists of at least three plain levels largely coincide with the above mentioned sedimentological grouping. The flood plain itself has the characteristic level land-basin land pattern of meandering rivers.

3.1.4 Topography and soils

The flood plain of Tana river constitutes essentially of only two physiographic units, the river levee and the river basin (Sombroak et al., 1974). The normal river levee land is mostly just above present day normal flooding level. The micro relief is flat but there are often considerable meso relief differences at relatively short distance. Deserted river channels, often partly filled with sediments, are also quite common. There is however little or no micro-relief. Soil consists mainly of fine to very fine loamy sands to loams to several metres depth with occasionally thin silty to clayey inter-spursed.

The sediments contain characteristically a high percentage of mica flakes. The topsoil is dark (reddish) brown, with a fair to low organic matter content (0.3-0.9%), a favorable structure (moderate fine sub angular blocky) and little or no surface sealing/capping. The subsoil mainly dark brown or yellowish brown, still maintains a distinct sedimentary stratification. The soils are slightly calcareous throughout and clayey layers may have both some salinity and alkalinity. According to (Sombroak et al., 1974) the soils are moderately rich and no immediate nutrient deficiency is to be expected, with the exception of the clay layers. Consistency of the soil is friable and soft to slightly hard

The normal river basin land is extensively flat and mostly only slightly below the level of the levee-land and only shallowly flooded if at all. In several places the land has a rather dense network of narrow gullies (about 3m wide, 1m deep). Often a substandard micro-relief occurs. The soil consists of predominantly of silty clay to heavy clay. The topsoil, is dark reddish brown with only a fair organic matter content (0.5-1.0%C). The structure

structure mostly fair only (prismatic to angular blocky). The soils are slightly moderately saline and alkali from some depth onward. Chemically the soils are quite rich and nutrient deficiencies are unlikely, (Sombroak et al., 1974).

3.1.5 Hydrology

Only Tana river is the perennial river, all the tributaries are ephemeral. Whenever rain falls, flooding of the tributaries is quite flashy due to high runoff. The seasonal rivers *(laghas)* are found along the entire length of the Tana river. During the wet season they provide water for both human and livestock.

3.1.6 Vegetation

On the level land, the natural vegetation is riverine forest, often quite high (30m to 50m) and consisting of a number of different species. *Acacia eleator, Acacia polycantha, Diospyros cornii and Ficus sp.* are common, while palms are relatively few. The basin lands are covered with (bushed) grassland, bush land or even bush thicket; the woody species never reaching much height. *Prosopis juliflora* (Mathenge) tree introduced in the 1980s for provision of firewood and ground cover has had a lot of adverse effects as it has become very dominant and tends to kill all other vegetation around it GoK (1997).

3.1.7 Land use

Extensive grazing and irrigated agriculture are the major uses. The major land use is nomadic pastoralism. Livestock distribution mainly follows the rainfall distribution patterns. During the rainy season most animals move away from the riverine areas which are mainly used for dry season grazing. The main types of livestock reared are cattle, sheep, goats, camels and donkeys. Currently about 2000 ha are under smallholder irrigation (Table 3). Due to high temperatures, growth is very rapid and continuous throughout the year under irrigation. The major crops grown are tomatoes, bananas, paw paws, kales/spinach, mangoes, quavas, citrus, hot and sweet peppers, melons and onions. All these crops are mainly grown for commercial purposes.

Table 3: Irrigation schemes and their acreages

SCHEME	ACREAGE (Ha)
1. Korakora	70
2 Nasib	40
3 Ifhin	50
4 Maendeleo farm	140
5. Dasheg	10
6 Nasra	60
7. Qahira	90
8. Tasbih	30
9. Laheley	40
10. Alfoley	50
11. Qabobey	110
12. Caymis	20
13. Halima Quter	10
14. First farm	190
15. Wathajir	200
16. Holwadag	150
17. Tawakal	230
18. Nasra	80
19. Lagdera	70
20. Raya	20
21. Sankuri	50
22. Umoja	50
23. Jamhuri	100
24. Bismillah	70
25. Ture farm	70

3.1.8 Irrigation suitability

The normal level lands are not very suitable for large-scale mechanized irrigation of field crops like cotton, rice or sugarcane. This is because of irregular topography, the high cost of clearing of the forest, and the relatively high infiltration rates. For small-scale

Irrigation schemes, however, in particular when cropping vegetables (high value crops) like melons and tomatoes is envisaged, the above limitations are of minor importance (Sombroak et al., 1974). The soils can be considered well suitable for horticultural crops as well as for fruit trees, because of the easy and deep rooting conditions, the easy tillage, and the location of the land very near a permanent water source from where pumping can take place The normal river-basin lands are not suitable for growth of vegetables because of difficult tillage and the poor rooting conditions. They are marginally suitable for field crops. Advantages are the regular flatness of most terrains and low infiltration. Disadvantages are the difficult tillage, the shallow rooting, the frequency of gullies in many places, and especially the low hydraulic conductivity of the subsoil, which prevent any deep drainage (Sombroak et al., 1974). There is a definite hazard that salinity / alkaliness of the soil will be increased to dangerous levels under sustained irrigation.

3.2 Data collection

3.2.1 Description of study site

The study was conducted in selected irrigation schemes along the flood plains of Tana river in Central division, Garissa District. Most of the schemes are located within 30 km radius, to the north and south of Garissa town, the district headquarters. This region is classified as arid and semi arid land and is covered by ecological zones IV to VI, where the climate is hot and dry with mean maximum monthly temperatures of 33-39^{0}C and mean monthly minimum of 15-25^{0}C (MoA, 1995).

The rainfall is low, inadequate, unreliable and the mean annual rainfall being 320 mm and is concentrated in two rainy seasonal; March to May (long rains) and October to December (short rains). The mean annual pan evaporation is 2700 mm and exceeds the precipitation in every month of the year. This implies that agriculture should ideally be practiced under irrigation or flood recession along a narrow strip next to River Tana, leaving the remaining vast expanse to livestock herding (GoK, 1997). The relief of the area under the schemes is generally flat. Within the irrigation schemes cultivation using furrow irrigation has been going on for the last thirty years. Outside the schemes, like other parts of the district, nomadic pastoral production is traditionally the major form of land use. Near the schemes cattle, sheep and goat are the main livestock species with few camels.

3.2.2 Experiment design and treatments

The study was mainly conducted on existing farming households / irrigation farms along the Tana river in Central Division of Garissa District.

3.2.2.1 Livelihood sample survey

A structured questionnaire approach based on open-ended and close ended questions was used for the livelihood survey on farming households along the Tana river in Central division of Garissa District. The information collected included general household (HH) information (age, sex, marital status, religion, household size, gender of head of household, level of education), farm production and marketing (crops grown, proximity to market centre, pest and diseases), irrigation and farm inputs (size of the plot, application fertilizers / manure, problems associated with soils factors contributing to soil problems and labour), household food security (ownership of livestock, occupation status, source of HH food security and insecurity) and wealth status of the household (financial credit availability, HH income before joining the irrigation scheme, HH income after joining the scheme, main source of income, major HH expenditure and wealth acquired after joining scheme).

Multi-stage sampling was used where Garissa District was purposively selected since Tana river passes along the eastern boundary of the district bordering Tana River District. Similarly the Central division was purposively selected since it has the largest concentration of smallholder irrigation schemes in the district with many former pastoralist now engaged in irrigation farming. This division provides the most representative of the target population (Mugenda, 1999). A sample of 45 farming household are randomly selected from the agro-pastoralist (irrigation farmers) using the table of random numbers. Agro-pastoralists were described as those households which owned an irrigated plot and were cultivating during the time of data collection which was the beginning of dry season, January 2007. In this study it was assumed that there was homogeneity within agro-pastoralists since the farms do not vary much in size and hence questionnaires administered on 45 farming households.

Simple interviews with a small group of farmers was assumed to provide adequate information on project status and hence the use of simple random sampling procedures to monitor the proportion of the farming households that exhibit pertinent characteristics (Casley and Kumar, 1987).

Data were collected on farm visits using a pre-tested, structured questionnaire which was administered to each of the selected farmers. Three enumerators assisted in data collection. They were all extension officers working with the Ministry of Agriculture and were trained for 2 days on data collection techniques and procedure. Before data collection began, the original questionnaires were pre-tested using 5 irrigation farmers. This was done as part of the training exercise for the enumerators and also to determine the appropriateness of the questionnaires in obtaining the desired information. After going through all the responses together with the enumerators, changes were made to the questionnaires to improve on their contents and design. The five farmers who participated in the pretest were also interviewed using the final questionnaires.

During data collection, appointments for interviews were made a day prior to the planned visits. A single visit approach was used. This was considered appropriate for the study. In this approach the farmer was visited on his farm and interviewed once only. On average, 2 farmers were visited by each interviewer each day. Depending on the preference of the respondents, the survey questions were posed either in Kiswahili or local dialect. Completed questionnaires were checked by the investigator for omissions, inconsistencies, illegible writing and any other problems before they were accepted for data processing. The details of the data collected at the farm level are contained in the attached questionnaire in Appendix 1.

3.2.2.2 Soil and water experiment

Soil and water sampling were carried out in different irrigation farms along the Tana river. The experiment design was a randomized complete block design (RCBD) replicated four times for soil and threes for water (irrigated farms serve as blocks). Treatment consist of the number of years an irrigation scheme has been in an existence for soils. That is T_1 - (< 5 years irrigated) – short period (SP), T_2 – (6 – 10 years irrigated) – medium period (MP), T_3- (> 10 years irrigated)- Long period (LP) and T_4 – (control not-irrigated) (NT) . Four sites for each of the four treatments randomly selected were studied. The selected farms were within the riverine zone (about 1km distance) on one major soil type identified from an existing soil map (Sombroak et al., 1974). Non-irrigated sites were selected such that they were adjacent to the irrigated sites.

Based on the augment that secondary salinization is more often than not caused by irrigation and its related management practices, the selection of the treatments was geared towards finding out if any significant difference exist between irrigated and non-irrigated soils in terms of their physical and chemical properties. The effect of time was investigated by selecting farms that had been subjected to irrigation for different periods (i.e. number of years of irrigation). The properties of the non-irrigated soils were taken to be the initial conditions (control) while the properties of the irrigated soils are assumed to give a picture of a soil having been affected by the irrigation.

From each selected farm, disturbed soil samples were taken from six spots determined by the procedure indicated in Figure 3. Soil samples were collected at two depths; 0-20 cm (surface soils) and 40-60 cm (sub-surface soils) at each of the six auger points. Samples from each of the auger points were transferred into a clean bucket and thoroughly mixed to make a composite sample. From this, about 2 kg soil was scoped and placed in a polythene bag. Separate buckets were used to collect composite samples for each depth. The bags were then labeled giving the field designation number, the depth (e.g. 0-20 cm) and the date the sample was collected. Sampling was done in two seasons i.e. season 1, referred to end of dry season: October 2006; and season 2, referred to end of rainy season: January 2007. In total 64 soil samples were taken for the two seasons (32 in each season).

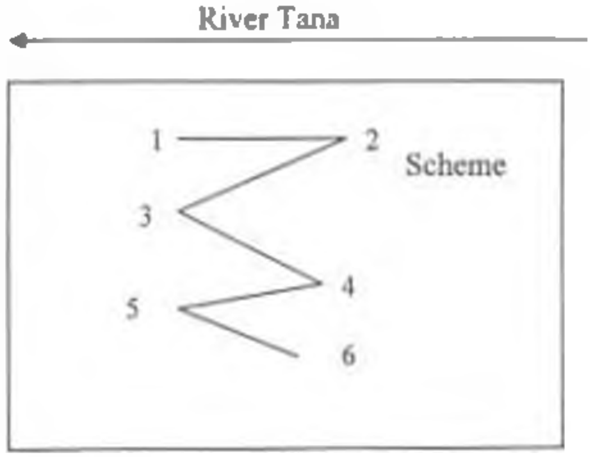

Figure 3: A sketch map showing how soils were sampled from the field.

The soil samples were air-dried in the Soil Science laboratories at Kabete, crushed and passed through the 2-mm sieve. A sub-sample was further passed through the 0.5-mm sieve for organic carbon analysis.

Undisturbed soil samples were obtained by using core rings of 5 cm diameter and height, driven vertically into the soil using a core sampler. A mini-pit to a depth of 40 cm depth was opened from where duplicated samples were taken at two different depth 0 – 10 cm (surface soils) and 20-30 cm (sub-surface soils). The core rings were labeled and wrapped in alluminium foil. These samples were used to determine saturated hydraulic conductivity and bulk density in the laboratory. In total 64 soil cores were collected.

For water, treatment consists of distances along an irrigation canal. Water was sampled at three different locations (distances from the river) along canals delivering water from the river to the farms as follows:

D_1 – at 0 m from the river (in take point)

D_2 – at 500 m distance from the river along a canal

D_3 – at 1000 m distance from the river along the same canal.

Clean, one-litre bottles were used to collect the water samples. The bottles were first rinsed with the water to be sampled. They were then tightly capped. The bottles were them labeled giving the field number, name of the canal, the distance from the river at which the water was sampled and the date the water sample was collected. The bottles were stored in a cool box and transported to Kabete. Quantitative water analysis according to Ayers and Westcot (1976) was carried out in the laboratory.

3.3 Laboratory analysis

3.3.1 Soil physical properties

3.3.1.1 Bulk density (P_b) determination

The method used was described by Blake and Hartge (1986). The soil core samples were placed in the oven at 105^{0}C for 24 hours to dry to a constant weight. Bulk density (P_b) was calculated by the equation.

$P_b = M_s/V_t$ .... (3.1)

Where P_b = bulk density (g/cm^3), M_s = weight of oven dry sample in (g), and V_t = volume of the soil sample as determined by the volume of the core ring (cm^3)

3.3.1.2 Total porosity

The method used was described by Vomocil (1965). Total porosity was calculated using the formula.

$f = 1 - (P_b/P_p) \times 100$ .... (3.2)

Where f = total porosity (%), P_b = bulk density (g/cm^3), P_b = particle density (g/cm^3) and in this case the value of particle density was taken as 2.65 g/cm^3).

3.3.1.3 Saturated hydraulic conductivity (K_s)

Saturated hydraulic conductivity was determined in the laboratory by the constant head method as outlined by Klute (1965). Each core sample was trimmed at the edges and a piece of cotton cloth was tied on one end of the sample ring using a rubber band. On top of each sample an identical empty cylinder was carefully secured in place with water proof tape so that there is no leak at the joint. The sample was moistened by placing in a shallow tray of water with the cloth-covered end dipped in water for 24 hours at room temperature

The fully saturated samples were mounted on constant head conductivity apparatus. After a duration of 1 hour, the volume of water collected was measured using a graduated cylinder. The saturated hydraulic conductivity was calculated using Darcy's equation and expressed in cm/h:

$K_s = (Q/At) \times (L/H)$ .... (3.3)

Where K_s = saturated hydraulic conductivity (cm/h), Q = volume of water collected in cm^3, t = time taken to collect Q in hours, A = cross-sectional area of the ring (cm^2), L = length of soil column in cm, and H= effective hydraulic head in cm ($H = \Delta h + L$, Δh = height of the water column above the soil core surface).

3.3.1.4 Soil texture

The soil texture analysis was determined by the Bouyoucos hydrometer method according to Gee and Baunder (1986). Soil samples which had been previously made to pass through a 2 mm sieve were used for textural analysis. The samples were pretreated with hydrogen peroxide to destroy organic matter component. Then sodium hexametaphosphate (calgan) was added for dispersion. The samples were then transferred into a shaking bottle and put on a reciprocal shaker for 6 hours, and then followed by analysis by the hydrometer. The soil textural class was determined from the standard U.S.D.A. textural triangle (USDA, 1975).

3.3.2 Soil and water chemical analysis

3.3.2.1 pH determination

For each sample pH was determined both in water and calcium chloride using the method described by Peech (1965). The ratio of soil: water/$CaCl_2$ was 1: 2.5. The mixtures were placed in plastic containers and shaken for 30 minutes and then allowed to stand for another 30 minutes. The readings were taken with a pH meter for both the water and $CaCl_2$.

3.3.2.2 Electrical conductivity (EC)

For EC determination, known amounts of soil and water at the ratio of 1:2:5 were placed in plastic containers. The containers were shaken for one hour with a reciprocal shaker to equilibrate. The mixtures was left to settle for 15 minutes and the reading taken with an EC meter at room temperature then was corrected to the standard $25^{\circ}C$ (Richards, 1954).

3.3.2.3 Cation exchange capacity (CEC)

The CEC was determined by successive shaking and centrifuging of 5.0 g of soil with four portions of 33 ml each of 1 N NaOAC of pH 8.2, three portions of 33 ml each of 95% ethanol and three portions each of 33 ml of 1N NH_4 OAC of pH 7.0. Exchangeable cations were determined from this leachate. The atomic absorption spectrophotometer (AAS) was used to determine Ca and Mg while Na and K were determined using the EEL - flame photometer. The procedure followed is similar to the one detailed by Black (1965)

3.3.2.4 Exchangeable cations

Exchangeable Na and K were analysed using EEL-flame photometer. Exchangeable calcium and magnesium were analysed using the atomic absorption spectrophotometer. In both cases tests were carried out on 1:2.5 soil / water extracts. Calcium and magnesium in water samples were determined by titrating with EDTA as titre and using calgon as calcium indicator and EBT as calcium plus magnesium indicator as described by Black (1965).

3.3.2.5 Organic carbon

The Walkley-Black dichromate method as outlined by Nelson and Sommers (1982) was used. Soil samples sieved through 2 mm sieves were passed through 0.5 mm sieve and used for organic carbon determination. The percentage of easily oxidizable organic carbon in soil was determined by digesting the soil with potassium dichromate in the presence of concentrated sulphuric acid.

3.3.2.6 Carbonates, bicarbonates, hydroxides and chlorides

For all the anions determined, a 50 ml aliquot was used. This involved titrating the water quality sample potion with sulphuric acid using phenopthalene indicator. To the same sample, methyl orange indicator was added and titration with sulphuric acid continued up to the point. To the same sample, 1 ml 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 phenophthalene as indicator, whereas bicarbonates were determined by the same titration but with methyl orange indicator and final tritration with silver nitrate gives the chlorides content. This procedure is described by Black (1965) and Dewis and Freitas (1970).

3.4 Data Analysis

The data generated by this study were analyzed using descriptive statistics (means, frequencies and percentages) and regression. The purpose of this type of analysis was to synthesize the livelihood characteristics of the households of the farmers interviewed, to describe small-holder irrigated agriculture in terms of crop production, marketing and identify main challenges the farmers faced in the study area.

Analysis of variance was carried out for all data. For the parameters that were significantly different, means were separated using S-N-K (student Neumann Keuls) tests (Steel and Torrie, 1980). Significance of the factors was done using the F-tests. Simple linear regression analysis was used to determine the relationship between K_s and some selected soil physical properties across the treatments.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Livelihoods evaluation

4.1.1 Household characteristics

Descriptive statistics presented in Table 4 indicate that the average age of the farmers was 46.3 years, the youngest and the oldest were 27 and 76 years old, respectively. Also 97.8% of farmers in the study area were male and only 2.2% were female. Of these 88.9% were married, 4.4% were single while 6.7% were widowed. On average, a family had 10 members while the largest family had 27 members.

Table 4: Descriptive statistics of smallholder farmers in Garissa irrigation schemes.

Description	Mean	Std. dev	Min.	Max.
Age of the household head	46.27	11.21	27	76
Household size	10.09	5.15	1	27
Children of school going age	4.33	3.06	0	15
Land size (acres)	3.06	2.69	0.25	15
Cropped area (acres)	3.03	2.65	0.5	15.6
Scheme membership in years	10.71	6.48	2	26

Education level of the farmers was low, with 38% of the household heads having no formal education and 20% having adult literacy education (figure 4). The rest had primary education (22%), secondary education (13%) and post secondary education (7%). The low level of education can be attributed to the pastoralist background of the farmers. Musebe (1990) argues that in less developed countries, substantial development on rural education is needed to increase the productivity of the farm to any reasonable magnitude. To this end, a lot need to be done to improve the educational level of the farmers to enable them achieve sustainable production. This study indicate that all school going age children are attending school which is a step in the right direction.

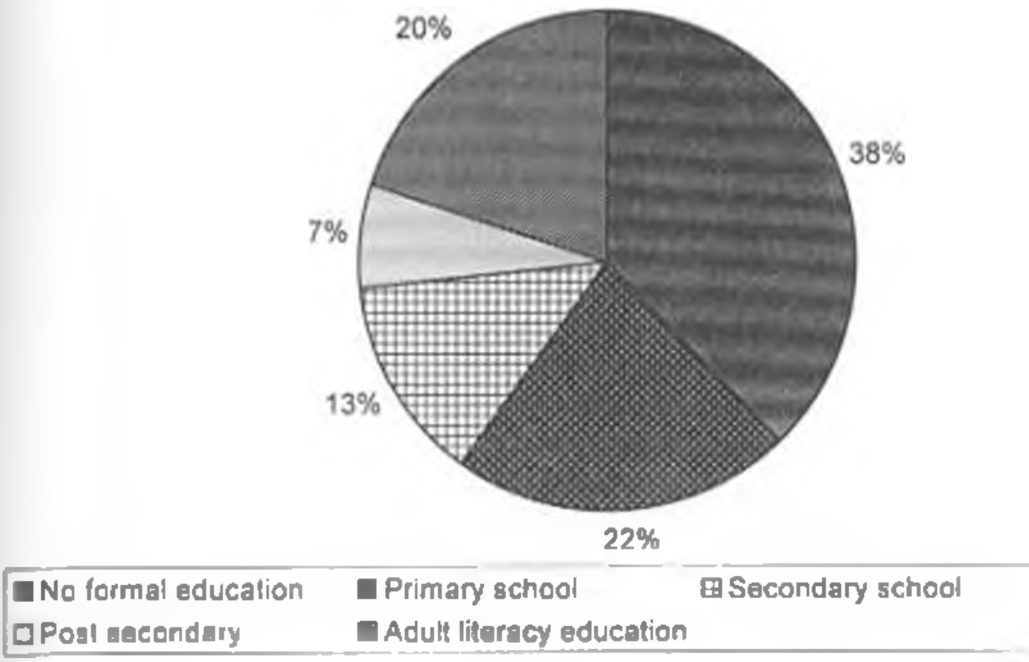

Figure 4: Education level of household heads

On average each household had 4 children of school-going age. Decision on who among the children went to school, herded animals or did farm work was based on family consultation (75.6%), gender bias (22.2%) and arbitrary decision by the house hold head (2.2%). This findings indicate that all school going age children attending school. This increase in number of children going to school is a deviation from what usually happens in pure pastoralist families where school enrollment is generally low. According to Kariuki (1995) pastoralists were generally reluctant to take their children to school because it interrupted the technical learning of pastoral skills, and also education made children to reject the values common to nomadic groups. Education is considered important in the process of agricultural development. Education has been shown to have a positive relationship with adoption of new and improved practices by farmers (Nyangito, 1986). The current low level of education among the household heads is a threat to agricultural performance. However this trend would reversed in the future as the upcoming generation is expected to have more educated farmers and this is expected to alleviate negative impacts associated with illiteracy among farming communities in the area.

Table 4 shows that the average land size for the farmers is 3 acres. From the survey, it was observed that 87% of the farmers felt that this was not adequate for all their needs and hence they required more land to increase area under cash crop as well as diversify produce. The farmers have been members of the irrigation schemes for an average period of 10.7 years. The shortest membership period was 2 years and the highest was 26 years.

The data from the survey indicate that 93% of the farmers grow crops both for home consumption and sale. Most farmers stated that there has been changes in acreage under crop production (figure 5). This changes were both an increase and a decrease as indicated by 62% and 16% of the farmers, respectively. An increase in the area under crop is due to expanded irrigation (opening up more land under irrigation) while a decrease is attributed to environmental calamities, especially the seasonal floods, river bank erosion and farmers abandoning schemes.

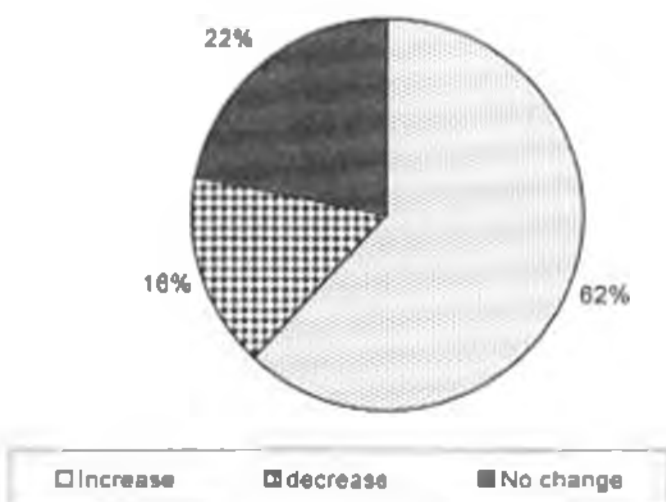

Figure 5: Perceptions of changes in cropped area in Garissa irrigation schemes.

4.1.2 Crop production

The farmers practiced mixed cropping with each growing at least three different crops in each season. Table 5 shows the different types of crops that are grown by the farmers in the irrigation schemes. Horticultural crops are the most widely grown. Bananas are the leading crop with 84% of the farmers growing on an average of 1.2 acres of land per farmer. Other important crops are tomatoes (71%), mangoes (71%) and melon (51%). The main food crop was maize that was grown by 11% of the farmers on an average of 0.3 -acre plots. Although grown by very few farmers (2%), fodder crops were allocated the biggest land size a acreage. The reason for the big acreage under fodder is that most farmers also keep livestock and so the fodder is partly used for the livestock. The other reason is fodder is sold as feed to pastoralists who are living next to the irrigation scheme but are not members of the irrigation schemes.

Table 5: Crops grown in Garissa irrigation schemes.

Crop	Farmers growing (%)	Land size (Ha)	Irrigation	
			Frequency/ week	Duration (hours)
Bananas	84.4	0.48	1.3	2.0
Tomatoes	71.1	0.24	2.2	1.8
Mangoes	71.1	0.32	1.1	2.8
Melon	51.1	0.24	1.8	2.2
Onions	20.0	0.12	1.9	1.6
Papaw	15.6	0.16	1.1	1.3
Maize	15.6	0.12	1.7	2.6
Capsicum	11.1	0.2	1.8	2.1
Citrus	11.1	0.12	0.9	2.3
Cowpeas	8.9	0.2	2	3
Vegetables	4.4	0.16	1	2
Coconut	4.4	0.04	1	1
Chilies	2.2	0.2	2	1.2
Guavas	2.2	0.04	1.5	2
Fodder	2.2	1.6	1	24
Sugarcane	2.2	0.04	1	2
Woodlot	2.2	0.2	1	24
Green grams	2.2	0.2	2	2

The cropping pattern shows a strong tendency towards production of high value horticultural crops, rather than food crops, an indication that the farming system is more commercial rather than subsistence agriculture. These findings are similar to the ones reported by Kariuki (1995) who found out that farmers in an irrigation scheme in Isiolo district shifted production away from food crops to high value horticultural crops.

Production of horticultural crops is labour intensive. Increased farm output as a result of irrigation stimulates demand for farm labour both within the main cropping season and across other cropping seasons, increasing both numbers of workers required and length of work period. In Isiolo District Hoggs (1987) observed that irrigation farming provided wage labour for those who settle around the schemes. A similar observation was made in the Rahad scheme by Tiffens (1984) where agro-pastoralists thrived from irrigation farming and migratory labour. In the study area, hired labour is very important, with 71% of the households using it. This labour was reported to be in short supply during the rainy season when its demand was highest. Hired labour cost the farmers Kshs. 172 per day. On comparison, only 38% of the livestock keepers hired labour. This suggests that labour was moving away from livestock herding to irrigation schemes.

Majority (93%) of households interviewed reported increases in income from sale of farm produce. This high income from sale of crops was therefore expected to significantly reduce the length of period during which households are food insecure. To improve plant and soil health, 87% of the farmers use agricultural chemicals. Those who did not use the agricultural chemicals cited high prices as the main disincentive. Access to information on better farming practices was good with 87% reporting to have access to extension services. The main source of information was agricultural extension staff (71%), farmers training centres (11%) and neighbours (18%).

Most of the farmers (71%) reported to have problems associated with soils. These problems include soil erosion, compaction/hard setting, salinization/ alkalinization and a decline in soil organic matter. Figure 6 shows how the farmers ranked the problems that are associated with soils.

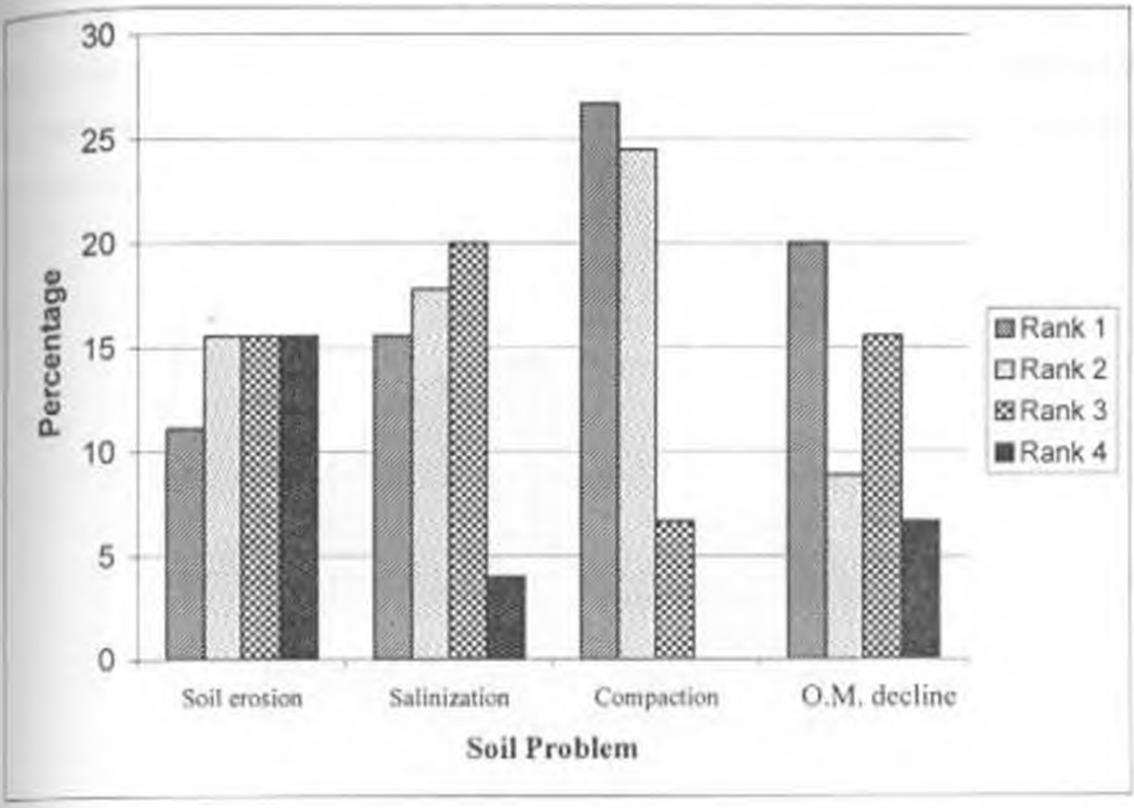

Figure 6: Farmers perception of problems associated with soils and how they rank them.

According to farmers, soil compaction seems to be the biggest soil problem, the majority of the farmers ranked it as first or second. Soil compaction is likely to be as a result of the weight from the use of farm implements during land preparation and trampling by livestock that graze in the farms after crop harvest. Soil compaction is known to reduce the infiltration of irrigation water, thus increasing bulk density of the soil. The soil particles are packed together leaving little space for free movement of air and water in the soil, which are essential for root growth. From figure 6, soil erosion has the least number of farmers ranking it as major problem. This is probably because the area is generally flat, hence soil erosion mainly occurs along the river bank or canals. Poor conservation was cited as the main factor contributing to problems associated with soils in the farms. To improve soil quality, farmers overcome problem of soil erosion, by maintaining a conservation strip to reduce river bank erosion. Farmers also use irrigation water more efficiently to reduce water logging and hence reduce salinization and also provide additional nutrients for the crops. About 60% of the farmers used fertilizers and manure. Animal manure is obtained either from their own farms, neighbours' farms or livestock markets (figure 7).

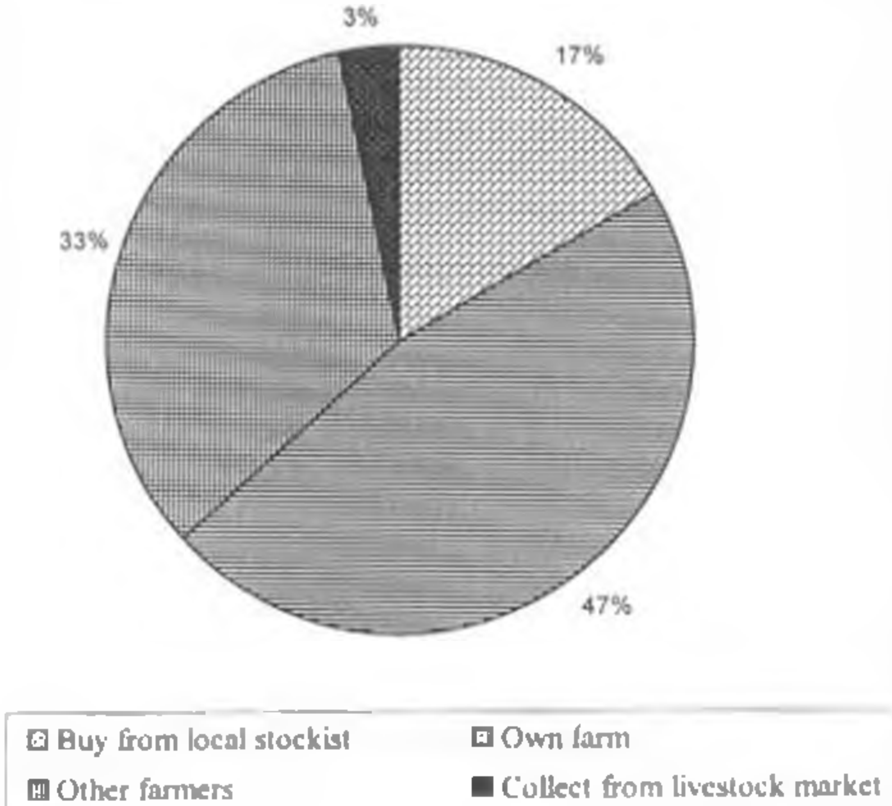

Figure 7: Sources of fertilizer and manure.

4.1.3 Marketing

The production of high value horticultural crops enables farmers to participate in the market economy. In the study area, farmers lack a marketing organization to sell agricultural produce on their behalf. For this reason, most of the farmers sell their products directly to the local buyers (Figure 8). They also have to rely on market information mostly obtained from the market place (73%) and other farmers (27%).

Transport problem was cited as one of the major constraints to marketing farm produce. Farmers have to cover long distance to sell their farm produce. Most of them live more 5 kms from the market places. The common mode of transport is the use of donkey carts, with the farmers taking the responsibility for transporting the produce to the market. The distance may not be a problem but the mode of transport for fresh farm produce (Donkey cart) for over 5 km to and from the market per day may be a problem.

Profitability was ranked first as the most important factor considered when deciding the crops to grow and their acreage by 82% of the farmers. About 71% of the farmers sell their produce in local markets. Low prices and unreliable markets were cited as the main problems faced in the marketing of farm produce.

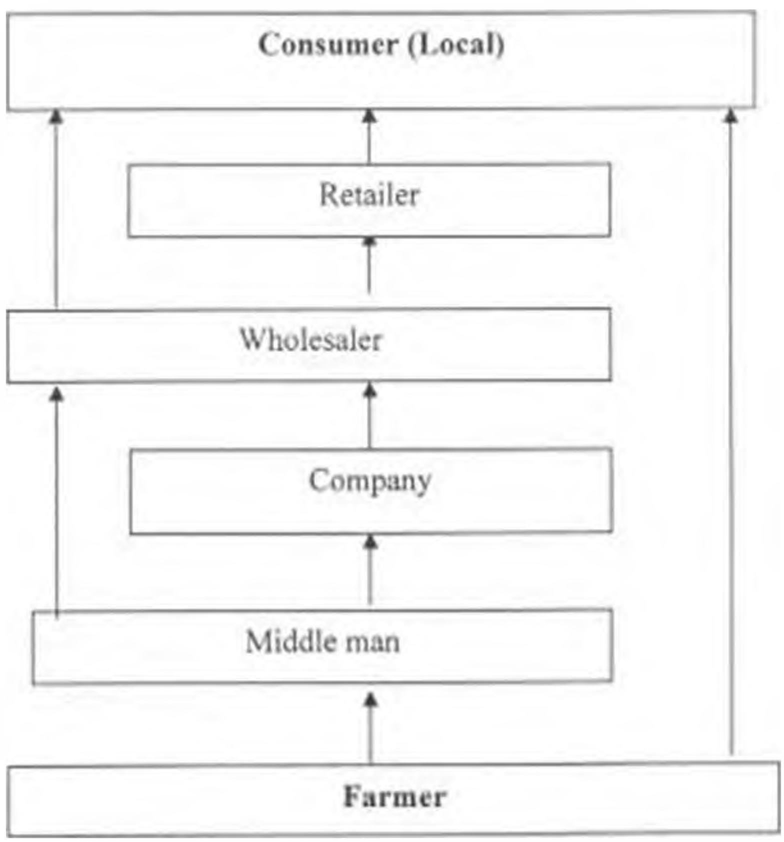

Figure 8: Farm produce marketing chain for Garissa farmers.

4.1.4 Irrigation and water management

Most of the crops were irrigated once a week (Table 5) and the average duration of water application at each interval was one hour. Tomatoes were the most frequently irrigated at 2.2 times a week, during which farmers irrigated for a duration of 1.8 hours. Other frequently irrigated crops were cowpeas, chilies, and green grams, which were irrigated twice in a week. Fodder and woodlots received water for the longest duration of 24 hours but only once a week.

On average, the farmers have been members of their irrigation schemes for a period of 11 years. Most of them learned of the existence of the scheme because they lived in the area when it was started. Their decision to join the schemes was mostly influenced by a feeling of being poor, which was measured by ownership of livestock. About 92% of the farmers felt that their income has increased since joining the irrigation schemes. Over 60% of the farmers had never abandoned their farms. Those who had abandoned cited the problem of flooding and pump breakdowns.

Irrigation schemes were generally well managed. This was evidenced by existence of management committees in most of the schemes. These committees are charged with the responsibility of managing the day-to-day affairs of the farming group. There are some aspects of democracy whereby the farmers choose the members of management committee either by appointment (73%) or secret ballot (24%). Almost all (98%) of the irrigation schemes had bylaws that governed their day-to-day operations. These bylaws were followed by 96% of the farmers.

The schemes have bank accounts where one or two officials were signatories. The banked money was used for operations and maintenance of the pump set (47%), farm operations (36%), buying new pump sets (7%) and other farm operations (7%). Most of the money used to run the affairs of the schemes is raised through monthly contribution by members. The amount to be contributed is decided by the farmers and spelt out in the bylaws of each scheme.

4.1.5 Food security

Irrigation farming contributes to food security directly through food supply and indirectly through income generation. The source of food security to these farmers is both crops and livestock. Up to 78% of the farmers who grew crops owned livestock mainly cattle, goats and camels. Most of the farmer 79% in the irrigation schemes were food secure most of the time, except during severe drought and / or floods (69%) (Table 6), and due to crop failure (7%) when they experienced food shortages. To overcome food shortages at such periods, they purchased food (93%), borrowed from relatives and friends (22%) or depended on food aid (27%).

All the households that depended on livestock for food security have an adequate food supply. Dependence on employment as the major source of household income was very low. However, all the households that depend on formal employment had adequate food Access to irrigation may have positive impacts on food security through the availability of increased and more stable food supplies. Thus the incidences of food inadequacy were fewer among farmers who depended more on crop farming for food security.

The values 4.87 (x^2) and 0.13 (significance) are statistics that explains significant of the valuable (Table 6). The numbers inside the bracket shows the percentage of the total respondent while the one outside the bracket shows the number of the respondents.

Table 6: Relationship between food adequacy and sources of food security

	Main source of household food security		
Adequate food	Farming	Livestock	Employment
Yes	33(69%)	0(0%)	1(100%)
No	9(31%)	2(100%)	0
χ^2	4.87		
Significance	0.13		

4.1.6 Income, assets and wealth

The farmers do not have access to credit because they have not title deeds to use as collateral since the land is communally owned and is kept in trust by the county council. Despite this, they have invested in good farming practices namely, use of fertilizers and pesticides. Most of them also had their own farm equipments. Improved farm productivity made sale of farm produce the major source of income for all the households contributing an average of 64% of the total household income (Fig 9). The farmers also had other non-farm incomes namely business, sale of labour, remittances from family members and formal employment.

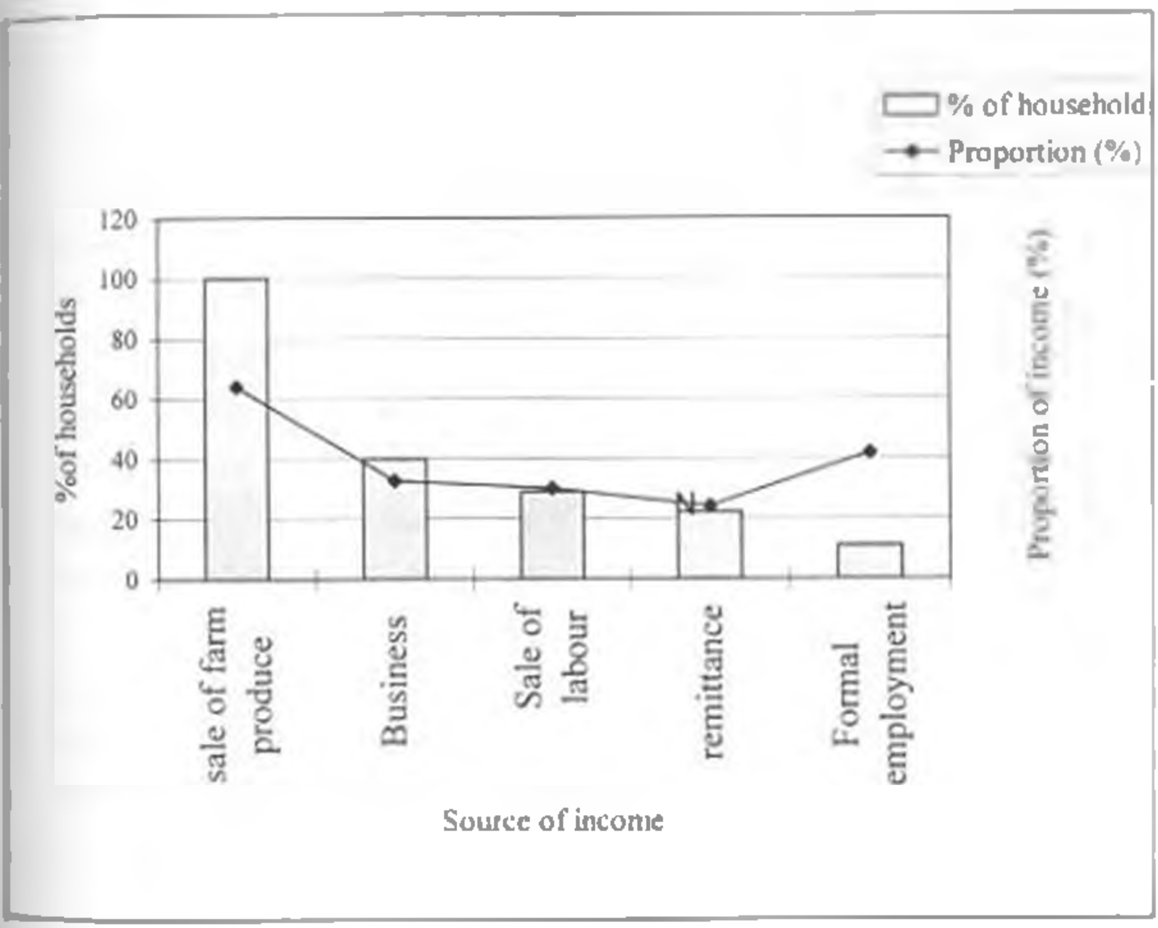

Figure 9: Sources of family income in Garissa irrigation schemes.

Income from the sale of crops was the biggest contributor to overall households' income. The change in cropped area showed a significant influence on the proportion of income coming from crops, with farmers who had increased their cropped area increasing their dependence on crops for their income. The relationship between changes in cropped area and proportion of household income from crops had a chi-square of 9.69 significant at 2% (Table 7).

Table 7: Relationship between changes in cropped area and contribution of crops to household income.

	Proportion of household income from crops (%)				Total
Change in crop area	80-100	50-79	25-49	Below 25	
Decrease	0 (0%)	2(17%)	3(23%)	2(100)	7 (21%)
Increase	7(100%)	10(83%)	10(77%)	0(0%)	27(79%)

$\chi^2 = 9.691$

Significance = 0.021

N = 45

Most farmers reported an increase in cropped areas over the years. All the farmers whose income from crops was over 80% reported an increase in cropped areas over the years. On the other hand, all the farmers whose income from crops was below 25% reported a decrease in the cropped areas over the years.

Most of the interviewed farmers reported an increase in income since joining the irrigation scheme. The first direct impact of irrigation farming is on output levels and reduction of variance over the seasons. The other beneficial effects of irrigation are on employment creation as a result of increased demand for agricultural labour and labour for maintenance of irrigation facilities. Figure 9 shows that before joining the scheme, the biggest proportion of the farmers were in the lowest income bracket (Ksh. 0-3000 per month). After joining the scheme, the lowest income bracket had the lowest proportion of farmers. Higher income brackets have a bigger proportion of farmers after joining the scheme. After joining the scheme, about 13% of the farmers started earning over Ksh. 12,000 per month (Fig. 10) a level that none of them earned before joining the scheme.

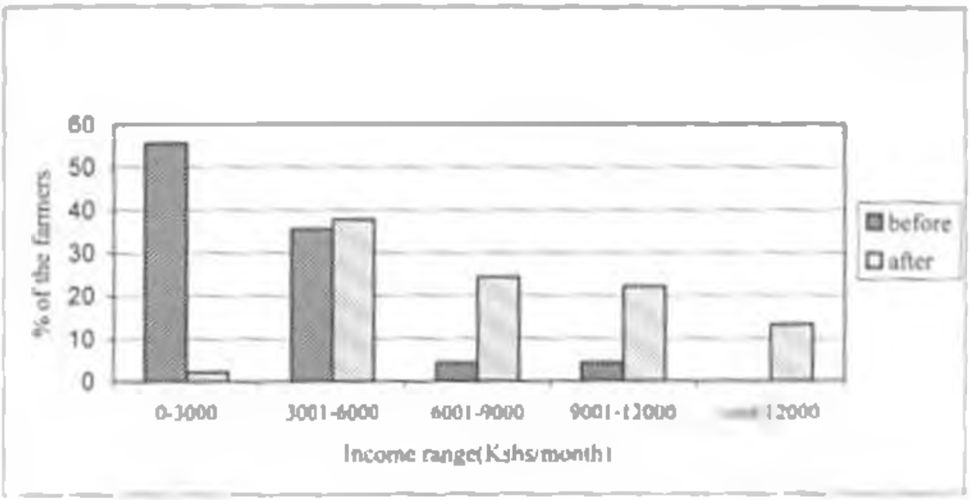

Figure 10: A comparison of income before and after joining the scheme at Garissa.

Irrigation boosts total farm output and hence, even with unchanged prices, raises farm incomes. According to Lipton *et al.* (2003) increased output levels may arise from improvement of yields through reduced crop loss due to erratic and insufficient rain, the possibility of multiple cropping and allowing a greater area of land to be used for crops in areas where rain fed production is impossible or marginal.

Table 8 indicates that only 5% of the farmers grew crops specifically for sale. The purpose for growing crops had an influence on the level of income, with those growing solely for sale an income of our Ksh.12,000 per month. The figures outside the bracket show the number of respondents while those inside the bracket shows the percentage of the total respondent. For example under the column of over Kshs12,000, two (2) respondents grew crops for sale and this constituted 33% of total respondent who had an income of greater than Ksh.12,000. Four (4) respondent grew crops for home consumption and sale and they constituted 67% of respondent with income of over Ksh.12,000. Therefore in total six (6) respondent had an income of over Ksh.12,000.

Table 8: Relationship between purpose for growing crops and income.

	Current monthly income (Ksh)					
Purpose for growing crops	0-3000	3001-6000	6001-9000	9001-12000	Over 12000	Total
For sale	0(0%)	0(0%)	0(0%)	0(0%)	2(33%)	2(5%)
Home consumption and sale	1(100%)	17(100%)	11(100%)	9(100%)	4(67%)	42(95%)

Chi-Square = 13.27

Significance = 0.01

The relationship between the current level of income and purpose for growing crops had a chi square value 13 significant at 1%. All the farmers with a monthly income of Ksh. 3000 to 12000 were growing crops for both home consumption and sale. Among the farmers with a monthly income exceeding Ksh. 12000, 33% produced for sale alone while 67% produced both for sale and home consumption.

The biggest proportion of household income came from crop farming (93%) while livestock contributed only 5%. The other sources of income contributed 2%. The income from farming activities has enabled 62% of the farmers to acquire a variety of assets. The most popular asset investments were building a house and buying farm implements.

Although 79% of the farmers own livestock, Figure 11 shows that among the farmers in Garissa irrigation scheme, crop farming was more important as a source of the farm families' income than livestock.

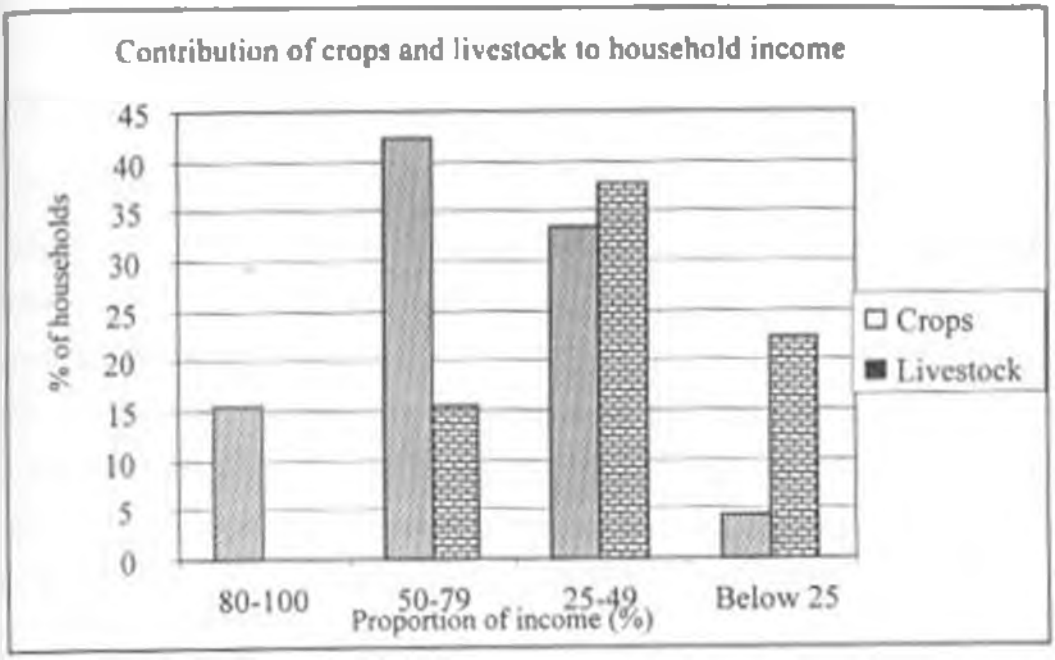

Figure 11: A comparison of contribution of crops and livestock to household income.

For some households, crops contributed up to 100% of the total household income, which did not happen with livestock farming. In order to concentrate on crop farming, about 6% of the farmers stopped rearing livestock, 43% graze near the irrigation schemes while 49% hired a person to herd livestock away from the irrigation schemes. The relative importance of crop farming to household income has made the farmers to invest more in crop farming than livestock. For instance 38% of the farmers purchased new farm implements in comparison to 13% who purchased more livestock. This deviates from the findings of a study that was done by Hendricksen (1975) who found out that the Turkana reinvested the profits realized from irrigation farming in livestock. This is evident that farmers in Garissa are replacing rearing of livestock with growing of crops as way of life.

4.2 Soil physical and chemical properties

4.2.1 Soil physical properties

4.2.1.1. Soil texture

Soil texture data (Table 9) indicate that the texture varied with the number of years of irrigation and also according to surface and sub-surface soil layers. The sand and clay components statistically and not show any no significant difference, either, according to surface or sub-surface soil layers or according to the number of years of irrigation. But the < 5 years irrigated site had significantly ($P \leq 0.01$) higher silt % content compared to the rest. This may be because of the over wash of the soils from other areas during the rains. The textural classes ranged from clay loam to sandy clay loam.

Table 9: Surface soil texture in Garissa irrigation schemes.

No. of years irrigated	Sand (%)	Silt (%)	Clay (%)	Texture class
< 5 years	35	36	29	Clay loam
6 – 10 years	45	26	29	Clay loam
>10 years	47	24	30	Sandy clay loam
Non-irrigated (control)	36	30	34	Clay loam

4.2.1.2 Bulk Density and Total Porosity

Bulk density varied from 1.16 to 1.35 g/cm^3 while total porosity varied from 29.00 to 56.38 for surface soil with non-irrigated having the lowest bulk density while 6 – 10 years samples the highest. For sub-surface soils bulk density varied from 1.23 to 1.29g/cm^3 while total porosity varied from 49.50 to 53.88; with <5 years soil having the least, while 6 – 10 years soils have the highest bulk density (Table 10).

Comparing the surface soil, non-irrigated has the highest percent, % organic carbon content compared to other treatments (Table 14), for both end of dry and rainy seasons. The high carbon content improved (lowered) the bulk density. The 6-10 years of irrigation sample showed the least % organic carbon contents thereby increasing soil bulk density and lowering the total porosity (Table 10 and 14). However significant difference ($P>0.05$) were observed between the treatments and between the depths for bulk density and total porosity. The low bulk density and high total porosity in 10 years treatment could be attributed to plant litter ploughed back into the soul over years resulting in an increase in organic carbon context lowering the bulk density.

Table 10: Means of soil physical properties in Garissa irrigation schemes.

No. of years irrigated	Bulk density g/cm³		Total porosity (%)		Ks (cm/h)	
	0-10 cm	20-30cm	0-10 cm	20-30cm	0-10cm	20-30cm
< 5 years irrigated	1.22	1.23	53.75	53.88	1.82	1.01
6 - 10 years irrigated	1.35	1.34	49	49.5	3.14	3.1
>10 years irrigated	1.18	1.25	55.75	52.63	4.9	2.77
Not-irrigated (control)	1.16	1.29	56.38	51.5	3.33	1.51

4.2.1.3 Saturated Hydraullic Conductivity

Saturated hydraulic conductivity (Ks) varied from 1.82 to 4-9 cm/hr and 1.01 to 3.1 cm/hr for surface and sub-surface soils >10years of irrigation had highest value while < 5 years had the least (Table 14). Saturated hydraulic conductivity was expected to increase with a decrease in bulk density or increasing total porosity. However, this was not evident in the study as non-irrigated site had the lowest bulk density (highest total porosity) but not the highest ks. The low bulk density provides stable soil aggregates which results in a greater number of continuous and interconnected pores (Magamy et al., 2000) and have the potential to influence infiltration (Heath man et al., 1995). However, not only the properties of the bulk soil but also that of aggregate pure characteristics constitutes unimportant factor affecting soil water conductivity and storage (Watko Roska – Watczakand Slawiski, 2005).

Any activity that disrupts macropores and their development and their stability affect soil water conductivity. Tillage, compaction from machinery and livestock, evident in the study, did lower saturated hydraulic conductivity. These activities are sufficient to cause substantial disruption to soil macroporosity and soil biomass activity (Pankhwt et al., 1997).

4.2.1.4 Relationship between soil physical properties

The relationships between soil physical properties are shown in Table 11. Saturated hydraulic conductivity had a negative relationship with bulk density, clay and silt. The correlation coefficients (r) were – 0.165, -0.279 and -0.246, respectively. This was because an increase in bulk density, clay and silt content resulted a decrease in saturated hydraulic conductivity. On the other hand hydraulic conductivity had a positive relationship with porosity and sand, with correlation coefficient of 0.197 and 0.308, respectively. However, these relations were not statically significant. This means that K_s has a direct relationship with sand and porosity and inverse relationship with bulk density, clay and silt.

Table 11: Correlation coefficients for various soil physical properties in Garissa Irrigation schemes.

		K_s	BD	Clay	Porosity	Sand	Silt
K_s	Pearson Correlation	1	-0.165	-0.279	0.197	0.308	-0.246
	Sig. (2-tailed)		0.366	0.122	0.281	0.086	0.175
BD	Pearson Correlation	-0.165	1	-.360*	-.998**	.431*	-.395*
	Sig. (2-tailed)	0.366		0.043	0	0.014	0.025
Clay	Pearson Correlation	-0.279	-.360*	1	.364*	-.924**	.461**
	Sig. (2-tailed)	0.122	0.043		0.041	0	0.008
Porosity	Pearson Correlation	0.197	-.998**	.364*	1	-.434*	.396*
	Sig. (2-tailed)	0.281	0	0.041		0.013	0.025
Sand	Pearson Correlation	0.308	.431*	-.924**	-.434*	1	-.766**
	Sig. (2-tailed)	0.086	0.014	0	0.013		0
Silt	Pearson Correlation	-0.246	-.395*	.461**	.396*	-.766**	1
	Sig. (2-tailed)	0.175	0.025	0.008	0.025	0	

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Porosity, silt and clay correlated negatively with bulk density. High bulk density means more compacted soil. Increase in clay and silt content tends to block macro-pores, resulting in reduced water transmission. The correlation coefficients -0.431, -0.36 and -0.395 were significant at $P \leq 0.001$, $P \leq 0.05$ and $P \leq 0.05$, respectively.

Sand correlated positively with bulk density (r= 0.431) and was significant at P = 0.014. This probably means that, the higher the percentage of sand in the soil the higher the bulk density. Silt, sand and porosity had a positive relationship with clay. The correlation coefficient of 0.461, 0.924 and 0.364 was significant at $P \leq 0.001$, $P \leq 0.001$ and $P \leq 0.05$, respectively.

4.2.1.5 Relationships between K_s and selected soil physical properties

A negative correlation was observed (r = -0.353) between bulk density and K_s and between silt and saturated hydraulic conductivity (r = 0.19) at the surface soil (Table 12). A positive but not significant correlation (r = 0.364) between bulk density and K_s at sub-surface soils. It was observed that the negative relationship between clay and saturated hydraulic conductivity at sub surface soils was significant ($P \leq 0.05$). Porosity and sand related positively (r = 0.399 and 0.184) to saturated hydraulic conductivity at surface soils but was not statistically significantly. At the surface soil, sand and saturated hydraulic conductivity had a positive and significant ($P \leq 0.05$) relationship.

Silt and porosity had a negative relationship at the sub-surface soil layer with saturated hydraulic conductivity. Increase in silt content resulted in low K_s since silt tends to block some macro-pores that transmit water.

Table 12: Relationship between saturated hydraulic conductivity and varies soil physical properties.

Depth	Bulk density (g/cm3)	Total Porosity	Clay (% wt)	Silt (% wt)	Sand (% wt)
0 - 10 cm	-0.353	0.399	-0.132	-0.19	0.184
20-30 cm	0.364	-0.37	-0.594*	-0.392	0.598*

4.2.1.6 Multiple regression

Multiple regression was used to quantify the contribution (influence) of some soil physical properties (bulk density, total porosity, clay silt and sand) to observed saturated hydraulic conductivity (Ks). The strength/magnitude of each of the parameter is indicated by the value of the coefficient β in the regression equation below:

$$Y = B_o + B_1 X_1 + B_2 X_2 + \text{---------} B_n X_n$$

Where n = number of variables

X_1, X_2 =Dependent Variables

Y = Independent variable

B_{1-n} = Regression coefficients (change induced in Y by each X).

Bo =Constant

Table 13: Dependent and independent variables in multiple regression analysis.

Code	Variable	Units
Y	Saturated hydraulic conductivity	cm/hr
X_1	Bulk density	g/cm^3
X_2	Porosity	% vol
X_3	Sand	% wt
X_4	Silt	% wt
X_5	Clay	% wt

In this case, the equation will be:

$Y = 122.4 - 2.61X_1 - 2.7 X_2 + 2.21 X_3 + 0.9 X_4 + 1.11 X_5$; $R^2 = 0.383$

Since R^2 is only 0.383, we conclude that the regression is not really a useful one in explaining the data.

The coefficient of determination (R^2) was found to be 0.383. This shows the amount of variation explained by the independent variables. This means that 38.3% of the variation in saturated hydraulic conductivity is explained or predicted by variables in the equation.

To find out the variables with the highest contribution to K_s the values of the coefficients (β) are used. The higher the value, the more it's contribution. For example porosity with a value of −2.74, had the highest contribution, while silt with a value of 0.89 had the smallest contribution which was also not significant.

4.2.2 Soil chemical properties

4.2.2.1 Soil pH

The soil PH varied from 7.57 to 8.04 and 7.86 to 8.24 for surface and sub-surface soils, respectively at the end of dry season while it varied from 7.51 to 7.61 and 7.48 to 7.75 for surface and sub-surface soils, respectively at the end of rainy season (Table 14). Soils of < 5 years of irrigation has the highest pH with non-irrigated sites having the least for surface soils at the end of dry season while for sub-surface soils, 6-10 years of irrigation had the highest pH with the non irrigated having the least after dry season. After end of rainy season, non-irrigated soils had the least with >10 years of irrigation exhibiting the highest for surface soils while >10 years for sub-surface soils had the least with 6-10 years of irrigated soils having the highest. However, significant differences were observed in the number of years of irrigation in each season and also between the two seasons.

The soil pH decreased at the end of rainy season compared to the end of dry season; except for >10 years (surface) where the pH increased at the end of rainy season compared to the dry season. The decline in pH at the end of the rainy season could be attributed to leaching of the soil soluble salts by the rains or floods that caused an increase in soil acidity at both depths. The increasing soil pH at > 10 years (surface) soils could be attributed to the fact that leaching for salt removal can be useful up to a certain level after which increase of leaching levels do not affect soil salinity or salt removal (Hoffman et al., 1979).

Comparing the different soil surface, soils pH was higher in sub-surface soils when compared to surface soil both at the end of dry and rainy season. This could be attributed to higher organic carbon contents as well as higher calcium (Ca) and magnesium (Mg) and lower sodium (Na) contents on surface soils compared to sub-surface soils. Organic carbon and calcium serve as soil amendments that brings soil pH to near neutral levels (Karlen et al., 1997).

Table 14: Means of soil chemical properties at the end of dry season Oct. 2006 and at the end of rainy season Jan. 2007.

SEASON	No of yrs of Irrigation	PH $CaCl_2$		EC 25°C dS/m		C (%)		CEC (cmol/kg)		Na (cmol/kg)		Ca (cmol/kg)		Mg (cmol/kg)		SAR		ESP (%)	
	DEPTH (cm)	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60	0-20	40-60
End of dry season Oct 2006	< 5 Yrs	8.04	8.16	0.50	0.35	1.15	0.70	17.7	17.1	0.53	0.73	8.44	8.75	5.01	5.62	0.20	0.27	2.9	4.1
	6-10 Yrs	7.86	8.24	0.38	0.38	1.01	0.65	14.0	11.70	0.32	0.45	7.44	6.69	4.37	3.22	0.13	0.21	2.0	4.0
	> 10 Yrs	7.59	7.91	0.65	0.28	1.36	0.60	13.6	12.5	0.91	0.58	6.60	5.88	3.13	3.44	0.41	0.28	6.7	3.8
	Non irrigated (Control)	7.57	7.86	0.63	0.90	2.18	1.02	15.0	11.7	0.78	1.58	6.56	4.38	4.38	3.65	0.39	0.60	5.1	9.6
End of rainy season Jan 2007	< 5 Yrs	7.52	7.72	0.33	0.38	1.80	1.18	23.3	18.6	0.84	1.00	11.40	8.88	7.28	6.45	0.26	0.35	3.4	5.3
	6-10 Yrs	7.60	7.75	0.23	0.25	1.40	1.09	13.1	17.8	0.22	0.38	5.98	8.85	4.58	6.86	0.11	0.13	1.7	3.0
	> 10 Yrs	7.61	7.48	0.30	0.30	1.82	1.43	30.0	23.7	0.57	0.79	9.73	11.70	7.82	8.86	0.19	0.23	2.4	3.8
	Non irrigated (Control)	[illegible]	7.64	0.28	0.32	1.90	1.02	22.5	17.4	0.76	0.99	9.98	7.85	6.40	7.07	0.26	0.12	3.3	4.2

* Means with the same letter superscript within a column and means with the same digit superscript between the depths are not significantly different at 5 % level

Soil pH was highest at <5 year of irrigation at the end of dry season, compared to other years of irrigation is attributed to high Ca, Mg and Cation Exchange Capacity (CEC) contents, while lowest at >10 years of irrigation at the end of rainy season owing to low organic carbon, Ca, Mg and CEC contents.

4.2.2.2 Electrical Conductivity

The electrical conductivity (EC), varied from 0.65 to 0.38 for surface soils after dry season with > 10 years of irrigation having the highest while 6-10 years had the least, (Table 14). For sub-surface soils, at end of dry season; EC varied from 0.28 to 0.9 with non-irrigated soils with the highest while > 10 years of irrigation the least. After rainy season, EC varied from 0.23 to 0.33 for surface soils with <5 years of irrigation the highest and 6-10 years the least; while for sub-surface soils, EC varied from 0.25 to 0.38 with <5 years of irrigation the highest with 6-10 years the least. Significant difference (P>0.05) were observed within the season and between the seasons.

The dry season increased the irrigation water salinity while the rainy season increased the leaching levels, both cases having an effect on EC. While the dry season increased the irrigation water salinity, EC also increased, while rains increased the leaching level of irrigation water causing a decline in EC at end of rainy season. Comparing the different soil surface, the sub-surface soils after rains had higher EC compared to surface soils. This could be attributed to higher soil pH levels and Na levels in the sub-surface soils that increased the salinity levels thus increasing the EC.

Surface soils received more water after rains, increasing the leaching levels, thus lowering the EC. This was the inverse during the dry season where salinity levels increased through irrigation while this reduced the leaching levels. Sub-surface soils in dry season exhibited the highest leaching levels compared to surface soils where salinity levels increased.

Comparing the number of years of irrigation, >10 years showed the highest EC at the end of dry season. This could be attributed to the length of irrigation which increased the SAR/ESP, thereby increasing salinity levels in the surface soils. This was the inverse after rains where in >10 years of irrigation, pH was higher compared to other treatments. This was due to increased organic carbon, Ca, Mg and CEC levels. In the dry seasons, higher Na^+ levels, could have resulted in colloidal fraction dispersion increasing the EC.

4.2.2.3 Caution Exchange Capacity

Cation exchange capacity (CEC) varied from 13.6 to 17.7 and 11.1 to 17.1 for surface and sub-surface soils, respectively, in the dry season, while it varied from 13.1 to 30.0 and 17.4 to 23.7 for surface and sub-surface soils, respectively, after rainy season (Table 14). However, significant differences were observed within and between the two seasons with CEC increasing after rainy seasons ($P > 0.05$). This could be as a result of the lower levels, of Na content which reduced the possibility of colloidal fraction dispersion, unlike in the dry season where high Na contents probably led to dispersion of colloidal fraction, thus lowering the CEC.

Comparing the number of years of irrigation, >10 years of irrigation at the end of dry season had the lowest CEC value compared to other treatments in the same season. This could have been as a result of Na build-up, which led to a decline in base saturation and CEC. However, after rainy season, the CEC Value at > 10 years irrigation was the highest. This could have been due to higher leaching levels, lowering the Na contents while the base saturation also increased significantly. CEC was highest in surface soils for both dry and rainy season due to high organic carbon contents on surface soils. The results are in agreement with Al-Zu'bi (2007) who found increasing C.E.C values with reducing Na contents.

4.2.2.4 Sodium

Sodium (Na) content varied from 0.32 to 0.91 and 0.45 to 1.58 for surface and sub-surface soils respectively after dry season, with >10 years having the highest in surface soils owing this to the build up after irrigation for so many years. After rainy season, Na content varied from 0.22 to 0.84 and 0.38 to 1.00 for surface and sub-surface soils respectively (Table 14).

Significant difference (P>0.05) were observed within and between the two seasons. The higher Na levels in <5 years of irrigation after rains for both surface and sub-surface soils could be attributed to the short – time (<5 years) of leading compared to other treatments. The short time of leaching resulted in an increase in (SAR/ESP). Alternatively the long period of dry spell (Jan Oct) provides suitable conditions for soil soluble salts for crystallizing / precipitating (soluble salts) e g Na up to the soil layer. This also increases the Na levels in soil especially in sub-surface soils.

4.2.2.5 Calcium and magnesium

Calcium (Ca) varied from 6.54 to 8.44 and 4.38 to 8.75 for surface and sub-surface soils respectively after dry season while magnesium (Mg) varied from 3.13 to 5.01 and 3.22 to 5.62 for surface and sub surface soils after dry season. After rainy season; Ca varied from 5.98to 11.40 and 7.85 to 11.70 for surface and sub surface soils respectively. Magnesium varied from 4.58 to 7.82 and 6.45 to 8.86 for both surface and sub-surface soils respectively (Table 14). However, significant differences (P>0.05) were observed within and between the seasons; with Ca and Mg increasing after rainy season in both surface and sub-surface soils compared to the dry season. In the rainy season, Ca and Mg are highly soluble thus increasing the soil solution Ca and Mg contents. The available calcium control sodication by natural processes and improving soil fertility (Genora, 1993).

4.2.2.6 Organic carbon

Organic carbon varied from 1.01 to 2.18 and 0.60 to 1.02 for surface and sub surface soils after dry season, while it varied from 1.40 to 1.90 and 1.02 to 1.43, respectively, after the rainy season for both surface and sub-surface soils (Table 14). Significant difference (p>0.05) were observed within and between the two seasons, with organic carbon increasing at the end of the rainy season compared to end of dry season. This could be attributed to low SAR at the end of rains season and increased leaching levels, which reduces the colloidal fraction dispersion. The results were in agreement with Botta et al., (2006) who found an increase in percentage of organic carbon with decreasing levels of Na contents.

Comparing the number of years of irrigation, non-irrigated soils exhibited the highest organic carbon contents compared to irrigated soils, in both seasons especially in surface soils. This could be attributed to organic matter buildup on the uncultivated soils over the years.

4.2.2.7 Sodium Absorption Ration and Exchangeable Sodium Percentage

Sodium absorption ration (SAR) and exchangeable sodium percentage (ESP) varied from 0.13 to 0.41 and 2.01 to 6.70 for surface soils, respectively, and 0.21 to 0.69 and 3.81 to 9.91 for sub-surface soils respectively after the dry season. After the rainy season, SAR and ESP varied from 0.11 to 0.26 and 1.74 to 3.38 for surface-soils, respectively and 0.13 to 0.35 and 2.00 to 5.28 for sub-surface soils, respectively.

Significant differences were observed ($P > 0.05$) within and between the two seasons (Table 14). Both indices were high in <5 years of irrigation for both surface and sub-surface soils compared to other treatments, after the rainy season. The short leaching period (Oct – Jan) every year and the long dry spell (Jan – Oct) every year increase the salinity levels, thus the proportion of Na in the soil.

4.3 Irrigation water quality

At the end of dry season, 0 m distance; bicarbonate (HCO^-_3) concentration was higher than at 500 m and 1000 m distance.This was probably due to higher temperature in the dry season which resulted in precipitation of carbonates. This increased HCO^-_3 concentration which resulted in an increase in residual sodium carbonate (RSC). At the end of rainy season, much of the calcium is leached, while carbonates precipitated as well as soluble salt (HCO^-_3)concentration from other areas brought in by floods at the intake (0 m) results in higher HCO^-_3) concentration, which increase the RSC. However, at the end of dry season, all the parameters analyzed showed no significant ($P>0.05$) differences at different distances, as observed also after the rainy season. However, significant different ($P>0.05$) were observed between the two seasons. (Table 15), with some parameters increasing while others decreased. The RSC values in both seasons were safe for irrigation according to guidelines by Ayers and Westcot (1976) who reported that values <1.25 me/l are probably safe for irrigation while value >2.5 me/l are unsuitable for irrigation while 1.25 to 2.5 me/l are marginally suitable for irrigation.

Comparing other parameters in the two seasons at different distances from source, no significant difference ($P>0.05$) were observed. However, at the end of the dry season pH was slightly higher at 1000 m distance. Comparing the pH at the end of the rainy season, significant differences ($P>0.05$) were observed with a drop in pH. The significant decline in Ca^{2+} concentration as well as Mg^{2+} especially at 1000 m distance coupled with the presence of HCO_3^- and CO_3^{2-} makes part of Ca and Mg precipitate, thus lowering the pH. Alternatively, the drop in pH could have been due to higher levels of leaching in rainy season increasing the soil acidity, as observed also by Hoffman et al., (1979) in an earlier study. According to Ayers and Westcot (1976) guidelines, the pH between 6.5 to 8.4 is considered to be within the normal range for irrigation, hence indicating the water in the canal was safe for irrigation.

Potassium (K^+) as well as chlorides (Cl^-) are highly soluble in water. This resulted in the significant differences ($p > 0.05$) found between the dry and rainy season where K^+ and Cl^- ions increased after rainy season. Floods with soluble salts brought into the river as runoff from other areas could have contributed to the high concentration of these cations (K^+ and Na^+) after rainy season.

The high Na^+ concentration after rains increase the SAR compared to the dry season. All the CO_3^{2-} after rains solubilizes and precipitated as HCO_3^- which resulted in a significant ($P > 0.05$) difference in RSC between the seasons, with an increase after the rainy season.

However, values obtained for CO^{2-} and HCO^{-}_{3} were less than 1.5 me/l, hence was suitable for irrigation (Ayers and Westcot, 1976). The chloride levels were also within the acceptable range (<4 me/l).

Table 15: Chemical characteristics of irrigation water from river Tana in the study area.

SEASON	Distance (m) from intake	pH CaCl2	EC dS/m	K me/l	Na me/l	Mg me/l	Ca me/l	CO_3^{2-} me/l	HCO_3 me/l	Cl me/l	SAR	SSP	RSC
End of dry season	0	8.13^{ab}	0.20^{b}	0.17^{a}	0.80^{ab}	0.33^{a}	0.14^{a}	0.27^{a}	0.87^{a}	0.43^{b}	1.68^{a}	55.99^{b}	0.40^{a}
	500	8.23^{a}	0.20^{b}	0.17^{a}	0.83^{a}	0.35^{a}	0.15^{a}	0.33^{a}	0.83^{a}	1.40^{a}	1.68^{a}	53.72^{a}	0.300^{c1}
	1000	8.25^{a}	0.23^{a}	0.17^{a}	0.83^{a}	0.35^{a}	0.14^{a}	0.27^{a}	0.80^{al}	0.30^{c}	1.70^{a}	53.29^{a}	0.38^{a}
End of rainy season	0	7.67^{a}	0.30^{a}	0.20^{a}	1.14^{a}	0.32^{a}	0.10^{ab}	0.00^{b}	0.68^{a}	0.43^{b}	2.48^{a}	65.00^{a}	1.24^{a}
	500	6.6[illegible]	0.30^{a}	0.18^{a}	1.10^{a}	0.29^{a}	0.09^{a}	0.00^{b}	1.00^{b}	0.43^{b}	2.59^{a}	66.00^{a}	0.62^{b}
	1000	7.50^{a}	0.27^{a}	0.18^{a}	1.14^{a}	0.28^{b}	0.10^{ab}	0.00^{b}	1.37^{ab}	0.40^{ab}	2.63^{a}	67.28^{a}	0.99^{ab}

• Means with the same letter and digit superscript within and between seasons, respectively, at different distances are not significantly different at 5% level.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study the livelihood and environmental (soil and water resources) evaluation of smallholder irrigation schemes along the Tana River in Garissa district was determined with a view to finding out to what extent are agro-pastoralists depending on irrigation schemes for their livelihoods and whether irrigation is sustainable from environmental point of view (i.e. determine the state of soil quality in the irrigated fields) and to determine the quality of irrigation water in the wet and dry season.

It was established that smallholder irrigation started in the district in the early 1970's as an intervention measure to successive droughts that led to loss of livestock by pastoralists making them destitute and hence loss of there livelihoods. The method by which agro-pastoralist became members of the irrigation schemes were many and happened over time. The first group of irrigation farmers were resettled through the intervention of the government. The other successive groups learnt of the existence of irrigation schemes from informed sources and took the decision to join the schemes independently as and when need arose. The practice of irrigation farming had increased and continued to increase even after the government & donors withdraw there support. This was in contrast to the findings, which showed that after the government and donor support withdrawal, the schemes collapsed. This was evidenced by the increase in acreage under crop production (80%) as a result of gains made by agro-pastoralists from irrigation farming.

The data from the survey indicate that 93% of the farmers grow crops both for home consumption and sale. Most farmers believe that there has been change in acreage under crop production. This change has been both an increase and decrease that was observed by 62% and 16% of the farmers respectively. An increase in acreage is attributed to opening up of more land under irrigation for crop production, while reduction was attributed to environmental calamities, especially seasonal floods. The use of fertilizer and manure enhanced soil fertility and thus increased crop yields and income.

Data from the survey shows that different types of crops are grown in the irrigation schemes, with horticultural crops being the most widely grown, banana being the leading with 84% of the farmers growing it. The cropping pattern shows a shift from growing food crops to growing high value crops an indication of change of farming systems from subsistence towards commercialized agriculture. Production of horticultural crops is labour intensive. Increased farm output as a result of irrigation stimulates demand for farm labour. In the study area, hired labour is very important with 71% of the household using it. This labour was reported to be in short supply during the rainy season when its demand was highest in comparison, only 38% of livestock keepers hired labour.

Majority of households interviewed reported increases in income (93%) from sale of farm produce. This high income from sale of crops was therefore expected to significantly reduce the length of period during which households are food insecure. The high income from farm produce is also reinvested in farming practices like purchase of farm inputs and paying for hired labour. Farmers also have acquired assets e.g. building permanent houses. Most farmers in the irrigation schemes are food secure (79%) most of the time. From livelihood point of view, it can be concluded that irrigation schemes in Garissa are moving from production to sustainability.

The result of soil physical and chemical analysis show that irrigation did not significantly affect soil quality. Also the number of years an irrigation scheme has been in existence has no significance on the soil physical and chemical properties, but rather it is the actual farming practices that is essential to achieving sustainable management of agricultural resources.

From the result, irrigation water quality varied with season, but generally, water quality fall in the low salinity (C1) and low sodium (SI) hazard class and therefore suitable for irrigation.

5.2 Recommendations

1. To boost the farmers efforts and to ensure higher incomes, a marketing system for the high value horticultural crops should be improved especially for tomatoes and mangoes whose prices fluctuate widely.

2. There is need for the farmers in the irrigation schemes to strengthen the management committees through capacity building.

3. Currently, the farmers are not benefiting from any credit services, therefore there is need for establishment of micro-finance institutions to enable the farmers to access affordable loans especially for purchase of farm inputs.

4. The continuous use of traditional farming implement like plain *jembes* at shallow depth has resulted in increased surface soil compaction, resulting in decreased water flow. Therefore farmers should be advised to frequently practice deep ploughing, such as ripping and sub-soiling to break-up hard pans and compacted soils to improve soil structure which will translate into improved crop performance, thus increased yields.

5. Farmers should be advised to practice crop rotation in the irrigation fields and leave as much crop residue on the fields as possible to increase the organic matter in the soil. Alternatively, livestock manure should be added to the soil in order to improve not only soil structure, but also the fertility.

6. There is need to carry out research to establish the crop water requirements for the various crops in the schemes so as to increase water use efficiency by reducing costs associated with pumping water.

7. There is need for further studies to be carried out to determine the causes of irrigation water quality variations with seasons and variation of soil physical and chemical properties with depth.

REFERENCES

Abrol, I.P., Chhabra, R., and Gupta, R.K. (1980). A fresh look at the diagnostic criteria for sodic soils. Proc. Intern. Symp. Salt-affected soils, Karmal, India. Pp. 142 – 147.

Ahmed A. N (1999). Social economic and ecological impact of smallholder irrigation schemes on pastoral nomads of Garrisa District, Kenya Unpublished MSc thesis. University of Nairobi.

Al Zu'bi, Y. (2007). Effect of irrigation water on agricultural soil in Jordan valley. An example from arid area condition. Journal of arid environments 7: 63 – 79.

Ali O.M; Yousaf, M. and Rhoades J.D. (1987). Dispersion of clay from some salt-affected arid land soil aggregates. Soil Sci. Soc. Am. J. 51: 920 – 924.

Anonimous (2008): Irrigation, Drainage and land reclamation sub sector.

Anonymous (2008): can soil structure affect irrigation extension.

Arany, S (1956) V.I. Congr. Int. Soil Sci. soc. VI 22: 615 – 9.

Arshad, M.A, B. Lowery and B. Grossman (1996). Physical tests for monitoring soil quality. P.123 – 142. In: Doran, J.W and A.J. Jones (Eds). Methods for assessing soil quality. Soil Sci. Soc. Am. Spec. Publ 49 SSSA, Madison, Wi

Ayers, R.S and Westcot, D.W (1976). Water quality for agriculture. FAO Irrigation and Drainage Paper No. 29. FAO, Rome.

Badhe, N.N and Kadwe, R.S. (1977). Quality of well waters and their suitability for irrigation in deep black soils. J. Soil and Water Conservation in India. 27: 89 – 94.

Batisse, M (1969). Problems facing arid land nations. In: McGinnies , W.G. and Bram. J. Goldman (Eds). The American Association for the Advancement of Science Washington. The University of Arizona Press.

Behnke, R and Scoones, I (1992). Rethinking range ecology: Implications for rangeland management in Africa. London.

Bhattacharyya R, Singh R.D, Chandra, S, Kundu, S and Gupta A (2006). Effect of tillage and irrigation on yield and soil properties under rice (*Oryza saliva*) – wheat (*Triticum aestivum*). System on a sandy clay loam of Uttaranchal. India Journal of Agricultural sciences.

Bhumbla, D.R (1977). Chemical composition of irrigation water and it's effect on crop growth and soil properties in Arid land irrigation in developing countries. Environmental problems and effects E.B. Worthington (Ed). Pergamon Press.

Black, C.A (1965). (Ed). Methods of Soil Analysis. Agron. No.9, Amer. Soc. Agro. Madison, Wisconsin.

Blake, G.R. and Hartge, K.H (986) Bulk density. In. methods of soil analysis part 1. pp 363 – 382. Klute, A. (Ed). Agr. ser. No.9. Amer. soc. Agr. Inc. Madison, Wisconsin.

Blank H.G et al., (2002). The changing face of irrigation in Kenya: Opportunities for anticipating change in Eastern and Southern Africa. IWMI.

Bloemen W, (1980). Calculation of hydraulic conductivities of soils from texture and organic matter content. Z. Pflanzenernah. Bodenkd; 43: 581 – 605.

Bonham, C.D. (1989). Measurements for terrestrial vegetation. John Wiley and sons, London.

Botta, G. d. Jorajuria,R. Balbuena, M. Ressia, C. Ferrero, 4. rosatto, and M.Tourn. 2006. Deep tillage and traffic effects on subsoild compaction and sunflower yields. Soil andtillage Research91: 164 – 172.

Brady M.C. and Weil R.R (2002). The nature and properties of soils. Thirteenth Edition. Pearson Education, Singapore.

Carter D.L. (1975). Problems of salinity in Agriculture. In: Poljakoff – Mayber and J. Gale (eds). Plants in saline environment. Ecological Studies 15.A. Springer-Verlag. Berlin. PP 25 – 35.

Carter M.R, J.R. Pearen, P.G. Karkanis, R.R. Cairus and D.W. McAndrew (1986). Improvement of soil properties and plant growth on a brown solonetzic soil using irrigation, calcium amendment and nitrogen. Can. J. Soil Sci. 66: 581 – 589.

Casley, D. J and Kumar, K (1987). Project monitoring and evaluation in agriculture. A World Bank Publication. Washington.

Chhabra R, (1996). Soil salinity and water quality. Oxford and IBH Publishing Company. PVT. LTO New Delhi.

Cosby B.J; Hornberger G.M; Clapp R.B, Ginn T.R (1984). A statistical exploration of soil physical properties of soils. Water Res. Res; 20: 682 – 690.

Czyz, E.A (2004) Effect of traffic on soil aeration, bulk density and growth of spring barley. Soil and tillage research 79: 153 – 166.

Dane J.H; Puckett W; (1994). Field soil hydraulic properties based on physical and mineralogical information. W. Geuchten et al (ed): Proceedings of the international workshop on indirect method for estimation of hydraulic properties of unsaturated soils, Univ. of California, Riverside, C.A; 389 403.

Dekkev, M (1991). Soil analysis: Physical and chemical methods. Inc. New York.

Delgado, C (1979). The southern Fulani farming system in upper Volta. A model for the integration of crop and livestock production in the West African savannah. Dept. of Agric. Economics, Michigan State University, African Rural Economy Paper No. 20.

Dewis, J and Freitas, E (1970). Physical and chemical methods of soil and water analysis. Soil Bulletin 10. FAO Publication. Rome.

Dresch, J (1975). Reflections on the future of the semi-arid regions in African environment: Problems and perspective In: Richards, P (Ed). African Special Report No.1, International African Institute, London.

Dutt, G.R. and Doneen, LD (1963). Predicting the solute composition of the saturation extract from soil undergoing salinization. Proc. Am. Soil Sci. Soc. 27, 627 – 630.

Eaton, F.M (1950). Significance of carbonates in irrigation waters. Soil Sci. 69: 123 – 133.

El-Guindy, S; El-Nasser, G.A; Abu Bakr, A; and El-siss, L. (1987). The effect of irrigation with drainage water on some chemical soil properties and the yield of different field crops. Drainage research institute water research centre Cairo. Egypt

El-Sayed. H El-Haddad and Maher M. Noaman, 2001. Leaching requirement and salinity threshold for yield and agronomic characteristics of halophytes under salt stress J. Arid Enviro. 49 865-74.

Evanylo, G and McGuinn, R (2000). Agricultural management practices and soil quality: Measuring, assessing and comparing laboratory and field test kit indicators of soil quality attributes. Rab. No. 452 – 400. Virginia Technology.

Eynard A., Schumacher T.E, Lindstrom M.J, Malo D..D and Kohl R.A (2004). Wettability of soil aggregates from cultivated and uncultivated ustolls and usterts. Aust. J. Soil Res. 42: 163 – 170.

FAO (1971). Salinity Seminar Baghdad. Irrig. and Drainage Paper No.7. FAO Rome.

FAO (1979). Soil survey investigations for irrigation. Soils Bull. No. 31. FAO, Rome in Tropical soil manual. Landon, J.R (Ed) (1984).

FAO (2006): A QUASTAT. FAO information system on water and agriculture FAO – Rome.

FAO/ UNESCO, (1990). Soil map of the world. 1:5,000,000 Vol.6. African UNESCO Paris.

Ferro. S (2006). Physical soil testing. Turf Diagnostic and design. Linwood, Kans. On line file://E./ physical soil testing United States Golf Association.htm. Visited on 19/3/2007.

Finkl, C.W. Jr. (1979). Conductivity, electrical, in Encyclopedia of soil Science, parts Fairbridge, R.W and Finkl, C.W Jr. eds, Dowden, Hutchinson and loss, Stroudsburg, Pc pp 97 -99.

Fireman M. and Kraus, Y (1965). Salinity control in irrigated Agriculture, Tahal, Israel. 46.

Gachene C.K. Kimaru G. (2003). Soil fertility and land productivity. Remla Tech. hand book No. 30.

Gee, G.W and J.W. Bauder (1986). Particle size analysis. In: Klute A. (Ed). Methods of soil analysis part 1, 2nd Edition. Agron. Ser. No.9. Amer. Soc. Agr. Madison. Wisconsin.

Genora, L.J. 1993. Estudio de la degradacion de suelso bajo riego complementario de cultiros extensiros con agues subterraneas del aquifero pampeano en el norte de Buenos Aires. Xiv congreso Argentirio de la ciencia del suelo, Mendoza, Argentina.

GoK (1995). Irrigation profile-Garissa District.

GoK (1997). District Development Plan (1997 – 2001) Garissa. Ministry of Planning and National Development.

GoK (2002). District Development Plan (2002 - 2008) Garissa District. Ministry of Planning and National Development

GoK (2007). Kenya vision 2030. A Globally competitive and prosperous Kenya Government Printer Nairobi.

GoK (2008) Agricultural sector development strategy 2009 – 2014. An agricultural, public and private sectors partnership. Nairobi, Kenya.

GoK, (2001). Poverty reduction strategy paper for the period. 2001 – 2004. GoK printer Nairobi. Kenya.

Grillot, G (1954). Utilization des Eaux salines. UNESCO, PP 11- 39. Quoted by Yaron (1973).

Harrod, M.F (1975). Field experience on light soils. In: Soil physical conditions and crop production, MAFF Tech. Bull. 29, London.

Hatcher, J.T, Blair, G.Y, C.A (1959). Soil Sci. 88, 98 – 100.

Heathman, G.C, L- L.R. Ahuja, J. tim/in and K.E. Johnsen. 1995. surface aggregate and macrospore effects on chemical transport in soul under rainfall. Soul Sci – Soc. Am. J 990 – 997.

Hendricksen, G (1975). Economic growth and ecological balance; problems of development in Turkana, occasional paper No. 11. University of Bergen.

Hesse P R. (1971). A text book of soil chemical analysis. John Murray London.

Hillel D. (1998). Environmental soil physics. Academic Press, San Diego, California.

Hoffman, G-J.I, S.L. rowlins, J.D Oster and J.D Merrill. 1979. leaching requirement for salinity control I wheat, sorghum and lettuce. Agro water management. 1..2 177 – 92.

Hoggs. R.S (1987). Settlement, pastoralism and practice of irrigation development in Northern, Kenya. In: David, A and Grove, R (eds). Conservation in Africa: People, policies and practice. Cambridge University Press.

Horowitz, MM (1980). Research Priorities in pasture studies: An agenda for the 1980s. In Galaty, J.etal (ends). The future of pastoral peoples"; proceeding of conference held in Nairobi kenya4-8 august 1980. IDRC – 175 e.

Hughes, F, (1987). Conflicting uses of forest resources in lower Tana Basin of Kenya. In: David Anderson and Paul Richards (Eds). Conservation in Africa: Peoples, Policies and practice. Cambridge University Press.

ILACO, B.V (1981). Agricultural compendium for rural development in the tropics and sub-tropics, Elsevier, Amsterdam.

Julander R.P and W. Jackson (1983). Drop former and double ring infiltrometers – a comparison. In: Advances in infilteration, ASAE, Proc. Nat. con. on Adv. in Infn. 1983, Chicago, Illinois.

Juve, R.L. and Lewis, G.C. (1955). Some effects of irrigation water quality or soil characteristics. Soil Science, 81:125-138.

Kamphorst. A. and Bolt, G.H (1978). Saline and sodic soils. pp 160 – 188. In: G.H. Bolt and M.G.M. Bruggen Wert (eds). Soil chemistry. A basic elements. Elsevier publishing company. Amsterdam. The Netherlands. pp. 423.

Kariuki, G.K (1995). Socio-economic and phytoecological environment of nomands in smallholder irrigation schemes in Isiolo District, Kenya

Karlen, D.L.I M.J.Mausbach. I.J.W. Doran,R.F. Harris; R-G cline and G.E Schumann – 1997. Soil quality. A concept, definition and framework for evaluation. Soil Sci soc Am. J. 61: 4-10.

Khogali, M.M (1981). Sedentarization of nomads in Sudan. In: The future of pastoral peoples. Proceedings of a Conference held in Nairobi, Kenya. 4-8 August 1980.

Kinyali, S.M; Karuku, G.N and Tirop, S. K (2000). Impact of siltation problems on production of fish in lake Baringo, Kenya. In: Soil Science Society of East Africa. Soil technologies for sustainable smallholder farming systems in East Africa. Proceedings of the 15th AGM. August 19 – 23rd 1996. 170 – 175.

Kironchi, G (1992). Effects of soil type vegetation and land use on infilteration rate and related soil physical properties in two semi-arid catchments in Laikipia District. Msc. thesis, University of Nairobi.

Kironchi, G, Liniger, H.P, and Mbuvi, J.P (2000). Degradation of soil physical properties in over grazed rangelands in Laikipia District. In: Gichuki et al (eds). Land and water management in Kenya. Towards sustainable land use. Nairobi, Kenya, 5 – 9.

Klute, A (1965). Laboratory measurement of hydraulic conductivity of saturated soils. In. methods of soil analysis part 1. Physical and mineralogical properties, including statistics of measurement and sampling. PP. 220 – 220. Black, C.A (Ed) Agr. Sev. No.9 Amer. Soc. Agr. Inc. Madison, Wisconsin.

Konczacki, Z.A. (1978). The economics of pastoralism: A case study of sub-Saharan African. Frank Case and Company ltd. London.

Kovda V.A (1960). (Ed). Quality of irrigation water. In: FAO/ UNESCO Rome irrigation, drainage and salinity. An international source book.

Kovda, V.A, B Yaron, and J. Shalnevet, (1973). Quality of irrigation water. In: Irrigation, drainage and salinity, V.A. Kovda, C. Van de Berg, and R.M. Hagan eds, Hutchinson / FAO/ UNESCO, London PP. 177 – 205.

Kundell J. (2008) editor. Water profile of Kenya In: Cutler J. Cleveland (Ed) Encyclopedia of Earth. FAO, Rome.

Lagat J. Kithinji G.K, Buigut S.K (2003). Determinants of the adoption of water harvesting technologies in the marginal areas of Nakuru District, Kenya: The case of trench and water pan technologies. East Africa Journal of Rural Development. Vol.19 (11). Pp. 63 -75.

Lal, R (1979). Physical characteristics of soils of the tropics: Determination and management, PP. 7 – 46 In: Lal, R and Greenland D.J (Eds) Wiley and sons, Chichester. Soil physical properties and crop production in tropics.

Lal, R. (1981). Physical properties in. Green land, D.J. (ed) characterization of soils. Oxford, Clarendon, 135 – 148.

Landon J.R (1984). (Ed). Booker tropical soil manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Inc., New York.

Lebron, I. Schaap M.G; Suarez, D.C; (1999). Saturated hydraulic conductivity as affected by pore size and pore geometry in soils with variable chemical composition. Water Resources Research 35; 10; 3149 – 3158.

Levy R. (1984) (Ed). Chemistry of irrigated soils, Bench mark Paper in Soil Science Series.

Li, L., 2008. Irrigated area stays stable. World watch Institute, Washington, DC

Lipton M, Hitch field J, Blackman R, De Zoysa D. 2003. Preliminary review of the impact of irrigation on poverty with special emphasis on Asia. FAO, Rome.

Magamy, D, B.J. Brodge and B.J. Radford. 2000. contrasting soil physicalproperties after zero and traditional tillage of an alluvial soil in semia-arid sub tropics soil till. Res. 53: 105 – 115.

Magisted D.C. and Christiansen J.E. (1944). USDA Cir. No. 707.

Maliwal, G.L (1968). Effect of irrigation waters of different qualities on soils and crops. PhD. Thesis, University, Udaipur, India.

McNeal, B.L (1968). Prediction of the effect of mixed salt solutions on soil hydraulic conductivity. Soil Sci.Soc. Am. Proc 32: 190 – 193.

McNeal, B.L; W.A. Norvell and N.T. Coleman (1966). Effect of solution composition on the swelling of extracted soil clays. Soil Sci. Am. Proc. 30: 313 – 317.

Metson, A. J (1971). Methods of chemical analysis for soil survey samples. New Zealand Department of Scientific and Industrial Research. Soil Bureau Bulletri 12.

Michael A. M (1978). Irrigation theory and practice, Vikas Publishing House, P.V.T. LTD, New Delhi.

Ministry of Agriculture (1999). Country focused training course on smallholder irrigation promotion. Tsukuba International Centre – Japan.

Ministry of Agriculture (2003). Annual Report-District Agricultural Office, Garissa.

Ministry of Water and Irrigation. 2006. Irrigation Development for Food Security, stakeholders Workshop held at Nairobi 28th-29th March 2006.

Mostafazadeh –fard, B; Heidarpour, M; Aghakhani, A, and Feizl, M (2007). Effects of irrigation water salinity and leaching on soil chemical properties in an Arid Region. International Journal of Agriculture and Biology; 3: 466 – 469.

Mott, C.J.B, (1988). Surface chemistry of soil particles. In. "Russels soil condition and plant growth" A. Wild (ed). Longman scientific and technical, U.K. 11th edition Pg. 239 – 281.

Mpahlele, R.E, Malakalaka, T.M, (2000). Characteristics of smallholder irrigation farming in South Africa: A case study of the Arable-Olifants River Irrigation Scheme (online). IMWI. Available from IMWI.-research- news@cgiar.org (date accesed 24.7.06).

Mugenda O. M, and Mugenda, A.G, (1999). Research methods: Quantitative and qualitative approaches. ACTS Press, Nairobi, Kenya.

Murdock, W.W. (1975). Environment: Resources, pollution and society. Library of Congress Catalog Card No. 74 – 24361.

Musebe, R.O. (1990). An analysis of agricultural credit markets in Vihiga Division, Kakamega District. Unpublished MSc. Thesis, University of Nairobi.

Mwaniki, N (1981). Pastoral societies and resistance to change; a re-evaluation. 3rd Ann. Graduate student paper competition co-writer. African students programme.

Nelson, D.W. and Sommers, L.E (1982). Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis Part 1 pp 539 – 579. Agron. No.9. Klute A (Ed). Amr. Soc of Agr. Inc. Madison, Wisconsin.

Nyangito, H.Z, (1986). A socio-economic analysis of the factors that determine and affect potato post harvest practices and storage technologies in Kinangop, Kenya. A case study. MSc. Thesis, University of Nairobi.

Omulubi J.E.A (1996). The effect of secondary salinization on soil physical properties of salt affected soils in Makindu, Kenya. Msc. Thesis University of Nairobi.

Osgood, D. and Lipper, L (2000). Methodological issues in analyzing the linkages between socio-economic and environmental systems (online) FAO. http://www.fao.org (Date accessed: 09/08/06).

OZdemir, N. (1998). Toprak Fizigi.OMU Zirat Fak. Ders Kitabi, No; 30, Samsun

Pankhust, K – Y, A.S. Hodgsson and C.R Espinndlla. 1997. influence of reduced tillage on organic matter, Microbial biomass, macro aggregate distribution and structural instability of the surface soil in a humid climate soil till. Res. 23: 361 – 372.

Pearson, K.E., Warrence N.J and Bauder J. (2003). The basics of salinity and sodicity effects on soil physical properties Montana state university.

Peech, M (1965). Hydrogen – ion activity. In: Methods of Soil Analysis Part 2. Agron. No.9. Black C.A. (ed). Am. Soc. Agron. Inc. Madison Wisconsin.

PINEP (1996). The African Pastoral Forum. University of Nairobi, Department of Range Management, Working Papers Series No.12.

PINEP (1999). The African Pastoral Forum, University of Nairobi, Department of Range Management Working Papers Series No.19.

Poonia, S.R. and O. Talibudeen (1977). Sodium – calcium exchange equilibria in salt-affected and normal soils. J. Soil Sci. 28: 276 – 288.

Puri A.N (1949). Soils: their physics and chemistry, Reinhold, 550.

Quick, J.P. and R.K. Schofield. 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci.6: 163 – 178.

Rhoades J.D. (1972). Quality of water for irrigation, In chemistry of irrigated soils.

Rhoades, J.D. (1968a). Mineral weathering correction for estimating the sodium hazard of irrigation waters. Soil Sci.Soc. Proc. 32: 648 – 652.

Rhoades, J.D; D.B. Krueger and M.J. Read (1968). The effect of soil mineral weathering on the sodium hazard of irrigation water. Soil Sci. Soc. AM Proc. 32:643 -647.

Richards, L.A. (1954). (Ed). Diagnosis and improvement of saline and alkali soils Agriculture Handbook 60, U.S. Department of Agriculture, Washington D.C.

Richards, L.A. and Hayward, H.E. (1957). Proc. 1st Intersoc. Conf. Irrigation Drainage, San Fransisco, Calif. 1957, Pg. 93 – 96.

Rietz D.N and Haynes R.J. (2003); effects of irrigation – induced salinity and sodicity on soil microbial activity. Soil Biology and Biochemistry. Vol. 35, issue 6, pp 845 – 854.

Rietz, D.N and Haynes, R.J. (2003). Effects of irrigation induced salinity and sodicity on soil microbial activity. Soil Bio and Biochem. Vol. 35, issue 6. pp 845 – 854.

Rodolfo, M; Irurtia C; Fernando, G. B; Pozzolo, O. Melcon, F.B; Rivero, D. and Bomben, M (2007). Effects of supplementary irrigation on chemical and physical soil properties in the rolling pampa region of Argentina.cien.Inv.Agr:34(3): 187 – 194.

Russell E.W. (1973). Soil conditions and plant growth. Tenth Edition. Longman, London.

Sanchez P.A. (1976). Properties and management of soils in the tropics. Wiley, Chichester.

Sanford, S (1983). Management of pastoral development – Third world countries. John Wiley and Sons.

Scherer, T.F. Seeling B and Franzen; D (1996) soil, water and plant characteristics important to irrigation. North Dakota.

Schofield C.S. (1953). Smith. Inst. Rep. 275 – 87.

Scofield R.K. and Taylor A.W (1955). Measurements of the activities of bases in soils. S. Soil Sci. 6: 137 – 146.

Shah, and Singh S. (1964). Boron adsorption equibrium in soils 98, 383 – 388.

Shainberg I and Oster, J.D. (1978). Quality of irrigation water. ILL C Publication No.2 International Irrigation Information Centre.

Shainberg, I, Rhoades J.D and R.J Prather (1981). Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of sodic soil. Soil Sci. Soc. Am J. 45: 273 – 277.

Shainberg, I., and J. Letey. 1984. Response of soils to sodic and saline conditions. Hilgardia. 52: 1 – 57.

Shainberg, I.J.D. Rhoades and R.J. Prather (1981). Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of sodic soil. Soil Sci. Soc. Am. J. 45 273 – 277.

Shalhevet, J. and J. Kamburov (1976). Effects of saline irrigation water on soils. In: Framji, K.K (ed). Irrigation and salinity - A world-wide survey. International commission on irrigation and drainage.

Sharma, D.P and K.V.G.K. Rao (1998) strategy for long term use of saline drainage water for irrigation in semi-arid regions. Soil Tillage Res. 48.287 – 95.

Sheinberg, I (1975). Salinity of soils, effects of salinity on the physics and chemistry of soils. In "plants in saline environments". Ecological studies 15.A. Poljakoff-Mayber and J.Gale (eds). Springer. Verlag. Berlin. PP. 39 – 55.

Sombroak, W.G; J.P. Mbuvi, J.M. Kibe and H.W. Okwaro (1974). A preliminary evaluation of the irrigation suitability of the lands in the middle-lower Tana Valley (Mbalambala – Garissa – Bura) Site Evaluation Report No. p14.

Spychalski, M, Kazmierowski, Kaczmarekz C. (2007). Estimation of saturated hydraulic conductivity on the basis of drainage porosity. Electronic Journal of Polish Agricultural Universities. Environmental Development. Vol. 10, Issue 1. http://www.ejpau.media.pl/volume10/issue1/art-04.html

Steel, R.G.D and Torrie J.H (1980). Principles and procedures of statistics. A biometrical Approach. 2nd Edition. McGraw. Hill, Inc. New York.

Steiner K.G. (1996) cause of soil degradation and development approaches to sustainable soil management. GTZ.

Stern R.D. Coe R. Allan E.F. Dale L.C (Ed) (2004). Good statistical practice for natural resources research. CABI. Publishing.

Tadingar, T. (1994). Pastoral development in sub-Saharan Africa An integration of modern and indigenous technical knowledge. Working Paper Series No.2. The African Pastoral Forum.

Tanwir, F.A. Saboor and Nawaz N. (2003). Soil salinity and the livelihood strategies of small farmers. A case study in Faisa Lahad district, Punjab, Pakistan. Int. J. Agric. Biol, 5:440-1.

Thorne, O.W. and Peterson, H.G. (1954). Irrigated soils, there fertility and management Biofiston, New York.

Tiffens, M (1984). Human resources in African irrigation. In: Blackie, J. M (ed). Regional symposium on small holder irrigation 5-7 September 1984. University of Zimbabwe Harare, Zimbabwe.

Tonui, D.K (1992). An evaluation of the influence of water quality and irrigation management on soil properties of some selected irrigation farms in Kiboko and Makindu. Msc. thesis UoN.

Troech .F.R, Hobbes J.A and Dohahue R.L (1980). Soil and water conservation for productivity and environmental protection.

Tum, J.C, 1996. Determination of the causes of secondary salinization in Kibwezi. MSc. thesis University of Nairobi.

U.S. Salinity laboratory (1954). Irrigation Ecological Studies Vol. 5 Springer – Verlag, Berlin. Unpublished MSc .Thesis, University of Nairobi.

Van Dyne G. M (1969). The ecosystem concept in Natural Resource Management. Academic Press New York.

Van Hoorn J.W. (1970). Salt tolerance and crop management on salt affected soils. In: Salinity Seminar, Baghdad. Report of Regional seminar on methods of amelioretion of saline and water logged soils. FAO. No.7. Rome.

Vomocil J.A (1965). Porosity. In. Methods of soil analysis part 1 PP 299 – 314. Black C.A. (Ed). Agri. Se No.9 . Amer. Soc. Agri. Inc. Madison, Wisconsin.

Wealth and Employment Creation. Proceedings of the National Irrigation

Whitbread A.M. Lefroy R.D.B. and Blair G.J (1996). Charge in soil physical properties and soil organic carbon fractions with cropping on a red brown earth soil. In: Proceeding of the 8th Australian Agronomy Conference, Toowoomba.

Wilcox L.V. (1958). Information Bull. 197, USDA Washington D.C.

Wilcox, L.V. (1960). Boron injury to plants. U.S. Dept. Agri. Int. Bull. 211, 7 PP

Witkowska - Walczak, B. and C Slawinski. 2005. Unsaturated water conductivity ahd diffusivity in soil aggregates. Polish J. Soil Sci 38: 11 – 22.

World Bank (2007), World Development report, Agriculture for Development. The Work Bank. Washington, D.C.

Worthington E. B (Ed) (1977). Arid land irrigation in developing countries: Environmental problems and effects. Publisher, city.

Xu, D; Mermoud, A: (2001). Top soil properties as affected by tillage practices in North China. Soil Till Res. 60: 11 -19.

Yaroh, B. (1973) Arid zone irrigation. Ecological studies Vol. 5. Springer-Verlag, Berlin.

Yousaf, M, Ali, O.M. and J.O. Rhoades (1987). Clay dispersion and hydraulic conductivity of some salt-affected arid soils. Soil Sci. Soc. Am. J. 51: 905 – 907.

Zahow, M.F. and Amrhein, C. (1992). Reclamation of a saline sodic soil using synthetic polymers and gypsum. Soil Sci.Soc. Am. J. 56: 1257 – 1260.

APPENDICES

Appendix 1: Survey Questionnaire

SURVEY QUESTIONNAIRE

Name of Interviewer ------------------------------ Questionnaire No. ------------

Name of Respondent ------------------------------

Date of survey ------------------------------------

Division ---------------- Location ----------------

Name of scheme / farm ------------------------------

A: GENERAL HOUSEHOLD INFORMATION

1. Name of household head ---------------------- Age........ Sex -----------
2. Name of the respondent ---------------------- Age........ Sex ------------
3. Relationship of respondent to household head (Tick one).
   (a) Head (b) Husband (c) Wife (d) son (e) daughter (f) Employee
   (g) Other (specify)--------------------
4. Marital status of household head (tick one)
   (a) Married (b) Single (c) separated / divorced (d) Widowed
5. Religion of household head (tick one).
   (a) Catholic (b) Protestant (c) Muslim (d) Other (specify) -----------
6. What are the sources of income for this household?
   (Please indicate the source of the support and the proportion the support contributes to the households' income)

Source	Proportion

   a) Remittance
   b) Sale of farm produce
   c) Business
   d) Sale of labour
   e) Formal employment
   f) No income
7. What is the size of your household? ----------------- members.
8. How many children of school going age do you have? ---------------------------
   (a) How many boys are attending school ---------------- boys.
   (b) How many girls are attending school --------------- girls.
   (c) How many herd animals? Boys --------- girls -------
   (d) How many do farm work? Boys -------- girls -------
9. How do you decide who among your children herd animals, do farm work or go to school? (Tick one)
   (a) Decision based on gender bias (b) Arbitrary
   (c) Family consultation (d) Others (specify)

10. What is the gender of the household head?
   1) Male
   2) Female
11. What is the level of education of the household head?
   0. No formal education
   1. Primary school
   2. Secondary school
   3. Post secondary
   4. Adult literacy education
   5. Illiterate

B. FARM PRODUCTION AND MARKETING

12. What are the main crops that you grow and their acreage?

	Crop	Present acreage
(i)	————	…………
(ii)	————	…………
(iii)	————	————
(iv)	————	————
(v)	————	————

13. What factors do you normally consider when deciding on the crops to grow and their acreage? (Rank 1,2,3).
   (a) Profitability.
   (b) Pest and disease resistant
   (c) Labour requirement
   (d) Food requirement
   (e) Others (specify) ————
14. (a) Where do you obtain the seeds / planting materials from? (Tick one)
   (i) Local stockist (ii) Other farmers (iii) Own farm
   (iv) Buy from local market (v) Others (specify) ————
   (b) What is the distance in Kilometers from the farm to the nearest major market center (Tick one).
   (i) 0 – 5 km (ii) 6 – 10 km (iii) 11 – 15 (iv) Over 15 km
15. (a) During which months, are pest and disease incidents highest? ————
   ————————————
   (b) How does this influence your planting dates? (tick one)
   (i) Avoid planting same crop
   (ii) Leave land fallow
   (iii) Apply chemicals
   (iv) Others (specify)————
16. For what purpose do you grow crops in your farm (tick one)
   (a) Home consumption
   (b) For sale
   (c) Both 1 and 2
   (d) Others (specify) ————
17. (a) Has there been changes in the acreage under crop production over the years?
   Yes —— No ——

   (b) If Yes, was it, an increase or a decrease? ————

   (c) What was the reason for the increase (Tick one)

   (i) Use of certified seed varieties
   (ii) Use of soil fertility enhancing technologies
   (iii) Pests and diseases control.
   (iv) Improved markets.
   (v) Others (specify) ————

(d) What was the reason for the decrease? (Tick one).
(i) Lack of certified seed varieties.
(ii) Lack of soil fertility enhancing technologies
(iii) Increased pest and diseases incidence
(iv) Others (specify) ---------------------------

18. (a) Did you apply any pesticides to your crops last season?
Yes ------------------------ No ----------------

(b) If No, state the reason (Tick one)
(i) Too expensive (can't afford).
(ii) No incidence of pests and diseases.
(iii) No stockist.
(iv) Others (specify) ---------------------------

19 During which months do you get the highest price for the crop?---------------------

20 Which would you say are the major constraint to crop production? (Rank 1,2,3)

Constraint	Rank
- Transport	
- Pest	
- Diseases	
- Lack of inputs	
- High cost of inputs	
- Low market prices	
- Poor soils	
- Other (specify)	

21 (a) Do you regularly get information on better farming practices? Yes ---- No ----
(b) If yes, from whom do you get the information (tick one)
(i) Agricultural extension staff.
(ii) Learnt in the farmers training center.
(iii) Through neighbours.
(iv) Others (specify) --------------------

22 What do you consider as the greatest problem affecting your access to extension services (tick one)
(i) Staff shortage
(ii) Poor infrastructure
(iii) Unqualified staff
(iv) Others (specify) ------------

23. In which months do you experience labour shortages mostly? ---------------------

----

24. (a) What kind of labour do you use (tick one)
(i) Family labour
(ii) Hired labour
(b) How much do you pay per day? -------------------------

25. What are the problems that affect a continuous supply of farm produce for sale (to commercial market) (Tick one)
(a) Poor yield
(b) Lack of market
(c) Water shortage (pump break down)
(d) Others (specify)

26. What is the distance from the farm to the nearest market place.
(a) 0 – 5 km
(b) 6 – 10 km
(c) 11 - 15 km
(d) over 15 km

27. How do you transport your farm produce from farm to the market (Tick one).
   (i) Head carrying
   (ii) Donkey carts
   (iii) Bus
   (iv) Other (specify) ——————
28. Who is responsible for transport (tick one).
   (a) Farmer
   (b) Trader
29. How do you sell your farm produce (forms of selling)
   (a) Directly (b) Indirectly (c) Pick - your own
   (d) Road side (e) Others (specify) ————
30. Who are the main buyers of your farm produce?
   (a) Locals (b) Company (c) Middlemen
   (d) Whole sellers (e) Others (specify) ————
31. What is the primary source of market information (Tick one)
   (i) From the market
   (ii) Other farmers
   (iii) Radio
   (iv) Extension staff
   (v) Other (specify)——————
32. What are the main problems with marketing of farm produce (Rank)

Constraint	Rank
(a) Low prices	
(b) Unreliable market	
(c) Transport problem	
(d) Lack of market information	
(e) Exploitation by middle men	
(f) Other (specify)	

33. (a) Is there a farmers marketing organization that carry out farm produce marketing on your behalf Yes —— No——
   (b) If yes, are you a member? Yes —— No——
   (c) If No, why are you not a member? (Tick one)
      (i) I don't trust it.
      (ii) It's not functioning well
      (iii) Other reasons (specify) ——————
34. (a) In the scheme where you are a member, is there a scheme management committee? Yes —— No ——
   (b) How are the members of the management committee elected?
      (i) Secret ballot by members
      (ii) Clan elders
      (iii) Appointed by members
      (iv) Others (specify)
   (c) When was the last general election for the scheme management held? (Tick one)
      (i) <1 year ago (ii) 1 year ago (iii) 2 years ago (iv) More than 2 years ago
   (d) Do you have by-laws in your scheme? Yes —— No——
   (e) Do you follow the by-laws of the scheme? Yes —— No ——
35. (a) Do you have a scheme bank account? Yes —— No——
   (b) How do you raise money for the bank account? (Tick one).
      (i) Share contribution (ii) Monthly contribution (iii) Harambee
      (iv) i & ii (v) Others (specify)————
   (c) What is the purpose of money in the bank?
      (i) Operation and maintenance of pump set
      (ii) Buy new pump set
      (iii) Other farm operations
      (iv) All.
      (v) Others (specify) ———

36. How did you become aware of the existance of the scheme / farm? (Tick one).
(a) From relatives
(b) Friends and neighbours
(c) Scheme officials, chiefs and extension officers.
(d) Wandered there and came across it.
(e) Lived there when it started.

37. What is the most important reason that made you become a member of the scheme/ farm?
(a) Lost livestock due to drought (Does not mean all livestock). (i) Some (ii) All
(b) Wanted a plot to cultivate.
(c) Poor and never had animals
(d) Others (e.g. more secure)

38. For how long have you been a member of the scheme/ farm? ------------- years

C: IRRIGATION AND FARM INPUTS

39. What is the total size of your farm --------- ha.

40. (a) Is the farm enough for all your farming activities? Yes ------ No -----
(b) If No, do you need more land to irrigate? Yes ----- No -----
(c) Why do you need more land to irrigate? (Tick one).
(i) Increase the area under cash crops.
(ii) Diversify the enterprises.
(iii) Grow more food crops
(iv) Others (specify) ------------

41. (a) Do you apply fertilizer / manure on your farm? Yes---- No-----
(b) If Yes, where do you get the fertilizer / manure from.
(i) Buy from local stockist.
(ii) Own farm
(iii) Other farmers
(iv) Others (specify)-----------------

42. (a) Do you have any problem(s) associated with soils? Yes ---- No-----
(b) If yes, name the major problems (Rank 1,2,3)
(i) Soil erosion
(ii) Compaction / hard setting
(iii) Salinization, alkalinization and acidification
(iv) Decline in soil organic matter.
(v) Others (specify) -------------

43. Name the major factors that contribute to soil problem in your farm (Rank 1,2,3)
(a) Deforestation.
(b) (ii) Poor conservation measures.
(c) (iii) Lack of application of fertilizer and manure.
(d) Lack of knowledge on conservation measures
(e) Others (specify) --------------------------------

44. What are the major problems farmers face in this irrigation scheme / farm?
(Rank 1,2,3)
(a) Poor water management
(b) Frequent breakdown of pump sets
(c) Limited market outlets
(d) Small farm sizes
(e) Labour shortage
(f) Poor infrastructure
(g) Others (specify) --------------

45. (a) What is the main source of labour that you engage to assist you in your farmer
(Tick one)
(i) Family labour
(ii) Hired labour
(iii) Others (specify) ------------------
(b) How much do you pay per day / person? --

46. Who provide the bulk of the family labour in the farm during all operations? (Tick one)

(i) Male

(ii) Female

47. How many times in a week do you apply water to your crops?

Crop	frequency of water application Time / week	Duration/ hrs
1. ------------	------------------------------	------------
2. ------------	------------------------------	------------
3. ------------	------------------------------	------------
4. ------------	------------------------------	------------
5. ------------	------------------------------	------------
6. ------------	------------------------------	------------

48 Which equipment do you use for land preparation? (Tick one)

(a) Oxen

(b) Hand hoe

(c) Tractor

(d) Other (Specify)

49 (a) Do you have your own equipment for land preparation? Yes--------- No-------

(b) If No, whose equipment do you use for your farm operation? (Tick one).

(i) Hired equipment from A.M.S.

(ii) Hire from other institutions e g. churches.

(iii) Other farmers

(iv) Others (specify)--------------------

50 What are the major problems facing farmers related to land preparation? (Rank 1, 2, 3 —)

(i) Lack of farm tractors

(ii) Lack of draft animals due to cultural barriers

(iii) High cost of hiring equipment

(iv) Others (specify)

51. (a) Have you ever abandoned your plot at any one time? Yes --------- No -------

(b) If yes, give reason (Tick one)

(i) Pump break down.

(ii) No profit from the farm

(iii) Gone back to pastoralism

(iv) Others (specify)----------------

D: HOUSEHOLD FOOD SECURITY

52. (a) Do you own livestock at present? Yes---------- No-----------

(b) How many livestock do you have?

No	Cattle	Camel	Goats	Sheep	Donkeys
1 - 5					
6 - 10					
11 - 15					
16 - 20					
Over 20					

(c) For how long do you keep your animals near the scheme / farm ------- months.

(d) How far from the scheme do you herd your animals --------- km.

(e) Compared to the period before you joined the scheme, how is the livestock movement different? (Tick one)

(i) Hired person to herd them away.

(ii) Animals now graze near the scheme / farm for closer observation.

(iii) Do not keep livestock any more.

(iv) Others (specify) --------------

53. (a) How many members of family are involved in livestock herding and how many are employed elsewhere?

Family member	Livestock herding (No.)	Other occupation	
		No	Occupation
Children < 18 years			
Adults 18 – 55			
Adults > 55 years			
Total			

Occupations status

(a) Un employed
(b) Temporary employed
(c) Permanent employed
(d) Farming / business
(e) Others (specify)

54. Who provide the bulk of the family labour
(a) Male
(b) Female

55. (a) Does the household always have adequate food? Yes -------- No--------
(b) If No, when? (Tick one)
(i) During drought / flood
(ii) Always
(iii) During crop failure
(iv) Others (specify) -----------------------
(c) What is the main source of household food security? (Tick one)
(i) Farming
(ii) Livestock
(iii) Employment
(iv) Others (specify) ---------------
(d) How long does the household face food shortage? ----------------------------
(e) How does the household overcome food shortage? (Tick one)
(i) Purchase
(ii) Borrowing
(iii) Gift
(iv) Food aid
(v) Others (Specify)

E: WEALTH STATUS OF THE HOUSEHOLD

56. (a) Have you ever obtained any financial credit? Yes------ No--------
(b) If yes, from who? (Tick one)
(i) Commercial bank
(ii) Agricultural Finance Co-operation
(iii) Local Financial Institutions.
(iv) Co-operatives
(v) Others (specify)

57. (a) Would you tell me the monthly income level of the household (in Kshs) before you become a member of the irrigation scheme? (Tick one)
(a) 0 – 3000 (b) 3001 – 6000 (c) 6001 - 9000
(d) 9001 – 12,000 (e) over 12,000
(b) What is the household monthly income level now (in Kshs) (tick one)
(i) 0 - 3000
(ii) 3001 – 6000
(iii) 6001 – 9000
(iv) 9001 – 12,000
(v) Over 12,000

Appendix 2: Soil chemical properties - Season 1 (October 2006)

...tment	Depth	Rep	pH in Water	pH in 0.01 m $CaCl_2$	EC 25°C	%C	C ml / kg			CEC Cmol/kg	SAR	ESP %	BS %
							Na	Ca	mg				
...rrigated ... years	0 - 20	1	9.02	8.62	0.30	0.34	0.03	4.50	2.10	11.00	0.02	0.27	67.54
	0 - 20	2	8.65	7.61	0.40	1.78	0.50	10.00	6.67	22.40	0.17	2.23	76.65
	0 - 20	3	8.76	8.08	0.30	0.79	0.75	8.00	3.75	14.40	0.31	5.21	86.81
	0 - 20	4	8.07	7.85	1.00	1.69	0.85	11.25	7.50	23.00	0.28	3.70	85.22
	40 60	1	8.94	8.30	0.30	0.92	0.60	9.25	5.00	17.40	0.22	3.45	85.34
	40 60	2	8.22	8.24	0.20	0.83	0.25	7.75	5.40	15.20	0.10	1.64	88.16
	40 60	3	9.00	8.20	0.30	0.61	0.85	9.50	5.42	17.20	0.31	4.94	91.69
	40 60	4	8.37	7.92	0.60	0.43	1.20	8.50	6.67	18.40	0.44	6.52	88.97
Irrigated ...0 years	0 - 20	1	8.90	8.13	0.30	0.61	0.25	6.25	3.75	11.80	0.11	2.12	86.86
	0 - 20	2	8.54	7.92	0.30	1.60	0.75	11.50	7.08	21.80	0.25	3.44	88.67
	0 - 20	3	8.94	8.14	0.30	0.92	0.25	6.50	2.90	11.20	0.16	2.23	86.16
	0 - 20	4	8.31	7.23	0.60	0.92	0.03	5.50	3.75	11.20	0.01	0.27	82.86
	40-60	1	9.09	8.26	0.30	0.56	0.30	3.50	1.67	6.40	0.19	4.69	85.47
	40-60	2	8.29	8.21	0.40	0.88	0.50	8.00	5.42	15.80	0.19	3.16	88.10
	40-60	3	9.05	8.49	0.30	0.52	0.50	6.75	2.90	11.20	0.23	4.46	90.63
	40-60	4	8.67	8.00	0.50	0.65	0.50	8.50	2.90	13.40	0.21	3.73	88.81
Irrigated 15 years	0 - 20	1	8.45	8.05	0.60	1.37	1.50	8.50	5.42	17.80	0.57	8.43	86.63
	0 - 20	2	8.59	7.70	0.40	1.06	1.30	5.50	2.92	11.80	0.63	11.00	82.37
	0 - 20	3	8.00	7.49	1.00	1.60	0.60	11.00	2.92	18.80	0.23	3.19	77.23
	0 - 20	4	8.61	7.13	0.60	1.42	0.25	1.75	1.25	6.00	0.20	4.17	54.17
	40-60	1	8.23	7.65	0.20	1.24	1.30	10.00	6.67	20.40	0.45	6.37	88.01
	40-60	2	9.11	7.57	0.30	0.11	0.25	2.25	1.67	6.20	0.18	4.03	67.26
	40-60	3	9.07	8.27	0.30	0.38	0.03	2.25	1.25	6.20	0.20	0.48	56.94
	40-60	4	8.94	8.13	0.30	0.65	0.75	9.00	4.17	17.20	0.29	4.36	80.93
Non-...ated ...trol)	0 - 20	1	8.18	7.65	0.50	2.70	0.60	7.75	5.42	16.80	0.23	3.57	81.96
	0 - 20	2	7.54	7.13	0.50	1.56	0.50	3.50	2.92	10.94	0.28	4.57	63.25
	0 - 20	3	8.51	7.80	0.50	1.37	1.00	7.50	5.00	15.60	0.40	6.41	86.54
	0 - 20	4	8.95	7.70	1.00	3.10	1.00	7.50	5.00	16.60	0.40	6.02	81.33
	40 -60	1	8.45	7.86	0.20	0.56	0.25	4.00	3.33	8.60	0.13	2.91	88.14
	40 -60	2	8.58	7.92	0.40	1.15	0.03	1.25	1.67	6.20	0.02	0.48	47.58
	40 -60	3	8.20	7.85	2.00	1.10	5.30	5.50	5.42	17.80	2.27	29.77	91.12
	40 -60	4	8.26	7.80	1.00	1.28	0.75	6.75	4.17	14.20	0.32	5.28	82.18

Appendix 3: Soil chemical properties - Season 2 (January 2007)

atment	Depth	Rep	pH in Water	pH in 0.01 m $CaCl_2$	EC 25°C	%C	C ml / kg			CEC	SAR	ESP	BS
							Na	Ca	mg				
- irrigated 5 years	0 - 20	1	8.64	7.40	0.20	1.28	0.35	8.20	4.96	18.20	0.14	1.92	74.23
	0 - 20	2	8.22	7.80	0.30	1.49	0.50	9.35	5.75	17.60	0.18	2.84	88.64
	0 - 20	3	8.30	7.09	0.40	2.15	1.25	14.22	9.92	29.40	0.34	4.25	86.36
	0 - 20	4	8.45	7.78	0.40	2.26	1.25	13.85	8.50	27.80	0.37	4.50	84.89
	40 -60	1	8.76	7.92	0.20	1.08	0.35	2.60	2.83	7.40	0.21	4.73	78.11
	40 -60	2	8.45	7.85	0.70	1.35	1.35	12.35	7.21	22.90	0.43	5.90	91.31
	40 -60	3	8.36	7.55	0.30	1.25	1.25	12.35	8.25	24.70	0.39	5.06	88.46
	40 -60	4	8.55	7.54	0.30	1.05	1.05	8.20	7.50	19.40	0.37	5.41	86.34
- Irrigated 10 years	0 - 20	1	8.54	7.79	0.20	1.00	0.18	4.10	3.25	9.40	0.09	1.91	80.11
	0 - 20	2	8.42	7.39	0.20	1.52	0.18	4.10	3.58	9.40	0.09	1.91	83.62
	0 - 20	3	8.71	7.62	0.20	1.00	0.18	6.60	3.25	12.20	0.08	1.48	82.21
	0 - 20	4	8.37	7.57	0.30	2.07	0.35	9.10	8.25	21.20	0.19	1.65	83.49
	40 -60	1	8.80	7.71	0.20	0.96	0.50	13.35	10.33	25.60	0.15	1.95	94.45
	40 -60	2	8.52	7.72	0.30	1.30	0.65	12.35	8.50	24.00	0.20	2.71	89.58
	40 -60	3	8.80	7.89	0.20	0.80	0.18	4.10	3.88	10.00	0.09	1.80	81.60
	40 -60	4	8.64	7.69	0.30	1.31	0.18	5.60	4.71	11.60	0.08	1.55	90.43
- Irrigated - 15 years	0 - 20	1	8.28	7.49	0.30	1.94	1.25	12.85	10.96	29.00	0.36	4.31	86.41
	0 - 20	2	8.43	7.55	0.30	1.83	0.18	7.60	7.29	18.00	0.07	1.00	83.72
	0 - 20	3	8.31	7.52	0.30	1.91	0.50	10.85	7.29	23.60	0.17	2.12	78.98
	0 -20	4	8.40	7.87	0.30	1.63	0.35	7.60	5.75	17.20	0.14	2.03	79.65
	40 -60	1	8.44	7.84	0.40	1.79	1.65	19.60	9.50	33.60	0.43	4.91	91.52
	40 -60	2	8.63	7.42	0.40	1.19	0.65	10.85	9.92	23.20	0.20	2.80	92.33
	40 -60	3	8.47	7.35	0.20	1.59	0.50	9.10	8.50	20.90	0.17	2.39	86.60
	40 -60	4	8.45	7.30	0.20	1.16	0.35	7.10	7.50	17.20	0.13	2.03	86.92
- Non-igated ontrol)	0 - 20	1	8.58	7.74	0.30	1.59	2.00	10.85	7.21	22.80	0.67	8.77	87.98
	0 - 20	2	8.54	7.48	0.30	1.79	0.35	8.60	5.75	21.00	0.13	1.67	70.00
	0 - 20	3	8.37	7.62	0.30	2.30	0.50	14.72	7.29	27.80	0.15	1.80	80.97
	0 -20	4	8.24	7.21	0.20	1.91	0.18	5.60	5.33	18.40	0.08	0.98	60.38
	40 -60	1	8.64	7.49	0.50	1.47	3.25	13.35	8.25	28.20	0.99	11.52	88.12
	40 -60	2	8.60	7.71	0.30	1.27	0.18	7.72	7.50	17.40	0.07	1.03	88.51
	40 -60	3	8.78	7.90	0.30	1.12	0.18	3.22	3.25	8.60	0.10	2.09	77.32
	40- 60	4	8.44	7.45	0.20	0.23	0.35	7.10	9.29	15.20	0.12	2.30	99.60

Appendix 4: Soil physical properties

Treatment / site	Rep	Depth cm	Bulk Density g/cm^2	Porosity %	Ksat cm/hr	Texture			
						Sand %	Silt %	Clay %	Class
T_1 Irrigation 1 - 5 years									
	1	0 -10	1.3	51	3.025	62	26	12	SL
	1	20 -30	1.21	55	2.07	30	44	26	CL
	2	0 -10	1.11	58	1.526	30	34	36	CL
	2	20 -30	1.23	54	0.078	36	34	30	CL
	3	0 -10	1.3	51	1.957	40	38	22	L
	3	20 -30	1.37	49	0.354	30	38	32	CL
	4	0- 10	1.2	55	0.755	24	36	40	CL
	4	20- 30	1.1	59	1.539	28	40	32	CL
T_2 Irrigation 6 – 10 years									
	1	0 -10	1.2	55	8.877	54	26	20	SCL
	1	20- 30	1.43	46	5.046	72	18	10	SL
	2	0 -10	1.11	58	1.49	16	34	50	C
	2	20 -30	1.1	59	1.193	18	32	50	C
	3	0 -10	1.54	42	1.808	46	24	30	SCL
	3	20 -30	1.43	46	5.103	54	24	22	SCL
	4	0 -10	1.55	42	0.385	42	26	32	CL
	4	20 -30	1.39	48	1.05	56	24	20	CL
T_3 Irrigation 11 – 15 years									
	1	0 -10	1.3	51	0.648	24	36	40	CL
	1	20- 30	1.23	54	0.178	20	26	54	C
	2	0-10	1.09	59	0.609	56	20	24	SCL
	2	20- 30	1.2	55	0.059	72	16	12	SL
	3	0-10	1.13	59	12.883	46	24	30	SCL
	3	20 -30	1.18	56	6.972	66	24	10	SL
	4	0- 10	1.22	54	5.372	42	21	37	CL
	4	20-30	1.4	47	3.888	48	22	30	SCL
T_4 Non- Irrigated (control)									
	1	0-10	1.18	56	3.346	22	34	44	C
	1	20-30	1.28	52	0.038	44	28	28	CL
	2	0-10	1.37	48	1.025	56	16	28	SCL
	2	20 -30	1.39	48	4.534	72	22	6	SL
	3	0 -10	1.08	59	1.921	26	40	34	CL
	3	20 -30	1.25	54	0.837	20	32	48	C
	4	0- 10	0.98	64	7.016	24	34	42	C
	4	20- 30	1.25	53	0.638	26	32	42	C

Appendix 5: Anova: Multiple Regression Result on the extent of influence or contribution of BD, porosity, clay, sand and silt on K_s.

Model	Sum of squares	Df	mean square	F	Sig.
1 Regression	29.028	5	5.806	1.242	.359
Residual	46.746	10	4.675		
Total	75.774	15			

	unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	122.404	450.206		0.272	0.791
BD	-53.006	189.811	-2.611	-0.279	0.786
Total Porosity	-1.459	5.025	-2.744	-0.29	0.778
Clay	0.168	0.69	1.107	0.244	0.812
Silt	0.251	0.788	0.889	0.319	0.756
Sand	0.254	0.716	2.21	0.355	0.73

Appendix 6: Chemical characteristics of irrigation water from river Tana at the study area

SEASON 1

Treatment	pH	Ec	Na	Mg	K	Ca	CO_3	HCO_3	Cl	SAR	SSP	SAR_{adj}	RSC
0m	8.02	0.2	0.8	0.31	0.2	0.12	0	1.3	0.5	1.73	56.00	2.08	0.87
500m	8.24	0.2	0.8	0.31	0.2	0.12	0	1.2	3.7	1.73	56.00	2.08	0.77
1000m	8.22	0.2	0.8	0.3	0.15	0.14	0.2	0.5	0.3	1.70	57.55	2.04	0.25
0m	8.04	0.2	0.8	0.27	0.15	0.12	0	1.2	0.4	1.81	59.70	1.81	0.81
500m	8.13	0.2	0.8	0.3	0.15	0.12	0	1.1	0.3	1.75	58.39	1.93	0.68
1000m	8.41	0.2	0.8	0.3	0.15	0.12	0	1.2	0.4	1.75	49.38	1.93	0.78
0m	8.34	0.2	0.8	0.4	0.15	0.18	0.8	0.1	0.4	1.49	52.29	2.09	0.48
500m	8.33	0.2	0.9	0.44	0.15	0.22	1	0.2	0.2	1.57	46.78	2.20	0.46
1000m	8.08	0.3	0.9	0.44	0.2	0.16	0.6	0.7	0.2	1.64	52.94	2.30	0.1

SEASON 2

Treatment	pH	EC	Na	Mg	K	Ca	Co_3	HCo_3	Cl	SAR	SSP	SAR_{adj}	RSC
0m	7.60	0.3	1.3	0.35	0.3	0.18	0	1	0.5	2.50	61.00	3.75	0.47
500m	7.60	0.3	1.01	0.36	0.25	0.12	0	1.4	0.6	2.06	56.42	2.88	0.92
1000m	7.50	0.3	1.3	0.35	0.25	0.16	0	2.7	0.5	2.58	63.10	3.87	2.19
0m	7.70	0.3	1.01	0.35	0.15	0.07	0	1.7	0.5	2.20	63.92	3.08	1.28
500m	7.70	0.3	1.2	0.23	0.15	0.07	0	0.9	0.4	3.10	72.72	4.34	0.6
1000m	7.70	0.3	1.01	0.27	0.15	0.06	0	0.6	0.3	2.48	67.78	3.47	0.27
0m	7.70	0.3	1.1	0.26	0.15	0.06	0	2.3	0.3	2.75	70.10	3.85	1.98
500m	7.50	0.3	1.1	0.28	0.15	0.07	0	0.7	0.3	2.63	68.75	3.68	0.35
1000m	7.30	0.2	1.1	0.23	0.15	0.07	0	0.8	0.4	2.84	70.96	3.98	0.5

Appendix 7: 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: Ayers and Wescot (1976)

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 8: Mean air temperatures (°C) at Garissa (1982 - 2004)

Monthly Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1982	29.5	30.1	30.5	28.9	28.0	26.4	25.9	25.8	26.4	27.7	29.2	28.7
1983	29.7	30.6	31.0	32.0	32.0	28.2	27.9	28.4	28.1	29.6	30.3	29.9
1984	29.6	29.5	30.8	31.1	29.2	27.4	27.5	26.7	27.7	28.6	V/A	25.0
1985	28.5	29.7	30.8	31.1	29.2	27.4	27.5	26.7	27.6	28.6	29.4	31.7
1986	29.2	29.8	30.9	29.5	28.0	27.5	26.7	25.1	27.3	29.7	29.6	27.8
1987	28.4	29.2	30.0	30.7	29.6	27.5	27.0	24.7	28.8	30.0	30.2	30.1
1988	29.7	30.9	30.6	30.3	29.5	27.4	27.8	27.5	27.6	29.5	28.0	28.3
1989	28.0	29.4	30.4	29.0	28.2	27.1	26.9	26.6	28.2	28.2	27.8	27.7
1990	28.5	30.2	30.0	28.7	29.0	27.0	26.6	26.8	27.6	29.2	29.1	27.8
1991	29.2	30.3	30.3	30.0	28.9	27.7	26.6	26.3	27.6	30.8	29.7	29.4
1992	27.1	31.2	31.1	31.0	30.0	28.2	26.6	26.3	27.8	28.9	28.8	28.2
1993	28.1	29.6	30.7	31.3	30.2	27.5	26.7	26.6	27.2	29.0	29.5	28.8
1994	29.8	30.3	30.9	30.7	29.2	27.8	26.7	27.4	28.1	29.8	28.0	28.1
1995	29.1	30.3	30.3	30.4	29.1	27.9	27.5	27.2	27.7	29.5	29.8	28.6
1996	30.0	30.8	26.0	30.1	28.8	27.9	27.1	28.4	27.4	29.1	29.3	29.1
1997	29.5	30.3	31.0	28.8	28.8	27.7	27.5	27.8	28.7	28.7	27.5	27.4
1998	27.9	29.7	31.0	31.0	29.3	27.9	26.8	26.3	28.0	29.2	29.0	29.5
1999	28.5	30.0	31.0	30.1	28.9	27.8	26.9	27.1	27.4	28.7	29.8	30.0
2000	29.6	30.3	31.2	29.4	28.1	26.9	26.8	27.0	28.0	28.8	29.1	27.6
2001	30.0	30.2	31.3	29.9	29.6	27.8	27.3	26.7	28.3	30.0	29.1	28.9
2002	30.0	30.1	31.5	30.0	29.0	27.5	26.3	26.9	27.8	29.4	29.2	29.2
2003	29.4	29.9	31.3	31.3	21.1	27.8	27.1	26.6	28.1	29.5	29.2	28.8
2004	29.3	30.3	31.3	30.1	28.6	27.5	26.8	27.9	28.6	29.6	29.2	29.3
Total	293.8	301.9	305.7	301.7	289.9	277.0	270.0	271.4	279.5	292.7	290.0	287.2
Mean	29.4	30.2	30.6	30.2	29.0	27.7	27.0	27.1	28.0	29.3	29.0	28.7

Appendix 9: Monthly rainfall (in mm) at Garissa (1970 – 2006)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1970	28.3	0	65.6	24.9	0	0.7	1.8	4.3	33.7	2.5	34.5	35.6	231.9
1971	0	0	16.9	210	11.8	30.8	0	0.2	7	2.1	64.7	4.8	348.6
1972	14.1	14.8	0	12.6	7.4	0	2.8	9.6	7.2	27.6	31.1	50.6	177.8
1973	5.6	30.4	36.6	38.6	0	1.1	0.2	6.9	12.4	3.9	119	4.6	259.2
1974	1.6	0	107	12.9	3.3	0.2	6.7	0	1.8	12	20.6	70	236.1
1975	2.3	0	8.6	84.6	132	0.3	5.7	0	2.8	0.1	80.6	0	316.7
1976	3.1	6.8	0	96	0.9	0	0.1	2.6	2.6	0	18	59.1	189.2
1977	6.1	0	6	118	3.2	0	0	34.2	2.6	4.1	123	103	399.1
1978	66	1.3	128	111	29.3	0	3.9	4.3	0	152	110	150	755.3
1979	96.3	8.2	76.1	97.7	53.7	23.3	7.7	0	4.1	3.2	102	59.7	531.6
1980	0	0	9.2	17.6	0	0	7.4	23.8	0.5	7.6	33.5	2.5	102.1
1981	0	0	113	81.3	19.9	0	0	6.6	1.5	12.1	61.2	6.4	302.2
1982	0	0.2	24.1	102	18.6	2.5	0	0.7	36.9	158	60.5	34.7	438.1
1983	9	5	2.4	40.2	5.1	10.6	1.6	1.1	7.7	13	2.6	18.7	117
1984	0	0	1.9	25.5	1.1	2.5	5.2	0	1.6	69.5	226	60	392.8
1985	0.5	0.1	24.9	34.3	18.2	0.2	6.8	9	3.8	23.3	16.9	34.6	172.6
1986	0	0	12.8	129	18.2	0	1	10.7	1.8	4.8	67	87.6	332.7
1987	19.2	0	1	82.3	20	0	17.1	14.3	1.1	0	20.9	1.8	177.7
1988	12.5	0.1	81.8	103	1.3	15.6	0.4	4.1	13.1	6.4	76	76.3	390.6
1989	27.1	0.7	4.6	274	2.2	0	0.9	1.4	5.9	85.3	235	0	636.2
1990	2.4	14.5	180	77.9	1.4	1.5	0	0	0.9	17.9	150	49.6	495.9
1991	2.2	0	34.5	120	5.3	3.1	41.4	2.9	2.2	10.9	32.4	64.8	319.5
1992	4.3	0	2.2	43.2	6.1	1.8	0.6	2.4	5.6	4.6	137	118	326.4
1993	89.9	4.3	8.2	0.7	3.6	16.3	2.6	2.6	6.9	14.4	128	76	353.8
1994	0	0	6.5	77.9	10.3	36.2	4.1	1.2	10.8	14.9	220	47.2	429.4
1995	0	1.1	43.2	127	8.3	0	2.9	75.7	2.7	42.1	16	59.9	379.2
1996	0	4.4	27.1	12.4	21.9	0.9	0.4	0	0	0.3	62	3.6	133
1997	0	0	140	91.5	5.6	21.7	0.1	0	0.4	166	350	174	950.2
1998	272	6.1	51.1	84.4	68.9	7.9	18.4	0.5	0.2	7.7	80.7	38.7	636.3
1999	0	0	42.9	36	27.4	1	0.5	3	2.1	3.8	77.7	81.9	276.3
2000	5.8	0	14.9	36.9	2	4.1	0	1.8	10	15.9	56.5	12.7	160.6
2001	3.2	0.6	8.8	62.2	9.9	2.4	0.9	0.3	0	4	118	39.3	249.8
2002	0.2	0.4	18.4	151	8.7	2.9	6.9	10.6	52.2	48.2	142	83.5	524.9
2003	1.7	0	18.4	104	44.7	1.5	2.5	5.3	0.7	41.5	106	19.2	346.1
2004	19.4	0	8.4	43	0	3.9	0.2	0.5	1	0.4	104	17.1	198.1
2005	0	1.7	2.5	12.8	76.1	0	8.5	2.2	2.7	1	22.9	3.5	133.9
2006	28.2	5.6	34.7	107	24.1	4.8	7.7	2.1	6.9	31.1	270	77.3	600.1
Total	721	106	1363	2883	670	198	167	245	253	1012	3576	1827	
Mean	20	2.95	37.9	80.1	18.6	5.49	4.63	6.8	7.04	28.1	99.3	50.7	