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SMALL HOLDER FARMERS ADAPTATION TO CLIMATE VARIABILITY IN THE SEMI-ARID ZONES OF MBEERE IN EASTERN KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the award of a Master of Science Degree in Dry Land Farming of Egerton University

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DECLARATION AND RECOMENDATION

DECLARATION

I declare that this research thesis is my original work and has not been submitted wholly or in part for any award in any institution of learning to the best of my knowledge.

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DEDICATION

This thesis is dedicated to my daughters Faith Mwende and Fiona Ndanu for their patience and endurance during my years of study and frequent periods of absence during my field work.

ACKNOWLEDGEMENTS

May glory to the Almighty God for providing me with the strength, good health and motivation during the course of this study and enabling me to this piece of work. I am immensely grateful to all Egerton University for giving me a chance to study in their institution. I wish to profoundly thank my supervisors, Prof. Nancy W Mungai and Prof. Isaiah M Tabu of the department of Crops, Horticulture and Soils whose technical guidance, constructive comments, encouragement and suggestions brought this long-term effort to a successful conclusion. I am indebted to all my lecturers, who successfully took me through the entire course units in preparation of my candidature for the thesis. Special thanks are extended to the Climate Adaptation Project (CAPro) headed by Prof. Francis Lelo for the research grant and opportunity to undergo special training on Applied Climatology and participatory research methods. Appreciation also goes to my fellow colleagues especially Mr. Stephen Karanja for sharing with me concrete ideas during data analysis. Finally. I wish to sincerely thank my enumerators Jane Daudi and Josephine of Mbeere for assisting me in data collection

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ABSTRACT

Small holder farmers in Mbeere are vulnerable to climate change related drought events that are a threat to agricultural production. A study was conducted in Kiritiri and Siakago divisions of Mbeere, Embu County between August, 2011 and June, 2012 to assess climate variability, determine its impacts on crop production and also identify agronomic adaptation strategies. This was achieved through analysis of secondary data, household interviews for 150 randomly sampled farmers and on-farm experimentation to assess the potential of zai pits as an adaptation strategy. Thirty years crop yield data for four main food crops and long term climatic data were obtained from the Agriculture and Meteorological departments respectively. Data was analyzed using INSTAT, SPSS and GENSTAT statistical packages. Findings showed that local people perceived a reduction in rainfall and an increase in temperature. Long-term climatic data analysis showed that annual rainfall declined by 3.1 mm and 11.4 mm per annum in Embu and Siakago respectively but increased by 0.97 mm per annum in Kiritiri. Annual rainfall totals however remained fairly variable with a Coefficient of Variation (CV) of 43.2%, 32.8% and 24.4% for Siakago, Kiritiri and Embu respectively. Seasonal rainfall totals were also highly variable and showed declining trends except in the October-December season in Kiritiri. Over 50% of the seasonal rainfall was received in one month. Mean minimum and maximum temperatures increased by between 0.02-0.03°C. Analysis of long term crop yield data showed declining trends. Correlation analysis showed significant and inverse correlation (r) between maize yields and temperature (r=-0.6,) and a significant and positive correlation between rainfall and crop yields (r=0.9, 0.5 and 0.5 for maize, sorghum and beans respectively). Based on the household survey, maize and beans were most vulnerable to impacts of climate variability while cowpeas and sorghum were least vulnerable. The number of farmers harvesting crop yields less than 0.45t ha^{-1} increased compared to 1980's. The primary adaptation strategies identified included water harvesting, early planting, soil fertility improvement and use of drought tolerant crops, ranked in that order. Sixty three percent (63%) of the population applied some form of adaptation while 37% applied none. Results of the field experiment established an increase in mean grain yield by 40% and 30% due to use of *zai* pits and by 213- 370% and 223-295% due to combined effects of *zai* and manure in Kiritiri and Siakago respectively. The study recommends use of practices that combine moisture conservation and soil fertility improvement as adaptive measures to climate variability within the study area and other semi-arid regions.

ACRONYMS AND ABBREVIATIONS

AEZ	Agro ecological zone
ALRMP	Arid Lands Resource Management Project
ASALs	Arid and Semi-Arid Lands
CGIAR	Consultative Group on International Agricultural Research
CSIRO	Commonwealth Scientific and Industrial Research Organization
CIMMYT	International Maize and Wheat Improvement Center
DAS	Days after Sowing
EDRP	Emergency Drought Recovery Project
GENSTAT	General Statistical Package
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
INSTAT	Interactive Statistical Package
IPCC	Intergovernmental Panel on Climate change
IFAD	International Fund for Agricultural Development.
KACCAL	Kenya Adaptation to Climate Change in the Arid Lands
KARI	Kenya Agricultural Research Institute
LM4	Lower Midland zone 4
MAM	March-April-May rainfall season
OECD	Organization for Economic Cooperation and Development
OND	October-November-December rainfall season
SPSS	Statistical Programme for the Social Sciences
SSA	Sub Saharan Africa.
UNFCCC:	UN Framework Convention for Climate Change

DEFINITION OF TERMS

Adaptive capacity Ability of a system to adapt to climate change and to moderate potential damages taking advantage of opportunities and coping with the consequences.

Climate Weather averaged over time, which is typically 30 years plus a measure of its variability.

Climate change A long term change in the statistical distribution of weather patterns over periods ranging from decades to millions of years.

Climate Change Adaptation The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

Climate Change mitigation An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.

Climate variability Variations in the mean state of climate beyond that of individual weather events

Climate smart Agriculture Agriculture that sustainably increases productivity, resilience, reduces/removes green house gases, and enables achievement of national food security and development goals.

Coping capacity The means by which people or organizations use available resources and abilities to face adverse consequences that lead to a disaster

El Niño Abnormal weather pattern caused by warming of the pacific ocean near the equator

La Nina Extensive cooling of the surface water of the eastern and central pacific ocean.

Resilience The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Vulnerability The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Weather Atmospheric condition at a particular place in terms of air temperature, pressure and humidity

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Agriculture in Sub Saharan Africa plays a vital role in providing food and income to a majority of the population. In Kenya, the sector contributes about 26% of the country's GDP and employs about 80 % of the population (DAFF, 2013). Climate change (the long term change in the statistical distribution of weather patterns over periods of years ranging from decades to millions of years) is often reflected in recurrent inter and intra-seasonal dry spells leading to crop failure, livestock mortality and loss of livelihoods. In the past century, global surface temperatures have warmed up by between 0.6-0.8^{0}C (Hansen *et al.*, 2006) because of increased concentrations of green house gases (GHG) arising from human activities (IPCC, 2007). Impacts of climate variability on agriculture have been seen in reduction of crop and livestock production due to decreasing rainfall, declining soil fertility, increased incidences of pests and diseases and increasing heat stress. Under the worst case scenario of climate change, the agricultural production across most of Africa could be reduced by 20-50% by 2020 (IPCC, 2007). Projected impacts vary across crops and regions and adaptation scenarios, with about 10% of projections for the period 2030–2049 showing yield gains of more than 10%, and about 10% of projections showing yield losses of more than 25%, compared to the late 20th century(IPCC,2014). Strengthening the resilience and preparedness to the impacts of climate related disasters on rain fed crops is therefore a priority for most African countries.

Over 80% of Kenya's landmass is classified as Arid and Semi Arid Lands (ASALs) that are characterized by variable rainfall (Jaetzold *et al.*, 2006). The changing weather patterns witnessed over the last 50 years is however a threat to sustainable livelihoods (GOK, 2010). Increased incidences of droughts and flood conditions (UNFCCC, 2007) have resulted in low agricultural and livestock production. All this, together with increasing unpredictability of the onset of rains and length of growing periods (LGP) has left Kenyan farmers extremely vulnerable.

Mbeere, in Eastern Kenya is one of the ASAL areas in Kenya where rain fed agriculture is the main source of livelihood. Increased variations in rainfall amounts, distribution and duration coupled with shortened growing periods and prolonged dry spells between rainy seasons have been cited as the main causes of declining crop yields in the region (Roncoli *et al.*, 2010). The

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magnitude of the current variability and climate risks is expected to increase hence mainstreaming current and future climate vulnerabilities into the development agenda is critical for most countries (Huq *et al.,* 2003;UNDP,2005). This can be achieved by reducing emissions of GHG or enhancing mechanisms that resist, cope and take advantage of the unavoidable changes. Since mitigation (reducing emissions of GHG) is a slow process, adaptation to the changing weather patterns is the primary option.

A lot of indigenous information and localized coping and adaptation strategies for reducing vulnerability due to climate change exist among local communities. There is however limited documentation of adaptation and coping strategies. Despite efforts by extension service providers to introduce interventions such as drip irrigation, water harvesting, agro forestry, soil fertility management and improved crop varieties to improve farm level productivity and rural livelihoods, many households still face poverty, hunger, food insecurity and malnutrition. Integration of land and water management can contribute significantly to improved agricultural productivity in drought prone areas like Mbeere (Ketiem *et al.*, 2010). Planting crops in *zai* pits (pits filled with a mixture of organic manure and top soil) helps to trap and conserve rain water for longer periods. The conserved soil moisture supports crop growth during harsh dry spells leading to an improvement in yields. Different studies suggest different pit sizes while the amount of organic manure remains unclear. It is anticipated that the outcome of this study will provide farmers with useful information on how best to cope with climate variability and in the long run adapt to future climatic changes.

Maize is the world's third most important cereal crop (after rice and wheat) and Africa's most important cereal crop (CIMMYT, 2011). It is particularly important to more than 300 million people in Sub-Saharan Africa (SSA) whose livelihoods are threatened by recurrent droughts responsible for crop failures. Drought is second only to low soil fertility as a constraint to maize production in developing countries. Considering the devastating impact of droughts on food security and economic development in SSA, effective solutions are of uttermost importance especially as the situation is set to worsen as climate change progresses.

1.2. Statement of the Problem

About 80% of Kenya's land mass is arid and semi-arid and depends entirely on rain fed agriculture. Climate variability is however a major threat to agricultural production in these areas. Increased incidences of extreme weather events such as droughts and floods coupled with increasing rainfall variability and poor distribution contribute immensely to a decline in agricultural productivity. This trend estimated to cause up to 50% crop yield reduction by 2020 and could severely affect food security and the economy. Generally, effects of climate change and variability have been observed and scientific findings indicate that precautionary and prompt action is necessary.

Farmers in Mbeere experience declining crop yields attributed mainly to low and variable rainfall. The long term climatic trends, their effects on crop yields and the way farmers cope with the perceived changes have rarely been determined. In addition, the contribution of drought coping strategies such as *zai* pits to crop growth and yield has also not been quantified. There is need to quantify the role of *zai* pits as a strategy for enhancing the resilience of the vulnerable small holder farmers to the impacts of climate variability and change. In general, the entire study aimed at enhancing the adaptive capacity of Mbeere's smallholder farmers to climate variability.

1.3 Objectives

1.3.1. Broad Objective

To contribute to improved food security in Mbeere by enhancing adaptive capacity of small holder farmers to impacts of climate variability and change.

1.3.2. Specific Objectives

1. To determine the changes in climate variables in Mbeere district using long term climatic data.
2. To determine the effects of climate variability on crop yield in Mbeere.
3. To identify strategies used by Mbeere farmers to cope with climate variability.
4. To determine the effects of *zai* pits on growth and yield of maize in Mbeere.

1.4. Hypotheses

1. Climate variables in Mbeere have no observable trend over the last three decades
2. Climate variability has no influence on crop yields in Mbeere.
3. Farmers have no specific adaptive strategies to cope with climate variability and change
4. *Zai* pits have no effect on maize growth and yield.

1.5. Justification

Agriculture, the back bone of Kenya's economy contributes about 26% to the country's Gross Domestic Product (GDP) and provides employment to about 80% of the population (MOA, 2009). The sector is however among those most vulnerable to climate change (WDR, 2010) because of its dependency on rainfall. Farmers in Mbeere, one of the ASAL areas (Jaetzold *et al.*, 2006) depend on rain fed agriculture for their livelihood. Majority of them are resource poor with limited capacity to adapt to climate variability. The increasing frequency of climate change associated crop failure exposes them to extreme hunger and poverty. Mbeere District receives up to 700 mm of rainfall in 2 seasons per year. The erratic nature of the rains however implies a crop failure for maize, the staple food crop. In order to boost rain fed agricultural production in the region, there is need to enhance the adaptive capacity of the vulnerable smallholder farmers.

Human societies have adapted to climate variability and other changes for millennia and much of the knowledge is embedded in the fabric of social structures operating at the community level. This knowledge is highly relevant for climate adaptation and provides an important supplementary source of expertise to the information generated by more formal scientific institutions and processes. Understanding and strengthening the agency of communities is imperative as much adaptation will be undertaken at the local level. Thus, local people have to be involved in identifying and evaluating climate variability adaptation strategies.

Drought coping strategies such as water harvesting and use of drought tolerant crops have been recommended for ASALs (Ketiem *et al.*, 2010). There is however limited documentation on existing coping strategies in the district. Adoption of these strategies has remained low due to limited adaptive capacity of the local people, limited access to information on suitable strategies for their region due to limited involvement of the people in localized evaluation. The study aimed at enhancing the adaptive capacity of the smallholder famers by involving them in identification, analysis and evaluation of climate variability coping strategies in the district.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climate change and variability

2.1.1 Climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change (CC) may be limited to a specific region, or may occur across the whole earth. It is attributed directly or indirectly to human activity that alters the composition of the global atmosphere. The United Nations Framework Convention for Climate Change (UNFCCC) makes a distinction between "climate change" attributable to human activities and "climate variability" attributable to natural causes. Anthropogenic greenhouse gas (GHG) emissions are the main causes of the observed climate change, and early mitigation measures would have been cheaper than later adaptation to potentially drastic climate impacts (IPCC, 2007).

Globally, climate change has had adverse impacts on weather patterns which have become erratic and difficult to predict. Increased rainfall variability and variability in growing seasons has disrupted subsistence agricultural production leading to famine and severe loss of livelihoods in many semi- arid regions of Africa (FAO, 1999). The IPCC (2007) report predicted that billions of people particularly in developing countries would face changes in rainfall patterns contributing to water shortages, flooding and rising temperatures.

Africa is the most susceptible continent (IPCC, 2007) where impacts of climate change are most visible and have widespread consequences on livelihoods of rural communities. Previous assessments (Hulme, 1996; IPCC, 1998) concluded that Africa is particularly vulnerable to the impacts of climate change because of widespread poverty, recurrent droughts inequitable land distribution and over-dependence on rain-fed agriculture. A survey of 11 African countries (Hassan, 2008) showed that agriculture and the welfare of its rural population are quite vulnerable to Climate Change. Since 1960's, the African continent has experienced a general warming trend with some regions experiencing more warming than others (Hulme *et al.*, 2001;Boko *et al.*, 2007).Variation in precipitation has also been experienced across the continent although much of it has been a decline in precipitation. Inter-annual variability has increased

with extreme precipitation events being on the rise (Boko *et al.*, 2007).According to IPCC, (2001), impacts of climate change have been experienced throughout sub Saharan Africa particularly in areas typical of rainfall variability and shifting growing seasons.

2.1.2 Climate variability

Climate variability refers to variations in the mean state and other statistics (occurrences of extremes, standard deviation, e.t.c) of climate on temporal and spatial scales beyond that of individual weather events (Lambrou and Nelson, 2010). Variability is thus an integral part of climate change in which a change in mean climatic conditions is experienced through changes in the nature and frequency of particular yearly conditions, including extremes. In East Africa, rainfall variability has been experienced with occurrences of extreme events in terms of droughts and floods. Since 1980's, droughts experienced in 1983/84, 1991/92, 1995/96, 1999/2001, 2004/2005, 2007/2008 resulted in total crop failures and death of livestock leading to severe famine (UNFCCC, 2007). *El Niño* related floods experienced in 1997/98 and 2009 led to massive destruction of crops and livestock leading to negative food security situation. The *lanina* related droughts of 1999/2001 affected agricultural production leading to famine and food insecurity. Small communities are often the most severely affected, yet the least equipped to cope with the impacts of climate change (IPCC, 2001).

The seasonality, amount, distribution and the timing of rainfall is of particular importance to a population that depends on rain-fed agriculture for their subsistence. Sub-Saharan Africa rain-fed agriculture which provides food for the populace represents a major share of the economies that follow precipitation pattern closely (UNEP, 2008). Short-term as well as long-term variations in rainfall patterns have important effects on crop and livestock farming (IPCC, 2007). In most sub- Saharan African countries, seasonal rainfall has been marked by delayed onsets, declining number of rain days and increased intensities which alter farming calendars with negative effects on the yields. Awuor and Ogola (1997) observed that global warming will likely cause changes in the length of growing periods. They predicted an increase in the length of growing period by about 10 days/°C increase in mean annual temperature in Canadian Prairie while in Kenya, a 4°C increase in temperature will result in a dramatic shortening of the length of the growing period (Awour and Ogola, 1997). The main growing rainfall seasons which occur in March, April and May (MAM) and December, January and February (DJF) have reportedly been declining since the 1980s in Ethiopia, Kenya, Tanzania, Zambia, Malawi, and Zimbabwe

(UCSB, 2008).

Decline in rainfall has been attributed to anomalies in moisture transport between the ocean and land due to rising sea surface temperatures over the Indian Ocean. Changes in rainfall patterns have negatively affected mixed rain-fed and highland perennial systems in the Great Lakes region and in other parts of East Africa (IPCC, 2007). Agriculture has progressively become more marginal in the arid and semi-arid areas (Fischer *et al.*, 2005). A significant decrease in suitable rain-fed agricultural land and production potential for cereals has been predicted under climate change by 2080 (Fischer *et al.*, 2005). Elsewhere, a combination of increased temperature and rainfall may result in longer growing seasons in some parts of the Ethiopian highlands and southern Africa such as Mozambique improving agricultural performance. Thus, for agricultural purposes changes in growing period are very important and must be viewed against possible changes in seasonality of rainfall, onset of rain days and intensity of rainfall.

2.1.3 Climate change and agricultural production

The agricultural sector is directly affected by changes in temperature, precipitation, and CO_2 concentrations in the atmosphere. In the developing countries, 70% of people live in rural areas, where agriculture is the largest supporter of livelihood and the economy. A large fraction of the world's poor population lives in ASALs which are already characterized by highly volatile climate conditions. Climate change is expected to cause a world-wide increase in climate variability and extreme weather events. This will have negative impacts on agriculture including a reduction of crop and livestock productivity and increased incidences of pests and diseases (Dinar *et al.*, 2008). The projected continued global warming (IPCC, 2001; Boko *et al.*, 2007) thus presents major challenges for smallholders which must be addressed to avert food security crisis.

Rain-fed agriculture, which accounts for ninety eight percent (98%) of the agricultural activities in Kenya (UNEP, 2009) is the backbone of the country's economy and is very vulnerable to increasing temperatures, droughts and floods, which reduce productivity. Drought results in agricultural losses, reduction in water quality and availability and is a major driver of food insecurity. On the other hand, floods lead to large-scale crop destruction, and devastation of food stores, farming equipment as well as erosion of agricultural land. Kabara (2010) noted that agricultural output in the country is negatively affected by changes in precipitation and

temperature anomalies. Regression results indicate loss of output when precipitation and temperature increases while an interaction between temperature and precipitation leads to a modest decrease in output (Kabara, 2010).

2.1.4 Impacts of Climate variability on crop production

Climate is fundamental for crop growth. While moisture stimulates seed germination, the time to emergence is temperature dependent. The rate of growth of roots, stem and leaves depends on the rate of photosynthesis which is in turn influenced by light, temperature, moisture and carbon dioxide (CO_2) (Howden and White, 2010). Temperatures and day length also determine when plants produce leaves, stems, flowers and consequently, grain filling or fruit expansion. Grain yield is dependent on the number of grains and grain weight at harvest which depends on biomass at anthesis and post anthesis moisture availability (Howden and White, 2010). Changes in temperature and rainfall patterns influence local seasonal and annual water balances; which, in turn, affect the growing season and consequently the production outcomes (Herrero *et al.*, 2010). Other varying effects are caused by changes in water availability, increased variability in growing seasons and frequency of weather extremes such as floods, heavy storms and droughts (IPCC, 2001). While some of these impacts have been studied in isolation, complex interactions between different factors and especially extreme events are still not well understood.

a) Carbon dioxide fertilization

The yield of most agricultural crops would increase under elevated CO_2 concentration due to increased photosynthesis (Rosenzweig, 1998). High levels of CO_2 also improve water-use efficiency of both C_3 and C_4 plants. At high CO_2 levels, plants partially close stomatal pores thus greatly reducing transpirational water losses (Wittwer, 2008). However, at above-optimum temperatures for reproductive growth processes, the benefits of elevated CO_2 could be overwhelmed by negative effects of high temperature, leading to lower seed yield. Some studies predict much less favorable crop response to elevated CO_2 in practice than asserted on experimental sites (Long *et al.*, 2006), while others agree with previous findings (Tubiello *et al.*, 2007). Thus, the magnitude of the positive effect due to enhanced CO_2 concentration is still uncertain (Parry *et al.*, 2004; Easterling *et al.*, 2007).

b) Higher temperature

Temperature is important in controlling phenological changes in development from germination and seedling emergence through vegetative growth to floral initiation and reproductive growth (Mutui *et al.*, 2012). It also has a major influence on the rate of evaporative loss from soils and leaf surfaces. Higher temperatures will increase the evapotranspiration rate leading to rapid drying of water reservoirs such as small dams, ponds and rivers. This will lead to water shortage for humans, animals and plants (Rasul *et al.*, 2010). In temperate regions, a rise in temperature implies lengthening of the growing season by 1.2- 3.6 days per decade (Gitay *et al.*, 2001). This allows earlier planting of crops in spring, earlier maturing and harvest, and the possibility for two or more cropping cycles. In the tropics, additional warming of less than 2°C will already lead to crop yield losses as opposed to temperate regions where they broadly benefit from the increase. In general, higher temperature causes faster crop development, shortening the growth stages during which pods, seeds, grains or bolls can absorb photosynthetic products. This in most cases is associated with lower yields (Stone, 2001). Temperature also impacts the rates of photosynthesis, respiration and grain-filling. For most crops, high temperature leads to declines in photosynthetic rate (Crafts-Brandner and Salvucci, 2002) therefore reducing the final grain yield. This is one reason yields are lower in the tropics since crop yield depends on both the rate of carbohydrate accumulation and the duration of the filling periods. Temperatures above 30°C are known to reduce rice and maize yields whereas cultivation of beans becomes very difficult. In addition, high temperatures lead to poor vernalization and reduced yield in many cereal crops (Alaje *et al.*, 2010).

High temperature and relative humidity conditions favor multiplication and spread of fungal diseases. Weeds, insects, and pathogen-mediated plant diseases are affected by climate and atmospheric constituents (Reilly, 1995). Resultant changes in the geographic distribution of these crop pests and their vigor in current ranges will likely affect crops (Reilly, 1995). The economic yields of both temperate and tropical crops grown in a warmer environment will remain low despite an increase in net photosynthetic rate (Rose, 1989). The predicted temperature rise of 1.4-5.8°C by 2100 (IPCC, 2007) will therefore have serious effects including crop yield reduction both in tropical and temperate regions (Easterling *et al.*, 2007). In their report, the WTO and UNEP state that in low-latitude regions, even a small temperature increase of 1°C would lead to reductions of 5-10% in the yields of major cereal crops. By 2020, crop

yields in African countries could fall by up to 50 %. In the Kenyan highlands, increases in temperature may remove crop growth constraints, thus potentially leading to higher yields.

Generally however, Kenya is predicted to experience country-wide losses in the production of key staples by between 10-55% depending on the scenario, crop model and GCM run (Herero *et al.*, 2010). Estimated marginal impacts of climate variables suggest that global warming is harmful for agricultural productivity and that changes in temperature are much more important than changes in precipitation (Mariara and Karanja, 2007). This confirms that the temperature component of global warming is much more important than precipitation and therefore the need for introduction of crops that are heat tolerant or shifting to farming techniques that tend to reduce temperature. The variation of temperature requirements and temperature extremes for different cultivars of the same species and among species, however, is quite wide for major crops such as wheat, rice, maize, and beans (Reilly, 1995). Such variation in requirements provides significant scope for adaptation through switching among existing cultivars and crops.

c) Water availability

Agriculture highly depends on water availability. Despite the fact that more than 80% of global cropland is rain-fed, irrigated cropland with an area share of 16% produces about 40% of the world's food. Climate impacts on crop productivity will fundamentally depend on precipitation changes whose projection shows large variability in quantity and distribution. Annual mean runoff largely follows projected changes in precipitation with an increase in high latitudes and the wet tropics, and a decrease in mid-latitudes and parts of the dry tropics (Solomon *et al.*, 2007). The projected decline in water availability will affect areas currently suitable for rain-fed crops mainly in sub-tropical regions of Africa and Australia (Easterling *et al.*, 2007). Moreover, water demand will increase in warmer and dryer regions mainly due to rising temperature and the growing global food demand. Rasul *et al.*, 2010 found out that rising temperatures will lead to subsequent increase in crop water requirement. Similarly, Ghazala and Mahmoud (2009) in an experiment in Pakistan reported an average increase in crop water demand by 11%, 19% and 29% for 1°C, 2°C and 3°C rise in temperature respectively. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress which is detrimental to crops particularly during flowering, pollination, and

grain-filling. As a result, there will be a need to develop crop varieties with greater drought tolerance.

Agricultural irrigation accounts for around 70% of global freshwater withdrawals (Gitay *et al.* 2001). While irrigated agriculture is expected to become more important, the available water supply may be insufficient to meet the demand. Since IPCC predicts periods of extreme rainfall events (floods), localized water harvesting and storage techniques would ensure adequate water for supplemental irrigation during mid-season dry spells (Baron and Okwach, 2005).

d) Soil degradation

Climate change affects soils by increasing the rate of nutrient leaching and soil erosion. Higher temperatures are likely to increase the natural decomposition of organic matter (Baker *et al.*, 2001; Basweti, 2009; Roberts, 2011). Soil erosion is induced by intensive rainfall which is likely to increase under climate change. A 1% increase in precipitation is expected to lead to 1.5-2% increase in erosion rates (Nearing *et al.*, 2004). Plant canopies reduce soil erosion by weakening the power of rain, roots stabilize soils, and crop residues reduce sediment transportation. In arid and semi-arid regions, dry soils are sensitive to soil erosion through wind and rain. Increased frequency of droughts further intensifies erosive losses as plant biomass and its positive effects on soils are reduced (Niklaus, 2007). Erosion in the arid areas can however be reduced by structures that capture and store run off for use by crops during drier periods. This would in turn lead to an increase in plant biomass and subsequently an increase in yield.

e) Climate impacts on food security

Food security has been defined as the condition when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2006). Food availability, stability of food supplies, access to food and food utilization are all affected by climate change (Gregory *et al.* 2005). Many factors including climate change and socio-economic development influence the number of people at risk. In addition, there are still a lot of uncertainties about regional climate impacts on food supply and demand. Few studies have tried to quantify the impacts of climate change and socio-economic factors on food security (Parry *et al.*, 2004; Fischer *et al.*, 2005). The number of people at risk of hunger will mostly depend on socio-economic development (Tubiello and Fischer, 2007). With strong global warming and high population growth, the number of additional people at risk of hunger may be as high as 500-600

million by 2080 (Parry *et al.*, 2004) if no interventions are put in place.

2.1.5 Farm level options to cope with climate variability and change

Most developing countries are located in the lower latitudes. Since they are dependent on rain fed agriculture, they will be strongly affected by climate impacts due to their limited adaptive capacity (IPCC, 2001). Creating more options for climate change adaptation and improving the adaptive capacity in the agricultural sector will be crucial for improving food security and preventing an increase in global inequality in living standards in the future. Adaptation to climate variability and change is the adjustment to moderate the impacts of climate change, taking advantage of new opportunities and coping with the consequences (IPCC, 2001). It involves actions that take place to respond to or in anticipation of projected or actual changes in climate to reduce adverse impacts or take advantage of opportunities posed by climate change (Parry *et al.*, 2005). Adaptation strategies are site specific and there is need for localized participatory identification and evaluation of strategies for each site.

Farmers have in the past demonstrated sufficient capacity to cope with weather variations on weekly, seasonal, annual and even longer timescales (Rosenzweig and Tubiello, 2007). Modern agricultural technologies have in the past minimized climate impacts through irrigation, the use of pesticides and fertilizers, and the manipulation of genetic resources (Kandlikar and Risbey, 2000). The climate is however expected to change at a rate that has not been previously experienced in human history. Developed countries are better equipped to cope with climate variations than developing countries. In developing countries, many possible new technologies are often not implemented because of lack of education (Kandlikar and Risbey, 2000; Smithers and Blay-Palmer, 2001). The adaptive capacity of farmers is a function of their wealth, human capital, information and technology, material resources and infrastructure, and institutions and entitlements of the society (Easterling *et al.*, 2007).

As part of targeting smallholders and solutions for climate change and variability, local knowledge of farmers becomes very important to enhancing their adaptive capacity. In climate change literature, traditional ecological knowledge (TEK) (Folke, 2004), local knowledge (LK) and local ecological knowledge (LEK) (Olsson., *et al,* 2004) are used to refer to the cumulative body of knowledge, practice and belief, that are location specific, acquired through long-term observation of (and interaction with) the environment, and transferred through oral traditions from generation to generation. Local knowledge refers to a cumulative body of knowledge on

weather and climate, developed and applied by smallholders, which shows how this knowledge is used to shape and interact with agricultural practices to enhance smallholders' adaptive capacity towards climatic variability. This knowledge is time, place and culture specific (Folke, 2004). Local knowledge is based on practice and assists farmers to make informed decisions about how to respond to environmental changes and how to improve the amount and quality of their yield (Boko, 2007). The validity of local knowledge has been shown by scientists through comparison with quantitative climate data analysis (Cabrera *et al.*, 2006). Majority of the studies show that farmers' resourcefulness matches quantitative data analysis. Local knowledge is used to respond to the vagaries of climate such as droughts, famines, floods and other stresses that threaten crops and livestock (Newsham *et al.*, 2011). Although there are cases where local knowledge failed to match quantitative climate data, making use of local knowledge may seem unreliable, e.g., as reported from Kenya by Rao *et al.*, (2011). Generally, there is consensus that local knowledge is part of the solution to effective adaptation (Thomas et al., 2007; Mertz *et al.*, 2009; Mubaya *et al.*, 2012). It is therefore necessary to establish and document localized adaptation and coping strategies to climate variability. The following are some of the technical improvements and management adjustments that can be done at farm level to cope with climate variability:

2.1.5.1 Change in cropping system

a) Shifting planting dates

This is an option to shift or adjust when in the year crops are planted. It is a simple and straightforward strategy that farmers can use to maintain or increase crop yields in the face of a changing climate (Lauer *et al.*, 1999). Farmers in parts of Africa and Asia, for instance, routinely shift planting dates by a month or more from year to year in response to variability when rains arrive (Falcon *et al.*, 2004;Tadross *et al.*, 2005). This adjustment allows farmers to take advantage of the longer growing season which is permitted by higher winter temperatures in temperate regions. The potential for earlier harvesting can avoid heat and drought stress in late summer (Rosenzweig and Tubiello, 2007). In a crop model simulation of US rain fed spring wheat under a warmer and wetter future climate, Tubiello *et al.*, (2002) found that systematically shifting planting to 2 weeks earlier transforms what would have been 20-25% yield losses by 2030 into modest gains. Jalota *et al.*, (2012) found that under the changed climate, shifting trans-planting date by 1 week for rice and 5 days for wheat resulted in least reduction in crop yields

and surfaced as a practical adaptation measure for sustaining yields in future. Studies done in Tharaka, a semi-arid district in Eastern Kenya (Recha *et al.*, 2012) found that the dates for onset of the seasonal rainfall varied from year to year. A similar study by Camperlin and Okoola, (2003) also observed that in Eastern Kenya, inter annual variability of the onset of the rains was larger than the withdrawal. This situation calls for farmers to make effective use of climate forecast information (on the date of onset, cessation and expected rainfall amount) and shift their planting dates accordingly. This would lead to significant optimization of rainfall leading to improved yields (Recha *et al.*, 2012).

b) Staggered planting (succession planting)

This is a technique of spreading harvests by planting crops at different times to cope with periodic uncertain drought conditions and uncertainty in the onset of the rains. It may also involve use of crops with a range of maturing dates. The practice aims at distributing risk by ensuring that any rain is utilized to the maximum by crops planted in a dry field (Liwenga, 2003). Staggered planting is common to many farmers in Tanzania (Mary and Majule, 2009) and Zimbabwe where farmers have changed their cropping calendars to include dry planting, early and late planting outside the normal planting time to minimize risk and maintain crop productivity (Mtambanengwe *et al.*, 2012). Many studies recommend staggering of sowing dates as an adaptation strategy to the changing climate (Kandji *et al.*, 2005; Kandji *et al.*, (2006); Mary and Majule, (2009) and Bryan *et al.*, 2010) but information of its effect on seasonal crop yields, especially in the semi-arid parts of this country is lacking. With the unpredictable weather patterns and uneven rainfall distribution within seasons, staggered planting could be a sure way of ensuring a harvest regardless of the season but requires further research.

c) Introduction of drought tolerant crop cultivars

Drought has become more frequent and more severe in recent years and drought-affected areas are projected to increase in extent (FAO, 2011). Drought ranks as the single most common cause of severe food shortages, particularly in developing countries, and represents one of the most important natural triggers of malnutrition and famine (FAO, 2011). Drought impacts on agriculture include crop losses, lower yields in both crop and livestock production, increased livestock deaths, increases in insect infestation and plant and animal diseases, forest and range fires, land degradation and soil erosion.

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Introduction of new, better adapted crop types and crop varieties can provide more appropriate thermal requirements and increased resistance to heat shock and drought. In the tropics, tremendous efforts have been made in developing tolerant varieties of dry land crops like sorghums, millets, early maturing maize, pigeon peas, cowpeas and chick pea. Research organizations like the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and The Kenya Agricultural Research Institute (KARI) have over the years, developed and released higher yielding and more drought and pest resistant crop varieties to improve the harvests for smallholder farmers in the arid and semi-arid regions of the country.

Lobell and Burke (2009) however found out that farming systems and local consumer taste preferences are often strongly intertwined and could possibly be inhibiting rapid adoption of improved crop varieties among small holders. Elsewhere, in a survey by IFPRI in 2005, farmers in Eastern Kenya expressed keen interest in using improved cultivars of dry land crops but were constrained by their availability through the existing seed systems (Nagarajan and Smale, 2005). The private firms lack sufficient economic incentives to reproduce and supply seeds of dry land crops due to the low profit margins and the lengthy certification procedures for major dry land cereals and legumes which limit the participation of private firms in seed-related activities (Nagarajan *et al.*, 2007).

Over the last two decades, several seed-related programs have been initiated in eastern Kenya to improve farmers' access to quality seeds of dry land cereals and legumes in smaller packets (Nagarajan *et al.*, 2007. Although public investments have been made in the development, testing, and release of improved varieties, they have not benefited farmers, as the formal and commercial seed sector prefers to focus on maize seed production and marketing, where there is a regular demand for seed. In the absence of any well-developed formal seed systems for the dry land crops, the local markets play a key role in meeting the seed needs of the farmers in these marginal environments (Sperling *et al.*, 2006).

d) Crop diversification

Crop diversification, defined as increasing the number of crops or the varieties and hybrids of a particular crop, is a potential farm-level response to climatic variability and change (Bradshaw *et al.*, 2005). Crop diversification in a subsistence farming system provides an alternative means of income generation for smallholder farmers, the majority of whom are vulnerable to climate change. The existing cropping patterns are becoming less productive

because of the changing rainfall patterns while crop intensification, through mixed cropping and integration of high-value crops such as horticultural production, is gaining prominence as a climate change adaptation strategy. Riyannsh (2008) noted that "due to shrinking natural resources and ever-increasing demand for food and raw materials, agricultural intensification is the main course of future growth of agriculture". Crop diversification not only reduces the risk of crop failure but also provides alternative means of income generation for small holder farmers. A broader crop mix will minimize the vulnerability due to weather variations in a certain growing season since different crops are affected differently by climate events (Adger *et al.*, 2003). The practice however, requires technical and management adjustments and may reduce some gains from specialization (Olesen and Bindi, 2002).

e) Improved fallow systems

This is a rotational system where fast growing leguminous trees /shrubs that fix atmospheric nitrogen are rotated with cereal crops like maize to improve their yields (Kwesiga, 2003). In this system, land is allowed to rest from cultivation and planted with species of leguminous trees, shrubs and herbaceous cover crops. These crops replenish soil fertility in one or at most two growing seasons. It leads to improved water infiltration and holding capacity of the soils, reduces weeds and also reduces soil temperature through mulching. The legumes shorten the time required to restore soil fertility. In southern Africa, this is one of the most promising strategies to improve soil fertility, control erosion and enhance the water holding capacity of soils. Trials at different sites in southern Africa reported a 300% increase in maize yield after a 2-year rotational improved fallow compared to the continuous cropping system, which normally produces 1-2 tonnes of maize per hectare (Kwesiga *et al.*, 2003). In Zambia this strategy has been found to reduce the effects of drought on maize yield (Kandji *et al.*, 2005).

The yield improvement is mainly due to improvement of soil conditions (chemical, biological and physical properties). In Kenya, the strategy has been practiced widely in western province and found to improve farmland productivity and increase the range of outputs because the woody fallow species can also produce fuel wood (Amadalo *et al.*, 2003). Trees and shrubs are introduced mainly during the long rains, left to grow alone during the short rains and then cut and incorporated into the soil the following year at the beginning of the long rains. Fallows can however be left for a longer period (1-3 years) depending on soil fertility. Recent studies however indicate that selection of improved fallows for short-term fertility enhancement has

implications for regional N_2O emissions for dry land regions (Hall *et al.*, 2006) since some species have been found to elevate N_2O and CO_2 efflux from soils.

2.1.5.2 Improved water management techniques

a) Supplemental irrigation

Supplemental irrigation is applied to rain fed crops in the occurrence of dry spells and also contributes to the development of off-season gardening, improving farm productivity. In general, supplementation requires that the crop be of high value in order to pay for the extra investment. Horticultural crops like capsicum and watermelon have been found to respond favorably to supplemental irrigation (Antony and Singandhupe, 2004; Cabello *et al.*, 2009). Supplementing irrigation water, when rainwater is lacking during the plant establishment and reproductive stages increases the water use efficiency (WUE) compared to applying irrigation water throughout the whole season (Kijne *et al.*, 2003). Since global warming could exacerbate the scarcity of water resources through reduced rainfall/runoff and higher evaporation regime, technologies such as micro-irrigation that allow the economical use of water should be given priority.

The drip irrigation system is a choice for dry areas to supplement rain fed crops in the occurrence of a dry spell during the growing period. Compared to surface irrigation, which can provide 60 per cent, water-use efficiency and sprinklers systems which can provide 75 per cent efficiency, drip irrigation can provide as much as 90 per cent water-use efficiency (Tanji and Kielen, 2002). In recent times, drip irrigation technology has received particular attention from farmers, as water needs for agricultural uses have increased and available resources have diminished.

b) Rain water harvesting

It is becoming increasingly clear that to face the food challenge over the coming 50 years, combined efforts of developing climate smart rain fed and irrigated agriculture will be required (Rockstrom, 2002). However, irrigation is too costly to make an impact on rural households' food security for the near future. It is therefore crucial to investigate the options to increase water productivity in rain-fed agriculture for increased food production.

Various types of low-cost "rainwater harvesting" practices have been developed in developing countries (Smit and Skinner, 2002). Some of these practices include:

i) *In situ* soil water conservation

In Sub Saharan Africa, the loss of rain water through run off, soil evaporation and drainage below the rooting zone is often considered as the major cause of moisture stress (Zougmoré *et al.*, 2004). Thus, it appears that if rainfall is low and unreliable, capturing the little that falls and making it available to crops could provide an effective and sensible way of improving farm productivity and reducing farmers' vulnerability to agricultural drought. This could be done using simple in situ soil water conservation techniques.

In situ soil water conservation (SWC) practices represent all the practices that are implemented with the aim of preventing net runoff from a given cropped area and rather holding rain water and prolonging the time for infiltration (ADB, 2009). There are numerous *in situ* soil moisture conservation practices but their implementation depends on land use systems, climate and landscapes. Examples include; *zai* pits (Burkina Faso), Pot hole technique (South Africa), half-moon technique, Nine seeded hole technique and *tumbukiza*, both practiced in Kenya, Negarims (for fruit trees), *Majaluba* bunds (Tanzania), and trapezoidal bunds (Ngigi, 2009). Whereas these techniques can differ in their design, they are basically established to concentrate rain water; increase infiltration and storage; and allow good plant growth (Ngigi, 2009). Most of them combine water harvesting and concentrated application of manure or compost leading to yield increase. With improved in-field water harvesting, harvested rainwater can possibly sustain crop production during mid-season dry spells and this will reduce crop failures and may ultimately lead to improved household food security. Implementation of most *in situ* soil water conservation practices however comes with additional labour requirement that many resource poor farmers cannot afford or may be unwilling to incur (Opolot, 2012).

"*Zai* pits" as an adaptation strategy

Zai pits are an example of indigenous Soil Water Conservation technology originating from Burkina Faso. Each pit is about 0.6 m in diameter and 0.3 m depth spaced at about 1 m and can hold 5-9 plants mostly sorghum, maize or millet (Mati 2007).In Kilifi district of Kenya, the layout is 0.6 m x 0.6 m – both row and inter-row spacing. The dimensions of 0.6 m long x 0.6 m wide x 0.6 m deep for 5 plants are easy to comprehend, even by illiterate farmers (Diang'a and Ngigi, 2009).The pits are prepared during the dry spell after which organic manure is added together with top soil in preparation for planting at the onset of the rains.Application of the *Zai* technique has been shown to increase production by up to 500% in Burkina Faso (IK Notes No

80, 2005) and by 200% in Niger (Fatondji, 2002). In Niger, Olaleye *et al.*, (2006) attributed higher yields on zai treatments to a build-up of the soil organic matter contents which may have increased the soil water holding capacity. Preliminary work in Kenya shows the system has great potential for improving crop production in dry areas (Hai, 1998). Since drought conditions are predicted to be more frequent and severe especially in ASALS, this would be one of the simple technologies to promote among small scale farmers in Mbeere and other arid and semi arid areas.

ii) Runoff water harvesting

Runoff water harvesting (RWH) involves rain water collection and storage in structures such as farm ponds, earth dams, water pans and underground tanks (Ngigi, 2009). Water so stored is used to supplement rainfall especially during critical stages of crop growth. It can also be used for drinking both by livestock and human beings. Under the climate change scenario, most ASAL areas are expected to experience increased intensity of rainfall which could result into floods and increased soil erosion. Harvesting and storage of such water would reduce the people's vulnerability to water stress and water scarcity. Runoff water harvesting minimizes the risk of crop failure during droughts, intra seasonal droughts and floods (Baron and Rockstrom, 2003).

2.1.5.3 Soil Fertility Management

a) Composting

Composting is an important organic practice and a very important tool for adaptation to climate change. It involves the accumulation and proper mixing of animal manure, crop residues, weeds and organic household waste so that they can be broken down into compost, which serves as a soil conditioner through the addition of humus and organic matter to the soil (Biala, 2011). During the composting processes fungi and bacteria decompose the raw material so that nutrients are stabilized within the organic matter. It also kills or reduces weed seeds, pests and diseases. Composting increases soil fertility by holding and gradually releasing nutrients and building up organic matter levels in the soil. Composting improves the water holding capacity of the soil and makes crops better able to survive droughts and floods (IFOAM, 2009).

Generally, carbon in manures is lost during composting and transformed into more stable carbon forms, and because of this, the remaining carbon is less decomposable when applied to land. Using compost is therefore an important tool in reducing both waste and agricultural greenhouse gas emissions and in helping to mitigate climate change (Biala, 2011). The use of

compost has been shown to give higher yields than the use of chemical fertilizer and generally doubled the grain yield when compared to each respective check (Edwards *et al.*, 2007).

b) Green mulch or manure

Mineral fertilizer is expensive for most smallholder farmers (Salasya *et al.*, 2007) while the use of animal manure is limited because it is not sufficiently available. Particularly, it is bulky and labor-intensive for transportation and application, and its quality is often poor (Okalebo *et al.*, 2006). The use of leguminous cover crops has therefore been widely promoted as an alternative strategy to enhance soil fertility in croplands (Becker and Johnson, 1998). Green mulches are usually leguminous plants that cover the ground as runners, grown together with other crops. The legume could be cut and incorporated into the soil while green as manure, or used as a cover crop. Crops such as *mukuna,* pumpkins or water melons have proved useful green mulches. The use of cover crop legumes to increase maize production has received substantial attention. Species like *Mucuna pruriens* have been used successfully to control weeds and improve farm productivity in West Africa (Carsky *et al.*, 2001). The use of green manures may be more economically justified when they provide multiple benefits such as N supply, pest reduction, and improvement of soil quality (Cherr *et al.*, 2006).

Zentner *et al.*, (2004) reported that long-term use of legume green manure was more cost effective than fallow (in a 3 year rotation) due to increases in subsequent grain protein, improvement in the N-supplying power of soil, and weed suppression. Studies conducted in the mid altitude areas of Uganda have shown that *Crotalaria ochroleuca* green manure can increase maize yield by 39% (Fischler *et al.*, 1999). In Kenya, averaged over two years, *C. ochroleuca* and *Mucuna pruriens* green manure improved maize grain yield by 1.5 t ha^{-1} compared to no incorporation (Ojiem *et al.*, 2000), while in southern Cameroon, Hauser and Nolte (2002) obtained maize yields greater than 4 t ha^{-1} after a short-term fallow with mucuna.

c) Conservation Agriculture

Traditionally, African smallholder farmers are accustomed to practicing conventional farming (CF), which involves disturbing the soil through ploughing, discing, harrowing and many other tilth conditioning operations (Mashingaidze and Mudhara, 2005). This practice has however been observed to compact the soil, promote salinization, accelerate soil erosion and deplete the soil of organic matter and nutrient content (FAO, 2001b). Studies show that CF can cause soil losses of up to 150 t ha^{-1} annually (Knowler and Bradshaw, 2007). As a solution to

problems caused by CF, many agricultural scientists have advocated for the use of conservation agriculture (CA) technologies. However, these technologies have been less widely adopted (Hobbs, 2006). FAO defines Conservation Agriculture (CA) as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits and high and sustained production levels while concurrently conserving the environment (http://www.fao.org/ag/ca/index.html).

CA consists of (i) minimum soil disturbance which basically means no soil inversion by tillage, (ii) soil surface cover with crop residues and/ or living plants, and (iii) crop rotations and has been referred to as a "unifying label" for a variety of integrated soil and water management practices and agricultural resources (Kaumbutho and Kienzle, 2007). The practice is believed to offer the means to prevent further destruction of the soils, increase rainwater use efficiency, labor productivity and ensure higher and more stable crop yields at reduced production costs. CA practices attempt to achieve at least a 30% ground cover using growing crops or dead mulch in order to protect the soil physically from sun, rain and wind and to feed soil biota contrasting with CF which emphasizes the need for a clean seedbed without crop residues (Erenstein, 2003). As documented by FAO (2001a & b), Hobbs (2006), and Wall (2007), CA ensures improved water infiltration and soil surface aggregation as well as reduced soil erosion and compaction. In addition, biological tillage is promoted, surface soil organic matter and carbon contents increased, soil temperatures moderated and weeds suppressed.

Proponents of CA sometimes argue that only when a number of agronomic management practices are applied simultaneously does CA become profitable, environmentally beneficial and ensures sustainable agricultural production in the short and long term (Gowing and Palmer, 2007).While the practice has been well adopted in countries like Brazil and Australia (Wall, 2007), across Africa, not all components have been adopted due to bio-physical factors (soils, climate, and topography), socio-economic factors, institutional factors and technology characteristics (Kaumbutho and Kienzle, 2007). For example, CA advocates for maintenance of a permanent or semi-permanent organic soil cover in the form of dry mulch or green cover crops throughout the cropping cycle to protect the soil from degradation by moderating soil temperature, suppressing weeds, diseases and pests and conserving soil moisture. Unfortunately, this is difficult to achieve in semi-arid areas due to competition for soil moisture, free grazing

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traditions, high prevalence of agro-pastoral communities, and high dependence on biomass as fuel, fodder and construction material (Rockstro¨m *et al.*, 2009).

Despite these challenges the practice has widely been promoted in Zimbabwe, Zambia and Malawi by CIMMYT (Chiputwa *et al.*, 2011). In East Africa, the technology has been widely promoted by CA-SARD Tanzania and Kenya and has been found to improve crop yields (FAO, 2011). Ngigi (2003) described CA as an efficient system, leading to yield increases of 50-150 %. Conservation tillage reduces soil manipulation, saves on labour requirement and improves soil productivity by minimizing compaction and improving soil moisture storage within the plough layer thus reducing soil and water losses (Kaumbutho, 2000). Participatory on-farm experiments on conservation farming systems for smallholder farmers carried out over 3-4 years (1999–2003) in Ethiopia, Kenya, Tanzania and Zambia reported consistent yield increase .Yields increased on average with 20-120% for maize and 35-100% for Teff while Labor needs for tillage reduced by at least 50% (Rockstro¨m *et al.*, 2009). Results also indicated a positive moisture conservation effect of conservation farming (Rockstro¨m *et al.*, 2009). Related studies by Kaumbutho and Mutua (2002) reported that CA increased maize grain yields by 30% and 150% in Machakos and Zambia respectively (RELMA, 2002). All CA systems tend to provide at least some climate change adaptation benefits relative to conventional farming systems, particularly related to soil fertility and water conservation and use.

2.1.6 Farmer perceptions on climate change and climate variability

Farmers' ability to perceive climate change is a key precondition for their choice to adapt (Gbetibouo, 2009). Surveys done in Kenya, Tanzania and Ethiopia generally showed that local farmers perceive that climate had been changing during the last few decades (Meze-Hausken 2004: Cooper *et al.*, 2008; Mary and Majule, 2009; Mengistu, 2011; Huho *et al.*, 2012). A study from selected districts in Kenya showed that majority of farmers perceived an increase in average temperatures, a decrease in average precipitation, an increase in prolonged periods of drought events and an increase in flood events (Bryan *et al.*, 2010). Similar work in Ghana also showed that majority of the farmers perceived increase in temperature and decrease in rainfall pattern (Acquah *et al.*, 2011).

Actual climate data analysis however gives conflicting scenarios. While some studies show no significant trends in average annual temperatures and precipitation (Meze-Hausken, 2004; Cooper *et al.*, 2008), others report a decline in annual precipitation and an increase in

temperature (Ogutu *et al.*, 2007; Mongi *et al.*, 2010). Cooper *et al.*, (2008) argued that the contrast is just a confusion of drivers of change in agricultural production and access to resources that increases in population density may have reduced the availability of water per family or peoples' need for rainfall may have increased leading to various environmental changes and ultimately reduced water availability. Temperature increases have a significant negative impact on water availability, thus exacerbating drought conditions. Thus, farmers' perceptions about climate change may be based on a decrease in water availability that is also affected by other environmental and social drivers. Perceptions may also be influenced by more recent climate trends such as the prolonged and severe droughts and rising temperatures during the 1990s (Ogutu *et al.*, 2007). This study therefore relied not only on farmers' perceptions but also analyzed long term climatic data to make conclusions on the state of climate in Mbeere.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The study was conducted in Kiritiri and Siakago divisions of Mbeere in Embu County, Eastern Kenya. Mbeere region comprises Mbeere North and South sub counties .It extends between latitudes $0^0 20'$ and $0^0 50'$ S and longitudes $37^0 16'$ and 37^0 56'E and rises from 1100 to 1500 metres above sea level (masl). Kiritiri division, one of the sites lies in agro ecological zones LM_4-LM_5, positioned at 0^0 40' 38" S and 37^0 39' 62" E at an elevation of 1163 m above sea level. It has a characteristic short to very short growing season of 55 to 85 days (Jaetzold *et al.*, 2006). The area receives an average annual rainfall of 845 mm and has a potential evapotranspiration of 47%. Siakago division lies in LM_3-LM_4, positioned at 0^0 36' 38"S and 37^0 34' 52" E at an elevation of 1236 m asl. The division receives about 900 to1100 mm of rainfall and has a longer growing period of 85 to 105 days. Except for very small pockets of medium potential agro ecological zones UM_3 and UM_4 towards the border with Embu Sub County, the bulk of Mbeere is marginal land with limited agricultural potential.

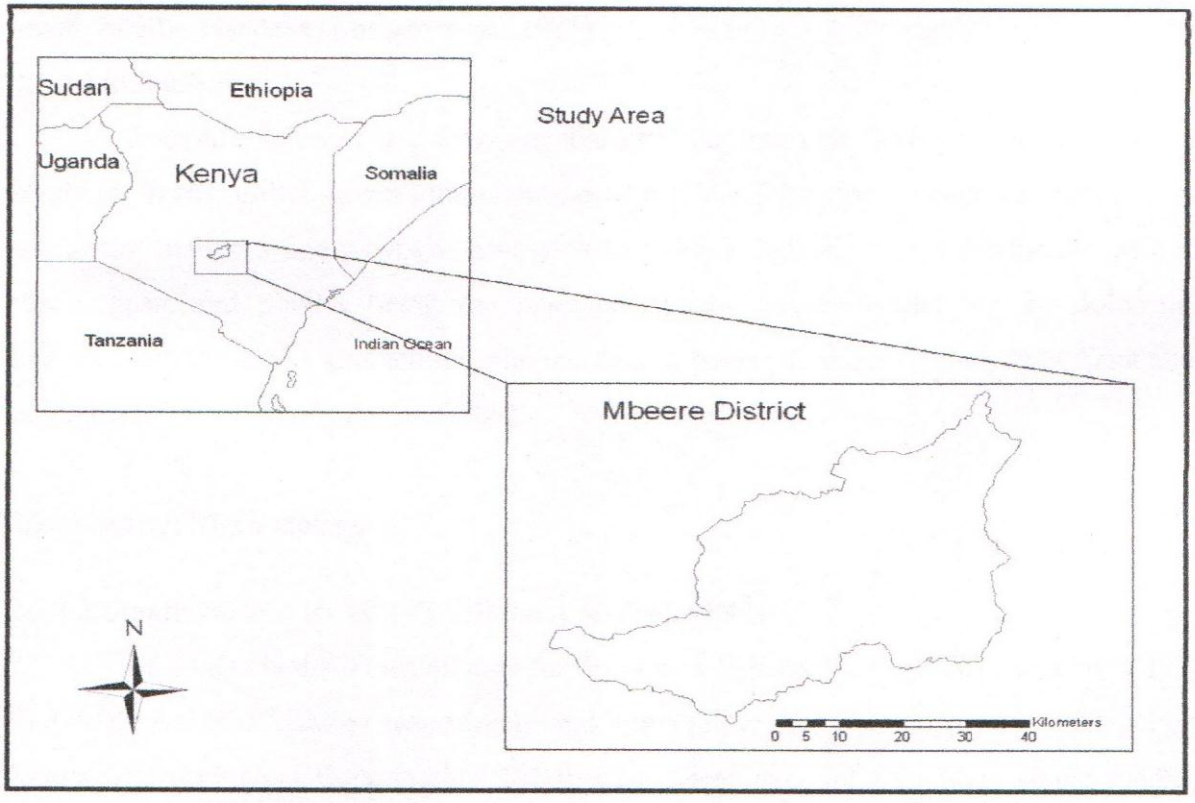


Figure 1. Map showing the location of Mbeere in Kenya

3.1.1 Soils and Agricultural activities

Soils

Soils in Mbeere include *rhodic Ferralsols, Ferralic Arenosols, Orthic Ferralsols* and *Acrisols.* The lower parts, the Mwea plains are covered by black cotton soils (*pellic Vertisols*) of low to moderate fertility (Van de Weg & Mbuvi, 1975; Sketchley *et al.*, 1982; Onduru *et al.*, 2002; Jaetzold *et al.*, 2006).

Before the experiment was set up, composite soil samples were collected from a depth of 0 – 30 cm. They were air – dried, crushed and tested for physical and chemical properties. Soils in both divisions were mainly deficient in carbon (0.37% and 0.32%) and phosphorus (8.56 and 9.67mg/kg) for Kiritiri and Siakago respectively, thus requiring use of manure to improve nutrient levels. Additionally, they were alkaline with a PH of 5.1 and 6.5 for Kiritiri and Siakago.

3.1.2 Topography and climate

Mbeere covers 2,098 km^2 and has a population of 219,220 (KNBS, 2010). It is mainly semi-arid with bimodal rainfall ranging from 550-1100 mm per annum. Long rains occur between March and May (MAM) and short rains between October and December (OND) with temperatures ranging from 20-32 ^{0}C. The district has two growing seasons per year with a total length of 90 – 119 days (Kassam *et al.*, 1991).

3.1.3 Land use

. Generally, Mbeere is a low potential dry zone with the following food crops; maize, sorghum, beans, millet, green grams, cow peas and the following cash crops; cotton, tobacco, sunflower, mangoes and pawpaw. Livestock keeping is second to crop production with cattle, sheep, goats and poultry being the main enterprises. Water availability for domestic and livestock use is a major problem despite the district having five dams along river Tana and five permanent rivers (Kinuthia *et al.*, 2009).

3.2 Research Methodology

3.2.1 Climate variability and its influence on crop yields

The study obtained rainfall data for the period 1982-2011, 1959-2011 and 1959-1993 for Embu, Kiritiri and Siakago respectively and temperature data for the period 1982-2011 from Kenya Meteorological Department (KMD). Crop yield data for four main staple foods from 1981-2011 was obtained from the Ministry of Agriculture in Mbeere and analyzed to determine

the trends and relationship with climate variables (rainfall and temperature). All data was examined and edited to remove any outliers before being entered into Microsoft office excel sheet.

3.2.2 Participatory identification, analysis and evaluation of coping strategies

Household interviews using structured questionnaire (Appendix 2) were used to gather information on farmers' perceptions of climate variability and change, evidence and indicators of climate variability, perceived impacts of the variability on agricultural production as well as identification of coping strategies used by farmers in the region.

Sampling design and sample size

Two divisions, Kiritiri and Siakago were purposively sampled because they represent the main agro ecological zones LM_3, LM_4 and LM_5 in Mbeere and are frequently faced by serious droughts leading to crop failure. Simple random sampling was then used to get farmers in each of the two divisions. A sample of 150 farmers was randomly selected from the population of farmers with over 10 years' experience in farming. The sample size was determined using Anderson's formula (Anderson *et al.*, 2007)

$$n = \frac{pq\,Z^2}{E^2} \quad \text{.....Equation 1}$$

Where n = sample size; Z = confidence interval ($\alpha = 0.05$); p = Proportion of population containing major interest; q = 1-p. Since the number of people who have lived and farmed in the area for more than 10 years is not known, it was assumed to be 50%, thus p = 0.5, q = 0.5; Z = 1.96 and E = 0.08, this resulted to a sample of 150 households. For ranking of climate variability coping strategies, each respondent was asked to rank top three strategies they used on their farms.

3.2.3 On farm assessment of the potential of zai pits in reducing the adverse impacts of climate variability and change

A field study was conducted in Kiritiri and Siakago divisions during the October-December (OND) rains of 2011 and March-May (MAM) rains of 2012 to evaluate the effect of *zai* pits on growth and development of maize and assess the potential of the pits as a suitable coping strategy for farmers.

i) Experimental layout and design

A two factor split plot experimental design was used in 2 sites with *zai* pits as factor 1 at two levels (Zai_1= no *zai*, Zai_2 = *zai* pits) and manure as factor 2 at two levels (0, 5t ha^{-1}). Treatment combinations were Zai_1+Manure$_1$; Zai_1+Manure$_2$; Zai_2+Manure$_1$; Zai_2+Manure$_2$. Two large plots, one with *zai* pits and the other without pits were the main plots. Each of them was subdivided into sub plots (3 m by 4 m) with the two levels of farm-yard manure randomly assigned to each of the subplots. Each treatment combination was replicated three times within the main plot. *Zai* pits were 0.6 x0.6 m wide, 0.6 m deep at spacing of 0.6 m between pits and 0.9 m between pit rows. Hybrid maize variety *DH01* was planted in the different plots at a spacing of 0.3 m between plants and 0.9 m between rows.

PLOT LAY OUT

- Main plot 1(Without zai pits-Zai_1)- **-Main plot 2(with *zai* pits-Zai_2)-**

Sub plot 1 5tons FYMha^{-1}	Sub plot 4 No Manure	Sub plot 5 5tons FYMha^{-1}	Sub plot 1 5tons FYMha^{-1}	Sub plot 4 No Manure	Sub plot 5 5tons FYMha^{-1}
Sub plot 2 No Manure	Sub plot 3 5tons FYMha^{-1}	Sub plot 6 No Manure	Sub plot 2 No Manure	Sub plot 3 5tons FYMha^{-1}	Sub plot 6 No Manure

Plot size: 3x4m 9 pits per plot; 6 seeds per pit

Experiment done in 2 sites- Kiritiri and Siakago divisions

ii) Agronomic Practices

Soil samples were taken from the two sites and analysis done at the beginning of the study. Soils in both divisions were deficient in both carbon (0.37% and 0.32%) and phosphorus (8.56 and 9.67mg/kg) and had a PH of 5.1 and 6.5 for Kiritiri and Siakago respectively.Land preparation was done by hand before the onset of the rains. This included ploughing of plain plots as well as *zai* pits establishment. Planting was done by hand at the onset of the rains. Planting in the pits was done at the rate of 6 seeds per pit giving a plant population of 45,000/ha. Hand weeding was done regularly to keep the plots free from weeds. At maturity, harvesting was done from a 2 m x 3 m plot size in all the plots and stooked to dry before the biomass yield was taken. The grains were shelled and dried to 12.5 % moisture content before recording the 100 seed weight and grain yield.

iii) Data collection

Data was collected on growth and yield components. Growth parameters included plant height, number of leaves and leaf area index (LAI) at 45 days after sowing and these were collected from five randomly sampled plants in each plot. Yield components included harvest index, 100 seed weight (g) and grain yield (t ha^{-1}).

3.3 Data Analysis

3.3.1. Long term climate data analysis

Temperature and rainfall data from meteorological stations were analyzed using Instat version 3.36 and Microsoft Office Excel 2003 to present patterns and trends of rainfall and temperature in the form of graphs. Linear regression was used for trend analysis.

3.3. 2. Crop yield data analysis

Instat's descriptive statistics and Microsoft Office Excel 2003 were used to establish crop yield trends over the study period. Further analysis was done to establish the correlation between crop yields and climate variables (rainfall and temperature).

3.3.3. Household interview data analysis

Data obtained was edited, coded and entered in a computer and the Statistical Package for Social Science (SPSS) software version 11.5 spread sheet was used for the analysis. Descriptive statistics were run to give frequencies and percentages before cross-tabulation was undertaken. Multiple response questions were analyzed so as to give frequencies and percentages. Tables and bar charts were used to present different variables.

3.3.4. Experimental data analysis

Experimental data was subjected to Analysis of Variance (ANOVA) using GENSTAT release 14.0 statistical package. Differences among treatment means were compared using Fisher's Least Significant Difference (LSD) test at 5% probability level.

Statistical Model: $y_{ijk}=\mu+\alpha_i+\beta_j+(\alpha\beta)_{ijk}+E_{ijk}$……Equation 2

For i = 1….2

j = 1……2

k = 1……3

Where:

Y_{ijk} =Observation under the i^{th} level of manure and the j^{th} level of zai in the k^{th} replicate

μ= overall mean

α_i = effect due to the i^{th} level of manure

β_j= Effect of the j level of zai

$(\alpha\beta)_{ij}$ = Interaction effect between the i^{th} level of manure and the j^{th} level of zai

E_{ijk} = Random error component

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Rainfall trends

4.1.1 Long term total annual rainfall characteristics

Generally, annual rainfall totals declined by 3.1 mm and 11.4 mm per annum in Embu and Siakago respectively but increased by 0.97 mm per annum in Kiritiri (Figure 2). The totals also varied from year to year i.e. Siakago (CV=43.2%) Kiritiri (CV=33.1%) and Embu (24.4%) (Table 1). The highest total annual rainfall (1904 mm) was received in Siakago in 1963 while the lowest was received in Siakago (0 mm) and Kiritiri (1.8 mm) in 1980 (Table 1). In Machakos and Makueni, Njiru *et al.*, (2010) reported declining trends of between 0.15-2.1mm per annum and increasing rainfall variability. A general decline in rainfall has also been noted in Tanzania (Mongi *et al.*, 2010). Shisanya *et al.*, (2011) noted that climate variability is persistent in the arid and semi-arid lands of Kenya and continues to affect vegetation condition and consequently crop production.

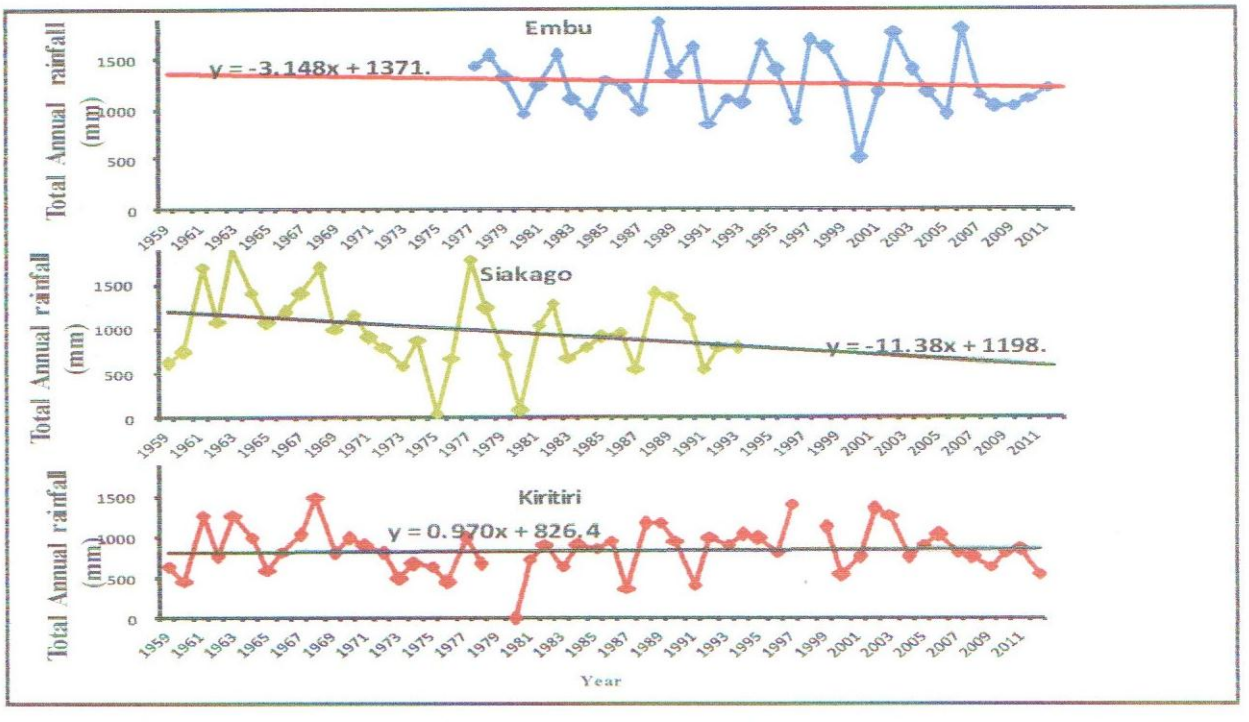


Figure 2. Long term annual rainfall trends in Embu, Siakago and Kiritiri stations in Eastern Kenya

Table 1. Long term annual rainfall characteristics; Embu, Siakago and Kiritiri stations

Station	Min(mm)	Year	Max(mm)	Year	Mean	S.D	C.V (%)
Embu	499.4	2000	1884	1988	1252	304.9	24.4
Siakago	0	1980	1904	1963	993.4	429.1	43.2
Kiritiri	1.8	1980	1493	1968	858.6	284.2	33.1

***S.D-Standard deviation** ***C.V- Coefficient of variation**

4.1.2 Long term seasonal rainfall trends and distribution

Seasonal rainfall totals in Kiritiri and Siakago were highly variable with C.Vs of 40.5% and 48.9% for Kiritiri and 50.3% and 53.3% for Siakago during March-May rainfall (MAM) and October-December rainfall (OND) respectively (Table 2). In addition, MAM rainfall totals gradually declined by 1.1 mm and 5.6 mm in Kiritiri and Siakago respectively (Figure 3). October-December rains declined by 1.3 mm in Siakago but increased by 2.1 mm in Kiritiri. The slight increase in rainfall may however not translate to increased agricultural productivity probably because increased temperature would increase evapotranspiration and offset any potential increase in productivity (Herero *et al.*, 2010).

Irrespective of site, OND total rainfall was higher than in MAM (Figure 3) though more variable (Table 2). Seasonal rainfall totals were higher in Siakago than Kiritiri but more variable (Table 2). The higher rainfall could be attributed to the fact that Siakago falls under a higher altitude than Kiritiri. Slightly over 50% of the total seasonal rainfall was received in the months of April and November (Figure 4), the other months received the rest of the rainfall. This distribution may be insufficient for crops to grow to maturity hence the need to focus on crops that require less moisture while at the same time practicing moisture conservation methods. In Laikipia East, Huho *et al.*, (2012) noted that the mean MAM (long rains) has been increasing but with a decrease in the number of rainy days. In Tharaka district, Recha *et al.*, (2012) found out that although both seasons were highly variable, OND rainfall remained persistently below mean while MAM showed higher within-season variability.

Table 2. Long term seasonal rainfall characteristics: Kiritiri and Siakago

	Min(mm)		Max(mm)		Mean		S.D		C.V (%)	
Station	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**
MAM Total	0	0	726.3	980.4	393.2	476.1	159.2	239.4	40.5	50.3
OND Total	0	0	957.6	1168	406.2	472.4	198.7	251.7	48.9	53.3

*S.D-Standard deviation *C.V- Coefficient of variation * OND-Oct-Dec rains *MAM- Mar-May rains

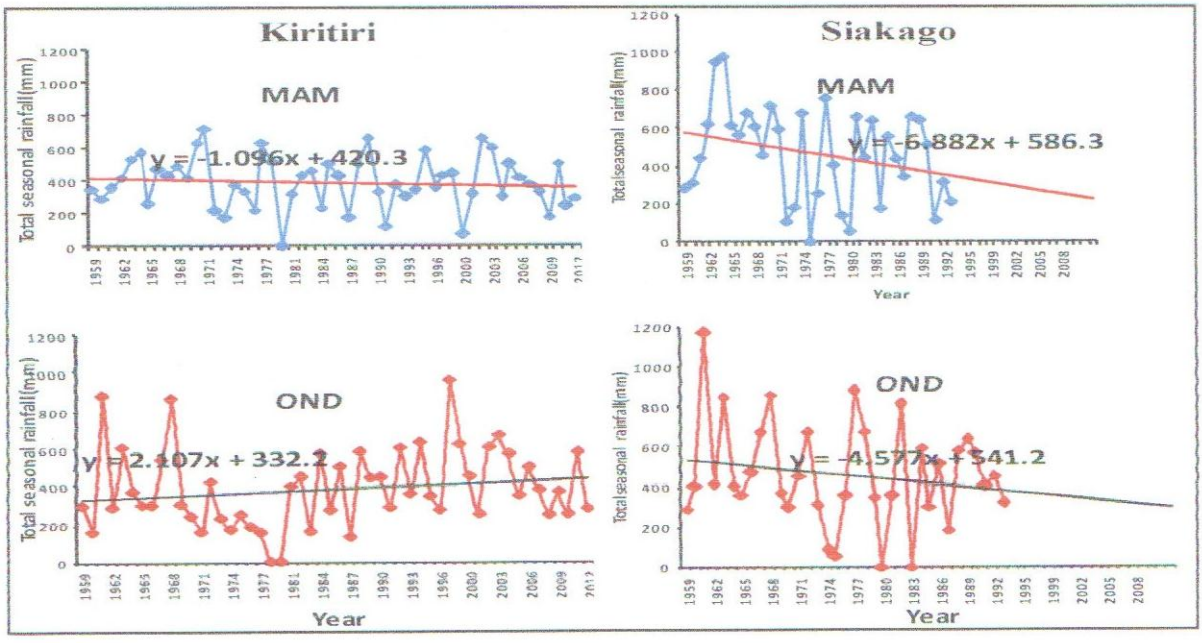


Figure 3. Long term total seasonal rainfall trends: Mbeere

* OND-Oct-Dec rains *MAM- Mar-May rains

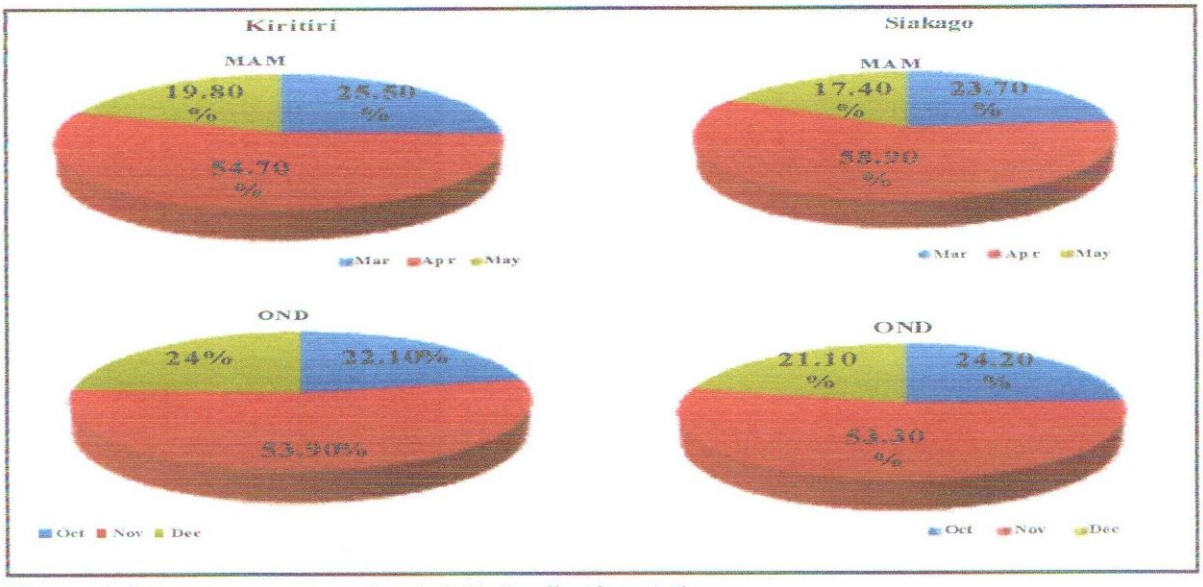


Figure 4. Long term seasonal rainfall distribution: Mbeere

* OND-Oct-Dec rains *MAM- Mar-May rains

4.1.3 Long term monthly rainfall characteristics

i) March-May (MAM) long term rainfall characteristics; Kiritiri and Siakago

During the period 1970 to 2000, most of the first season rain was received in April. March and May however received minimal rain (around 100 mm). Generally, April rains declined by 0.7 mm and 1.4 mm in Kiritiri and Siakago respectively during this period (Figure 5). March rains declined by 0.9 mm and 3.8 mm in Kiritiri and Siakago respectively. In addition, monthly rainfall totals varied from year to year with a coefficient of variation (C.V) of 76.7%, 48.6% and 86.3% in March, April and May respectively for Kiritiri and 78.7%, 53.6% and 93.5% for the same months in Siakago (Table 3). In both stations, rainfall variability was highest in May followed by March while April rains were less variable. Huho *et al.*, (2012) in their analysis of rainfall trends in Laikipia East also found April rains to be getting less variable compared to May and March, while May rainfall was increasingly more erratic and unreliable.

The high variability and the reducing monthly and seasonal amounts are likely to contribute to declining crop yield. Nyong (2008) observed that variability in rainfall characteristics has the potential to influence crop production significantly. Rainfall variability from season to season and during the growing period greatly affects soil water availability and hence crop production. It is therefore vital for the farming community to embrace measures that enhance soil moisture conservation as well as growing drought tolerant crop cultivars for production of adequate food.

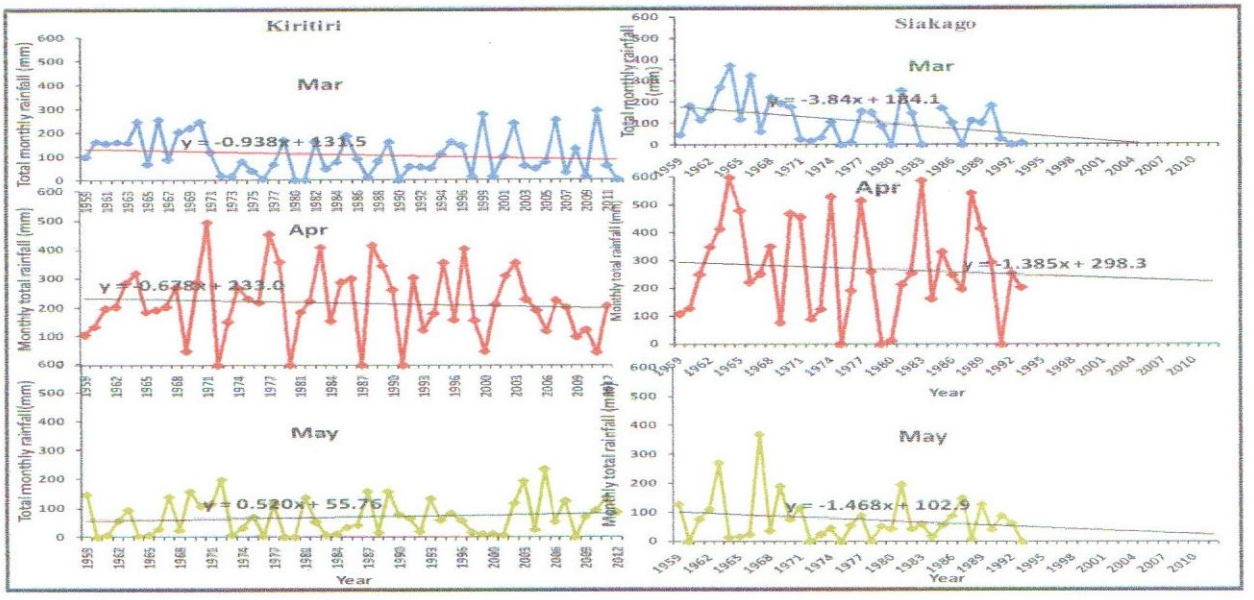


Figure 5. March-May long term monthly rainfall trends for Kiritiri and Siakago

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Table 3. March-May long term monthly rainfall characteristics

	Min(mm)		Max(mm)		Mean		S.D		C.V (%)	
Station	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**	**Kiritiri**	**Siakago**
March	0	0	289.0	369.8	108.8	123.1	83.38	98.0	76.7	78.7
April	0	0	494.1	596.9	228.7	299.0	111.1	160.2	48.6	53.6
May	0	0	233.4	368.4	72.1	86.4	62.2	80.7	86.3	93.5

*S.D-Standard Deviation *CV- Coefficient of variation

ii) October-December (OND) long term monthly rainfall characteristics: Mbeere

A large fraction of the population in South Eastern Kenya (including Mbeere) depend on October-December rains for livelihood because they consider it to be more reliable and can be predicted with a reasonable degree of accuracy (Hansen and Indeje, 2004; Cooper *et al.*, 2008; Recha *et al.*, 2012. Figure 6 shows the long-term monthly rainfall trends during the short rainy season in Kiritiri (1959-2012) and Siakago (1959-1993). In both cases, November was the wettest month with peaks of about 500 mm before 1970's and later in the late 1990's for Kiritiri (Figure 6). October and December rainfall totals remained low but slightly higher than the March- May rainfall amounts. In Kiritiri, monthly rainfall increased by 1.0 mm in November and 1.2 mm in December but declined by 0.2 mm in October. In Siakago, rainfall increased by 0.15 mm and 0.2 mm in October and December respectively but decreased by 1.6 mm in November. Rainfall amounts within the 3 months were extremely variable (Table 4) with coefficients of variation of 89% and 90.5% in October, 57.9% and 52.2% in November and 99.4% and 64.1% in December for Kiritiri and Siakago respectively (Table 4). Rainfall in November has been less variable but extremely variable in October and December.

While the reported decline may not have significant effects on crop growth, high rainfall variability experienced during this critical growing period may have significant negative impacts on agricultural productivity and ultimately food security. Similar work in southeastern Kenya also concluded that the October-December (OND) growing season is more reliable than the March-May (MAM) season (Shisanya *et al.*, 2011). Van de Steer *et al.*, (2009) in Makindu, Eastern Kenya also noted high rainfall variability during this season. The slight increase in rainfall may however not lead to increase in agricultural productivity because increased temperature would increase evapotranspiration and offset potential increase in productivity (Herero *et al.*, 2010).

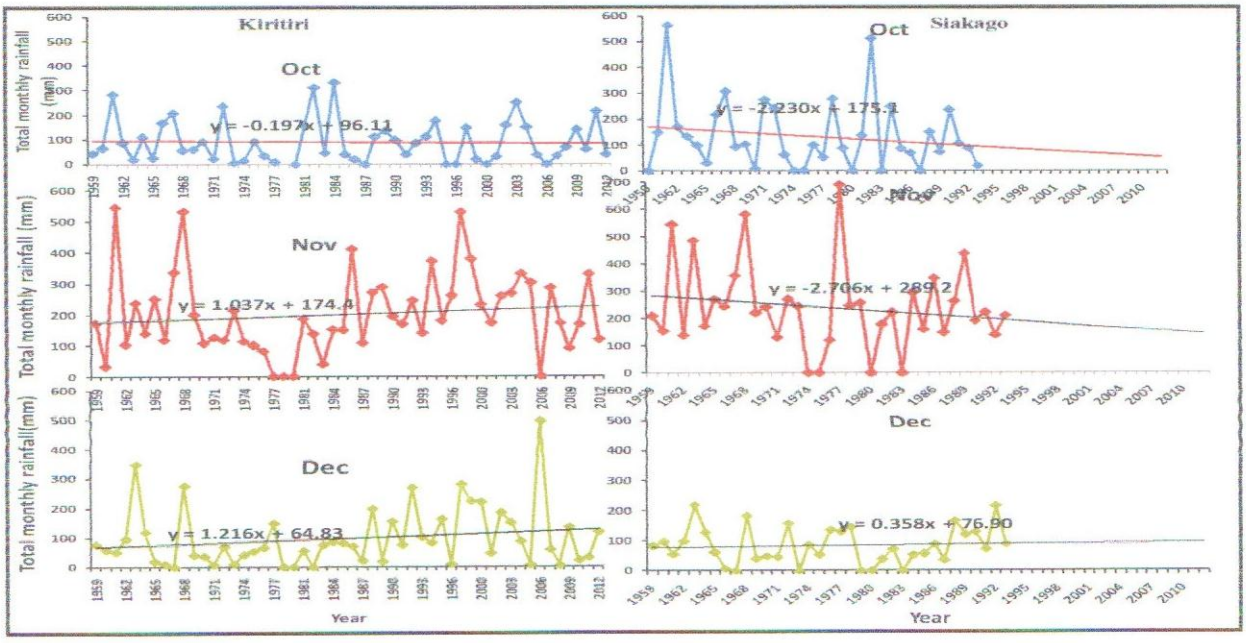


Figure 6. October-December long term monthly rainfall trends for Kiritiri and Siakago

Table 4. October-December long term monthly rainfall characteristics

	Min(mm)		Max(mm)		Mean		S.D		C.V (%)	
Station	Kiritiri	Siakago	Kiritiri	Siakago	Kiritiri	Siakago	Kiritiri	Siakago	Kiritiri	Siakago
Oct	0	0	332.8	564.2	97.7	142.2	87.0	133.2	89.0	93.7
Nov	0	0	545.8	693.3	216.3	263.0	125.3	147.4	57.9	56.0
Dec	0	0	495.1	219.7	102.7	88.4	102.1	59.7	99.4	67.5

S.D - Standard Deviation *CV- Coefficient of variation

4.2. Temperature trends: Embu

4.2.1 Mean annual temperature trends

There was a gradual increase in minimum and maximum temperatures from 1982-2011 (Figure 7). Mean maximum and minimum temperatures increased by 0.03°C and 0.02°C per year respectively. In Machakos and Makueni, Njiru *et al.*, 2010 reported a temperature increase of 0.04°C and 0.03°C in mean maximum and minimum temperatures respectively. The results are consistent with previous studies that reported warming over most parts of Kenya (Kinguyu *et al.*, 2000) and also in Tanzania (Mongi *et al.*, 2010). Studies using temperature records have shown that the mean global surface temperature has increased by about 0.3-0.6°C over the last 100 years (Kinguyu *et al.*, 2000). Rosenzweig and Tubiello (2007) projected a decrease in the availability of water resources, productivity of grazing lands and livestock, and a change in the distribution

of agricultural pests and diseases, as a result of rising temperatures. Fischer *et al.*, (2005) predicted significant crop losses due to heat and water stress. Wheeler *et al.*, (2000) pointed out that the effects of hot temperature episodes close to the time of anthesis were of more importance to the yield of crops than the effects of the increase in mean seasonal temperature of about 2°C. Studies have shown that temperatures above 35°C are lethal to maize pollen viability (Dupuis and Dumas 1990). Leaf photosynthetic rate of maize has a high temperature optimum of 33°C to 38°C (Crafts- Brandner and Salvucci (2002). A study by Commuri and Jones (2001) found that temperatures above 30°C increasingly impaired cell division and amyloplast replication in maize kernels, and thus reduced grain sink strength and yield. The vegetative development of sorghum has a temperature optimum of 34°C (Alagarswamy and Ritchie 1991) while its reproductive development has a temperature optimum of 31°C (Prasad *et al.* 2006).

High temperature accelerates physiological development, resulting in hastened maturation and reduced crop yield (Rosenzweig and Hillel, 1995; Sasson, 2012). Since crop yield depends on the rate of carbohydrate accumulation and the duration of grain filling periods (Rose, 1989), when temperatures exceed the optimal level for biological processes, crops often respond negatively with a steep drop in net growth and yield. Heat stress might affect the whole physiological development, maturation and finally yield of cultivated crops (Khanal, 2009). The rising temperature trends (Figure 7) seem to be approaching the optimum for the main food crops. This implies that in future, it might be impossible to grow the ordinary food crops in the region unless measures are put in place to reduce temperatures or introduce crop varieties that are heat tolerant.

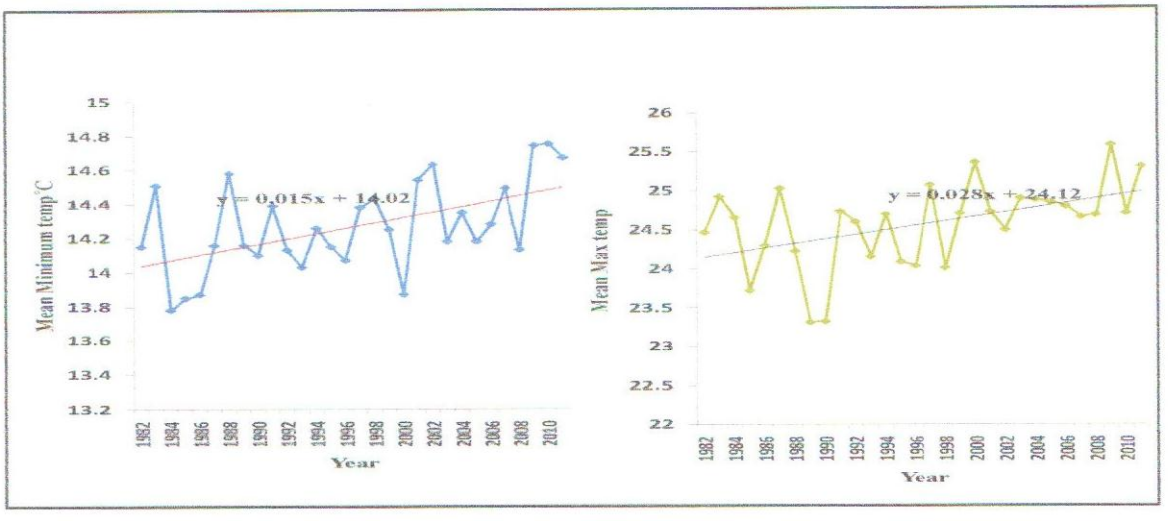


Figure 7. Mean minimum and maximum temperature trends in Embu

4.2.2 Monthly minimum and maximum temperature trends during the cropping season

Generally, there was a gradual increase in minimum and maximum monthly temperatures for the period 1986-2010 (Figure 8). Maximum temperatures were highest during the Mar-May rainfall season compared to October-December season. This could perhaps have contributed to lower crop yields during this season since high temperature accelerates physiological development, resulting in hastened maturation and reduced crop yield (Rosenzweig and Hillel, 1995; Sasson, 2012). The hottest months during the cropping calendar were March and October which are mainly periods for the onset of the rains. This could lead to an increase in the rate of evaporation from the ground surface during the planting time. Increased evaporation will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance (Rossenzweig and Hillel, 1995).

Increased evaporation from surface water would also hasten the drying of rivers which are a major source of water for both human and livestock (Table 6). Warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility (Baker *et al.*, 2001; Basweti, 2009; Roberts, 2011). Additional application of fertilizer and manure may thus be required to counteract these processes. The process of nitrogen fixation, associated with greater root development, is also predicted to increase in warmer conditions and with higher CO_2, if soil moisture is not limiting (Khanal, 2009). Where they occur, drier soil conditions will suppress root growth and increase vulnerability to wind erosion, especially if winds intensify.

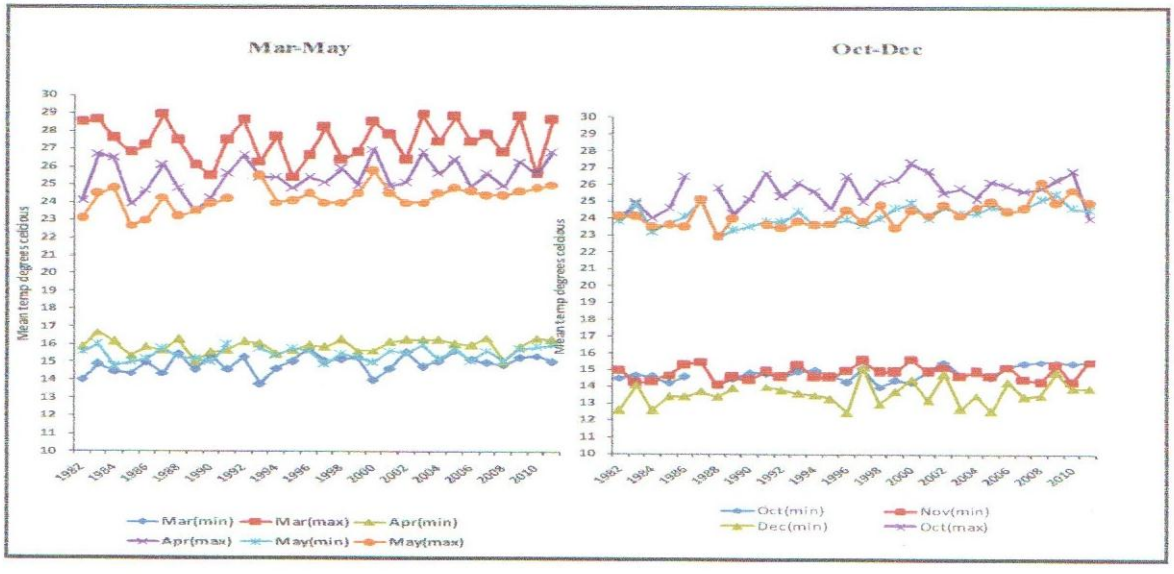


Figure 8. Long term monthly minimum and maximum temperature trends in Embu

4.3 Climate variability and crop production

4.3.1 Crop yield trends in Mbeere, Eastern Kenya

Yields of major food crops in Mbeere have been declining over time (Figure 9). Yields for maize, sorghum and beans declined at a rate of 13.8kg, 2.9kg and 4.4kg per ha per year respectively. In contrast, cow pea yield increased at the rate of 0.9kg/ha/year. Maize yield showed the greatest decline, indicating that it was most vulnerable to climate variability. The results are consistent with several studies in Kenya and Africa. In Eastern Kenya, most respondents attributed the decline in crop yields to low and variable rainfall (Onduru and Du Prez, 2008). Similarly, Kinama *et al.,* (2007) attributed crop yield declines in semi-arid eastern Kenya to seasonal rainfall variability. In Somalia, Belay and Jama (2011) attributed crop yield decline to declining rainfall and increased variability while in Nigeria, Jagtap and Abamu (2003) observed a decline in maize and bean yields from a potential of 6 t ha^{-1} and 5 t ha^{-1} to less than 1 t ha^{-1} and 0.5 t ha^{-1} respectively.

Simulations using the Agricultural Production Systems Simulator (APSIM) of the impact of climate change scenarios on average potential grain yield in Bulawayo, Zimbabwe predicted a 16% grain yield reduction due to temperature rise and 6% and 8% grain yield reductions for sorghum and maize respectively due to reduced rainfall. An overall grain yield reduction of 22% and 25% for sorghum and maize due to combined effects of climate change were simulated (Dimes *et al.*, 2008).

Analysis of long term rainfall data for Mbeere during the same period revealed a gentle decline in both annual and seasonal rainfall and a high inter annual and inter seasonal rainfall variability (section 4.1.1). This could possibly have contributed to the crop yield declines although other factors such as declining soil fertility could also contribute to the decline. Studies done in Ethiopia however reveal that the major constraint facing rainfed agricultural production is not nutrient deficiency *per se* but rather low soil water holding capacity, which hinders crop growth and efficient utilization of available nutrients (Amede *et al.*, 2011)

The occurrence of extreme climate variability characterized by a prolonged dry period or heavy rainfall spell coinciding with the critical stages of crop growth and development may lead to reduced crop yield and extensive crop losses (Oseni and Masarirambi, 2011). Strategies to enhance local adaptation capacity are therefore needed to minimize climatic impacts and to maintain stability in food production.

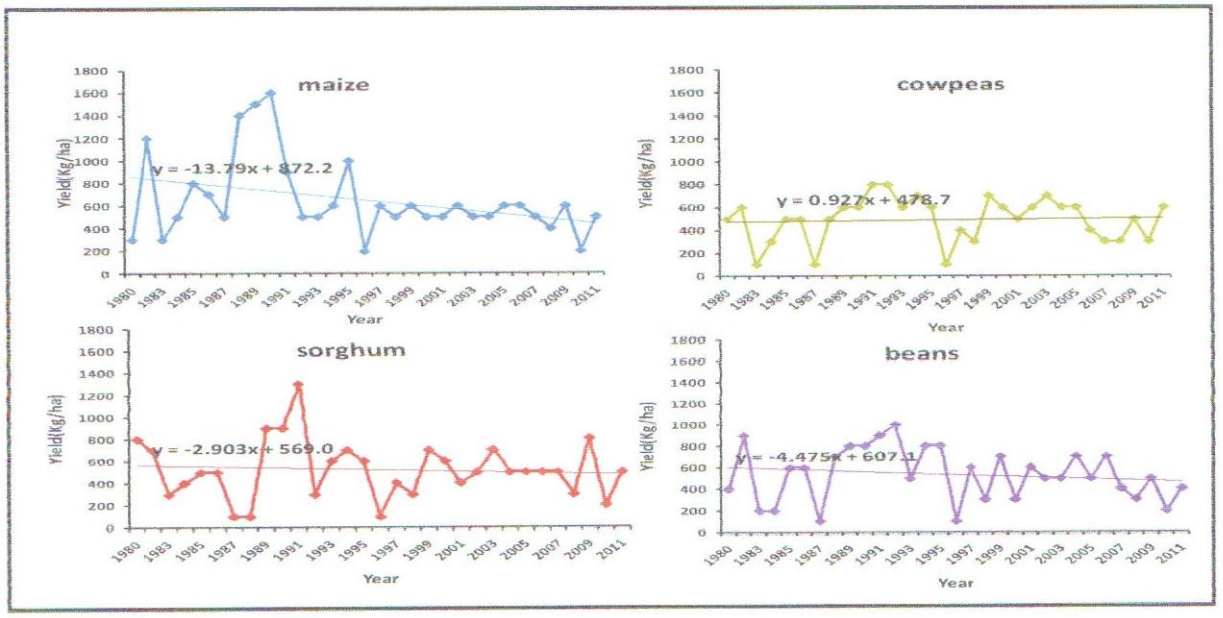


Figure 9. Long term crop yield trends (1980-2011); Mbeere

Source: Ministry of Agriculture, Mbeere

4.3.2 Farmer perceptions of long term crop yield trends

a) Maize

The number of farmers not cultivating maize dropped from 20% by 1980's to 0% by 2010 (Figure 10). According to Karugia (2011), 58% of the registered and released maize varieties between 1964 and 2009 are suitable for arid and semi-arid areas of Kenya and have potential yield of 1-4t ha^{-1}. In Mbeere, 61% by 2010 and 51% of the farmers by 2000 were getting 0-0.45t ha^{-1}. However in the 1980's, only 6% of the farmers got the same yield (Figure 10) thus an increase in the number of farmers harvesting $\leq$0.45 t ha^{-1}. While 15% of the respondents reported maize yields >2.25t ha^{-1} (10 bags/acre) in the 1980's, none mentioned the same by 2010 (Figure 10). Ketiem *et al.*, (2008) also found that maize yields per unit area of land have been declining over time in Mtwapa and Kitale and related it to rainfall variability which is associated to climate change. Similarly, Jagtap and Abamu (2003), in Nigeria also reported decline of up to 85% in maize. A projection of the likely impact of climate change on maize yield in Africa and Latin America during the coming decades predicts drastic declines in maize yields (CGIAR, 2011). Thornton *et al.*, (2009) projected that maize yield will reduce by 20% by 2050 in most semi-arid areas of Kenya and Tanzania.

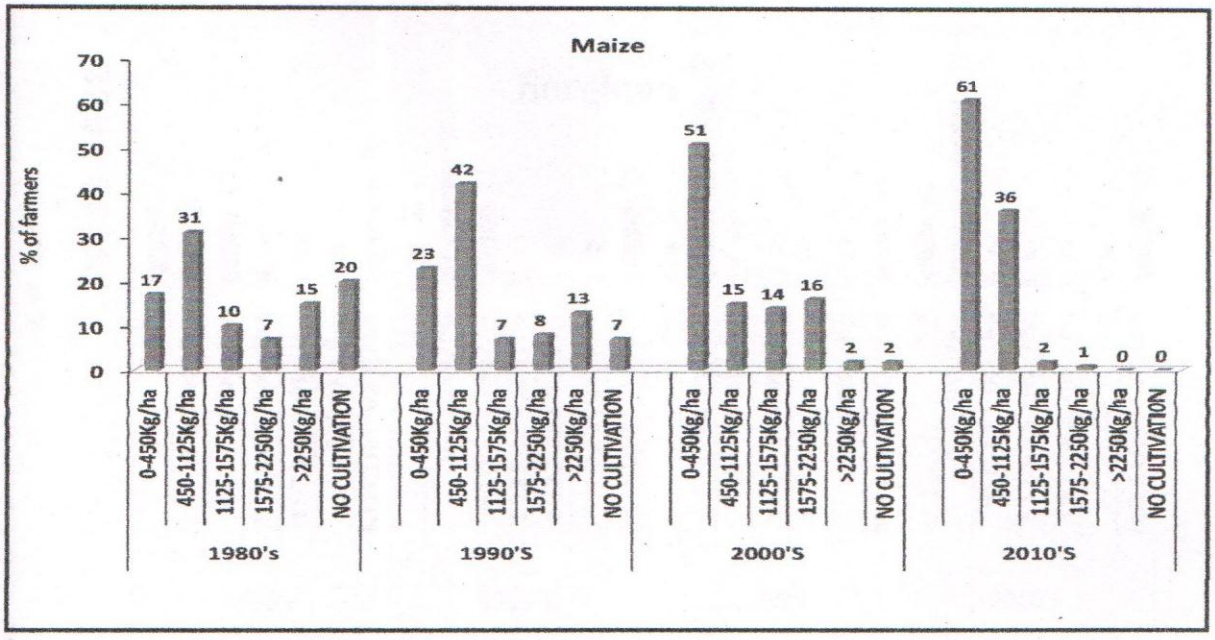


Figure 10.Perceived long term yield trends for maize: Mbeere

Source; field survey, August, 2011

b) Sorghum

Twenty eight percent (28%) of the Sorghum varieties that have been developed and released during the period 1970 to 2008 are drought tolerant with a potential yield of 1-4.5 t ha^{-1} (Karugia, 2011). Between 1980's and 1990's, a majority of farmers in Mbeere harvested 0.45-1.13t ha^{-1} (Figure 11). However, between 2000 and 2010, 71% harvested 0-0.45t ha^{-1} (Figure 11). The proportion of those not planting sorghum decreased from 38% in the 1980s to 23% in the year 2000 but increased to 27% by 2010. Though sorghum is relatively more tolerant to drought than maize, changes in eating habits may have caused this change. In addition, growing sorghum requires extra labour especially for bird scaring and harvesting. The proportion of those harvesting nothing increased from 18% in 1980's to 22% by 2010, a situation they attributed to low and unreliable rainfall.

Simulations of the impact of climate change scenarios on average potential grain yield of sorghum in Bulawayo, Zimbabwe predicted a 16% grain yield reduction due to temperature rise, 6% grain yield reductions for sorghum due to reduced rainfall and an overall grain yield reduction of 22% due to combined effects of climate change (Dimes *et al.*, 2008). In the dry highlands of Nakuru and Baringo, Ouma and Akuja (2013) reported significant reduction in grain yield of sorghum due to reduced rainfall.

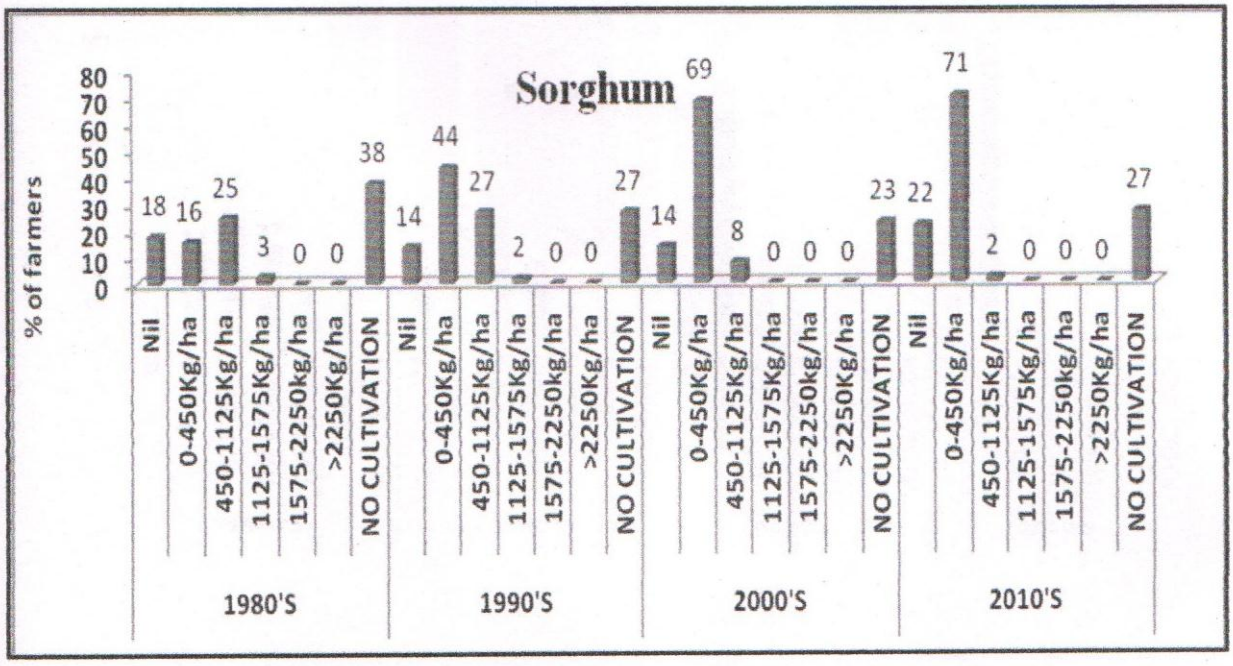


Figure 11 .Perceived long term yield trends for sorghum: Mbeere
(Source; Field survey, August, 2011)

c) Beans

During the period 1995-2008, the Kenya Agricultural Research Institute (KARI) developed and released four improved bean varieties (Kat X56, Kat X 69, Kat/Bean 1(Katheka), and Kat-Bean 9) that are suitable for arid and semi-arid conditions with a yield potential of 1.4-2 t ha^{-1} (Karugia, 2011). However, a majority (84% and 70%) of the farmers were harvesting less than 0.45 t ha^{-1} by 2010 and 2000 respectively compared to 25% and 33% in the 1980's and 1990's (Figure 12). This implies an increase in the number of farmers harvesting less than 0.5t/ha over the years. The proportion of farmers harvesting 1-1.6 t ha^{-1} decreased from 27% in the 1980's to 16% in the 1990's and further to 2% and nil by 2000 and 2010 respectively (Figure 12). Those harvesting 0.45-1t ha^{-1} decreased from 39% in the 1980's to only 4% by 2010. The findings show a great decline in bean yields. Jagtap and Abamu (2003), in Nigeria also reported a considerable decline in bean yield from a potential of 5 t ha^{-1} to less than 0.5t ha^{-1}.

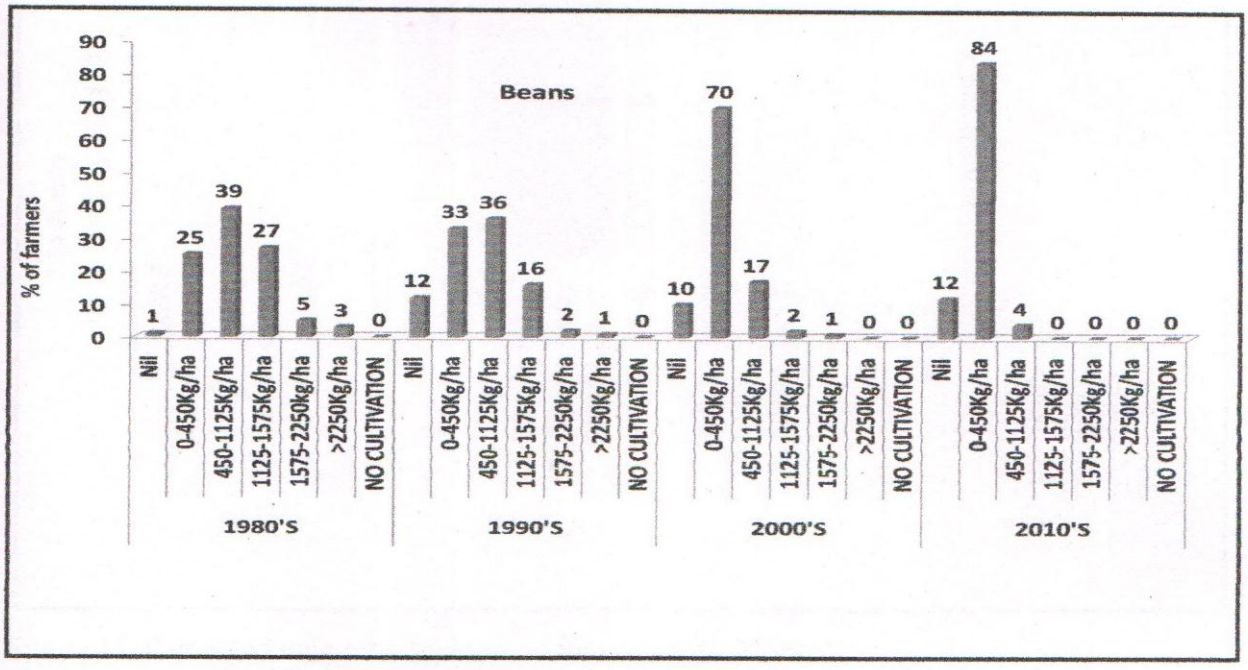


Figure 12. Perceived long term yield trend for beans: Mbeere
Source; field survey, August, 2011

d) Cowpeas

During the period 1987-2000, KARI in collaboration with the International Institute of Tropical Agriculture (IITA) developed and released seven cowpea varieties for drought prone areas like Mbeere that had a potential yield of 0.8-1.8 t ha^{-1} (Karugia, 2011). Despite this, cowpea yield declined to less than 0.45 t ha^{-1} between 2000 and 2010 (Figure 13). The number of farmers not cultivating cow peas declined from 23% in 1980's to only 2% by 2010 probably because the crop is more drought and heat tolerant compared to other legumes like beans. Fifty percent (50%) of the farmers in the household survey (Table 7) used drought tolerant crops such as cowpeas as a coping strategy to the changing weather patterns. Cowpea is a drought-tolerant crop (Fatokun *et al.*, 2002) whose optimum temperature for growth and development is around 30 °C and therefore does better than other crops under limited moisture and high temperatures. This possibly explains why most farmers have embraced the crop under the changing weather patterns thus the reduced number of farmers not planting the crop.

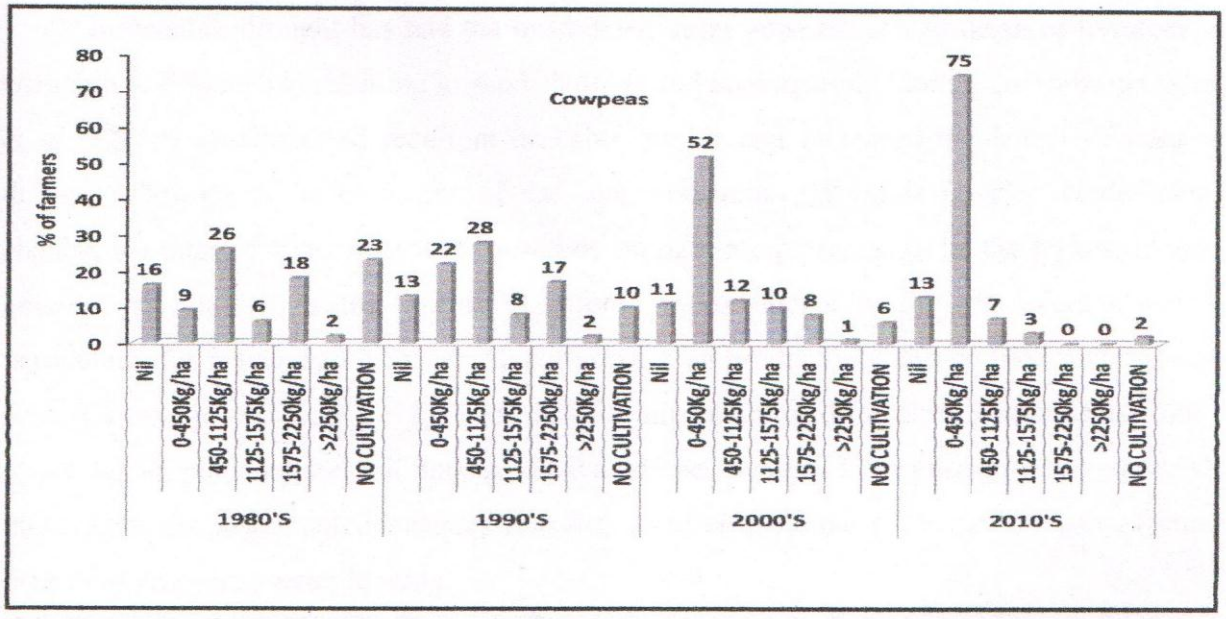


Figure 13. Perceived long term yield trend for cow peas: Mbeere
Source; field survey, August, 2011

4.3.3 Farmer perceptions of the effects of climate variability on crop production

Respondents interviewed during the study period reported crop yield declines, wilting/drying, poor germination and an increase in pest disease occurrence as the main effects of climate variability on crops (Figure 14). Analysis of long term secondary data also established declining crop yield trends in the same region (section 4.3.1). Bryan *et al.*, (2010) similarly reported crop yield declines in the same region. Other studies done in Tanzania (Mongi *et al.*,2010), Somalia (Belay and Jama,2011) and Malawi also reported crop yield declines as a result of declining rainfall amounts and increasing variability.

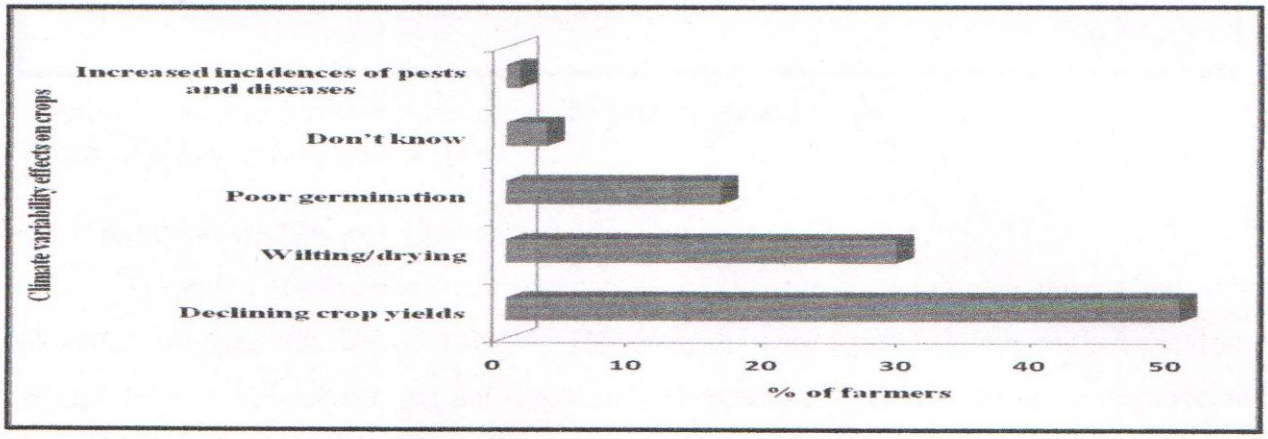


Figure 14. Perceived effects of climate variability on crop production; Mbeere
Source: field survey, August, 2011

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In general, drought has had the most devastating impacts such as death of livestock and crop failure (Figure 15) resulting to food shortage and consequently famine. In Tanzania, Mongi *et al.*, (2010) also reported recurrent droughts, floods and increased incidences of pests and diseases. Drought is currently one of the main constrains for yields in SSA. Under climate change, the rates of yield reduction caused by drought are projected to be the highest in Africa amongst all regions of the world. Therefore, improvements in drought tolerant varieties, particularly for maize, can have substantial impacts on productivity and on food security across SSA (Cennacchi and Koo, 2011). The *El Niño* rains had mixed impacts. Respondents from the upper, higher potential areas of Siakago cited a bumper harvest (33%) during *El Niño* rains while those from the lower potential areas (Kiritiri) cited crop failure (35%) as a result of stunted growth of crops and water logging.

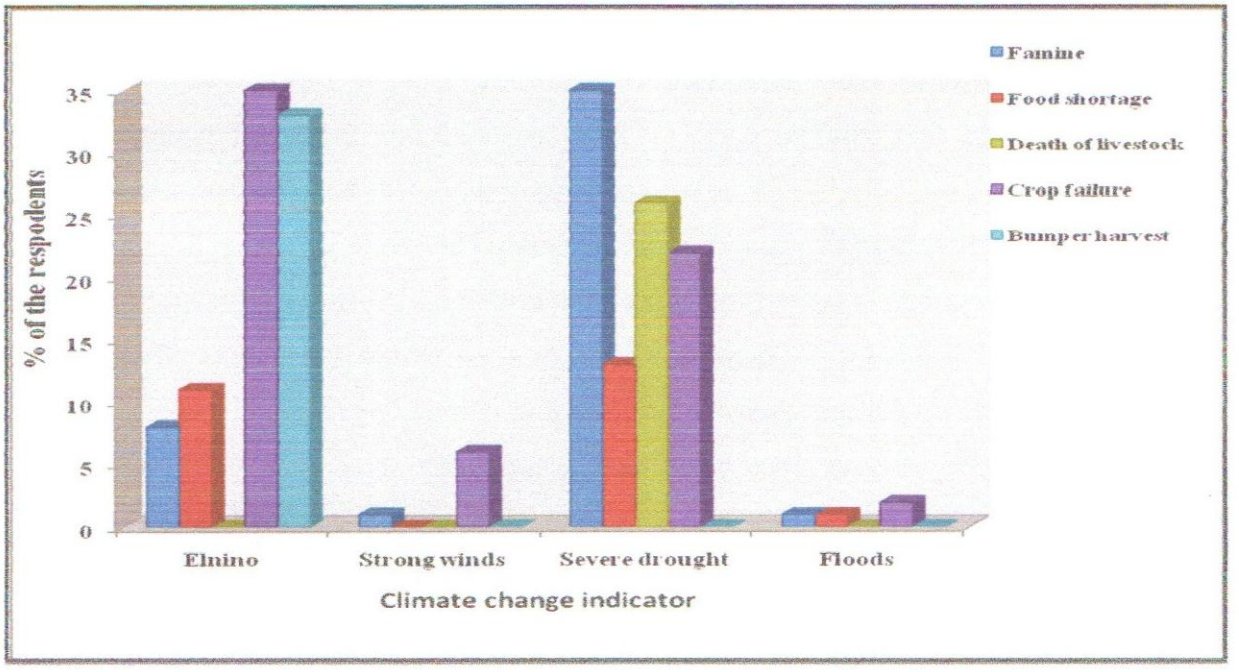


Figure 15. Extreme events experienced in the past 20 years: Mbeere
Source: Field survey, August, 2011

4.3.4. Relationship between climate variables and crop yield

There was positive and significant correlation between annual rainfall amount and yields of maize, sorghum and beans (Table 5). However, the correlation between cowpea yield and rainfall (r=0.3) was positive but not significant. Maximum temperature showed a negative and significant correlation with maize yield (r=-0.612) and weak negative correlation with the yields of the other crops. Generally, the crops are sensitive to an increase in temperature. The effect

was however expressed more for maize (r=-0.6) and beans (r=-0.3). Cowpeas had the weakest negative correlation (r=-0.04), an indication that the crop is more tolerant to high temperatures than the other crops and would therefore perform better under increased temperatures. Survey findings in figure 16 indicate that both cowpeas and sorghum were more tolerant and less affected by harsh climatic conditions compared to maize and beans and could therefore be the choice crops under the already confirmed scenarios of increasing temperatures (Figures 7 and 8). On the other hand, an increase in rainfall led to an increase in crop yields. The positive relationship was more pronounced for maize (r=+0.9) and sorghum (r=+0.5) in Siakago compared to Kiritiri where r=+0.4 for both maize and sorghum. Siakago stands at a higher altitude (section 3.1) than Kiritiri and receives more rainfall. An increase in rainfall would lead to higher yields in Siakago than it would for Kirititi. In the household survey findings (Figure 13), 35% of respondents reported a bumper harvest while 33% reported crop failure during *El nino* rains of 1997. Most of those who reported crop failure were from Kiritiri. The results confirm findings by Ifabiji and Omoyosoye (2011) who reported that annual rain days and annual rainfall amount had the greatest effect on maize yield in a similar study conducted in Kwara State, Nigeria. Adamgbe and Ujoh (2013) in their study in Nigeria also showed that rainy days and rainfall amount had strong positive relationship (r = 0.747 and r = 0.599), respectively to maize yield. In Kenya, a similar study reported a strong positive linear correlation of 94% and 87% between maize yields and rainfall in Kitale and Mtwapa respectively (Ketiem *et al.*, 2008). The findings imply that variations in annual rainfall amounts account to some extend for the annual variations in crop yield. Thus, the higher the amount of rainfall in a year, the higher the crop yields per hectare in the area and vice versa.

The fact that there is a strong positive and significant correlation between cereal production and rainfall amount in the region suggest that farmers in these areas are vulnerable to food insecurity related to rainfall variability. Thus there is a need for management of water resources including household level rainwater harvesting and conservation for crop production. Woldeamlak (2006) reported that household level rainwater harvesting, with appropriate management and utilization has a potential to serve as an adaptation strategy to current rainfall variability and supplement rain fed crop production by enabling production of high market value crops such as vegetables and fruits, with implications for adaptation to future climate change as well.

Table 5. Relationship between climate variables and crop yield

	Crop yield(t/ha)			
Climate variable	**Maize**	**Sorghum**	**Cowpeas**	**Beans**
Total annual rainfall(Siakago)	0.896**	0.538*	0.270	0.467*
Total annual rainfall(Kiritiri)	0.394*	0.404*	0.328	0.388*
Average minimum temperature	-0.155	-0.117	-0.068	-0.046
Average maximum temperature	-0.612**	-0.191	-0.039	-0.281

**** Significant at p ≤ 0.01 level** *** Significant at p ≤ 0.05 level**

4.4 Participatory identification and ranking of climate variability coping strategies

4.4.1 Farm and farmer characteristics

Sixty one percent (61%) of the sampled households were male headed while 39% were female headed (Table 6). Majority (81%) of them were over 45years old and had farm sizes ranging from 1 to 6 acres (Table 6.). Majority of the farmers in Mbeere had tenure security since 92% of the sampled households owned their land while only 6% farmed on rented land. Land tenure provides the farmer with ownership and user rights which are necessary in long term projects and collateral which allows the farmer to access credit facilities to fund the investment (Mwirigi *et al.*, 2009). Only 3% had not accessed formal education, implying that 97% of those sampled could read and write. However, majority of them had attained primary (48.2%) and secondary (28.6%) education with only 6% attaining tertiary education.

Residents in the study area mainly depend on firewood as their source of energy. With the declining forest cover, this is likely to be affected. Only 9 % of the residents use charcoal despite the fact that charcoal is an alternative source of livelihood for 31% of the respondents. Mbeere residents drew their water mainly from boreholes (45%) and rivers (33%). Fourteen percent (14%) had invested in roof water harvesting while only 8% had access to piped water. With climate change, rivers are projected to dry up due to declining rainfall while boreholes will dry up as the water table reportedly goes down (Milly *et al.*, 2005). Residents will therefore have to get alternative sources of water. The only opportunity is for residents to improve on roof water harvesting while at the same time investing in other on-farm water harvesting technologies. Apart from farming, charcoal burning was the main source of livelihood, practiced by 31% of the

sampled households. This was followed by micro-business (20%) and sand harvesting (18%). Ten percent (10 %) of the sampled population had no alternative source of livelihood.

Table 6. Farmer and farm characteristics

i)Age(years)	Percent	vi) Farm Size(Acres)	Percent
25 -3 4	7.1	1-3	46.4
35 - 44	11.7	4-6	43.8
45 - 54	33.9	7-9	7.1
>55	47.3	>9	2.7
Total	100.0	Total	100
ii)Gender		**vii) Land tenure**	
Male	60.7	Owned	92.9
Female	39.3	Rented	6.2
		Other	0.9
Total	100.0	Total	100.0
iii)Marital status		**viii)Energy Source**	
Married	81.3	Firewood	88.4
Single	8.9	Charcoal	8.9
Divorced	2.7	Kerosene	1.8
Widowed	7.1	Electricity	0.9
Total	100.0	Total	100.0
iv)Education level		**ix)Source of water**	
Primary	48.2	Borehole	44.6
Secondary	28.6	River	33.0
Tertiary	6.2	Roof catchment	14.3
Other	14.3	Tap water	8.1
None	2.7		
Total	100.0	Total	100
v)Household size(No's)		**x)Alternative source of livelihood**	
1 - 3	30.4	Charcoal burning	31.2
3 - 6	58.9	Micro business	19.6
7 – 9	8.0	Sand harvesting	17.9
≥10	2.7	Selling calabashes	5.4
		Selling bee hives	0.9
		Boda boda	1.8
		Others	13.4
		None	9.8
Total	100	Total	100

N=150

4.4.2 General climate change issues

Respondents perceived that the climate had changed. They observed that in the past (1980's), March-May rains were more than the October-December rains but the situation had now changed. It was further reported that the onset of the rains had changed from March to April and from October to November for the long and short rains, respectively. Analysis of long term climate data (Figure 3),showed that March-May rains have declined and are lower than October-December rains. However, monthly rainfall during the growing period was highly variable and this might be responsible for the changes being experienced by the farmers. Similarly, Mengistu (2011) reported reduced rainfall and changed rainfall patterns in Ethiopia.

i. Indicators of climate change

The main indicators of observed climate variability included a decline in rainfall amounts, frequent drought and increased heat stress (Figure 16). The respondents linked observed climate changes to the drying of rivers, boreholes and springs, drying of vegetation (including Mango trees) and a complete seasonal change. Respondents also reported delayed and uncertain onset of the rains and poor distribution during the growing period. Roncoli *et al.*, (2010) similarly reported variations in rainfall patterns, shortening of the rainy seasons as well as increased heat stress as the main indicators of climate variability in the same area.

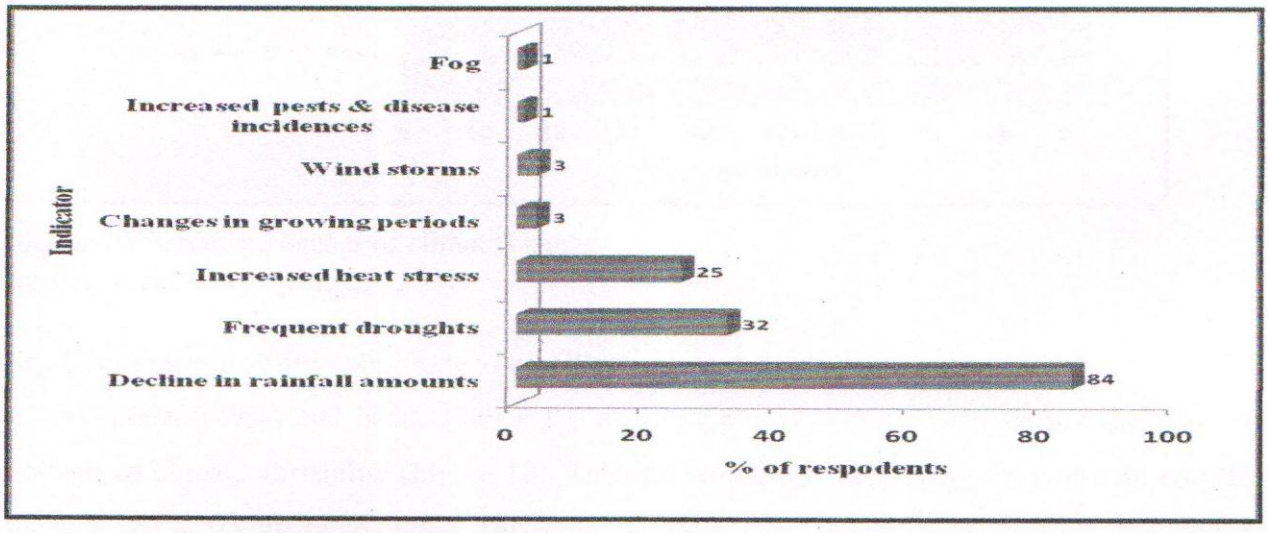


Figure 16. Observed indicators of climate change
Source: Field survey, August, 2011

ii) Perceived causes of climate change

Climate change is perceived to have been caused mainly by cutting down of trees and charcoal burning while 14% of the population believed that sand harvesting had contributed to rapid drying of rivers leading to serious water shortage (Figure 17). Roncoli *et al.*, (2010) also reported that in Eastern Kenya, cutting down of trees, sand harvesting and planting wrong tree species were to blame for the changing climate. It is important to note that 31% of residents derived their livelihood from charcoal burning while 18% were in the sand harvesting business (Table 6). Thus a big fraction of the population derived their livelihood by engaging in perceived "destructive" methods. It is therefore important for farmers to seek for alternative sources of livelihood and affordable fuel sources and building material to replace charcoal and sand respectively.

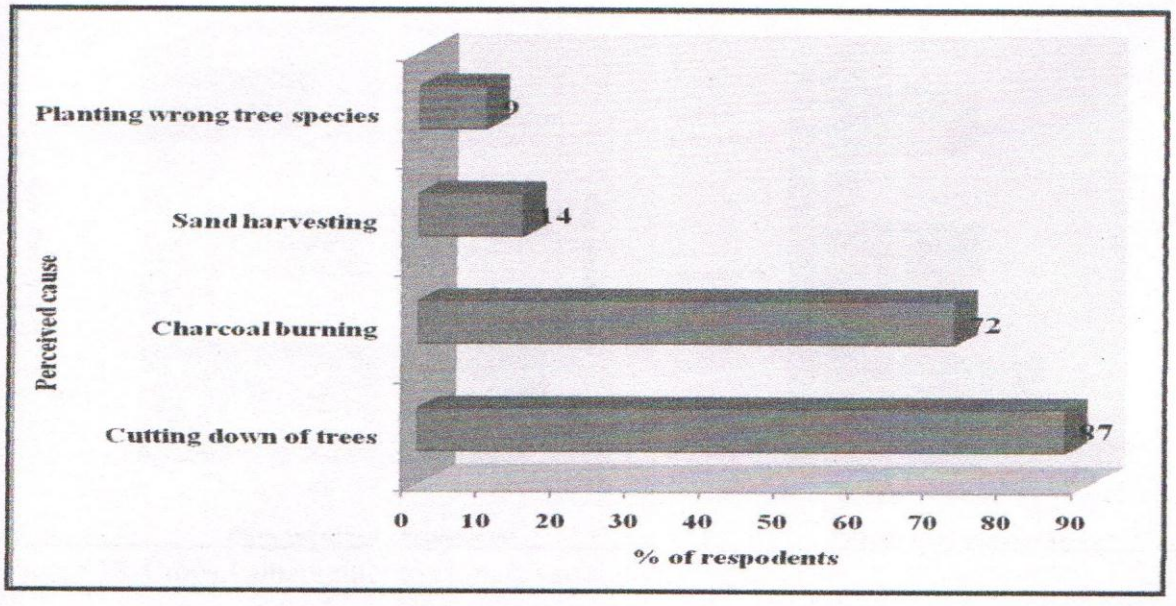


Figure 17. Perceived causes of climate change
Source: Field survey; August, 2011

iii). Crops vulnerability to climate variability

Maize (49%) and beans (78%), the major staple food crops were most vulnerable to impacts of climate variability (Figure 18). Tobacco which was previously a major cash crop in the area was also vulnerable (25%). This could be one reason why most residents had abandoned the crop. Miraa (Khat), sorghum and cowpeas were however reported to be most tolerant to effects of climate variability by 40%, 28% and 27% of the respondents respectively. As a result

of decreasing rainfall amounts, farmers have gradually been reducing the area under beans and replacing it with the more tolerant cowpeas.

Maize is more susceptible to water stress than other crops probably because of the unusual floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem (Huang *et al.*, 2006). Maize is particularly susceptible to water stress at the flowering stage when yield potential is being set (Colless ,1992; Birch *et al.*, 2003; Srinivasan *et al.*, 2004). Under water stress, ear growth will slow more than tassel growth and there is a delay in silk emergence relative to pollen shed; the interval between pollen release and silk emergence (anthesis-silking interval) increases, pollen is shed before silks emerge leading to a poor seed set or abortion (Edmeades, 2013).

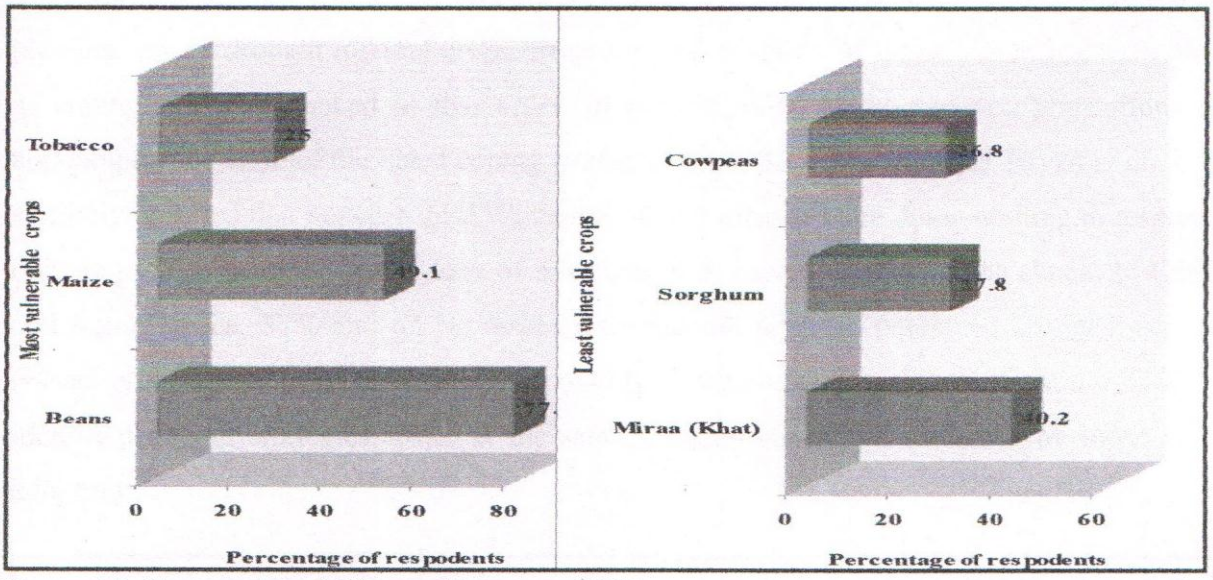


Figure 18. Crops vulnerability to climate variability

4.4.3 Coping strategies in crop production

How people are currently managing climate hazards is a key indicator of their capacity to adapt to future climate change. The study explored the coping strategies employed by the community as well as new strategies that would reduce their vulnerability to climate variability and change. Priority strategies were water harvesting, manure/fertilizer use, early planting and use of drought tolerant crops (Appendix 3). Although irrigation has the potential of improving crop productivity in the region, water shortage is a limiting factor as respondents reported drying of rivers and boreholes due to declining rainfall and increased surface temperatures thus its poor ranking. In an earlier study, Bryan *et al.*, (2010) established that farmers in Mbeere had the

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desire to invest in irrigation but are prevented by lack of capital. From the soil analysis carried out at the beginning of the study, soils were mainly deficient in both carbon (0.37% and 0.32%) and phosphorus (8.56 and 9.67mg/kg) for Kiritiri and Siakago respectively, thus requiring use of manure to improve nutrient levels.

Sixteen percent (16%) of the sampled population was doing some form of water harvesting. Early planting and increased use of organic and inorganic fertilizer were ranked 2nd and 3rd at 14.5% and 13% respectively (Figure 19). Strategy no. 4 was use of drought tolerant crops (12.5%). *Crop diversification, replanting and irrigation were coping strategies but only* practiced by 5.75%, 0.75% and 0.5% of the population respectively. Possibly an investment in these three could improve the current crop yields which are below 0.5t ha^{-1} (Figures 9, 10 and 11). Kirwa *et al.*, (2012) in a similar study in Machakos and Makueni counties reported early planting, use of drought tolerant crops, irrigation and adoption of water harvesting technologies as coping strategies ranked in that order. In general, 63% of the sampled populations were applying one or more of the listed coping strategies while 37% applied none. Bryan *et al.*, (2010) similarly reported that between 11-33% households in Mbeere were doing nothing in response to climate shocks, possibly due to lack of information or capital to counter the shock. In Ethiopia and South Africa, 37% and 62 %, respectively did not adapt to perceived changes in climate (Bryan *et al.* 2009). Interventions could possibly involve targeting this population with already identified coping strategies while at the same time improving on their use by those already adopting.

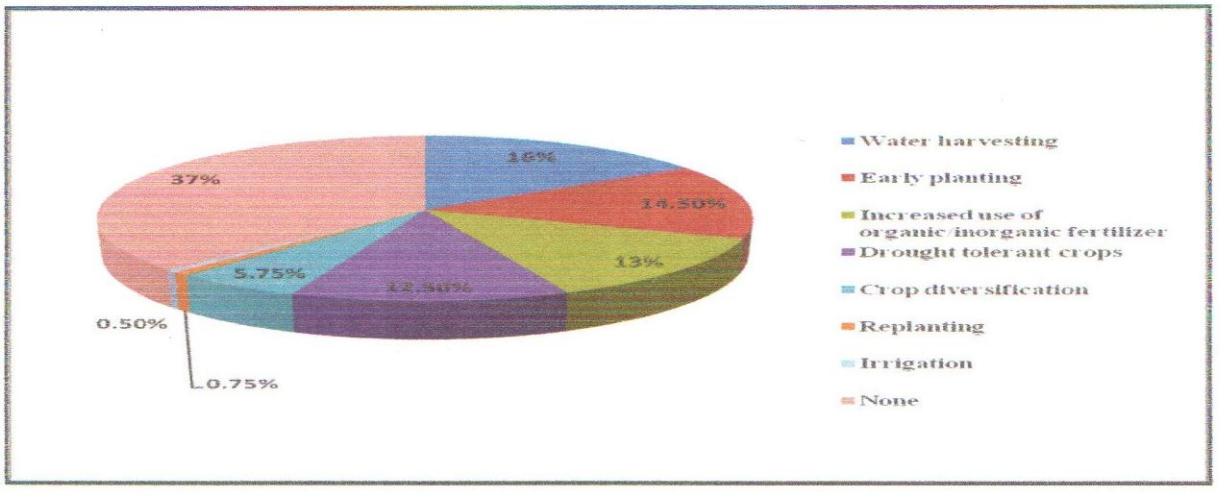


Figure 19. Ranked coping strategies in crop production
Source: field survey, August, 2011

The overall ranking identified water harvesting as the first strategy used by farmers (Figure 19). The study went further to establish the structures used and the result is shown in figure 20. Terraces (38%) and furrows (24%) are the most commonly used water harvesting structures. Other structures mentioned included trash lines, grass strips, trenches and shallow wells. Planting pits (*zai*) were not popular, practiced by only 2% of the sampled population. Most farmers had heard about them but not implemented citing high labour requirement. Normally, farmers use oxen for ploughing/planting hence find it difficult digging *zai* pits. The few respondents who had adopted the technology reported an increase in crop yield with one farmer reporting a 67% increase in maize yield during the 2009/2010 season. For attainment of food self-sufficiency, this could probably be one of the technologies that could be encouraged to cope with the increasing drought events in the region because apart from labour, the technology has no other financial requirement. Farmers could be encouraged to use family labour during the long dry season between June and August. As Ngigi (2009) found out, pit planting combines water harvesting and concentrated application of manure or compost leading to yield increase. This technique could therefore offer a lasting solution for semi-arid areas already vulnerable to increasing incidences of drought events. The *zai* system has been adopted from the Sahel Region of West Africa and is commonly practiced in the East and South Africa (Reij *et al.*, 1996, Hai, 1998). The system has recently been introduced in parts of South Eastern districts such as Kitui and Mwingi and farmers have reported an increase in crop yields.

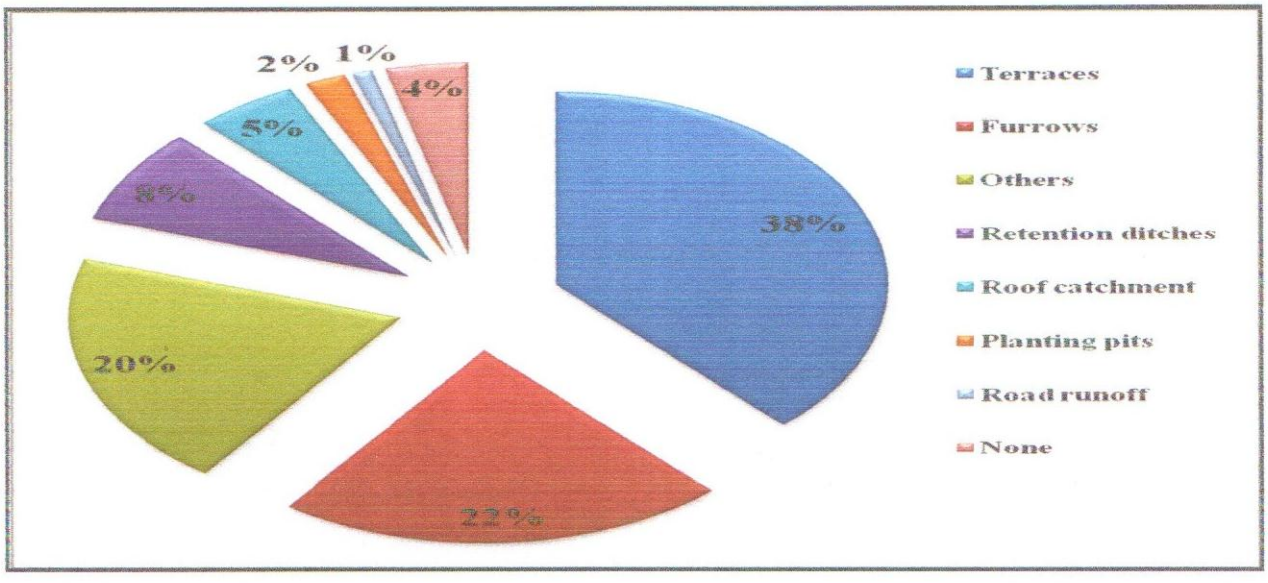


Figure 20. Water harvesting structures used by farmers in Mbeere
Source: field survey, August, 2011

4.5. Effects of zai pit on growth and yield of maize

4.5.1 Seasonal rainfall characteristics during the experimentation period

In both sites, rainfall received during October-November (OND) was higher and better distributed throughout the cropping season compared to that of March-May (MAM) season (Figure 19). Over 70% of the total seasonal rainfall in MAM was received during the month of April while the month of March remained dry in both sites. Since the onset of the rain was in April, most of the rainfall was therefore received during the vegetative phase with only 30% received during flowering and later stages of development. This must have contributed to a reduction in grain yield.

Fifty seven percent (57%) and 46%) of the total OND rainfall was received in November in Kiritiri and Siakago respectively. This was fair distribution as both vegetative and flowering phase of the crop had rainfall and this must have contributed to higher grain yield compared to MAM season. Seasonal rainfall amount ranged from 577 mm to 642 mm in OND and from 276 mm to 291 mm in MAM. The rainfall was concentrated to a limited period of 35-37 days in OND and 20-27 days in MAM (Table 7). This is substantial amount of water, which could produce good grain yield per hectare if all water could be used effectively for crop growth and development. As Rockström, (2003) suggested, there is an urgent need to change from the traditional cultivation practices to more efficient and robust approaches that promote soil and nutrient conservation while channeling more water to the root zone where they have high potential for attaining improved yields.

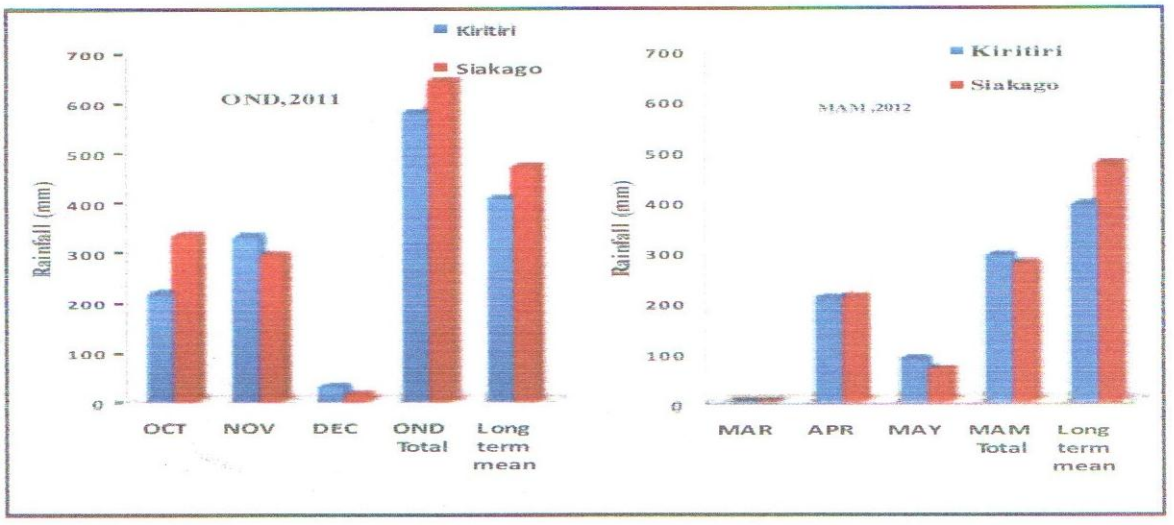


Figure 21. Seasonal rainfall characteristics in Mbeere (2011 and 2012)

Table 7. Number of rainy days, 2011 and 2012

OND ,2011			MAM, 2012		
	Kiritiri	Siakago		Kiritiri	Siakago
Oct	14	15	Mar	0	0
Nov	18	20	Apr	14	18
Dec	5	1	May	6	9
OND Total	37	36	MAM Total	20	27

* A rainy day refers to a period of 24 hours (10:00 am - 10:00 am local time) with at least 1 mm of recorded rainfall amount

4.5.2 Effects of zai and manure on growth and yield of maize

Growth and yield were significant at the 5% level (Table 8) in the two sites and during both seasons. Joint effects of zai and manure (Z_2M_2) were more superior to individual effects of either of the two. In this investigation, the highest grain yield, harvest index and 100 seed weight were observed on (Z_2M_2) treatment with average (2.3 t ha^{-1}), (0.5) and (29g) respectively (Table 8). On the other hand, lowest grain yield, harvest index, and 100 seed weight were obtained from (Z_1M_1) and (Z_2M_1) treatments with average (0.38 t ha^{-1}), (0.23) and (11.9 g) respectively.

While addition of manure improved both growth and yield attributes, a combination of manure and zai pit (Z_2M_2) gave the greatest improvement on growth and yield of maize in the two sites. Means for Z_1M_1 and Z_2M_1 treatments were not significantly different; an indication that manure played a key role to growth and yield improvement. This confirms results of the household survey where use of manure and fertilizer was one of the key strategies to cope with increased rainfall variability (Figure 17) possibly due to its ability to improve not only soil fertility but also other physical properties of the soil like its water holding capacity. Yield and yield attributes were higher during the OND season, an indication that rainfall amount played a key role since rainfall amount was also higher and well distributed during the OND season (Figure 19). Plant height was however significantly higher during MAM season. This could have been due to the fact that there was heavy rainfall during the month of April (Figure 19) which caused water logging in the pits; this resulted in very tall plants with slender leaves which did not positively impact on the LAI and final yield.

In Kiritiri, Z_2M_2 gave the highest grain yield of 2.0 and 1.2 t ha^{-1} in OND and MAM seasons respectively while grain yields for Siakago were 2.3 and 1.4 t ha^{-1} during OND and MAM seasons respectively. Yields from Z_1M_2 were 1.5 and 0.8 t ha^{-1} in Kiritiri and 1.8 and 1.1 t

ha^{-1} in Siakago for OND and MAM respectively. In general yields were higher in Siakago during both seasons. This could be explained by the fact that Siakago lies in a higher agro-ecological zone (LM3), received well distributed rainfall (Figure 18) and has a longer growing period compared to Kiritiri (LM5) as reported in section 3.1. In Kiritiri, grain yield due to combined effects of zai and manure (Z_2M_2) increased by 370% and 213% during OND and MAM while in Siakago, the increase was by 295% and 224% during OND and MAM respectively. On the other hand, grain yield due to manure alone (Z_1M_2) increased by 236 % (OND) and 114 % (MAM) in Kiritiri and by 177% (OND) and 155 % (MAM) in Siakago, compared to the control (Z_1M_1).

The differences in grain yield could be attributed to the additional soil moisture conserved in the zai pits leading to increased crop water use. Further, application of manure is not only known to efficiently conserve soil moisture and improve availability of nutrients but also to improve the soil physical properties (Gaur, 2002). In situ rain water harvesting systems have been reported to increase (rain) water use efficiency by 20-60 % (Kauffman *et al.*, 2003). Increases in maize grain yield due to improved soil moisture conditions and application of FYM have also been observed by Gaur (2002) in a watershed in Rajasthan and by Arora and Hadda (2003) and Hadda *et al.*, (2005) in sub-montane region of Punjab. The combination of zai pit and application of manure promotes some kind of positive synergy effect, which is not obtained by only applying manure to a conventionally tilled field, and definitely not by only changing the tillage from ploughing to pitting, which gave very poor yields across the sites and seasons. More water may have become available in the manured pits through improved pore size and distribution thus increasing infiltration and consequently improving root development.

Table 8. Growth and yield parameters of maize as influenced by *zai* and manure

Treatment	Growth parameters						Yield components					
	Plant height		Number of leaves		LAI		Harvest Index		100 seed wt(g)		Grain yield (ton/ha)	
	OND 2011	MAM 2012	OND 2011	MAM 2012	OND 2011	MAM 2012	OND 2011	MAM 2012	OND 2011	MAM 2012	OND 2011	MAM 2012
KIRITIRI												
Z_1M_1	53.33c	68.9c	8.43c	9.20c	0.453d	0.337c	0.2697c	0.2307d	13.27c	11.90cd	0.433d	0.3801d
Z_1M_2	83.57b	113.2b	11.03b	11.13ab	0.993b	0.837b	0.4315b	0.3591b	17.83b	16.87b	1.455b	0.8129b
Z_2M_1	47.47d	67.4cd	7.27d	8.70cd	0.677c	0.477bc	0.2551d	0.2407c	12.90cd	12.20c	0.614c	0.5153c
Z_2M_2	104.03a	125.2a	11.93a	11.80a	2.407a	1.413a	0.5324a	0.4567a	29.30a	22.60a	2.036a	1.1930a
SED	1.341	4.32	0.1886	0.342	0.0366	0.2073	0.02637	0.00834	0.481	0.446	0.0388	0.01753
LSD (5%)	3.093	9.97	0.4348	0.790	0.0844	0.4779	0.06080	0.0192	1.109	1.028	0.0895	0.04042
%CV	2.3	5.7	2.4	4.1	4.0	33.1	8.7	3.2	3.2	3.4	4.2	3
P value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
SIAKAGO												
Z_1M_1	51.60d	68.0cd	8.267c	9.30cd	0.487d	0.407cd	0.2962cd	0.2406d	15.30d	13.33cd	0.573d	0.429d
Z_1M_2	75.23b	108.2b	10.667ab	11.53ab	1.090b	0.883b	0.4209b	0.3816ab	17.37b	17.27b	1.752b	1.0923b
Z_2M_1	56.50c	68.3c	7.80d	8.63c	0.780c	0.527c	0.2739c	0.2419c	16.13c	14.10c	0.768c	0.555c
Z_2M_2	106.70a	118.7a	10.93a	11.97a	2.867a	1.703a	0.4814a	0.4755a	25.40a	22.83a	2.264a	1.3886a
SED	2.124	2.87	0.1633	0.303	0.0793	0.1138	0.01201	0.01011	0.296	0.434	0.0688	0.02635
LSD (5%)	4.898	6.62	0.3766	0.698	0.183	0.2625	0.0277	0.0233	0.683	1.001	0.1586	0.06077
%CV	3.6	3.9	2.1	3.6	7.4	15.8	4.0	3.7	2.0	3.1	6.3	3.7
P value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001

*** Means within a column (per site) followed by the same letter are not significantly different at P ≤0.05: *M_1-0t/ha; M_2=5 t/ha: *Z_1=No zai; Z_2=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.**

4.5.3 Effect of zai and manure on plant height

The difference in plant height between manure level 1(0 t ha^{-1}) and 2 (5 t ha^{-1}) was greater for maize planted in *zai* pits (Z_2) than those planted on level ground (Z_1). Manure application was beneficial with or without *zai* but it was most beneficial when applied in *zai* pits (Figure 22). Planting maize in *zai* pits together with farm yard manure on average improved plant height much more (Figure 22).The increase in height due to *zai* * manure interaction ranged from 8.9-9 cm and from 10-16.2 cm during OND and MAM seasons respectively. The greater increase in height due to *zai**manure (Z_2M_2) could be attributed to improvement of the water holding capacity of the soil by manure and moisture conservation effect of the *zai* pits. Farmyard manure in the pits improved the nutritional environment and this seems to have promoted plant height and growth of individual leaves by way of active cell division and elongation, which might have increased interception, absorption and utilization of radiant energy, consequently increasing LAI and CGR and thereby overall growth and grain yield. These results support the findings of Singh and Totawat (2002). Plant height was higher during the MAM

season for both sites, perhaps due to the heavy rains received during the month of April (Figure 19) which led to very tall unhealthy plants (Appendix 2, plate1).

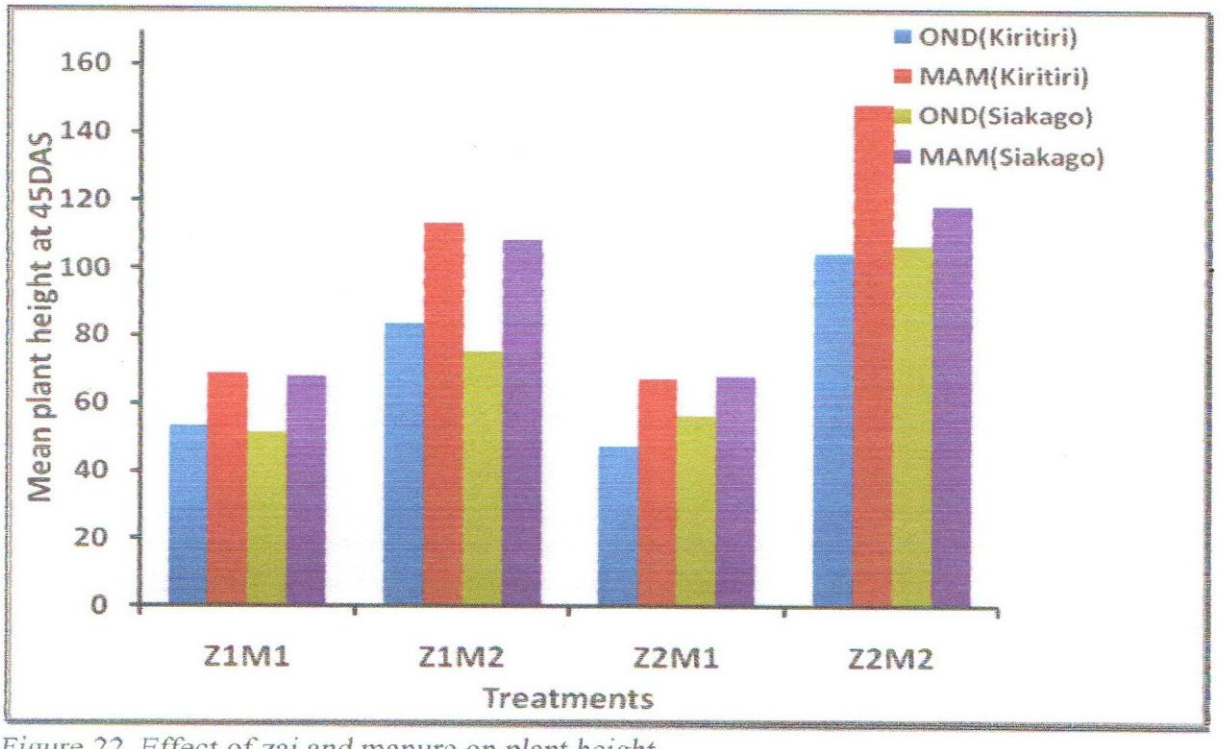


Figure 22. Effect of zai and manure on plant height

*$Manure_1$-0t/ha; $Manure_2$=5 t/ha: *Zai_1=No zai; Zai_2=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

4.5.4 Effect of *zai* and manure on number of leaves

In both sites, planting maize in *zai* pits together with farmyard manure greatly improved the number of leaves during the two seasons although addition of manure alone still increased the number of leaves. Planting maize in *zai* pits without manure was worse than planting on flat ground since it recorded the lowest number of leaves in both seasons and in both sites (Figure 23).The increase in number of leaves due to *zai**manure interaction (Z_2M_2) was highest ranging from 0.6-0.9 while the increase due to manure alone ranged from 0.4-0.5. The greater increase in leaf numbers due to *zai**manure (Z_2M_2) could be attributed to improvement of the water holding capacity of the soil by manure and moisture conservation effect of the *zai* pits. The positive response due to FYM application is due to nutrients availed to the plants after mineralization due to its influence on soil organic matter. Organic matter increases the moisture retention of soils and more importantly improves soil structure and in turn soil porosity. This allows better nutrient uptake and hence better growth.

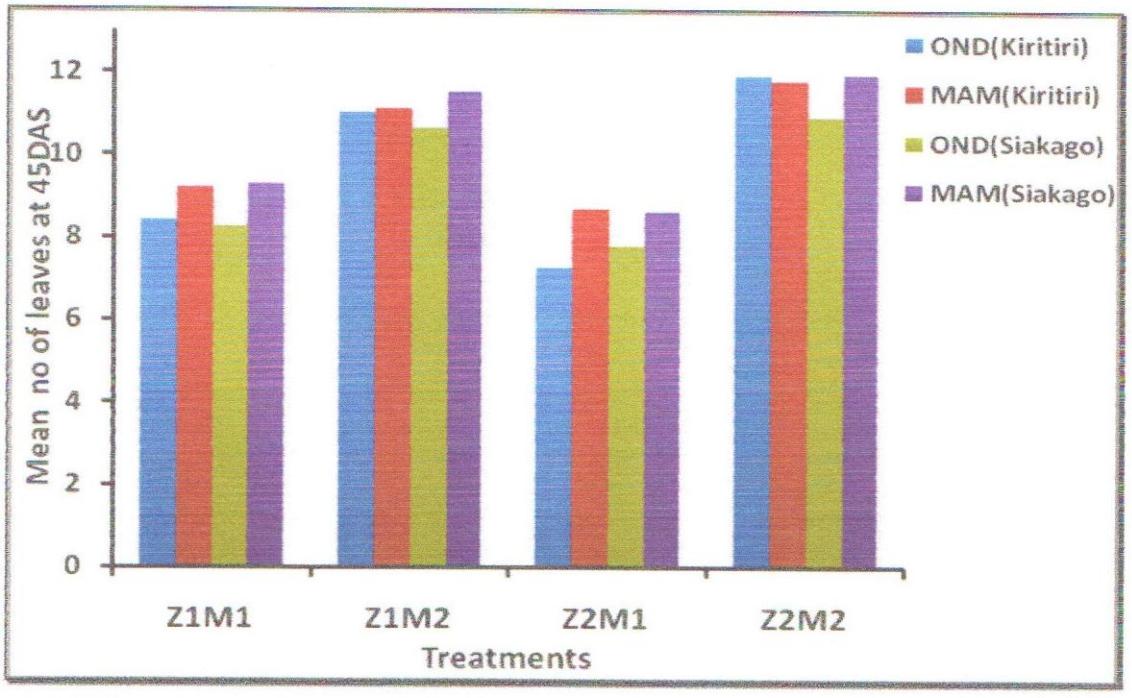


Figure 23.Effect of *zai* and manure of number of leaves

*Manure$_1$-0t/ha; Manure$_2$=5 t/ha: *Zai$_1$=No zai; Zai$_2$=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

4.5.5 Effect of *zai* and manure on leaf area index

The leaf area index (LAI) of a crop at a particular growth stage indicates its photosynthetic potential or the level of its dry matter accumulation. The greater the LAI, the higher the dry matter accumulation potential of the crop and vice-versa. A higher LAI would translate to a higher crop yield. During both seasons, LAI for maize planted in *zai* pits was greater than for maize planted on normal ground but the difference was greater when manure was added to the *zai* pits (Figure 24). The increase in LAI due to *zai* * manure interaction ranged from 0.12-0.36 while the increase due to manure alone ranged from 0.02-0.06. It is therefore more beneficial to use manure together with *zai* pits since the interaction effect of moisture conserved in the pits and manure contributed to higher leaf area index which would in turn lead to higher grain yield. Leaf area index was lower during the long rains (MAM) for both sites.

Analysis of Secondary rainfall data for the two sites revealed that rainfall was not only highly variable during the MAM rainfall season but has been declining (Figures 3-5). Seasonal rainfall data obtained (Figure 21) indicates that MAM received less rainfall and had fewer rainy days compared to OND (Table 7). Rainfall received was poorly distributed since most of it was

received in April. The highly variable nature of the rains during this season makes it less reliable and insufficient for crops to grow to full maturity. A lower LAI during this season must have translated into lower 100 seed weight and overall grain yield reported in tables 13 and 14 respectively. A lower LAI means a reduction in light interception and photosynthesis because both are strongly correlated (Spitters, 1983) and consequently a reduction in grain yield.

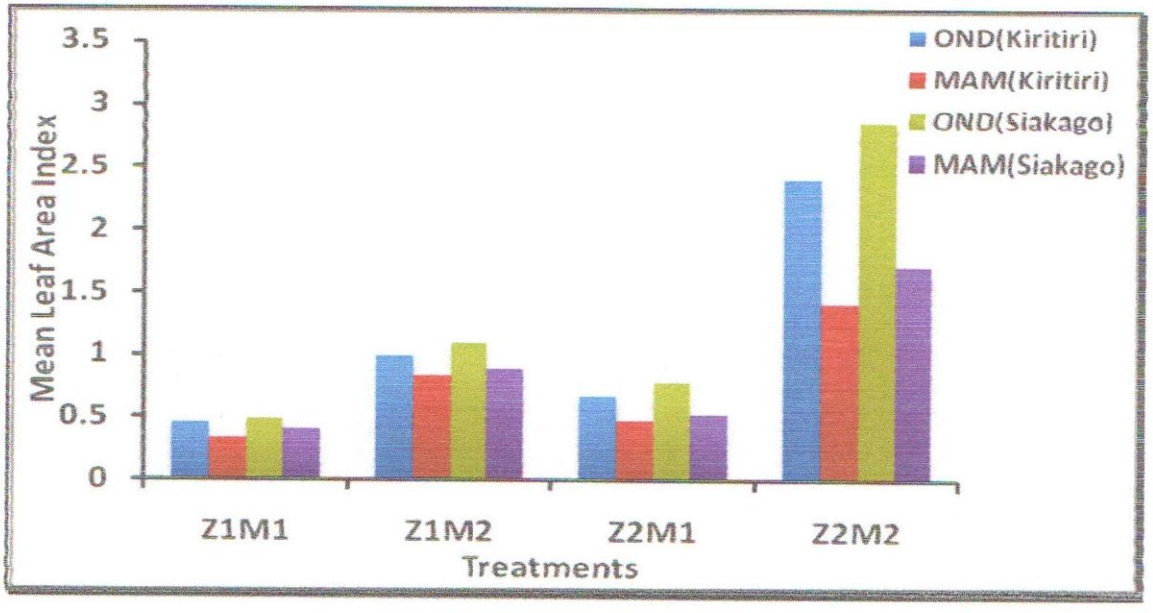


Figure 24 Effect of zai and manure on leaf area index

*Manure$_1$-0t/ha; Manure$_2$=5 t/ha: *Zai$_1$=No zai; Zai$_2$=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

4.5.6 Effect of zai and manure on harvest index

Harvest index (HI) shows the physiological efficiency of plants to convert a fraction of photo assimilates into grain yield. It is an indicator of the amount of dry matter in a season that has been directed to the harvesting portion. Harvest index is computed as the ratio between maize grain yield and aboveground total dry matter production. The presence of any stress such as moisture that may alter plant growth thus affecting the source efficiency may be a limiting factor to the crop's harvest index hence crop yield. In this experiment, Harvest index increased with introduction of *zai* pit technology combined with farmyard manure (Z_2M_2) in both sites during the two seasons (Figure 25).This could be attributed to improved soil fertility and moisture in this treatment. The highest harvest index (0.52) was achieved in Siakago during the OND season for Z_2M_2 treatment while the lowest (0.23) was achieved in Kiritiri during the MAM season for Z_1M_1. OND season had a higher harvest index for both sites, probably because

there was more rainfall during that season (Figure 21). The interaction effect of *zai* and manure increased harvest index by 0.02 and 0.01 in Kiritiri and Siakago respectively. In Kiritiri, addition of manure without *zai* pits did not increase harvest index. Efficient crop and soil management practices could improve grain crop harvest index and consequently grain yield (Ahmad *et al.*, 2007).

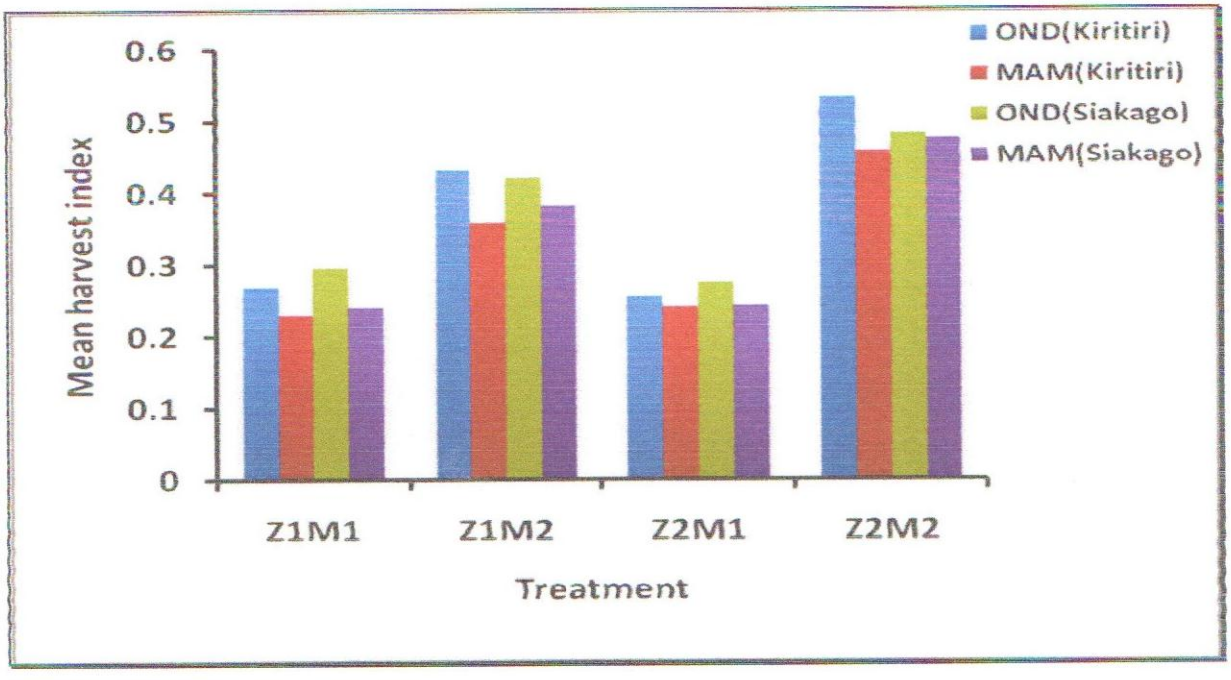


Figure 25 Effect of zai and manure on harvest index

*Manure$_1$-0t/ha; Manure$_2$=5 t/ha: *Zai$_1$=No zai; Zai$_2$=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

4.5.7 Effect of *zai* and manure on 100 seed weight

Interaction of *zai* pits and farmyard manure significantly increased 100 seed weight at $p \leq 0.05$ during both seasons and across the two sites (Figure 26). There was greater difference between *zai* levels 1 and 2 for maize planted with manure than for maize planted with no manure (Figure 26). Interaction of *zai* and manure increased 100 seed weight by 2.29g (12.8%) and 1.14g (6.8%) in Kiritiri and by1.6 (9.2%) and 1.1g (6.3%) in Siakago during the OND and MAM seasons respectively. 100 seed weight was lower during the MAM season. Addition of manure alone (Z_1M_2) still increased 100 seed weight although the increase was not significant. The greatest interaction effect was in Kiritiri during the OND season while the worst was in Siakago during the MAM season.

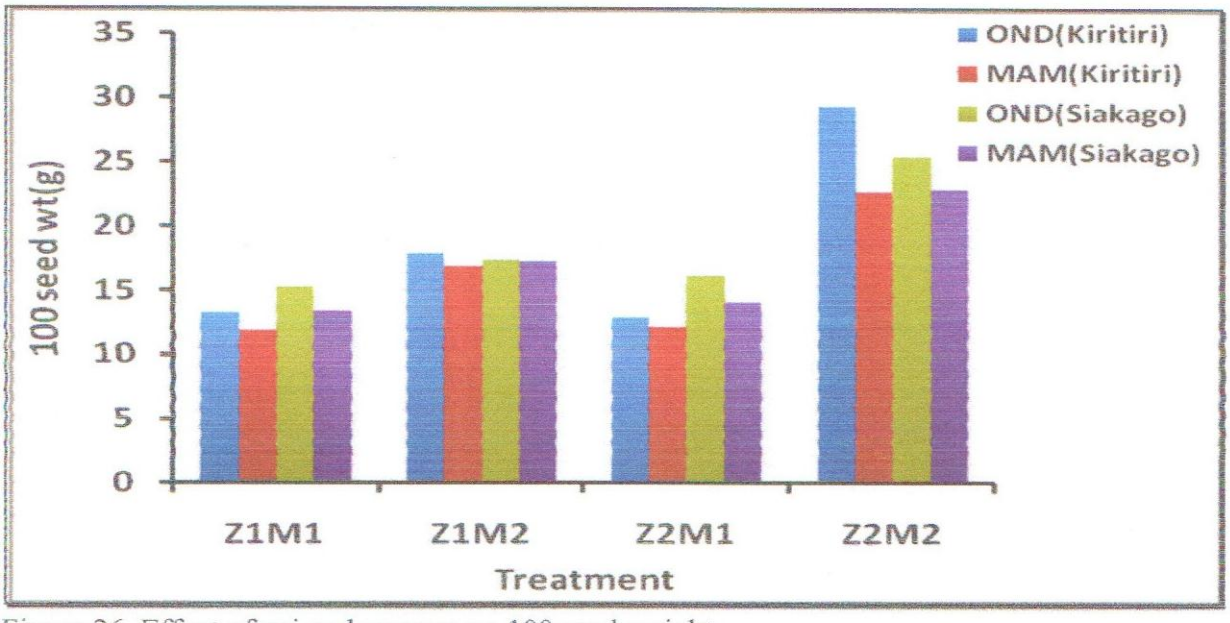


Figure 26 Effect of zai and manure on 100 seed weight

*Manure$_1$-0t/ha; Manure$_2$=5 t/ha: *Zai$_1$=No zai; Zai$_2$=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

4.5.8 Effect of *zai* and manure on grain yield

Combined effects of *zai* and manure pits increased grain yield in both sites during both seasons but the increase was higher during OND season (Figure 27). The difference in grain yield between 0 and 5 tons manure levels was greater for maize planted in *zai* pits (Figure 27). Manure application increased grain yield but the increase was higher when manure was used together with *zai* pits. The combination of *zai* pit and application of manure promotes some kind of positive synergy effect, which is not obtained by only applying manure to a conventionally tilled field, and definitely not by changing the tillage from ploughing to pitting, which gave very poor yields across the sites and seasons. Increase in grain yield could also be attributed to prolonged grain filling period as a result of plants using moisture stored in the pits. *Zai* pits increased infiltration thereby improving root development, thus increasing crop water availability as compared to conventional tillage. More water became available in the manured pits through improved pore size and distribution thus increasing infiltration and consequently improving root development, vegetative growth and consequently grain yield. The increase in grain yields could also partly be attributed to the ability of farmyard manure to promote vigorous growth, increase meristematic and physiological activities in the plants due to supply of plant nutrient and improvement in the soil properties, thereby, resulting in the synthesis of more photo-

assimilates, which are used in grain filling. In Niger, Olaleye *et al.*, (2006) attributed higher yields on zai treatments to a build-up of the soil organic matter contents which may have increased the soil water holding capacity. Within the small-scale agricultural sector it is claimed that with the use of rainwater harvesting (RWH) there is a potential to double current crop yields (Rockström *et al.*, 2002) and lift farmers out of the poverty trap (Barron, 2004).

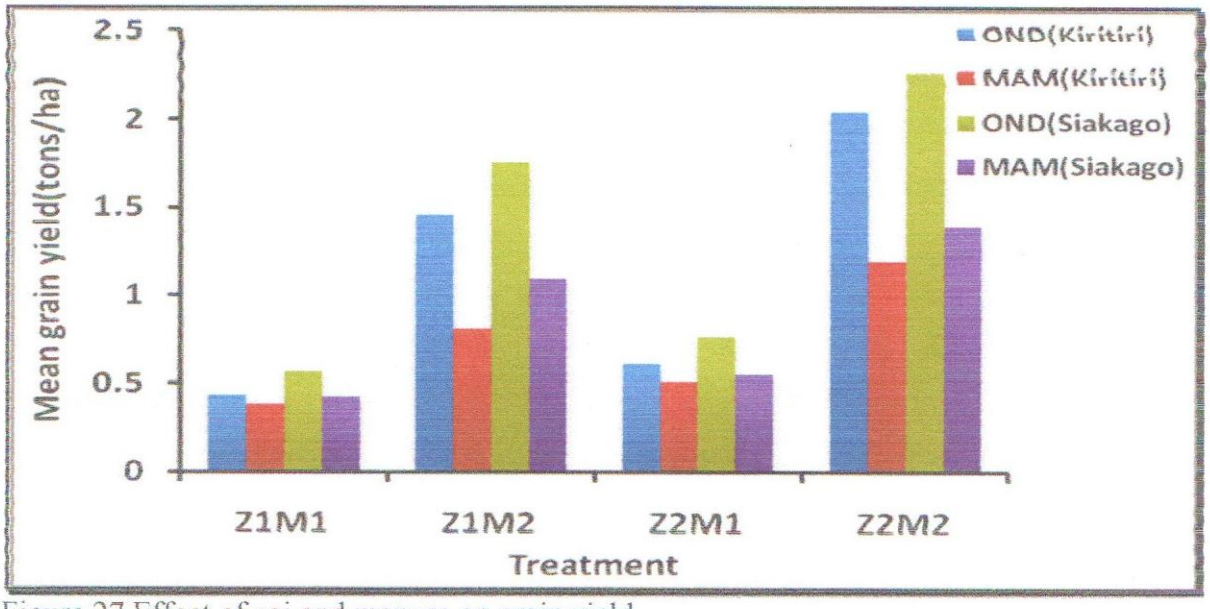


Figure 27 Effect of zai and manure on grain yield

*Manure$_1$-0t/ha; Manure$_2$=5 t/ha: *Zai$_1$=No zai; Zai$_2$=zai pit: * OND=Oct-Dec rains; MAM=March-May rains.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

There was a gradual decline and high variability in both annual and seasonal rainfall with over 50% of the total seasonal rainfall being received in one of the three- month rainy seasons. Both minimum and maximum temperatures (1982-2011) had increased by 0.03^0C and 0.02^0C respectively per year. Local people perceived a reduction in rainfall and an increase in temperature which they perceived had negatively affected crops and livestock resulting in reduced productivity. Moreover, there was a positive correlation between rainfall and crop yields and a negative correlation between crop yields and temperature.

Crop yields gradually declined between 1982 and 2011, generally oscillating below 0.5 t ha^{-1}in the study area. Further, the number of farmers getting yields (of maize, beans, cowpeas and sorghum) below 0.45t ha^{-1} was steadily increasing since 1980. Since these are the main basic foods for the local community, there is need for investment in crop management strategies that lead to yield improvement.

Water harvesting, early planting, increased use of fertilizer/ manure and use of drought tolerant crops were top adaptation strategies ranked in that order. Sixty three percent (63%) of the population was practicing one or more of the identified adaptation strategies while thirty seven percent practiced none at all.

Zai pits increased growth and yield attributes of maize in Mbeere. The *Zai* technology increased grain yield by 40% and 30% in Kiritiri and Siakago respectively. Application of zai+manure however increased yield by 213-370% and 223-295% in Kiritiri and Siakago respectively. The study established an interaction between zai and manure since combined use of zai+ manure was superior to using either manure or zai alone.

Use of *zai* pits and manure under water stress conditions is an important approach in crop management for optimizing productivity. This research has shown that interaction effects of *zai* and manure application can increase the survival capacity of maize under water deficit conditions and increase the overall grain yield. The reasons for yield improvements were two-fold: (1) the water harvesting and conservation effect of the *zai*pit and (2) the soil fertility effect of concentrating manure in the pits. The study concluded that upgrading rain fed small-holder

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farming systems in semi-arid tropics requires addressing occurrence of extremely frequent dry spells through integrated water and soil fertility management. The *zai* pit technology like other in-situ water harvesting and a conservation technique serves to secure crop water availability during critical growth stages and in turn minimize risk of crop failure and stabilize yields. Stabilized yields may be an incentive for farmers to further invest in crop management and farm activities.

5.2 *Recommendations*

This study recommends that farmers be advised to use several if not all identified strategies since they complement each other e.g. early planting of drought tolerant crops with improved soil fertility and soil moisture conservation can guarantee crop yield improvement even in years of depressed rainfall. With over 50% of the seasonal rainfall being received in a single month, soil moisture conservation will play a crucial role in ensuring moisture availability during key stages of crop development and subsequently translate into improved yields.

Thirty seven percent (37%) of the population applied no adaptation strategy at all. The study recommends further investigation as to why they were not applying any measures since most (63%) of their neighbors were doing it. Extension agencies should intensify campaigns among the farming community on the need to use a combination of the identified strategies for enhanced yields and improved food security.

This study did not monitor soil moisture and nutrient dynamics to establish why zai pits and manure improved growth and yield parameters. Further research is therefore recommended in this area.

Finally, this study only tested the effect of *zai* combined with 5t FYM ha^{-1}. There is need for more research with different levels of manure to establish the optimum level of manure that will give maximum crop yield when used in *zai* pits under semi- arid conditions.

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APPENDICES

Appendix 1: List of plates

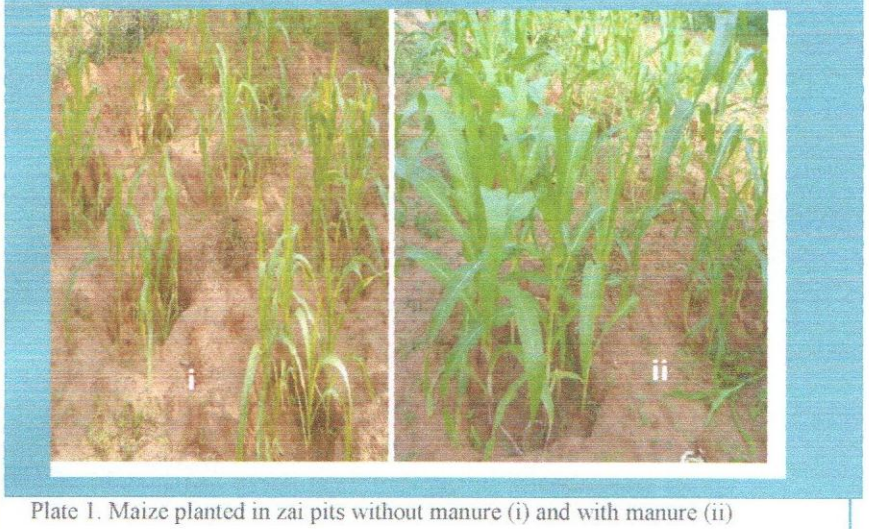


Plate 1. Maize planted in zai pits without manure (i) and with manure (ii)

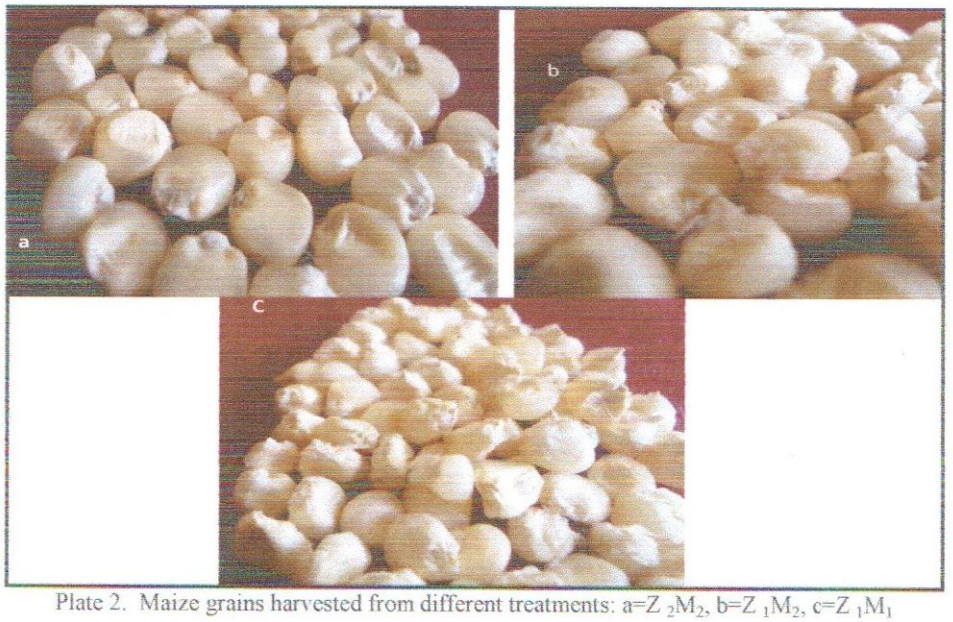


Plate 2. Maize grains harvested from different treatments: a=Z_2M_2, b=Z_1M_2, c=Z_1M_1

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Appendix 2: Household Questionnaire

QUESTIONAIRE NO.....

I am an MSc student at Egerton University carrying out Research in Mbeere District. Its focus is on ***"Assessment of impacts of climate change on agricultural production and community based adaptation strategies within the district"***. Please answer the questions below with utmost sincerity to make the research a success. The information you provide will be treated confidentially.

Ruth M. Mutie (Cell Phone 0722394709) **Enumerator's cell phone No.....Head of Household No**..... (Optional)

(A) Household Information

District.....
Location..... Division.....
Sub-location ..... Village .....
Area of residence.....Urban [ ] Rural [ ]
Agro ecological zone ..... Soil type.....
Average rainfall (mm) per annum.....
Average Temperatures .....^{0}C Min.....^{0}C Max .....^{0}C.

(A1) Information of the household head

Sex	Age in Yrs	Marital status	Formal education	Household size	Source of energy most frequently used	Source of water
1=Male 2=Female		1=Married 2=Single 3=Divorced 4=Widowed 5=Other (specify)	1=Primary 2=Secondary 3=Tertiary 4=others (specify)	People living in the homestead over the last one year	1=Charcoal 2=Fuel 3=Wood 4=Electricity 5=Solar 6=Petroleum products 7=Other(specify)	1=River 2=Bore-hole 3=Tap water 4= Rain water 5=Roof catchment 6=Other (Specify)
[ ]		[ ]	[ ]		[ ]	[ ]

(A.2) HOUSEHOLD COMPOSITION

	Household Member's Name	Sex	Age (Years)	Relationship to the household head	Highest level of Formal education attained	Months resident at the location during the last 12 months	Experience in farming
1							
2							
3							
4							
5							
6							
		1=Male 2=Female		1=Household head 2=Spouse 3=Daughter 4=Son 5=Other relative 6=Other non-relative (Specify)_____			Number of years in farming

(A3) Farm area (in acres)

	Size in Acres	Rental Price (Ksh.) Per acre	Approximate Value (Ksh.) Per acre	Land tenure
1=Owned				
2=Rented				
3= Leased				
4=Others (specify).....				

Codes for land tenure

1=Freehold with certificate/title deed
2= Freehold without certificate/title deed
3= other *(specify)*.....

` (A4) Land use

Land use	Size in Acres	Years in Same use	Rank : 1 for major
1. Homestead			
2. Forest			
3. Subsistence Crops			
4. Cash crops			

5. Livestock			
6.Other *(specify)*			

A 5) Apart from livestock and crops, what other source of livelihood do you have?
1=Making bricks 2=Sand harvesting 3=Making ballast 4=Boda boda 5= selling calabashes and gourds 6=small kiosk 7 =selling bee hives 8= Charcoal burning 9 = others. (*Specify*).....

PART B- GENERAL CLIMATE CHANGE ISSUES

B 1 what are the indicators of the evidence of climate change in your area? ☐

1=Heat Stress 2=Windstorms 3=Change in growing period 4=Fog 5=Change in rainfall amounts (decrease/increase) 6=Change in rainfall distribution 7=Floods 8=Disease occurrence 9= Frequent drought 10 others. (*Specify*).....

B 2 what in your opinion are the causes of climate change? ☐

1=Cutting down of trees 2 = sand harvesting 3 =charcoal burning 4 =planting wrong tree species 5 = others (*specify*) .....

B 3) what extreme events have you experienced in your area in the last 20 years?

EVENT	YEAR OF OCCURRENCE	IMPACTS

- ***If event occurred more than once, indicate all the years***

1=Strong winds 2=*Elnino* rains 3=Severe drought 4=Floods 5=Livestock loss 6= others (*Specify*).....

Impact e.g. 1= famine,2=food shortage in market ,3 = death of livestock 4 =relief food 5 = severe famine 6 =crop failure 7 = others (specify)

B 4) Do you receive weather information? Yes or no ☐

If yes, through what means do you receive weather information?

1=Radio 2=T.V 3=Friends 4=Fellow farmer 5=Internet 6=Mobile SMS 7=Extension officer 8=others. (*Specify*).....

PART C1-C13 IMPACTS OF CLIMATE CHANGE ON CROP PRODUCTION

C1) list down all crops and varieties grown in this area in order of importance

S/No	Before 2000	Currently 2000 to date	which crops have been abandoned	which have shown declining acreage	Which crops have emerged since 1990?
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

1=maize, 2=beans 3=cowpeas 4=Rice 5=Miraa 6=cotton 7=tobacco 8 = sorghum 9=millet

10 = Mango 11 =green grams 12=pigeon pea 13 others (*Specify*).....

C 3 i) what were your crop yields in bags/acre in (Oct-Dec rains)

Crop	2010	2000	1990	1980
Maize				
Beans				
Cowpeas				
Sorghum				

1 = 0-2 bags 2 =2-5 bags 3 = 5-7 bags 4 =7-10 bags 5 = >10 bags 6 = nil

C 3ii) what were your crop yields in the last 4 seasons in bags/acre ☐

	Oct rain 2009	March rains 2010	Oct rains 2010	March rains 2011
Maize				
Beans				
Cowpeas				
Sorghum				

1 = 0- 2 bags 2 = 2-5 bags 3 = 5-7 bags 4 = 7-10 bags 5 = >10 bags 6 = nil

C 4 which crops are most affected by changes in climate (give *3 in order of vulnerability*)

1=maize 2=beans 3=cowpeas 4 = sorghum 5=millet 6=cotton 7=tobacco 8=miraa 9 =mango 10 green grams 11= pigeon pea 12 0thers (*Specify*)…… ☐

C 5) Of the three crops listed, how has climate change affected their production on your farm? ☐

1=increased yields 2 = decreased yields 3= increased pest and disease incidences 4= increased weeds 5= wilting/drying of crops 6 = poor germination 7 = others (Specify)……

C 6) which crops are least affected by climate change in this area? (Give *3 in order of tolerance)*

1=maize 2=beans 3=cowpeas 4 = sorghum 5=millet 6=cotton 7=tobacco 8=miraa 9 =mango 10 = green grams 11= pigeon pea 12 others (*Specify*)……

C 7) what coping strategies have you used in crop production on your farm? .....

1=water harvesting, 2= terraces 3=increased use of manure/fertilizer 4=early planting 5=drought tolerant crops 6=crop diversification 7=replanting 8 = irrigation 9 = staggering planting dates 10 = planting agro forestry trees 11. Others (Specify)……

C 8) which water harvesting structures do you have on your farm for crop production? .....1 = planting pits/holes 2 = water pans 3=furrows 4 = retention ditch 5 = terraces 6 = road run off harvesting 7 =roof catchment 8 = trenches 9 = others (specify) ……

C 9) In C 8 above state for how long you have continuously used each structure

Planting pits …… terraces ……furrows ……road runoff…… Roof catchment ……water pan ……retention ditch……trenches …….

Others (……) 1 = 1 season 2 = 2 seasons 3 =seasons 4 = 4 seasons 5 = more than 2 years

C 10 what factors hinder implementation of C 7 above?

1 = labor intensive 2 = lack of money 3 =inadequate rainfall 4 = high maintenance cost 5 = inadequate technical knowledge 6 gender issues 7 = others (specify) ……

C 11) When weather related changes occur which institutions are in the frontline to mitigate its effects? ☐

1 = Farm Concern International 2=Provincial administration 3=Ministry of Health (MOH) 4=Kenya Forest service (K F S) 5= 6=Ministry of Agriculture (M.O.A), 7=Ministry of Livestock Devt (MOLD) 8= 9 Catholic Diocese –(Kamurugu) 10= SAC DEP 11 = MKEPP 12 = Kilimo Salama 13 = Other *(Specify)*.....

C 12) what specific support do you get from these institutions?

Institution	Support
MOA	
MOH	
KFS	
SAC DEP	
KAMURUGU	
CCS-MAYORI	
FARM CONCERN	
OTHERS	

1=Relief food 2= Relief Seeds 3=Fertilizers 4=Technical training5= Tree seedlings 6 = Crop insurance 7 = others *(Specify)*.....

C 13) what work do the following persons engage in so as to mitigate the effects of climate change?

Men ☐ **Women** ☐ **Young women** ☐ **Young men** ☐

1=Water harvesting structures 2= planting Agro forestry trees 3= planting drought tolerant crops (cassava, s/potatoes/millets) 4=food storage 5. = others *(Specify)*.....

Appendix 3: Ranking of climate change adaptation strategies in Mbeere

Coping strategy	Ranking (%)				Cumulative
	1st strategy	2nd strategy	3rd strategy	4th strategy	
Water harvesting	44	16	3	1	64
Increased use of organic and inorganic fertilizer	31	10	10	1	52
Early planting	17	33	6	2	58
Drought tolerant crops	4	8	33	5	50
Crop diversification	1	1	3	18	23
Irrigation	1	0	1	0	2
Replanting	0	0	1	2	3
None	2	32	43	71	148
Total	**100**	**100**	**100**	**100**	

Appendix 4: List of Anova tables

KIRITIRI SEASON 1 (OCT-DEC, 2011)

Analysis of variance

Variate: Ht_at_45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	159.870	159.870	59.25	<.001	
manure	1	5650.680	5650.680	2094.14	<.001	
zai.manure	1	520.083	520.083	192.74	<.001	
Residual	8	21.587	2.698			
Total	11	6352.220				

Lsd (P ≤ 0.05) = 3.093 **sed = 1.341** **cv% = 2.3**

Variate: Lf_No_at 45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.05333	0.05333	1.00	0.347	
manure	1	39.60333	39.60333	742.56	<.001	
zai.manure	1	3.20333	3.20333	60.06	<.001	
Residual	8	0.42667	0.05333			
Total	11	43.28667				

Lsd (P ≤ 0.05) = 0.435 **sed = 0.1886** **cv% = 2.4**

Variate: LAI_at_45DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	2.009008	2.009008	1000.34	<.001	
manure	1	3.864675	3.864675	1924.32	<.001	
zai.manure	1	1.062075	1.062075	528.83	<.001	
Residual	8	0.016067	0.002008			
Total	11	6.951825				

Lsd (P ≤ 0.05) = 0.0844 **sed = 0.0366** **cv% = 4.0**

Variate: Harvest_index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.005587	0.005587	5.36	0.049	
manure	1	0.144582	0.144582	138.66	<.001	
zai.manure	1	0.010019	0.010019	9.61	0.015	
Residual	8	0.008341	0.001043			
Total	11	0.168529				

Lsd (P ≤ 0.05) = 0.0608 **sed = 0.0264** **cv% = 8.7**

Variate: 100 seed wt_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	92.4075	92.4075	266.56	<.001
manure	1	329.7008	329.7008	951.06	<.001
zai.manure	1	105.0208	105.0208	302.94	<.001
Residual	8	2.7733	0.3467		
Total	11	529.9025			

Lsd (P ≤ 0.05) = 1.109. **sed = 0.481** **cv% = 3.2**

Variate: Grain_yield_tons_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.434983	0.434983	192.38	<.001
manure	1	4.480692	4.480692	1981.64	<.001
zai.manure	1	0.120663	0.120663	53.36	<.001
Residual	8	0.018089	0.002261		
Total	11	5.054427			

Lsd(P ≤ 0.05) = 0.0895 **sed = 0.0388** **cv% = 4.2**

KIRITIRI SEASON 2(March-May, 2012)

Variate: Ht_at_45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	83.53	83.53	2.98	0.123
manure	1	7816.27	7816.27	278.87	<.001
zai.manure	1	136.96	136.96	4.89	0.058
Residual	8	224.22	28.03		
Total	11	8260.98			

Lsd (P ≤ 0.05) = 9.97 **sed = 4.32** **cv% = 5.7**

Variate: Lf_No_at 45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.0208	0.0208	0.12	0.740
manure	1	19.0008	19.0008	108.06	<.001
zai.manure	1	1.0208	1.0208	5.81	0.043
Residual	8	1.4067	0.1758		
Total	11	21.4492			

Lsd (P ≤ 0.05) = 0.790 **sed = 0.342** **cv% = 4.1**

Variate: LAI_at_45 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.38521	0.38521	5.98	0.040
manure	1	1.54801	1.54801	24.02	0.001
zai.manure	1	0.14301	0.14301	2.22	0.175
Residual	8	0.51547	0.06443		
Total	11	2.59169			

Lsd (P ≤ 0.05) = 0.4779 **sed = 0.2073** **cv% = 33.1**

Variate: Harvest_index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.0086829	0.0086829	83.31	<.001
manure	1	0.0889856	0.0889856	853.84	<.001
zai.manure	1	0.0057516	0.0057516	55.19	<.001
Residual	8	0.0008337	0.0001042		
Total	11	0.1042537			

Lsd (P ≤ 0.05) = 0.01922 **sed = 0.00834** **cv% = 3.2**

Variate: 100_grain_wt_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	27.3008	27.3008	91.51	<.001
manure	1	177.1008	177.1008	593.63	<.001
zai.manure	1	22.1408	22.1408	74.22	<.001
Residual	8	2.3867	0.2983		
Total	11	228.9292			

Lsd(P ≤ 0.05) = 1.028 **sed = 0.446** **cv% = 3.4**

Variate: Grain_yield_tons_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.1991369	0.1991369	432.18	<.001
manure	1	0.9249893	0.9249893	2007.47	<.001
zai.manure	1	0.0449787	0.0449787	97.62	<.001
Residual	8	0.0036862	0.0004608		
Total	11	1.1727911			

Lsd (P ≤ 0.05) = 0.04042 **sed = 0.01753** **cv% = 3.0**

SIAKAGO SEASON 1 (OCT-DEC, 2011)

Variate: Ht_at_45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	991.901	991.901	146.60	<.001	
manure	1	4088.521	4088.521	604.29	<.001	
zai.manure	1	529.341	529.341	78.24	<.001	
Residual	8	54.127	6.766			
Total	11	5663.889				

Lsd (P ≤ 0.05) = 4.898 **sed = 2.124** **cv% = 3.6**

Variate: Lf_No_at 45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.03000	0.03000	0.75	0.412	
manure	1	22.96333	22.96333	574.08	<.001	
zai.manure	1	0.40333	0.40333	10.08	0.013	
Residual	8	0.32000	0.04000			
Total	11	23.71667				

Lsd = 0.3766 **sed = 0.1633** **cv% = 2.1**

Variate: LAI_at_45DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	3.213675	3.213675	340.37	<.001	
manure	1	5.427075	5.427075	574.80	<.001	
zai.manure	1	1.650208	1.650208	174.78	<.001	
Residual	8	0.075533	0.009442			
Total	11	10.366492				

Lsd (P ≤ 0.05) = 0.1830 **sed = 0.0793** **cv% = 7.4**

Variate: Harvest_index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.0010947	0.0010947	5.06	0.055	
manure	1	0.0827410	0.0827410	382.32	<.001	
zai.manure	1	0.0051578	0.0051578	23.83	0.001	
Residual	8	0.0017313	0.0002164			
Total	11	0.0907249				

Lsd (P ≤ 0.05) = 0.0277 **sed = 0 .1201** **cv% = 4.0**

Variate: 100_grain_wt_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	58.9633	58.9633	447.82	<.001	
manure	1	96.3333	96.3333	731.65	<.001	
zai.manure	1	38.8800	38.8800	295.29	<.001	
Residual	8	1.0533	0.1317			
Total	11	195.2300				

Lsd (P ≤ 0.05) = 0.683		**sed = 0.296**		**cv% = 2.0**	
Variate: Grain_yield_tons_ha					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
zai	1	0.374251	0.374251	52.77	<.001
manure	1	5.363242	5.363242	756.23	<.001
zai.manure	1	0.074955	0.074955	10.57	0.012
Residual	8	0.056736	0.007092		
Total	11	5.869184			
Lsd (P ≤ 0.05) = 0.1586		**sed = 0.0688**		**cv% = 6.3**	

SIAKAGO SEASON 2 (March-May, 2012)

Variate: Ht_at_45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	87.26	87.26	7.07	0.029	
manure	1	6158.08	6158.08	498.59	<.001	
zai.manure	1	77.32	77.32	6.26	0.037	
Residual	8	98.81	12.35			
Total	11	6421.47				
Lsd (P ≤ 0.05) = 6.62		**sed = 2.87**		**cv% = 3.9**		

Variate: Lf_No_at 45_DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.0408	0.0408	0.30	0.601	
manure	1	23.2408	23.2408	169.02	<.001	
zai.manure	1	0.9075	0.9075	6.60	0.033	
Residual	8	1.1000	0.1375			
Total	11	25.2892				
Lsd(P ≤ 0.05) = 0.698		**sed = 0.303**		**cv% = 3.6**		

Variate: LAI_at_45DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.66270	0.66270	34.10	<.001	
manure	1	2.05013	2.05013	105.50	<.001	
zai.manure	1	0.36750	0.36750	18.91	0.002	
Residual	8	0.15547	0.01943			
Total	11	3.23580				
Lsd (P ≤ 0.05) = 0.1138		**sed = 0.2625**		**cv% = 15.8**		

Variate: Harvest_index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.0068037	0.0068037	44.41	<.001	
manure	1	0.1052223	0.1052223	686.84	<.001	

zai.manure	1	0.0064212	0.0064212	41.91	<.001
Residual	8	0.0012256	0.0001532		
Total	11	0.1196727			

Lsd(P ≤ 0.05) = 0.0233 **sed = 0.01011** **cv% = 3.7**

Variate: 100_grain_wt_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	30.0833	30.0833	106.49	<.001	
manure	1	120.3333	120.3333	425.96	<.001	
zai.manure	1	17.2800	17.2800	61.17	<.001	
Residual	8	2.2600	0.2825			
Total	11	169.9567				

Lsd(P ≤ 0.05) = 1.001 **sed = 0.434** **cv% = 3.1**

Variate: Grain_yield_tons_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	
zai	1	0.133520	0.133520	128.16	<.001	
manure	1	1.681509	1.681509	1614.03	<.001	
zai.manure	1	0.021867	0.021867	20.99	0.002	
Residual	8	0.008334	0.001042			
Total	11	1.845230				

Lsd (P ≤ 0.05) = 0.06077 **sed = 0.02635** **cv% = 3.7**

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