EVALUATION OF LAND COVER AND CROP TYPE CHANGE: BUILDING EVIDENCE ON THE EFFECT OF CROPPING SYSTEMS AND ORGANIC INPUTS ON SORGHUM YIELD AND ENHANCING FARMERS CLIMATE CHANGE ADAPTIVE CAPPACITY

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

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DEDICATION

*I dedicate this thesis to my family; parents Linnet and Peter Agesa and siblings Elvis Igunza and Keight Agesa***.** *Thank you for the never ending love and support throughout my masters programme. God Bless You!*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APSIM	Agricultural Production Systems sIMulator
ASALs	Arid and Semi-Arid Lands
CSIRO	Commonwealth Scientific and Industrial Research Organization
DST	Decision Support Tools
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
GCM	General Circulation Model
GENSTAT	General Statistics
GOK	Government of Kenya
KARI	Kenya Agricultural Research Institute
ICRISAT	International Crop Research Institute for Semi-Arid Tropics
IPCC	Intergovernmental Panel on Climate Change
LR	Long Rains
NMRSE	Normalized Root Mean Square Error
RCMRD	Regional Centre for Mapping of Resources for Development
SRES	Special Report on Emission Scenarios
SR	Short Rains
UNDP	United Nation Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
RMSE	Root Mean Square Error
RR	Range Ratio

GENERAL ABSTRACT

The Arid and Semi Arid Lands (ASALs), which in Kenya constitutes 80% of its landmass, are the most affected by climate change. Crop production is most affected as a result of climate variability with farmers being the most affected in terms of reduced crop yields, poverty and food insecurity. A study was carried out in Yatta sub – County, Kenya to assess farmers' perceptions, coping and adaptation strategies, crop type change within the past two decades in relation to climate change. Additionally, climate change effects on the growth and yield of sorghum under different cropping systems and organic inputs was modelled. A semi structured questionnaire administered to 60 farmers in the two study divisions of Yatta sub - County (Katangi and Ikombe) was used to collect the said information and ground truthing to estafblish the crop type change. Geographical Information Systems using Landsat imageries from the years 1986, 2000 and 2012 were used to assess the change in crop type over the past two decades. Field experiments were carried out in two seasons (short rains from October – December 2010; long rains from May – July 2011;) to determine the effects of cropping systems (monocropping, intercropping and rotation) and organic inputs (farm yard manure and compost) on sorghum performance. A randomized complete block design (RCBD) with a split plot design replicated three times was used. The main plots were the cropping systems while the subplots comprised of the organic inputs. The Agricultural Production Systems sIMulator (APSIM) was employed to model the effects of climate change on the growth and yield of sorghum under the different cropping systems and organic inputs. Correlation coefficient, root mean square error (RSME), normalized root mean square (NMRSE) and range ratio (RR) were used to test the model efficiency. Climate change scenarios were used to simulate future climatic effects on sorghum production under different cropping systems and organic inputs. The farmers in the region were aware of climate change and the major aspects of climate change mentioned were erratic rainfall (62%), low rainfall (43%), prolonged droughts (39%), increased temperatures (35%) and flooding (10%). The major causes of climate change were deforestation (63%), industrial pollution/chemicals (22%) and human activities (8%). Farmers in both divisions observed that reduced crop yield (52%) and crop failure (41%) were significant effects felt as a result of climate change. Introduction of drought tolerant crops (45%), reduced yields (43%) and change in planting time (38%) were the three main impacts of climate change on crop production in Yatta sub – County. The farmers identified early land preparation/planting on time (52%), use of organic and inorganic fertilizers (37%), planting early maturing crop varieties (28%) and water - soil conservation (18%) as the top adaptation strategies to climate change. Significant changes in crop types were also observed with maize and beans covering 72% while traditional crops, shrub land, bare land and riverine forest covered 14, 6, 3 and 5% of the land in 2012 respectively. There was a significant (P=0.000) decline in the area under traditional crops (28.4 and 45.33%), and a significant (P=0.000) increase in maize (41.14 and 140.93%) and beans (363.56 and 8.57%) between the years 1986 – 2000 and 2000 – 2012 respectively. Sorghum yields under rotation cropping system with applied farm yard manure had the highest significant yields (1.380 t/ha) compared to the other treatments. There were no significant differences between the observed and simulated yields with $R^2 = 0.96$ for the short rains and $R^2 = 0.8$ for the long rains and RMSE values of 0.87 t/ha and 0.72 t/ha for the short and long rains respectively with the mean differences between the observed and simulated values averaging to 821 kg/ha for the short rains and 708 kg/ha for the long rains. These results indicated good model performance. The Normalized Root Mean Square Error (NRMSE) was 2.4% for the short rains and 1.48% for the long rains which was low as well as the RR values which were 35.62% and 36% for the long and short rains respectively on the grain yield, both values being low further emphasizing on the good model performance. Climate change in terms of increased temperatures [To+1.6^{0}C (Tmax), To+1.8^{0}C (Tmin)] and reduced rainfall (R_0-10%) had a negative effect on sorghum yields resulting in a mean average biomass yield change of 5% (190.9 kg/ha) in increased temperature as compared to 1.2% (48.04 kg/ha) for reduced rainfall while grain yield reduced by 3.7% (72.5 kg/ha) and 2.4% (44.3 kg/ha) respectively. Increase in rainfall (R_0+10%), and a combination of increase in both temperature and rainfall predicted an increase in grain yields across both seasons at 3.6 (66.4 kg/ha) and 4.7% (89.9 kg/ha) respectively. Therefore this study will act as a benchmark to facilitate achievement of food security through increased crop yields as a result of using organic amendments and cropping systems. To further cushion farmers against the adverse effects of climate change, this study will facilitate capacity building on the effects, adaptation and coping strategies against climate variability as well as encourage the reintroduction of traditional crops such as sorghum through developing management options that will ensure maximum crop productivity using Decision Support tools (DSTs).

CHAPTER ONE

INTRODUCTION

1.0 GENERAL INTRODUCTION

Climate change is among major risk factors impacting on agricultural systems performance and management in many parts of the world (Kurukulasuriya and Mendelson, 2006). Scientific evidence on seriousness of the climate threat to agriculture is now unambiguous, though the exact magnitude is uncertain due to the complex interactions and feedback processes in the ecosystem and the socio – economic circumstances (World Bank Annual Report, 2007).

The agricultural systems and food production in the entire Sub-Saharan Africa (SSA) primarily relies on rain-fed production that is climate sensitive (IITA, 1993) and are particularly vulnerable change impacts because of their limited capacity to adapt. The development challenges that many African countries face are already considerable and climate change will only add to these challenges (FAOSTAT 2010). Developing countries, arid and semi-arid Lands (ASALs) and the poor in society are the most vulnerable and likely to be affected hardest by climate change due to their low adaptive capacity (IPCC, 2000). Climate change coupled with declining soil fertility brings in new challenges to the ASALs environment and other natural resources as it will further deteriorate the prevailing arid and semi-arid conditions.

Over 80% of Kenya's landmass is classified as ASALs characterized by fragile environmental conditions comprising of frequent and prolonged droughts, erratic rainfalls, low and declining soil fertility and persistent conflicts resulting from scarce resources (United Nations 2000). Predictions indicate more severe crop production declines are expected leading to hunger, malnutrition, insecurity and migrations of people and wildlife (United Nations, 2000). Agriculture, however, remains critical for Kenya as a developing country contributing an average of 26% of gross domestic product (GDP) and the main source of employment for majority of the population. With 75 percent of the 9.2 million person labor force engaged in farming, the agricultural sector is the mainstay of the Kenyan economy (GoK, 2002).

Compared to other areas, a large proportion of soils in the semi - arid areas has low inherent fertility and exhibits a variety of constraints among them nutrient deficiency, low organic matter content, moisture stress and high erodibility. It has been observed that moisture stress affects over two thirds of soils in the ASALs while soil fertility degradation has been described as the second most important constraint to food security. Organic matter addition to the soil and cropping systems have been known to have marked effects in the improvement of soil fertility and physical structure as well as water holding capacity (Ugboh and Ulebor, 2011).

Farmers in the ASALs of Kenya currently cultivate a variety of crops, the main being maize, sorghum, green grams, beans and cowpeas under rain-fed agriculture as well as horticultural crops such as mangoes, bananas, tomato, onions, kale, capsicum, pawpaw and citrus (MoA, 2009). Most of the crops are introduced cash crops mostly preferred over traditional crops (crops that have been grown since time immemorial/ neglected and underutilized crops) that were most dominant in the past due to their economic importance though they are not adaptable to the harsh climate conditions of ASAL areas (IPGRI, 1998).

Traditional food crops such as sorghum have been the fundamental sources of food and nutrition since time immemorial, providing food security for local people since they are adaptable to harsh climatic conditions especially in the ASAL areas (Shava 2005; Asafo-Adjei 2004). However, with the introduction of exotic cash crops, traditional crops have been marginalized and excluded by introduced/exotic crops and conventional agricultural practices and their value as food sources has declined as they have been superseded by commercialized hybrid food crop varieties (Shava 2005; Asafo-Adjei 2004). It is important therefore to establish the trend at which the traditional crops have been abandoned and replaced by introduced/exotic crops.

Over the years, remote sensing techniques and Geographical Information Systems (GIS) have proven to be efficient tools to monitor agricultural activities as they provide methods for analysis of land use and tools for modelling and planning purposes. Despite this, many limitations are encountered in the operational usage of the tools to estimate cropped areas for instance due to cloud cover which may preclude the use of satellite images in some periods of the years (Asner, 2001). Consequently, the integration of remote sensing techniques with ground surveys has been the focus of research in past years (Pradhan, 2001; Epiphanio et al., 2002; Gallego, 2004). By understanding the driving forces behind crop type change and managing the current situation with modern Geographical Information System (GIS) tools, it becomes possible to develop plans for multiple uses of natural resources in view of the ever changing climate. To achieve this, a detailed knowledge of the effects of climate change on agricultural activities is the first step in the development of strategies towards adequate and sustainable food production through better understanding of farmers' perceptions of climate change and ongoing coping and adaptation measures.

Since agriculture production remains the main source of income by most rural communities in the region, farmers adaptation to climate change is imperative to enhance the resilience of the agriculture sector hence protecting the livelihoods of the poor and ensuring food security. Adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to climate change and variability, moderating potential damages and helping them cope with adverse consequences (IPCC 2001).The ability of communities and agricultural stakeholders in SSA to cope better with the constraints and opportunities of current climate variability must first be enhanced for them to be able to adapt to climate change and the predicted future increases in climate variability (Cooper et al., 2008). Olorunfemi (2009) indicated that timely and useful information is necessary about the possible consequences of climate change, people's perceptions of those consequences, available adaptation options, and the benefits of slowing the rate of climate change.

Adaptation to climate change includes many possible responses such as changes in crop management practices, choice of crop to plant, fields, planting date and cropping densities and crop varieties. Planting a range of drought-tolerant crops such as sorghum reduces the risk of total loss during drought because they are readily available, and have been grown for generations in the ASALs and is one of the major crops widely grown by the resource poor farmers in the semi-arid parts of Kenya for subsistence and as a source of income (Macharia, 2004).

In Kenya, sorghum is ranked the third among cereals and is grown principally in the often drought prone marginal agricultural areas of Eastern, Nyanza and Coastal regions. According to FAO estimates, in 1999–2003, production in Sub-Saharan Africa was 19.0 million t/year from

22.8 million ha which indicates a decline in its production. C4 plants are often considered to have mastered the art of drought control particularly as they are able to maintain leaf photosynthesis with closed stomata. Sorghum, for example, is considered to be better adapted to water-limiting environments than most other crops such as maize (Sanchez *et al.*, 2002). Sorghum is adapted to warm and dry climate and also stays greener than other crops under water stress and therefore continues to photosynthesize during drought (Jones et al., 2001). By virtue of the significance the traditional crops hold, there is need to promote these crops, however with the climate change challenge, there is need to come up with technological packages that can address effects of climate change on crop production. Tools and approaches are now available that allow for a better understanding, characterization and mapping of the agricultural implications of climate variability and can be made possible through the application of Decision Support Tools (DSTs)

Crop growth is a very complex phenomenon and a product of a series of complicated interactions of soil, plant and weather. Dynamic crop growth simulation modeling is a relatively recent technique that facilitates quantitative understanding of the effects of these factors and agronomic management factors on crop growth and productivity. These models are quantitative description of the mechanisms and processes such as crop physiological, meteorological, physical and chemical processes that result in growth of the crop (Bouman *et al*., 1994). Such a modeling assumes that the rate of change of system can be closely approximated by considering the rate of processes to be constant during short time periods based on state variable approach in which current states such as weight of plant parts, evapotranspiration and leaf area index are updated after every short interval considering the previous state and the rate which is influenced by internal crop properties and environments (Bouman *et al*., 1994).

The application of crop simulation models to study the potential impact of climate change and climate variability provides a direct link between models, agro-meteorology and the concerns of the society (Deressa *et al.*, 2005). As climate change deals with future issues, the use of General Circulation Models (GCMs) and crop simulation models provides a more scientific approach to study its impact on agricultural production and world food security. This approach will presumably anchor well with farmers who in the past have expressed pervasive dissatisfaction with research and development aimed at providing the “quick fix”, and has increasingly become interested in the development of research methodologies that address the long term economic and ecological issues (Carberry *et al*., 2004; Dimes, 2005). The use of such models, with long runs (30 years or more) of daily climatic data thus provides a quick and much less costly opportunity of ‘accelerated learning’ compared with the more traditional multi-seasonal and multi-factorial field trials (Carberry *et al.,* 2004).

In Kenya crop simulation models have been successfully used in the interpretation of research results in complex and highly variable cropping systems (Shisanya, 1996). However, sophisticated models of soil-water-dynamics like WOFOST or CERES including all climatic, soil-hydraulic and plant physiological parameters show a very limited success in forecasting yield potentials on a regional level (Rotter, 1989; Hornetz, 1997). Moreover, they do not have the capability to predict the impact of climate change on crop production and biophysical and socio economic factors. However, Agricultural Production System Simulator (APSIM), which is a soil – crop modelling tool, contains well-tested algorithms that deal with temperature effects on crop growth and development as well as soil water and nitrogen dynamics (Ncube, 2007) hence its advantage over most crop models. It is a modelling framework that allows individual modules of key components of the farming system to be plugged in (McCown *et al.,* 1996). The model includes a ‘climate change’ module that allows temperature and rainfall data to be adjusted by nominated amounts and, for some crop modules, includes carbon assimilation algorithms that respond to increased carbon dioxide (CO_2) cconcentrations.

In this study, the APSIM model will thus provide an opportunity to explore not only today’s issues of agronomic management but also the long-term prospects for sustaining agricultural production in the ASAL areas of Kenya. It is therefore hypothesized that use of the APSIM model will be a powerful tool for predicting the impact of climate change on soil and agronomic factors of sorghum growth and development in the ASALs (McCown, *et al.*, 1996).

Improved understanding of the potential effects of climate change on growth and performance of sorghum is central to planning appropriate and timely responses hence the need to model the effects of climate change on the crop in the ASALs of Kenya.

1.2 STATEMENT OF THE PROBLEM

Climate change in the form of higher temperature, reduced rainfall and increased rainfall variability reduces crop yield and threatens food security in low-income and agriculture-based economies especially the ASALs (IAC, 2004; IPCC, 2001). The dilemma facing agriculture in Africa and most of the other third world countries especially the ASALs is how to achieve sufficient food production in the face of declining soil fertility and productivity coupled with rising costs of agricultural inputs and intensive and continuous cultivation of land due to increasing population (Adetunji, 1997). Much of Africa lags behind other regions in its present capacity to produce food to feed the ever increasing population (FAOSTAT, 2010). Sub – Saharan Africa is majorly affected by declining soil fertility. However, mineral and organic fertilizer use is usually low in these regions (de Jager *et al.,* 2003). In the dry parts of Kenya, the problem of soil fertility is exacerbated by the vagaries of weather, especially rainfall. Consequently, risk-averse farmers are unwilling to invest in fertilizers and other inputs that are required for high levels of agricultural production. (Giller *et al.,* 1998). However, despite this, economic emphasis has been on the production of exotic crops like maize and beans which require a lot of inputs for enhanced production at the expense of traditional crops which are more resilient and adaptable to the prevailing conditions in the ASALs. Most of the traditional crops, including sorghum, have been marginalized and excluded by the introduction of exotic crops due to their economic importance (IPGRI, 1998). Most studies related to the interaction between crops and climate in the arid and semi-arid areas have concentrated more on crops such as maize, rice, cotton cultivar improvement, pests and diseases and neglected the traditional crops (Taylor, 2002).As a result, most farmers will remain poor and vulnerable to future climate shocks. The exact nature and impacts of climate change on temperature and rainfall distribution patterns remain uncertain with very little research work having been done on sorghum in relation to its interaction with climate. It is therefore important to increase crop productivity through improved soil fertility and reintroduction of traditional crops and increasing crop resilience and farmer adaptation through predicting effects of climate variability on crop production.

1.3 JUSTIFICATION OF THE STUDY

With the current cllimate variability and declining soil fertility, crop yields are expected to severely decrease especially in the ASAls. It has therefore become paramount to help farmers better adapt and cope with climate change in order to cushion them against adverse climate change effects. Agricultural production could therefore be increased by doubling the crop areas or by investing in agriculture management and technology. The former is not an option due to the ever increasing human population that has put pressure on the land resources available and has threatened food security.

The fact that climate has been changing in the past and continues to change in the future implies the need to understand how farmers perceive climate change and adapt in order to guide strategies for adaptation in the future especially in the ASALs. Given this scenario, integrated nutrient management (INM) which refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner such as the use of organic inputs and cropping systems are thus seen as one of the most important strategies for increasing crop production in these areas, while simultaneously conserving the environment.

Traditional crops are typically hardy and well suited and adapted for the ASALs as compared to exotic/introduced crops. Reintroduction of these traditional crops that are more drought tolerant will ensure food supply throughout the year with ecological and nutritional significance as well as surplus food for income and crop diversity. Cultivating these crops with the application of organic inputs will further increase the soil fertility levels and the moisture levels in the soils in the ASALs where unreliable and erratic rainfall is frequent and inherently lead to increased food sufficiency.

To cushion against the adverse effects of climate change, it is necessary to predict climate change effects to enable farmers better prepare on how to adapt to climate variability. There is need therefore to understand this variability through use of decision support tools like APSIM with an intention of reducing climate change impacts on crop production particularly sorghum in the area through predicting crop performance as a result of climate change. APSIM is most suitable because of its ability forecast yield potential and predict impact of climate change on crop production, biophysical and socio economic factors as opposed to other models.

1.4 RESEARCH OBJECTIVES

1.4.1 Broad objective

To contribute towards current and future sorghum crop yields through interaction of legumes and use of organic inputs in smallholder farming systems of the ASALs of Kenya

1.4.2 Specific objectives

1. To determine farmer’s perception, coping and adaptation strategies on climate change.
2. To assess trends in land cover and crop type change in Yatta sub - County over the past two decades.
3. To calibrate and validate APSIM model to simulatre growth and yield of sorghum under different cropping systems and organic inputs and climate change scenarios

1.5 Research hypotheses

1. Farmers are aware of climate change and its causes and have devised various adaptation and coping strategies to climate change.
2. There is a distinct trend in land cover and crop type change in Yatta sub - County due to climate change over the past two decades.
3. The APSIM model will effectively simulate the effect of climate change on growth and yield of sorghum under different cropping systems and organic inputs.

CHAPTER TWO

2.0 GENERAL LITERATURE REVIEW

2.1 Climate change in Africa

Many areas in Africa are recognized as having climates that are among the most variable in the world on seasonal and decadal time scales (UNFCC, 2007). Climate change scenarios (Washington *et al*., 2004; Stige *et al*., 2006) like higher temperatures for most of Africa for example mean annual temperatures in Sudan increased significantly by 0.076 to 0.2 C per decade specifically in the central and the southern regions (Elagib and Mansell, 2000). Projections for precipitation trends include slight increases in West Africa and slight decreases in Southern Africa. African rainfall has changed substantially over the last 60 years whereby during 1961-1990 it declined by up to 30% compared with 1931-1960 (Sivakumar *et al*., 2005). Semi-arid and sub-humid zones of West Africa (1968-1997) decreased by 15-40% (Nicholson *et al*. 2000) while the Sahelian region (1930s and 1950s) decreased by 20-30% (Hulme, 2001)

It is universally accepted that climate change is one of the greatest challenges facing humanity this century. Kenya like the rest of the world is experiencing climate change and variability and the associated adverse impacts. This phenomenon is intensifying at an alarming rate as is evident fron countrywide temperature increases and rainfall irregularity and intensification (NCCRS, 2010). The Kenya Meteorological Department (KMD) has provided data of temperature and rainfall changes in Kenya over the last fifty years. From the early 1960s, Kenya has generally experienced increasing temperatures over vast areas with observations showing the average annual temperatures increased by 1^0C between 1960 – 2003 and the drier regions being higher by 1.5^0C. There is a projected increase in temperature by 2060 to 2.8^0 C and by 2100 temperatures could increase up to 4^0C. These incidences of climate change and variability present a number of socioeconomic and environmental challenges and opportunities for Kenya (UNEP, 2009).

2.1.1 Climate Change and agriculture

Climate is a generalization of weather changes and is represented by a set of weather conditions in a given spatial area over a given time interval (Gruza et al., 2004). A statistical description in terms of means, extremes, variability indices for certain parameters, and frequencies of events over a given time period is used for climate characterization. As such any climatic variables can be used for scientific analysis of climate variability and changes, and any base periods including those different from 30 years can be used for estimating deviations from averages. Climate Variability and Change (CVC) is an important socio-economic and environmental issue. It is defined by (Molla et al., 2011) as a shift in the mean state of the climate or its variability, persisting for an extended period, decade or longer (or a continuous spectrum of changes in meteorological and oceanic characteristics, (Gruza et al., 2004).

Climate is an essential component of the natural capital. In many regions of the world, such as Africa, climates are extremely variable from year to year. Climate change in the form of higher temperature, reduced rainfall and increased rainfall variability reduced crop yield and threatens food security in low income and agriculture based economies (IPCC, 2001). Adverse climate change impacts are considered to be particularly strong in countries located in Sub Saharan Africa such as Kenya that depend on Agriculture as their main source of livelihood.

It seems obvious that any significant change in climate on a global scale should impact local agriculture, and therefore affect the world's food supply. Considerable study has gone into questions of just how farming might be affected in different regions, and by how much; and whether the net result may be harmful or beneficial, and to whom. However, several uncertainties limit the accuracy of current projections.

In terms of the role of agricultural productivity in reducing poverty, Thirtle *et al*. (2001) concluded from cross-country regression analysis that, on average, every 1% increase in labour productivity in agriculture reduced the number of people living on less than a dollar a day by between 0.6 and 1.2%. No other sector of the economy shows such a strong 10 correlation between productivity gains and poverty reduction. Poverty remains a predominantly rural problem and agriculture is generally central to rural livelihoods. Some 70% of the workforce in sub-Saharan Africa is at least partly engaged in agriculture (Maxwell, 2001). Therefore, any improvement in rural incomes should – if only by sheer weight of numbers – have a major impact on poverty.

2.1.2 Climate change in the Arid and Semi - Arid lands of Kenya

The ASAL areas in Kenya cover 48 million hectares, of which 9.6 million hectares supports agriculture, almost 15 million hectares are only suitable only for largely sedentary livestock production and the remaining 24 million hectares are dry and suitable for nomadic pastoralism (NEMA, 2003). ASAL areas in Kenya are home to about 30% (about 10 million) of human and 50% of livestock populations respectively, and are habitat to about 75% of wildlife, the backbone of Kenya's tourism sector. Population has also significantly increased in Kenya undermining the coping ability of most communities, particularly in the ASAL areas hence rendering people more vulnerable. The recurrence and intensity of droughts has increased in Kenya, particularly affecting ASAL areas, which now experience droughts almost on an annual basis.

The inhabitants of the Arid and Semi-Arid Lands (ASAL) of Kenya are among the poorest and most vulnerable populations on the planet. They suffer from an increasing array of both natural and human-made shocks that serve as effective barriers to productive and sustainable livelihoods and relegate a majority of the population to a state of chronic poverty. The increasing frequency of droughts, floods and climate-related disease epidemics coupled with unfavourable socio-economic trends and underdeveloped infrastructure highlights the predicament facing Kenya's ASAL populations and institutions concerned with their welfare and development. Kenya's economy depends largely on its natural resources through agriculture, livestock production, fisheries, forestry, tourism and agro-based industries (UNEP and GoK, 2000). Agriculture is the main economic sector contributing 16.6% of the Gross Domestic Product (GDP). Of the 53% economically active population, approximately 74% is employed in agriculture. About 80% of all people working in agriculture are smallholders. The country often has food deficits as a result of periodic droughts and low access to production resources. In the ASALs, about 2 million people are permanently on famine relief and the number sometimes rises to 5 million during severe droughts. Despite 80% of the country being ASAL, agriculture in Kenya is predominantly rain-fed making it highly vulnerable to climate change.

2.1.3 Adaptation to climate change

Because of the speed at which climate change is happening due to global temperature rise, it is urgent that the vulnerability of developing countries to climate change is reduced and their capacity to adapt is increased and national adaptation plans are implemented. Future vulnerability depends not only on climate change but also on the type of development path that is pursued. Thus adaptation should be implemented in the context of national and global sustainable development efforts. The international community is identifying resources, tools and approaches to support this effort. (UNFCC, 2007)

In order to cushion the agricultural sector against the impacts of climate change, it is important to identify adaptation and mitigation needs of the country. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). It reduces vulnerability and increases resilience. It helps to reduce the risks associated with climate change and is now widely recognized as an equally important and complementary response to climate change impacts. Adaptation therefore is a vital part of Kenya's response to a problem that will disproportionately affect the poor. Common adaptation methods in agriculture include producing and promoting of drought tolerant, diseases and pest resistant as well as early maturing crop varieties; promoting orphan crops such as sorghum, cassava, pigeon pea, sweet potato; promoting agricultural produce post-harvest processing, storage and value addition, use of new crop varieties and livestock species that are better suited to drier conditions, irrigation, crop diversification, adoption of mixed crop and livestock farming systems, and changing planting dates (Bradshaw *et al*., 2004; Kurukulasuriya and Mendelsohn, 2008; Nhemachena and Hassan, 2007).

2.1.4 Land cover and crop type change

The need to provide food, water and shelter to people worldwide has led to changes in land use/cover such as forests and agricultural lands. Researchers have in the past decades recognized the need to understand how land use/cover change processes link to broader changes in the global environment and how environmental sustainability can be achieved. Enormous efforts have been made to understand the driving forces of land use/cover change and to develop regionally and globally integrated models of land use/cover change (Lambin *et al*., 1999). The great interest in land use/cover results from their direct relationship to many of the earth's fundamental characteristics and processes, such as land productivity, diversity of plant and animal species, and the biochemical and hydrological cycles (De Sherbinin, 2002). Land cover is transformed by land-use changes, for example, forest can be converted to agricultural land or pasture. Overgrazing and other agricultural practices lead to land degradation and desertification. Its recognised that, a systematic analysis of local scale land use/cover change studies, conducted over a range of timescales, helps to uncover general principles to provide an explanation and prediction of new land-use changes (Lambin *et al*., 2003).

Mutie *et al*. (2006) analysed land cover change of the trans-boundary Mara River Basin from dry season LANDSAT MSS, TM and ETM images of 1973, 1986 and 2000 respectively. Digital image analysis using IDRISI showed that between 1973 and 2000, forests and shrub-land had reduced by 32% and 34% respectively. Grass-land, savannah and water bodies reduced by 45, 26, and 47% respectively. However agricultural land, tea and open forests, and wetlands all increased by over 100% as a result of land use pressure in the basin.

Research work by JICA (1992) in Lake Victoria Basin found that, replacement of indigenous vegetation by exotic plantations had reduced interception of storm water, increased peak flows and loss through evapo-transpiration by about 18%**.** Results from the work done in Itare sub-catchment within the Lake Victoria Drainage Basin, of Kenya indicated that, there has been a tremendous change in land use in the catchment, with more conspicuous being the reduction in forest cover by 33% and increased land under the various uses such as urbanization, development of road network, provision of social facilities, agriculture and settlement (Nyangaga, 2008).

In the case-study of Nzoia River Catchment by Patts *et al.* (2010), area under forest cover decreased between 1970's and 1986 by 6.4% in the northwest and south of the catchment. But between the 1980's and the 2000's there was an increase in area under forest cover by 41.3% as a result of afforestation. Agricultural land use showed an increase in areal coverage between 1970's and 1986 by 6.7%, but in the year 2000's the agricultural activities declined by 4.6%. The area under bush-land, shrub-land or riverine agriculture increased between the 1970's, 1986 and the 2000's by about 123.4% and 11.10% respectively

Simple agro climatic indices combined with GIS have been used to provide an initial evaluation of both global agricultural climate change impacts and shifts in agricultural suitable areas in particular regions. The agro climatic indices are based on simple relationships of crop suitability or potential to climate (e.g., identifying the temperature thresholds of a given crop or using accumulated temperature over the growing season to predict crop yields; e.g., Holden, 2001). This type of empirically derived coefficient is especially useful for broad-scale mapping of areas of potential impact.

When combined with a spatially comprehensive database of climate, crops, and GIS, simple agro climatic indices are an inexpensive and rapid way of mapping altered crop potential for quite large areas. Applying agro climatic indices in Africa (Badini et al., 1997) has provided understanding of the relationships between the weather, soils, and agricultural production systems and the complexities associated with their variability. Carter and Saarikko (1996) describe basic methods for agro climatic spatial analysis.

2.1.5 Farmer's perceptions on climate change

The degree to which an agricultural system is affected by climate change depends on its adaptive capacity. Indeed, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences (IPCC 2001). Thus, the adaptive capacity of a system or society describes its ability to modify its characteristics or behavior so as to cope better with changes in external conditions.

According to Adegeye and Dittoh (1985), most agricultural decisions are taken in the environment of risks and uncertainty. Farmers will have to make decisions now, which will affect their production later. The farmers are not sure of weather, government policies, and new changes in technology – factors which make it difficult for them to predict the future with certainty. Farmers are unable to take actions which will extricate them from poverty because they are poor. The vicious circle of poverty takes many forms but one key element in many versions of the spiral, in any country or environment, is risk aversion. If poor people are risk-averse to the extent that they are unwilling, to invest in the acquisition of modern assets because that involves taking risks, they will remain poor. (Mosley and Verschoor, 2003).

Recent research shows that farmers have a rich understanding of the problems and solutions to soil fertility (Mairura *et al*., 2007; Moges and Holden, 2007). Continued degradation may imply that adoption of corrective technologies is either too slow or limited, probably owing to the nature of the technology itself, socio-economic and institutional factors (Makokha *et al*., 1999). Research findings however, indicate that technologies and the underlying knowledge have not been disseminated adequately to farmers and therefore still have had little effect at the farm level (Devel and Ramisch, 2004). The need for improved dissemination of knowledge (Semalulu *et al*. 1999), and active participation by farmers, the local administration and the communities in general (Dofoer, 2000), are considered most appropriate.

Communities must build resilience (UNFCCC, 2007); adopting appropriate technologies while making the most of traditional knowledge, diversifying their livelihoods to cope with current and future climate stress, local coping strategies and traditional knowledge need to be used in synergy with government and local interventions.

A study carried out in the Nile Basin of Ethiopia to determine farmers' choice of adaptation methods analyzed the factors affecting the choice of adaptation strategies to climate change based on a cross-sectional survey data collected during the 2004/2005 agricultural production year in the Nile basin of Ethiopia. The farmers indicated to have observed changes over the past 20 years on climatic conditions and were trying to adapt through soil conservation, different crop varieties, change planting dates and irrigate their farms to reduce the negative impacts of climate change. Those who did not adapt mentioned lack of information on adaptation methods and financial constraints to using any of the adaptation methods (Temesgen et. al, 2008).

2.1.6 Farmers adaptation strategies to climate change

According to a study carried out by IFPRI on behalf of World Bank, Washington DC, 67% of farmers stated that they are aware of the link between agriculture and Climate Change, possibly because of extensive media reports Government campaigns and speeches related to climate change Carbon Mitigation project located in Kenya. Results from a research carried out in Kenya showed that an overwhelming majority of farmers perceived an increase in average temperatures and a decrease in average precipitation over the last 20 years. Rainfall had become more erratic and there were changes in the timing of rainfall with 71% reporting that rains are coming later than expected and 15% reporting that rainfall was occurring earlier than expected. Farmers also noted increasingly prolonged periods of drought over the past 20 years (Bryan *et al*. 2011).

Farmers concerns about changes in rainfall variability are warranted given that rainfed agriculture is the dominant source of staple food and cash crop production and livelihood for the majority of the rural poor. Climate variability, in particular the occurrence of drought is a robust determinant of agricultural performance as well as general economic performance in the country (Herrero *et al*. 2010).

One of the most often mentioned adaptation strategy pertained to planting decisions. This includes planting more drought resistant crops (cassava, sweet potatoes, pigeon peas, dolichos) and early maturing varieties as well as improved hybrid seed for greater productivity.

Adapting to climate change will entail adjustments and changes at every level – from community to national and international. Communities must build their resilience, including adopting appropriate technologies while making the most of traditional knowledge, and diversifying their livelihoods to cope with current and future climate stress. Local coping strategies and traditional knowledge need to be used in synergy with government and local interventions (UNFCC, 2006 – 2007).

2.2 Modelling effects of climate change on crop performance

There is strong evidence for the existence of climate change (Suppiah and Hennessy, 1998;

Collins et al., 2000; IPCC, 2001) with subsequent impacts on agricultural systems (Howden *et al.*, 2003). Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system and the incomplete status of present knowledge, it becomes impossible to completely represent the system in mathematical terms and hence, agricultural models are but crude images of the reality (Passioura 1973, 1996). Unlike in the fields of physics and engineering, universal models do not exist within the agricultural sector. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system. One such model is the Agricultural production system simulator (APSIM). The Agricultural Production Systems Simulator (APSIM) is a crop modelling environment and it uses diverse modules to simulate cultivating systems in the semi-arid tropics. It is an effective tool for analyzing whole-farm systems, including crop and pasture sequences and rotations, and for considering strategic and tactical planning. The diverse modules are composed of biological, environmental, managerial and or economic which are linked together via the APSIM engine (McCown, et al., 1996).

APSIM model is able to simulate the growth (leaf area index and biomass) and yield of a variety of crops (maize, soybean, chickpea, lucerne, sorghum, sugarcane, cotton, hemp, weeds, millet, cowpea, sunflower, etc.) in response to mixing crops, changing management practices and rotation sequences, as well as that for pastures and livestock (Keating et al. 2003). It is very flexible and can simulate short as well as on long term effects; allowing users to understand the long-term trends in soil productivity due to climate variability, fertility depletion and erosion. Biophysical effects of these climate changes on agricultural production respond differently for various agricultural systems and regions (Parry et al., 2004). Projected changes in yield are calculated using transfer functions derived from crop model simulations with observed climate data and projected climate change scenarios (Shin, et al., 2009).

2.2.1 Crop modelling in Kenya

In Kenya, Simulation modelling is increasingly being applied in research, teaching, farm and resource management, policy analysis and production forecasts. A summary of the potential benefits that can be derived from using the modelling approach was described by Boote *et al*. (1996).

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world (IPCC, 1994). It is an alternative image of how the future can unfold and not a forecast. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions). A set of scenarios is often adopted to reflect the range of uncertainty in projections, (IPCC, 2007). Climate scenarios are plausible representations of the future with our understanding of the effect of increased atmospheric concentrations of green house gases (GHG) on global climate. Unlike weather forecasts, climate scenarios are not predictions. They are consistent with assumptions about future emissions of GHG and other pollutants. A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change. This in turn helps policy makers decide on appropriate policy responses to the change, (Lu, 2006).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 STUDY AREA

The study site is located in the Yatta sub - County in the Machakos County (Figure 1). The sub - County has three administrative divisions: Ikombe, Yatta and Katangi. The total area of the study site is 372.17 km^2 with a total population of 39,184 people (Table 1).

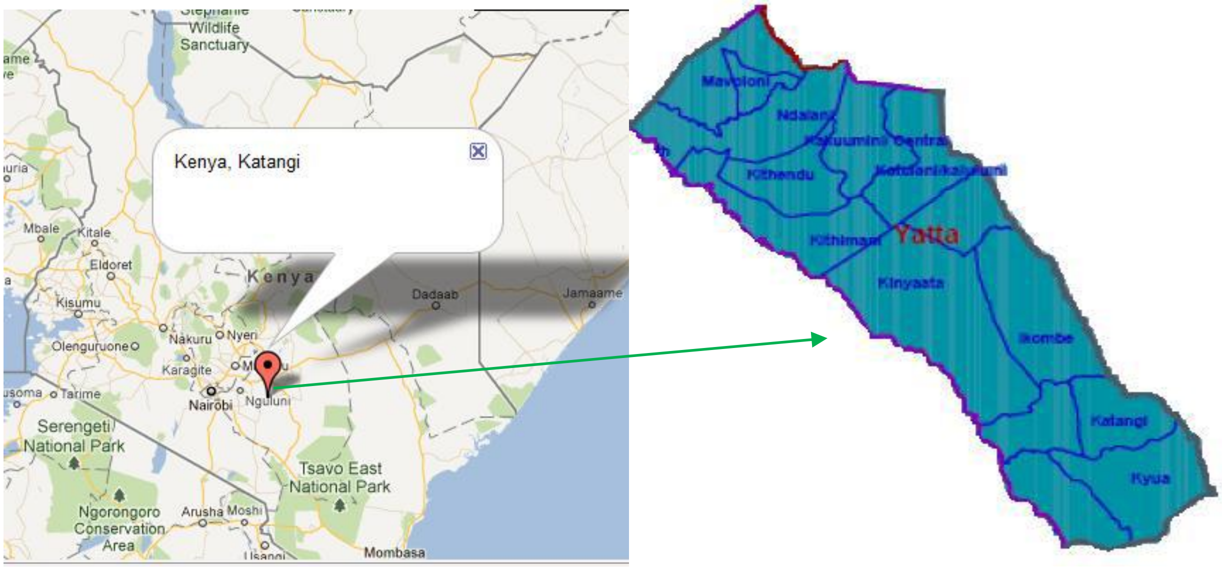


Figure 1: Map showing study area

The total population of the area is reflected in table 1 below;

Table 1**:** Demographic characteristics

	Male	**Female**	**Total**	**Number of Households**	**Area in km2**	**Density**
KATANGI	4258	4761	9019	1740	90.5	100
KINYAATA	7173	8145	15318	2664	154.77	74
IKOMBE	6889	7958	14847	2623	126.9	117

The sub - County is mainly in agro-climatic zone IV and is classified as semi-arid land (Jaetzold and Schmidt 1983). The primary soils in Yatta sub - County are a combination of Luvisols, Lithisols, and Ferralsols (Jaetzold and Schmidt 1983). The three Yatta soils are well drained, moderately to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay, with high moisture storage capacity and low nutrient availability (Kibunja *et al.* 2010). The topsoil is loamy sand to sandy loam in texture with nutrient levels as shown in Table 2 below:

Table 2: Soil physical and chemical characteristics of Yatta sub - County

Parameter	**Unit**	**Remarks**
pH H_2O	6.32	Slightly acidic
pH 0.01M ($CaCl_2$)	6.02	Slightly acidic
EC (dsm^{-1})	0.2	
% C	1.26	Moderate
% N	0.1	Low
Na (Cmol/kg)	0.25	Moderate
K (Cmol/kg)	1.5	Moderate
CEC (Cmol/kg)	29.2	High
P (ppm)	6	Low
Texture: Sand (%)	50	
Silt (%)	18	
Clay (%)	32	

Yatta sub -County has a semi-arid climate with mean annual temperature ranging from 17ºC at night to 24ºC during the day and experiences bimodal rainfall . The long rainy (LR) season typically runs from the end of March to May (about 400 mm) and the short rainy (SR) season runs from the end of October to December (500 mm). Most farming systems are based on rain-fed crop production integrated with varying levels of livestock rearing and, where water supplies permit, limited furrow irrigation (KARI-NDFRC, 1995). The main rain-fed crops are maize and beans, which are grown in monoculture or as mixed crops complemented by smaller areas of pigeon pea, cowpea, sorghum and millet. Irrigated agriculture is dominated by vegetables such as tomato, eggplant, okra, pepper, hot chilli and onion. Most farmers use semi-extensive grazing systems to rear indigenous cattle, which are resistant to local diseases and adapted to poor quality local feed, although there are a few zero grazing livestock units in the area where improved crossbred animals are kept. (Macharia, 2004).

3.2 STUDY APPROACH

The study consisted of farmer surveys, analysis of LANDSAT imageries from the year 1976 to 2011 and field trials. Farmer surveys were conducted to determine the farmers' perceptions, knowledge, adaptation, coping and mitigation strategies in view of climate change as well as determine the trend in land and crop cover change from traditional crops to modern crops by administering questionnaires to 60 farmers selected by a simple random method. The data collected from the surveys were analyzed for means, descriptive analysis and correlations by SPSS version 16. LANDSAT imageries were analyzed to identify trends in vegetation cover change particularly from traditional crops to modern crops over the past 30 years using satellite images of the years 1986, 2000 and 2012 and Chi-square test done to test significance levels among the percentage changes. A randomized complete block design (RCBD) of 10m by 10m with a split plot design replicated three times was used to determine effects of cropping systems and organic inputs on sorghum. The main plots comprised of the cropping systems (monocrop, intercrop and crop rotation) while the sub-plots comprised of the organic inputs (farm yard manure and compost). The APSIM model was used to model the growth and performance of sorghum under the different cropping systems and organic inputs. The model was evaluated using the Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE), Coefficient of Efficiency (E*i*), linear regression (R^2) and Range Ratio (RR). The variables measured included the observed and simulated grain and biomass yield data.

CHAPTER FOUR

FARMERS' PERCEPTION, COPING AND ADAPTATION STRATEGIES ON CLIMATE CHANGE.

4.1 ABSTRACT

Yatta sub - County is composed of lands that are semi-arid to arid with a major reliance on rain fed agriculture. However, just like many areas of Kenya, the farmers in the region have been affected by climate change and variability resulting in reduced crop yields and soil fertility decline. It is against this backdrop that a survey was carried out to determine farmer's perceptions, coping and adaptation measures to climate change in the sub – County to increase farmers' understanding of causes and impacts of climate change and better adapt to the changes. A semi-structured questionnaire was administered in a simple random manner to 60 farmers in two divisions of the sub – County; Ikombe and Katangi with some of the key questions asked being are you aware of climate change and the causes?, what are the impacts of climate change on crop production?, what are the responses to climate change?, e.t.c. Results showed that 98% of the farmers in the region were aware of climate change with the major indicators being erratic and low rainfall, droughts and rising temperatures. Deforestation was cited by respondents in both divisions as the main cause of climate change. Other causes included industrial pollution/chemicals such as agricultural fungicides/pesticides, fuel, vehicles (22%) and human activities such as cutting down of trees, charcoal burning, (8%). The farmers first noticed climate change over 10 years ago in the form of erratic rainfall (62%), low rainfall (43%), prolonged droughts (39%), increased temperatures (35%) and flooding (10%). Farmers in both divisions observed that crop yield (52%) and crop failure (41%) were significant effects felt as a result of climate change. Introduction of drought tolerant crops (45%), reduced yields (43%) and change in planting time (38%) were identified by the farmers as the three main impacts of climate change on crop production in Yatta sub – County. The farmers identified early land preparation/planting on time (52%), use of organic and inorganic fertilizers (37%), planting early maturing crop varieties (28%) and water and soil conservation (18%) as the top four responses to climate change. The farmers also identified agro forestry, application of fertilizers, rain water harvesting and planting of appropriate crop varieties suitable for the region as the major coping strategies to climate change. Farmers in Yatta sub – county are therefore aware of climate change and its effects and have devised a series of coping and adaptation strategies. However, despite this, there is still limited knowledge on whether farmers perceive climate change and how they are responding to the effects of a changing climate. There is therefore need to increase their capacity to better adapt to the changes by predicting the effects of climate change on their crop production through the use of Decision Support Tools (DST’s) that will help farmers put in place appropriate measures. However, it is important to note that local perceptions cannot be estimnated by models hence the need to document how the farmers are affected by the changing climate. This will ensure sustainable agricultural production and improved food security.

Key words: **Climate Change, Impact, Crop production, Coping, Adaptation**

4.2 INTRODUCTION

It has been argued that the world's climate is changing and will continue to change at rates unprecedented in human history, and that all societies need to enhance their adaptive capacity to face both present and future challenges of climate change (Adger et al. 2003). Climate change has thus become the most important topical development policy and global governance issue in the 21st century (African Development Bank 2010).

The declining agricultural productivity in Kenya is worrisome and a real challenge given the ever increasing population. Worse still are the expected adverse effects of climate change in the future with global circulation models predicting that there will be increased temperatures of about 4^{o}C and variability in rainfall of up to 20% by the year 2030 adversely affecting agriculture in both the arid and semi-arid areas and high potential areas (Mariana and Karanja, 2007)

Countries in Sub-Saharan Africa are particularly vulnerable to climate change impacts, because of their limited capacity to adapt. In Kenya where the poverty rate is 52% and 73% of the labor force depends on agricultural production for their livelihood, poor farmers especially in the ASALs are likely to experience many adverse impacts from the climate change (FAOSTAT, 2010). Because agricultural production remains the main source of income for most rural communities in the region, adaptation of the agricultural sector is imperative to enhance the resilience of the agriculture sector, protect the livelihoods of the poor and ensure food security. According to UNEP (2009), adaptation refers to reducing the negative effects of climate change by modifying systems to take into account new or anticipated climatic conditions.

There is a large deficit of information and knowledge on climate change causes and effects and its adaptation in the arid and semi – arid regions regarded as being vulnerable which in turn impedes decision making and assessment of climate related risks, and adaptation (McSweeny et al., 2010). Information about this issue may be put into two groups: (1) climate trend analysis and future projections from climate scientists and (2) the perception and adaptation information from people at risk in those regions (mainly farmers). Farmers' ability to perceive climate change is a key precondition for their choice to adapt. In Kenya, Farmers have been mentioned to perceive and even adapt to changes in the climate with socioeconomic and environmental factors having been demonstrated in various studies to influence farmers’ perception and adaptation to changes in the climate (Deressa et al., 2011)

Adaptation dictates that a farmer recognize that climate has changed and then look for useful ways to adapt to the change and implement them (Maddison 2006). Adaptation is widely recognized as a vital component of any policy response to climate change. Studies show that without adaptation, climate change is generally detrimental to the agriculture sector; but with adaptation, vulnerability can largely be reduced (Smit and Skinner, 2002). Thus, the adaptive capacity of a system or society describes its ability to modify its characteristics or behavior so as to cope better with changes in external conditions. Adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to climate change and variability, moderating potential damages and helping them cope with adverse consequences (IPCC, 2001). A better understanding of farmers’ perceptions of climate change, ongoing adaptation measures, and the decision making process is important to inform policies aimed at promoting successful adaptation of the agricultural sector. Adaptation will require the involvement of multiple stakeholders, including policymakers, extension agents, NGOs, researchers, communities and farmers.

The reduced availability of resources (particularly food, energy and water) has positively changed the rural community’s outlook towards the need to conserve resources and ensure increased crop productivity especially in the ASALs. To ensure increased food production in the ASAL regions, farmers would therefore have to come up with effective coping and adaptation measures to climate change. There is however, little knowledge on how farmers perceive climate change and if they have formulated adaptation measures (Fosu-Mensah et al. 2012). Hence, this paper seeks to explore farmers’ perception, coping and adaptation to climate change and investigate the factors and barriers affecting the adaptation process. The objective of this research therefore, was to document the perceptions on climate change and the coping and adaptation mechanisms by individual farmers and/or community to mitigate against effects of climate change and variability.

4.3 METHODOLOGY

4.3.1 Study area

The study was conducted in Yatta sub – county as described in Chapter two of this thesis. The study was carried out in two administrative divisions; Katangi and Ikombe.

4.3.2 Data collection

The sampling size was done by proportion in line with the population size of the location based on Cochrane formulae (Cochran, 1977).

Cochran's formula

$$SS = \frac{Z^2 * (p) * (1-p)}{c^2}$$

Where: Z = Z value (e.g. 1.96 for 95% confidence level), p = percentage picking a choice, expressed as decimal (0.5 used for sample size needed), c = confidence interval, expressed as decimal (e.g., 0 .04 = ±4)

Using a semi structured pre-tested questionnaire, a total of 60 households equally distributed in the 2 divisions (Katangi and Ikombe) were randomly picked. In total 60 adult farmers identified as heads of households were individually interviewed (30 per division). Heads of household were considered as it was hypothesized that he/she will be the one to make decisions about agricultural adaptation practices and that his/her knowledge and perception were to be taken into account.

The questionnaires were pretested among colleagues to determine how long the questionnaire will take and how the questions would be understood and answered. Household were then selected in a simple random manner and interviews carried out. Informal individual interviews were carried out to determine if the informant was willing to take part in the survey. Key data collected by the questionnaires included farmers knowledge on climate change, causes of climate change, effects of climate change, adaption to climate change and future predictions of climate change (Table 3).

Table 3: Key perception, coping and adaptation questions

Key Component	Related questions	Assumption
Perception	- What aspects of climate change are you aware of? - Have you ever experienced climate change in your locality? - What are the causes of climate change? - What are the impacts of climate change?	Farmers are not aware of climate change, the causes and impacts.
Coping	- What assist you in decision making regarding your farming practices? - What strategies do farmers in the region carry out to cope with climate change?	Farmers have devised coping strategies
Adaptation	- How are you responding to climate change?	Farmers have devised adaptation strategies

4.3.3 Data analysis

The data was analyzed using the Statistical Package for Social Scientists (SPSS) Version 16.0 for Windows (Miller et al., 2006). Depending on the type of data, means, frequencies, correlations and tables were computed.

4.4 RESULTS AND DISCUSSION

4.4.1 Demographic characteristics

The farmers interviewed were aged between 22 and 81 years old with 42% being male and 58% female consisting between 3 – 16 household members. Seventy eight percent of the farmers own between 5 - 10 acres of land while 22% own between 10 – 40 acres of land. Majority of the farmers (90%) had allocated 8 acres and below for crop production while 87% had allocated up to 1 acre for the homestead and 85% having allocated up to 4 acres for livestock production.

The highest level of education attained by the father (Head of the household) for the majority of the population attended upper primary school (46%) with 24% having attended secondary school, 15% never went to school and 13% attended lower primary school, as well as the mother (48%) with 25% having attended secondary school and 14% never went to school.

87% of the farmers indicated farming as their main source of income with 13 % indicating business, Pension/retirement and employment as other sources of income. Majority of the farmers interviewed (48%) earned over 10,000 shillings from farming, 19% earning between 4000 – 10,000 shillings, between 2000 – 4000 shillings and 500 – 2000 shillings at 14% respectively and 5% earning between 0 – 500 shillings.

Of the 13% who indicated they have alternative sources of income, 49% earned more than 10,000 shillings from the alternative sources of income, 19% between 500 – 2000 shillings, 16% between 4000 – 10.000 shillings, 14% between 2000 – 4000 shillings and a negligible number <5% between 0 – 500 shillings

4.4.2 Farmers perceptions on climate change

The farmers in Yatta sub-County were aware of climate change (Table 4). Farmers have been aware of climate change due to the adverse effects on their crop production such as reduced crop yields and pests and diseases. Studies indicate that farmers do perceive that climate is changing and are therefore adapting to reduce the negative impacts of climate change (David et al., 2007; Ishaya and Abaje, 2008; Mertz et al., 2009).

Table 4: Farmers knowledge on climate change in Ikombe and Katangi

Division	Knowledge of climate change		
	Know (%)	**Do not know (%)**	**Total (%)**
Ikombe	96.2	3.8	100
Katangi	100	0	100
Total	98.3	1.7	100

N=60

The respondents identified erratic and low rainfall and droughts as the main aspects/evidences of climate change in both divisions (Figure 2).Less than 20% of farmers recognized rising temperatures, floods and cold spells as evidence of the changing climate in both divisions (Figure 2). This is mainly because farmers in the county depend on rain fed agriculture hence the quick realization in a change in rainfall amount.

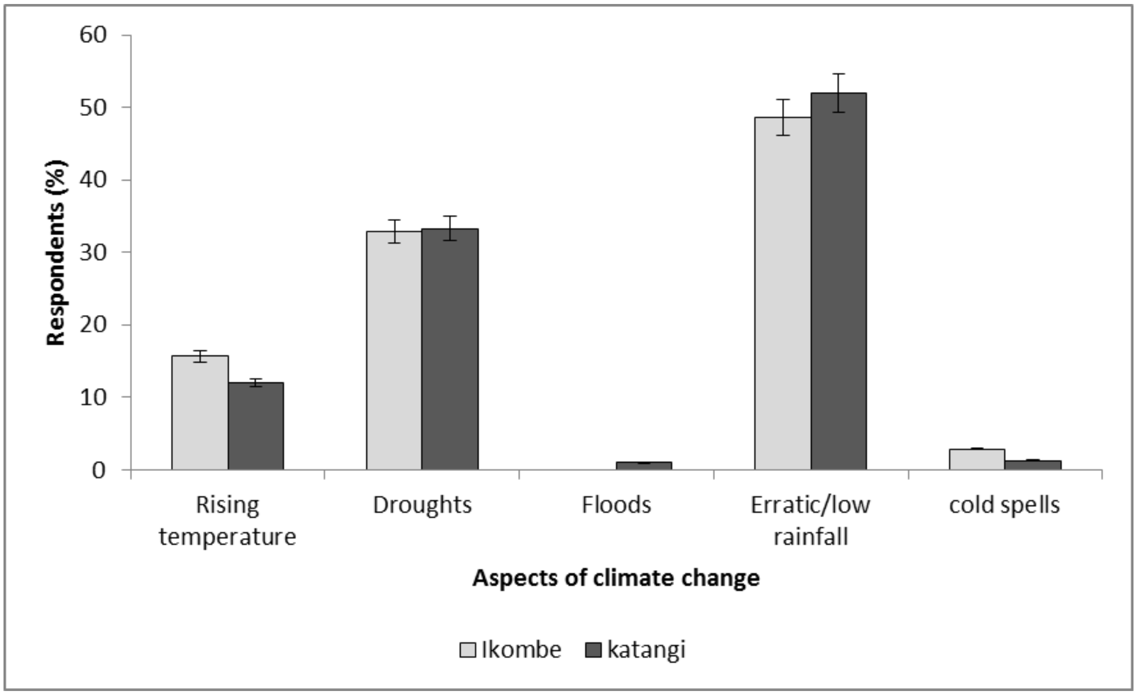


Figure 2: Indicators of climate change in Yatta sub-county

Bryan (2011) similarly reported that an overwhelming majority of farmers were aware of climate change manifested in the form of increased temperatures and a decrease in rainfall amount with the rainfall being erratic and increased prolonged droughts while floods and increase in rainfall were less reported. Studies have also shown that key indicators of climate change include rise in temperature, unusual early rains followed by weeks of dryness, low rainfall, erratic rainfall pattern, drying of rivers, long period of dry season, increased diseases and low crop yields (Kuria 2009; Farauta et al. 2011). According to a report by the NCCRS (2010), evidence of climate change in Kenya is unmistakable with rainfall becoming irregular and unpredictable, extreme and harsh weather is now the norm and frequent droughts during the long rainy seasons.

Farmers first noticed climate change over 10 years ago (Table 5). Climatic data of Yatta sub-County over the past 50 years shows that there has been a decline in rainfall and an increase in temperature. Similarly, Kalungu et al. (2013) showed that farmers have experienced changes in the climate in the past 30 years than in the past 10 years with more changes having been experienced in the semi – arid than sub – humid regions. The changes were easily noticed by the farmers due to the fact that most rural communities depend on rain fed agriculture hence any changes in the climate were almost immediately noted.

Table 5: Farmers perceptions on beginning of climate change

	<5 years (%)	**5 – 10 years (%)**	**>10 years (%)**
Increased temperatures	15	32	25
Droughts	17	38	38
Flooding	7	2	10
Low rainfall	18	33	43
Erratic rainfall	10	7	62

N=60

The main sources of information on climate for the farmers in Yatta sub-county were extension officers, friends and radio (Table 6). Other sources were own knowledge, newspaper, and seminars/meetings (Table 6). The high percentage of farmers getting their information through radio and extension officers may be attributed to the fact that more focus is being put on agriculture by making information available to the small holder farmers through radio and extension officers. Studies have also shown that farmers perceptions are hinged on farmers experience and availability of free extension advice specifically related to climate change (Maddison 2006). In line with this study also is Gbetibouo (2009) who argued that farmers with access to extension services were likely to perceive changes in climate because extension services provided information about climate and weather.

Table 6: Farmers sources of information on climate change

		Percent (%)
Information sources	Radio	15
	Newspaper	8
	Friends	22
	Extension officers	45
	Own knowledge	9
	Seminars and meetings	2
Total		**100**

N = 60

Sixty nine percent of farmers in Ikombe and fifty seven percent of farmers in Katangi identified deforestation as the main cause of climate change (Figure 3). Other causes of climate change identified were, industrial pollution/chemicals (22%) and human activities (8%). Twelve percent did not know the causes of climate change (Figure 3). This was because most farmers noted that in the past, a huge percentage of the land was covered by forest cover but this has since made way for land cultivation as a result of an increasing population. Past studies have shown that deforestation and other human activities such as industrial practices are altering the composition of the atmosphere and contributing majorly to climate change which is in line with the current study findings (Kuria 2009). Deforestation could be as a result of an increase in population and settlement in the region over the years as well as poverty and low income level leading to encroachment into forests for settlement.

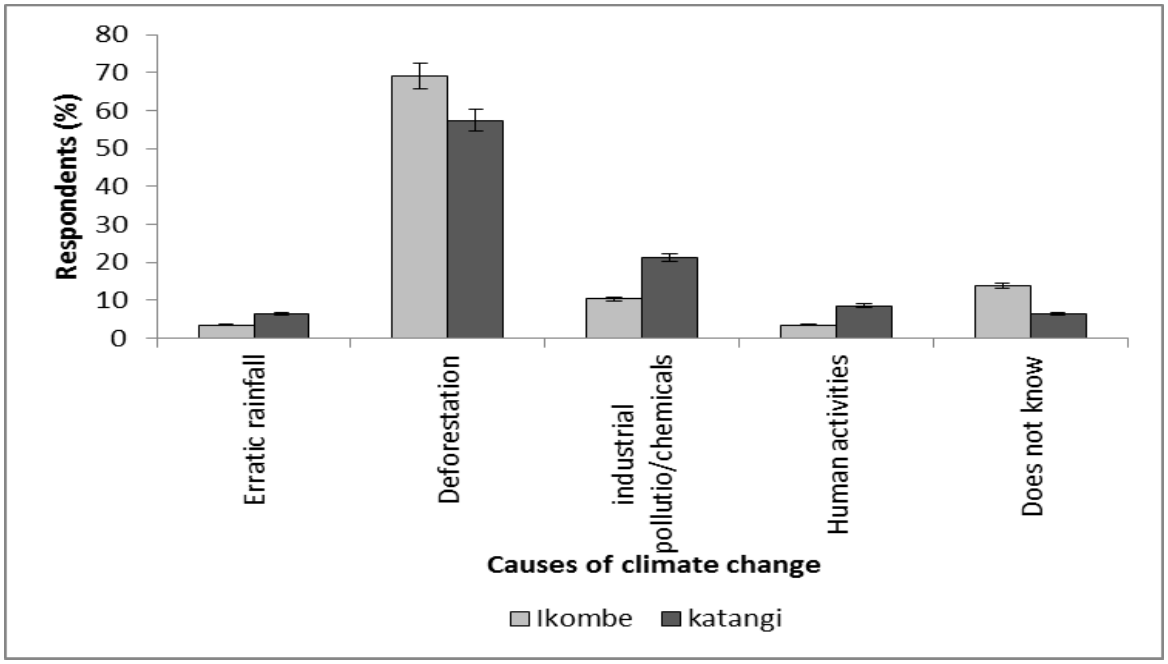


Figure 3: Causes of climate change

4.4.3 Climate change impact on crop production

Most (65%) of the farmers in Yatta sub - county have been practicing farming for over 30 years. All of the farmers use oxen plough in land preparation with 88% using oxen plough only, 8% using both oxen plough and hand hoes, <5% using tractors and oxen and <5% using all three, tractors, oxen and hand hoes. Most of the farmers preferred oxen plough because of various reasons with 90% saying it was cheaper and faster, 37% saying it is easily available and 20% saying it is effective in breaking of the hard pan. The other reasons were it was effective in preparing large sizes of land (12%), is a means to water conservation (12%) and makes planting easier (12%).

Crop production is one of the main agricultural activities highly affected by climate change. Seventy seven percent of the farmers however pointed out that their farming had deteriorated over the years. According to 95% of the farmers, unreliable rainfall was the main reason for the deteriorating crop performance followed by 68%, 55% and 37% who identified low soil moisture, drought and low soil fertility respectively. Other factors included pests and diseases (28%), lack of inputs (17%), planting of the wrong crop type (12%), and lack of inputs (7%)

(Figure 4). This is because farmers in the county rely on rain fed agriculture hence rainfall failure results in reduced crop yields. A study by Mongi et al. (2010) showed similar results where majority of the farmers interviewed associated the declining food crop production with the impact of climate change and variability. However, the declining food crop production trend could also be due to other non - climatic related factors such as declining soil fertility, pest and diseases and inadequate extension services.

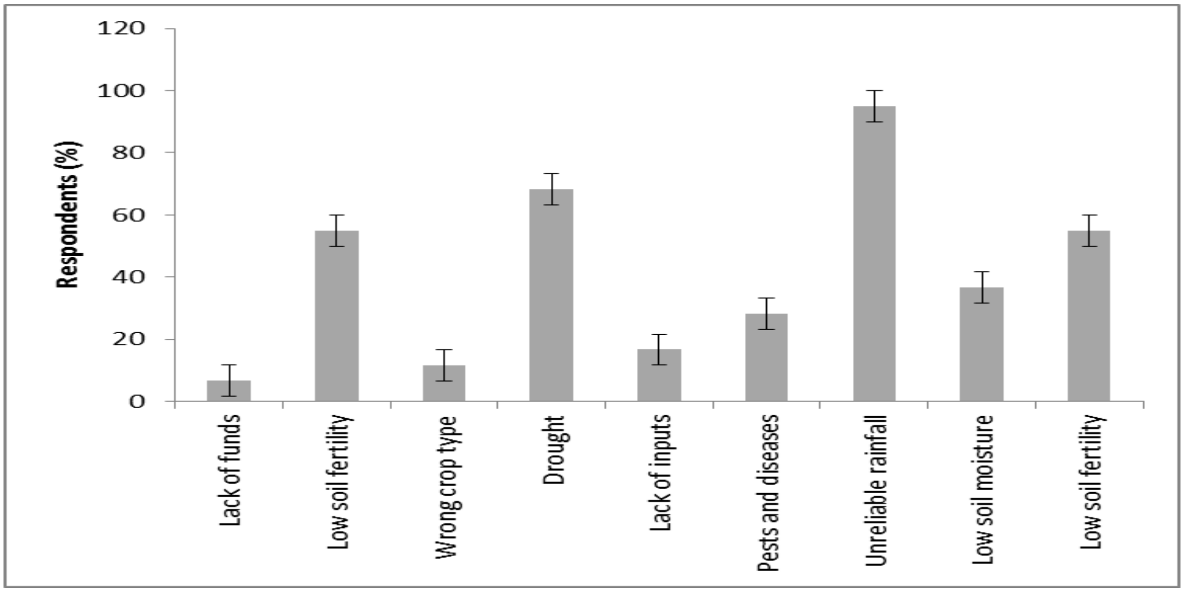


Figure 4: Factors affecting crop production in the study area

Similar to this study, Thornton et al. (2009) also showed that crop production declined due to climate change namely increases in temperatures and low and unreliable rainfall, land degradation, pests and diseases, high cost of inputs and decreasing land sizes. Temperature increase and a decrease in precipitation resulted in many famers being affected for example, from 1996 to 2003, there was a decline in rainfall of 50-150 mm per season (March to May) and corresponding decline in long-cycle crops (e.g., slowly maturing varieties of sorghum and maize) across most of eastern Africa (Funk et al., 2005).

Reduced crop yield, change in planting time, crop failure and reduced soil moisture were some of the impacts identified by farmers in the sub – County as a result of climate change (Table 7). Farmers in both Ikombe and Katangi observed that crop yield (52%) and crop failure (41%) were significantly felt as a result of climate change. Change in planting time (55%), pest and disease infestation (56%) and reduced soil moisture (63%) were moderately felt while flooding of crop fields (93%) was only slightly felt as a result of climate change (Table 6). This is because, farming is the mainstay of the farmers in the sub – County hence a reduction in crop yields or complete crop loss is easily noted. This combined with the farmers' observation of reduced and unreliable rainfall results in reduced water availability hence reduced soil moisture. The farmers also identified the onset of rainfall (65%) and timing of the period of rainfall (27%) as the major determinants of when to prepare land for planting for farmers in the region. Planting was mainly determined by weather forecasting (53%), weeding mainly determined by schedule for weeding after planting (83%) while harvesting mainly determined by physiological maturity (90%).

Table 7: Impacts of climate change on crop production

Effect	**Location**	**Slightly (%)**	**Moderately (%)**	**Significantly (%)**
Reduced crop yield	Ikombe	0	50	50
	Katangi	2.9	44.1	52.9
	Total	1.7	46.7	51.7
Change in planting time	Ikombe	24	68	8
	Katangi	24.2	45.5	30.3
	Total	24.1	55.2	20.7
Crop failure	Ikombe	4.2	58.3	37.5
	Katangi	20.6	38.2	41.2
	Total	13.8	46.6	38.7
Pests and disease infestation	Ikombe	16.7	62.5	20.8
	Katangi	45.5	51.5	3
	Total	33.3	56.1	10.1
Flooding of crop fields	Ikombe	100	0	0
	Katangi	90.9	9.1	0
	Total	92.9	7.1	0
Reduced soil moisture	Ikombe	4.2	83.3	12.5
	Katangi	45.5	48.5	6.1
	Total	28.1	63.2	8.8

Of significance to note was that 30% of farmers in Katangi observed that change in planting time was affected significantly as compared to 8% in Ikombe as well as 21% of farmers in Ikombe observing that pests and diseases were affected significantly as compared to 3% in Katangi. According to Zhu (2005), climate change has both positive and negative effects on agriculture, but there could be a more negative influence in the long run which may lead to food scarcity if there is no immediate effort to confront these problems. Crop yields are affected by many factors associated with climate change which includes: temperature, rainfall, extreme weather events, climate variability and even carbon dioxide concentration in the atmosphere which is predicted to cause global warming that will have a significant impact on crop production (USDA 2007). Akponikpe et al. (2010) and Macharia et al. (2010) showed that there is a change in planting time, a decrease in crop yield, crop failure, increased pests and disease incidences and reduced soil fertility as a result of climate change which is in agreement with the current study.

As a result of climate change, farmers have introduced drought tolerant crops (45%), experienced reduced yields (43%) and changed the planting time (38%) (Figure 5). Other responses include change in cropping systems from mono cropping to mixed and intercropping (25%), introduction of pest and disease free crops (20%), change from traditional crops to exotic crops (15%), increased pests and diseases (8%), crop failure (7%), food insecurity (3%) and low water availability (3%) (Figure 5). This can be attributed to the fact that climate change in the form of reduced/unreliable rainfall and increased temperatures results in reduced crop yields therefore farmers are forced to plant more drought tolerant varieties and planting at the appropriate time (at onset of rainfall). Change in crop variety, change in planting dates and change in crop types have been recognized as the major impacts of climate change in crop production (Bryan et al. 2011) which is in agreement with the current study. Some of the impacts of climate change and variability are the reduction of agricultural productivity which causes production instability and poor incomes in areas developing world and especially Africa (FAO 2012).

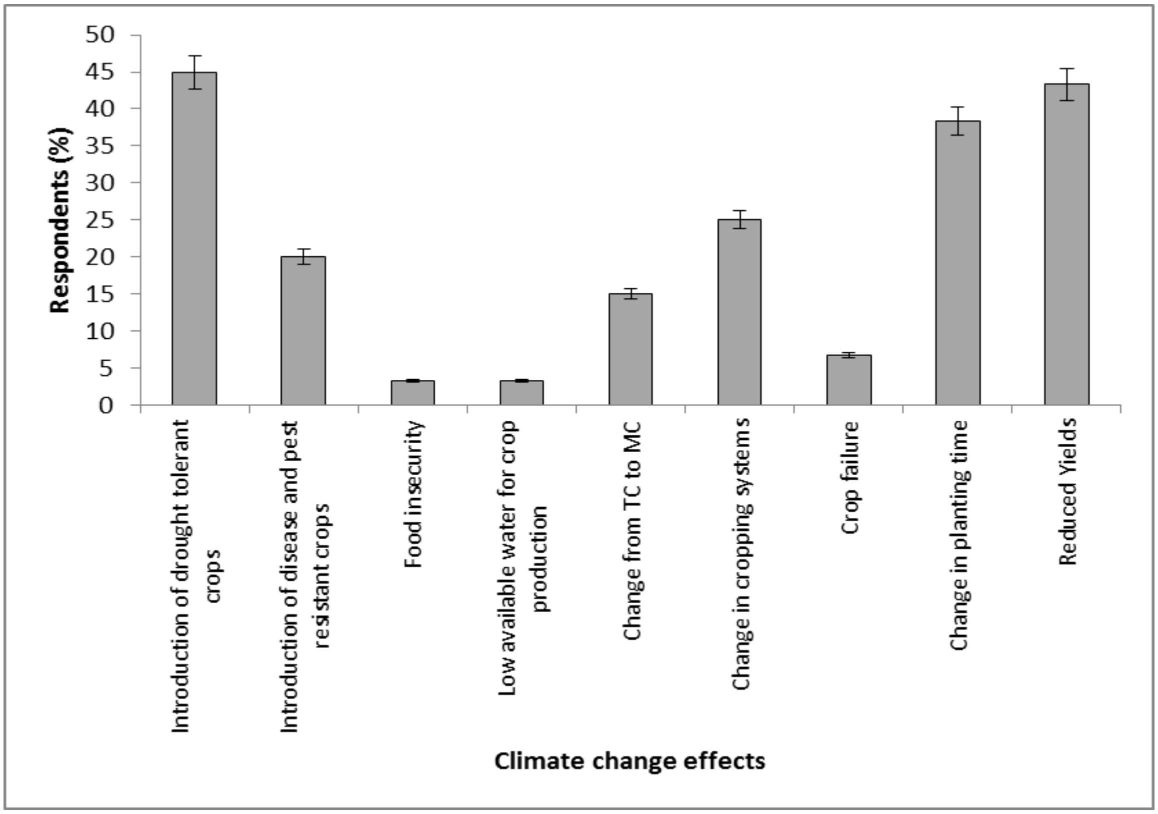


Figure 5: Effects of climate change on crop production in the study area

In accordance with this study, Brett (2009) projected that agricultural production and access to food will be severely compromised by climate variability and change in precipitation whereby the area suitable for agriculture, the length of growing seasons and yield potential particularly in the semi-arid and arid areas are expected to decrease. Penaranda, et al. (2012) also showed that the main adapting mechanism that was consciously acknowledged by the farmers as a direct result of the climate changes in climate was the shifting of planting. Most farmers in Yatta sub – County intimated that while in the past they would begin planting in March, they now begin in either April or, most frequently, as late as May.

To increase crop production, 98% of the farmers were in agreement that the application of organic fertilizers would increase crop production as well as application of inorganic fertilizers (62%) and changing crop varieties (37%). Soil fertility was identified as one of the major reasons for declining crop production in the sub-county therefore to increase crop production, there is need to increase soil nutrient fertility. Studies have shown that through the use of organic and inorganic fertilizers, soil fertility and nutrients can be increased hence increasing crop production. Other factors also identified were use of pesticides (10%), use of new technologies in water conservation like earth dams (7%) and a negligible number (<5%) identifying change in cropping systems to intercropping and crop rotation and planting of certified and appropriate seeds. Water conservation as well as change in cropping systems are known to help mitigate against adverse climate change effects ensuring improved soil moisture content hence improved crop yields.

Thirty three percent of the farmers were however not willing to change their farming practices to improve their farming. This can be mostly attributed to the economic implications with most of the farmers being financially unable to meet the costs of improving their farming. However, 67% were willing to change with 17% citing improved cropping systems, 17% citing changing of crop types, 17% citing irrigation, 17% citing stopping production of some crops, 8% citing addition of organic and inorganic fertilizers, 8% citing water harvesting, 7% citing using of appropriate and certified seeds, 3% citing carrying out alternative farming such as dairy and poultry farming, 3% citing timely planting and finally 3% citing adopting modern farming as ways to improve their farming practices. A similar study by Gbetibouo, 2008 showed that even though a large number of farmers noticed changes in climate, almost two-thirds chose not to undertake any remedial action due to the cost implications. Among those farmers who did adapt, common responses included planting different crops, changing crop varieties, changing planting dates, increasing irrigation, diversifying crops, changing the amount of land grazed or under cultivation, and supplementing livestock feed.

Most of the farmers (77%) had changed the crop types cultivated over the years. Most crops grown in the region had been grown for over 20 years. The trends in the types of crops produced clearly show a shift from traditional crops to introduced/exotic crops with maize and beans increasing in area under production over the years while yams, finger millet, cassava, sweetpotatoes, arrowroots, sunflower and cotton were diminishing over the past two decades (Figure 6).

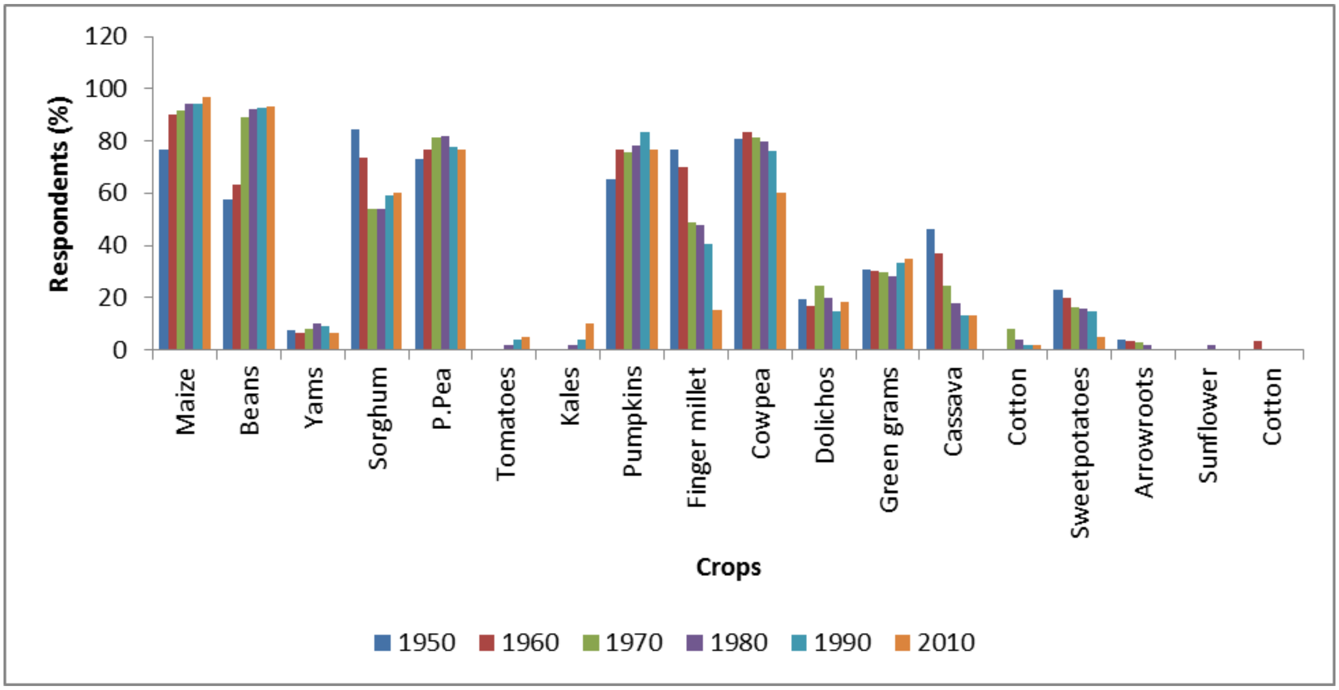


Figure 6: Crops grown between 1950 and 2010

However, there are crops that had been abandoned over the years with most having been abandoned almost 20 years ago. This is around the time that most farmers in the region said that they started experiencing climate change. Most of the crops abandoned were traditional crops as shown in the figure 13 above which are more hardy and adapted to the local conditons. The farmers identified several reasons for stopping their production whereby 51% identified pests and diseases, 31% identified lack of labour and inputs, 24% identified low rainfall and 18% identified unreliable rainfall. The other reasons were lack of market (13%), low economic returns (7%) and tedious (7%) and low yields (<5%)

This trend in crop type change according to the community was due to several reasons with 92% of the farmers citing low unreliable rainfall, 42% citing population increase, 42% also citing low inputs and finally 37% citing poverty (Figure 7). Gbetibouo, (2008) similarly observed thatpoverty, lack of access to credit, and lack of savings were major contributors to the type of crop grown by farmers. Insecure property rights and lack of markets were also significant barriers.

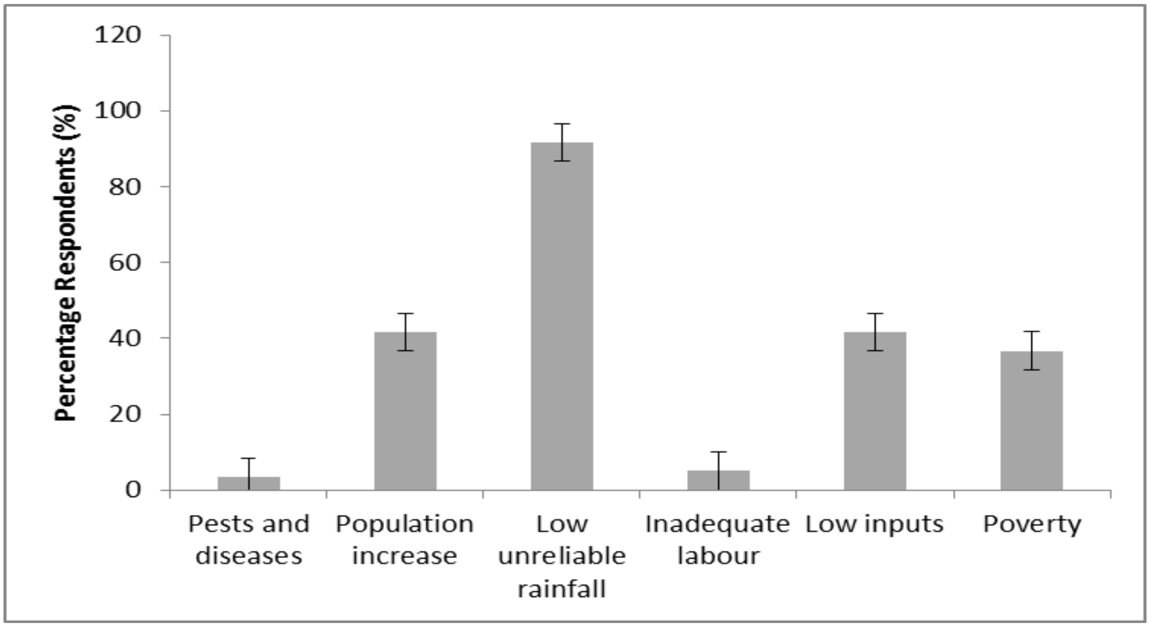


Figure 7: Factors affecting crop type change in Yatta sub - county

4.4.4 Coping strategies to climate change

Farmers in the sub - county identified agro forestry, application of fertilizers, rain water harvesting and planting of appropriate crop varieties suitable for the region as the major coping strategies to climate change (Figure 8). Studies have shown that trees attract rainfall hence the preference for agro forestry by the farmers. Fertilizer application increases soil fertility while water harvesting will lead to increased soil moisture resulting in an increase in crop yields. Soil and water conservation measures and use different cropping systems (intercropping and crop rotations) were also identified. These are measures that ensure increased soil water moisture even during drought periods hence ensuring the presence of a crop in the field despite climate variability. Planting of drought tolerant crops and irrigation are less practiced in the sub - County (Figure 8). This is because these practices are costly to most farmers who are not financially stable and do not have access to credit facilities. According to Hellmuth et al. (2007), there is a link between farmers practicing improved farming practices to cope with climate variability and their financial status. .

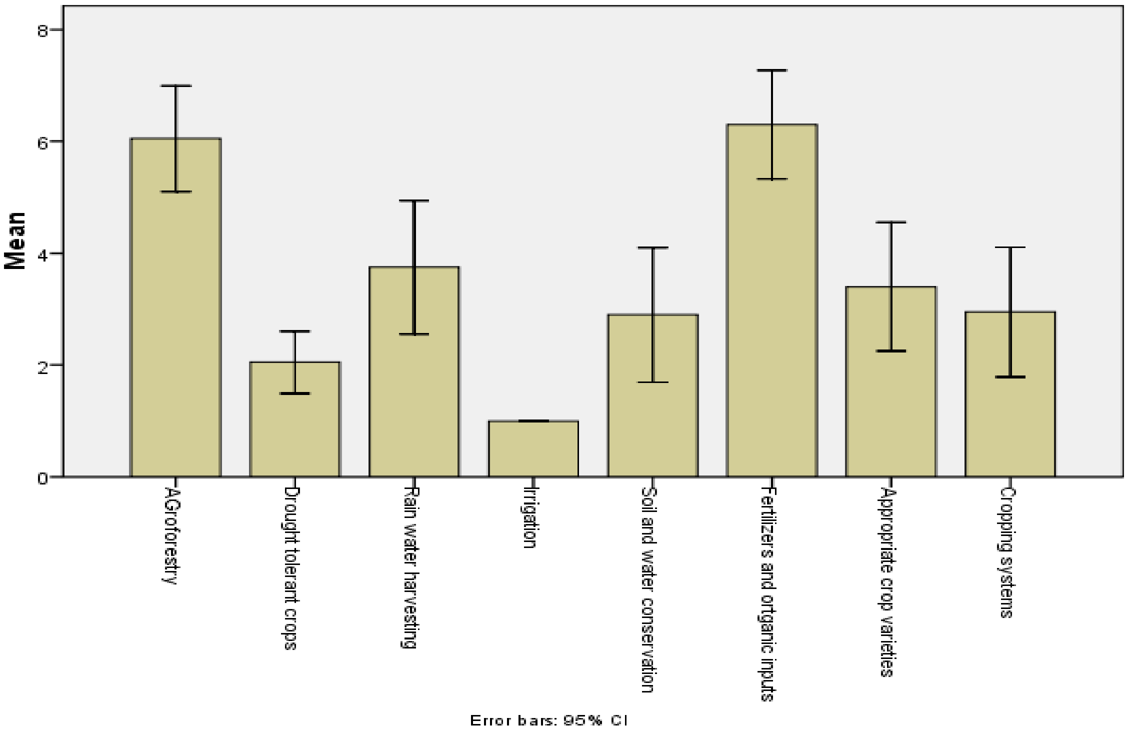


Figure 8: Coping strategies to climate change

Most (87%) of the farmers practice agro-forestry in the sub - county with 73% planting indigenous trees. This can be attributed to the fact that farmers are aware that deforestation is the major cause of climate change hence the understanding of the importance of trees. All the farmers were aware of the benefits of trees with 52% identifying provision of fuel wood, 43% identifying provision of organic inputs to the soil, 35% identifying source of food – fruits and 33% identifying provision of timber as the main benefits (Figure 9). Rainfall attraction, fixing of nutrients, conserving soil and water, provision of shade, provision of feed for livestock, provision of medicine, source of income, wind breaking effect and purifying of the air were identified as other benefits (Figure 9). Twenty eight percent of the farmers were aware that trees attract rainfall and 14% were aware that they are essential in water and soil conservation. Studies have shown that forests are important rainfall catchment areas therefore planting trees is very important. This is in line with Macharia et al. (2010) who showed that fuel wood was the major reason for planting trees followed by provision of timber and environmental rehabilitation and a source of food for both humans and animals. He also identified windbreakers, medicinal purposes, shade and income purposes as the other usefulness of trees.

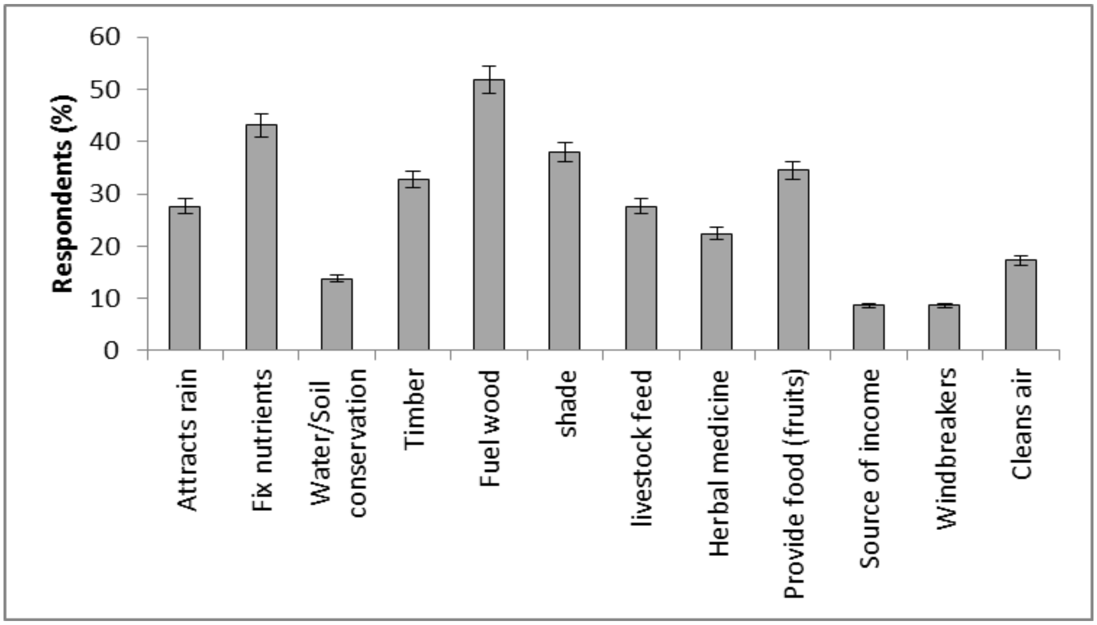


Figure 9: Factors motivating tree planting by farmers

Despite this, 95% of the farmers in the sub - County were in agreement that the forest cover was decreasing over the years with 72% citing the reason as deforestation, 39% citing expansion of land for cultivation and settlement, 22% citing poverty and 12% citing lack of knowledge on the importance of trees (Figure 10). A negligible number (<5%) felt that it would increase attributing this to the fact that more trees will be planted and the community understanding the importance of trees (Figure 10). One of the major reasons of deforestation has been the clearing of land for cultivation due to population increase.

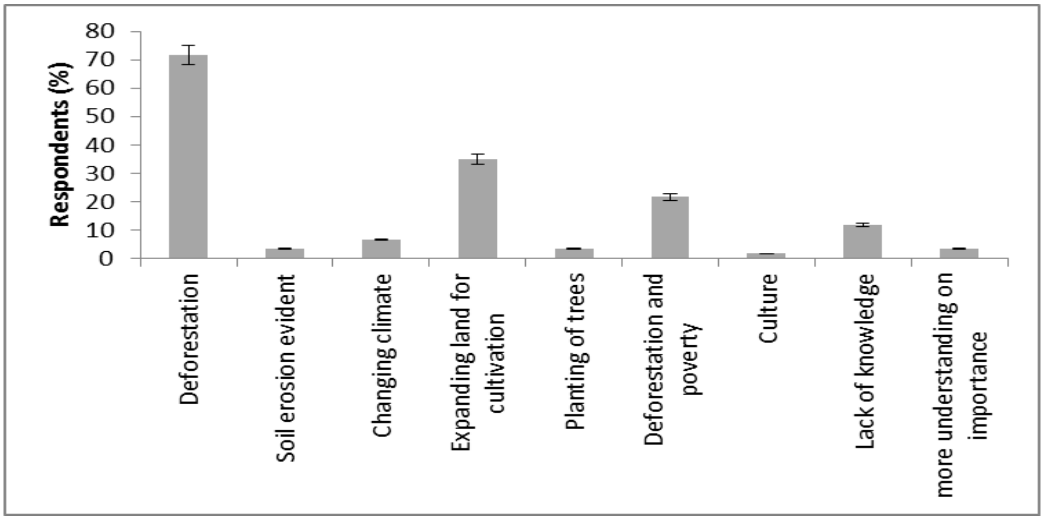


Figure 10: Factors affecting forest cover

4.4.5 Adaptation to climate change

Various adaptive measures were identified as being used by the farmers to cushion the adverse effects of climate change. Early land preparation and planting on time (at the onset of rains) (52%), addition of organic and inorganic fertilizers (37%), planting early maturing crop varieties (28%) and water and soil conservation (18%) were the top four responses to climate change within the sub - County (Figure 10). These strategies are a result of erratic and unreliable rainfall hence ensuring increased crop yields. Early land preparation enables farmers to plant at the onset of the rains therefore ensuring maximum utilization of the rainfall water by the crop as well as planting of early maturing crop varieties. Use of organic and inorganic fertilizers increase soil fertility as well as soil structure assisting in high water storage capacity in the soil. Tree planting (13%), changing cropping systems (12%), introduction of new and modern farming technologies for example zai pits,irrigation (8%), and storing of crops after harvest (<5%) were also cited as responses to climate change. A negligible number of farmers (<5%) did not know how to respond to climate change (Figure 10).

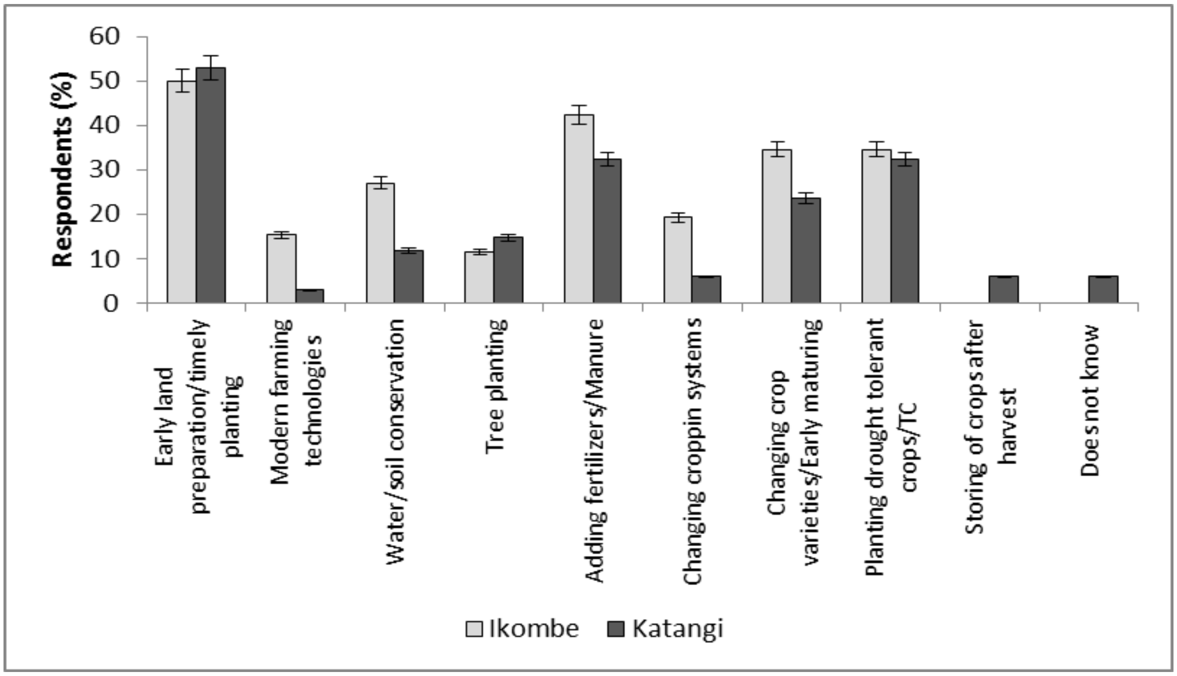


Figure 10: Adaptation mechanisms to climate change

New crop varieties, use of manure and inorganic fertilizers, planting on time and reforestation have been recognized as some of the main responses to climate change (Mertz et al., 2008). According to Boko et al. (2007), the emerging of new traits and varieties of crops offers farmers greater flexibility in adapting to climate change. The traits make the varieties tolerance to drought and heat, and early maturation in order to shorten the growing season and reduce farmer's exposure to risk of extreme weather events. In Kenya, several pigeon pea varieties such as Mbaazi 3, Katumani 60/8, among others have been developed which are resistant to disease and insect attacks as well as tolerant to moisture stress. These varieties were developed especially for the arid and semi arid agro ecological zones as they are drought tolerant (GoK 2012). The Government of Kenya has in turn set up many interventions as a response to climate change such as promoting irrigated agriculture, conservation agriculture, support for community based adaptation including provision of climate information to farmers and enhanced financial and technical support to drought tolerant crops (NCCAP, 2013). Studies further show that the perception or awareness of climate change (Sampei and Aoyagi-Usui 2009; Akter and Bennett, 2009, Semenza et al., 2008) and taking adaptive measures (Maddison, 2006; Hassan and Nhemachena, 2008) are influenced by different socio-economic and environmental factors. Without adaptation, climate change is generally detrimental to the agriculture sector but with adaptation, vulnerability can be largely reduced (Smit and Skinner, 2002).

Farmers in Yatta sub – county would also like to introduce new crops such as pumpkins, millet, cassava, chick pea, dolichos, green grams, sweet potatoes, sorghum e.t.c in their farms in view of the changing climate. Of these the crops that were ranked highest in preference for introduction were cassava and green grams followed by millet, hybrid maize, sorghum and fruit trees. The farmers also identified reasons for the preference of these crops with 58% stating that the crops are drought tolerant and will ensure continuous production, 19% stated nutritional significance, 13% stated more economic returns and 10% stated food security (Figure 11). Cassava, millet and sorghum have been identified as drought tolerant crops with drought tolerant hybrid maize varieties suitable for the arid and semi - arid region having been developed.

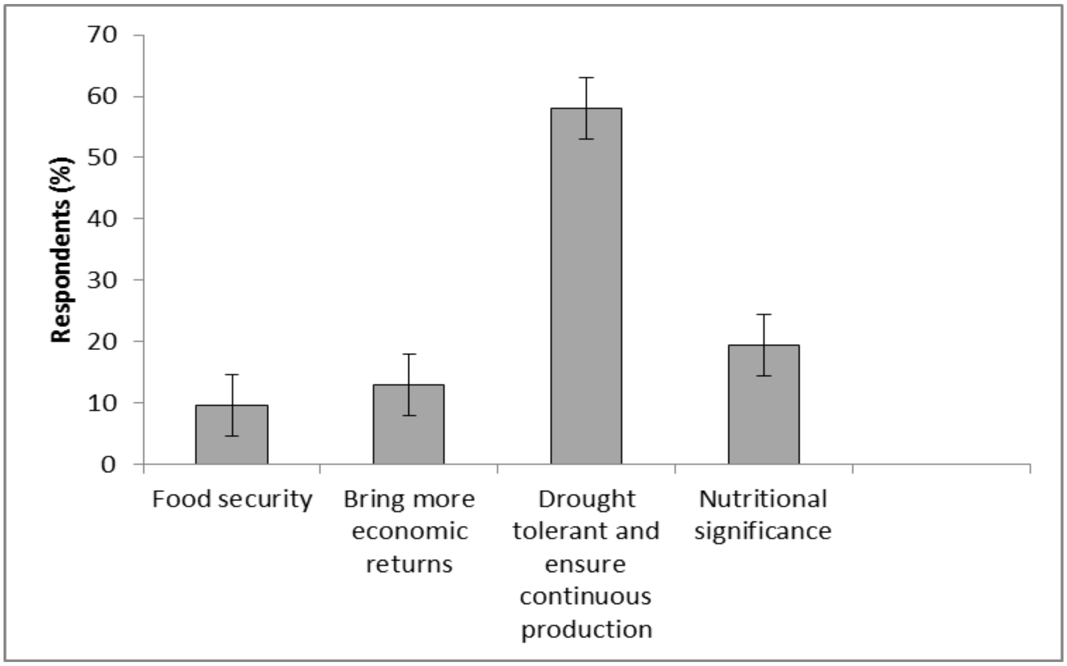


Figure 11: Factors motivating introduction of new crops by farmers

Farmers identified greengrams, cassava, fruit trees, sorghum and millet as the major crops they would like to reintroduce. Most of these crops were appropriate and recommended for the region. This was a sign that the farmers are slowly appreciating the importance of the abandoned crops hence the need to reintroduce them.

4.4.6 Future climate predictions

Most of the farmers (90%) anticipated change in the climate in the near future with 83% of the farmers anticipating low rainfall and 78% anticipating high temperatures while 18% anticipate increased rainfall and 17% anticipate a decrease in temperatures (Figure 12). Currently, farmers observed that climate has been changing over the past few years with climate variability becoming more pronounced currently. Climate projctions have also shown an expected decrease in rainfall and increase in temperature especially in the ASALs.

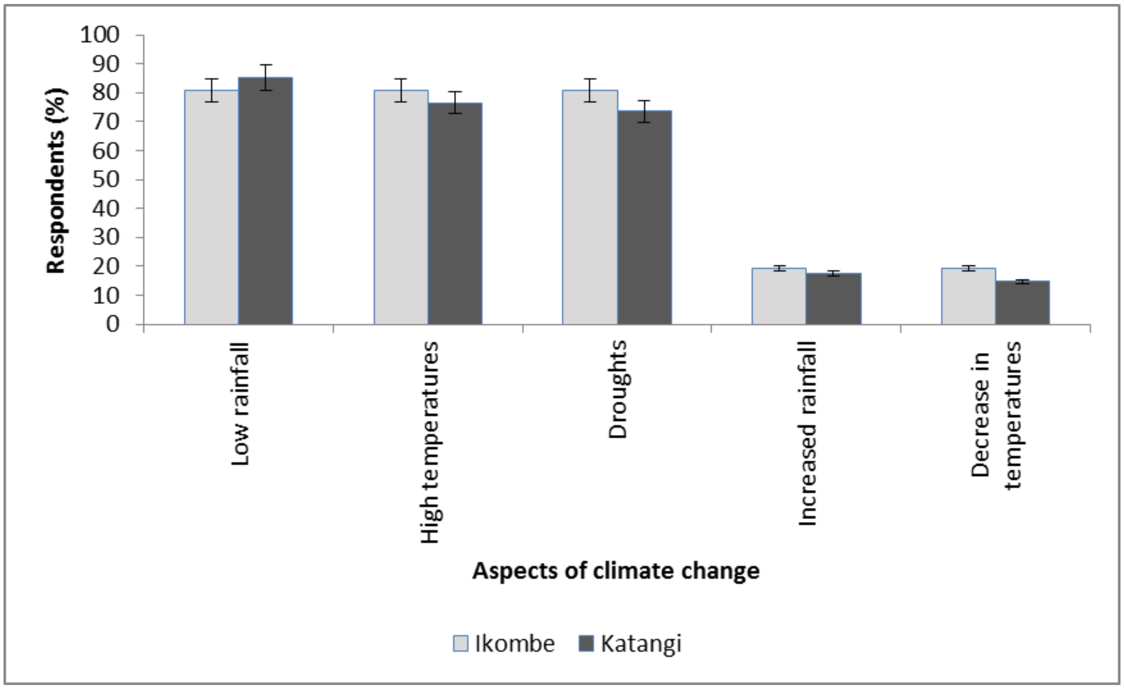


Figure 12: Anticipated climatic changes

These changes in rain, temperature and droughts are mostly anticipated within the next 0 – 5 years with 70% of the farmers indicating changes in rain, 71% indicating changes in drought and 66% indicating changes in temperatures in the next 0 – 5 years (Table 8).

Table 8: Farmers anticipation of climate change in years

Climate aspect	**0 – 5 years (%)**	**5 – 10 years (%)**	**10 – 20 years (%)**	**Over 30 years (%)**
Rainfall	70	22	6	2
Temperatures	66	24	6	4
Droughts	71	25	2	2

These anticipated changes are due to the fact that the farmers recognize that there will be more deforestation occurring in the region due to increase in population and human activities as a result of clearing forests to create more land for settling and farming. Rainfall and temperature are a major determinant of agricultural production in sub-Saharan Africa (Barrios et al. 2008). However, lack of awareness on climate change and its causes can also be regarded as a major driver of this observation (UNDP, 2012). General Circulation Models (GCM) used to develop future climate change scenarios have indicated increased temperatures in the ASALs, reduced rainfall as well as doubling of CO^2 in the near future in Kenya. It is expected that increase in intensity and frequency of droughts will occur and with the projected climatic changes, will enhance the adverse impacts of droughts (UNDP, 2012). Increased temperatures, droughts and floods will reduce productivity leading to increased vulnerability of agriculture which is heavily reliant on rain (UNEP, 2009). Farmers concerns about changes in rainfall variability are valid given that rain fed agriculture is the dominant source of staple food and cash crop production and livelihood for the majority of the rural poor. Climate variability, in particularly the occurrence of drought is a strong determinant of agricultural performance as well as general economic performance of the country (Herrero et al. 2010).

In order for farmers to be able to better adapt and cope with the effects of climate change, it is necessary to have access and knowledge of weather forecasting techniques. Farmers used both traditional and scientific methods of weather forecasting. Sixty five percent of the farmers used traditional techniques in predicting weather while 20% used scientific methods and 15% used both traditional and scientific methods (Figure 13). The farmers identified the reasons for relying on their given method of weather prediction with 84% stating reliability and accuracy, while 9% stating ready availability and this would explain why traditional methods of weather forecasting were most preferred. Scientific weather prediction methods were rated as moderate by 58% of the farmers in terms of accuracy with 17% rating it as high and 13% rating it as low in terms of reliability. Weather forecasting has proved to be an effective adaptation mechanism for farmers as it enables farmers to know when to prepare land and planting time, two of the adaptation mechanisms identified by farmers.

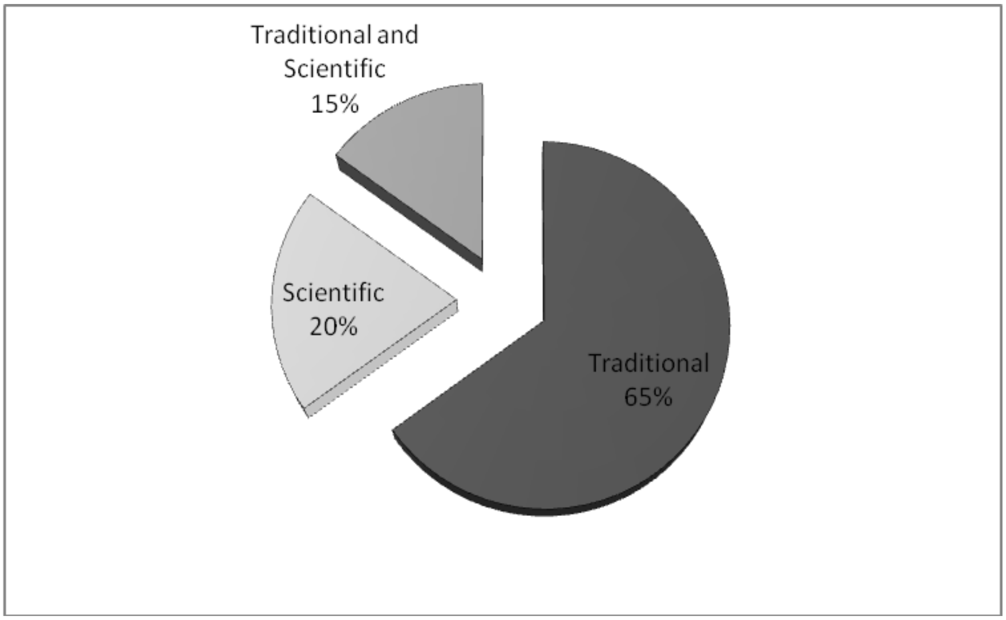


Figure 13: Weather forecasting techniques

Improved climate forecasting is a central part of improved early warning systems. Traditional techniques of weather prediction such as, tree shading (75%), cloud movement (55%), birds and insect movement (20%) and the local knowledge on the timing of the season (15%) were identified by the farmers as the major techniques of weather prediction. The other techniques identified were emergence of specific plants (9%), appearance of the sun/moon (7%) and temperature fluctuations (2%). Weather forecasts are very important and have enabled the Yatta community to make appropriate decisions in terms of timely planting (47%), planting of appropriate crops (35%), and choosing the appropriate crop types and seed varieties to plant (.12%). Hassan and Nhemachena (2007) found that access to information about climate change forecasting is important in determining the use of various adaptation strategies and important farming decisions. Similar studies by Tasara and Maposa (2012) have shown that the scientific methods of weather forecasting are flawed, to some extent and therefore communities are more reliant on own close observations on environmental phenomena in regards to weather forecasting (traditional weather forecasting) such as use of trees, birds and animals, insects, wind and terrestrial objects like the sun, the moon and clouds considered as the major methods used by the communities to determine weather forecasting.

4.5 CONCLUSION

Farmers of Yatta sub - County are aware of climate change (98%), its causes and its impact on their crop production which included reduced crop yield, change in planting time, crop failure and reduced soil moisture. The farmers are also aware of the several aspects of climate change such as reduced rainfall, droughts and increased temperatures. . The farmers in the sub – county were also aware of the coping and adaptation strategies to climate change whereby agro forestry, application of fertilizers, rain water harvesting and planting of appropriate crop varieties were identified as the main coping strategies and early land preparation and planting on time (at the onset of rains), addition of organic and inorganic fertilizers, planting early maturing crop varieties and water and soil conservation as the main adaptation strategies identified by the farmers. The farmers also observed that the climate will keep changing with expected decreases in rainfall and increases in temperatures and droughts in the near future which will therefore result in increased crop declines within the area. Despite this, the adaptation and coping strategies are not sufficient to cushion them against the adverse climate change effects. This coupled with poverty and lack of access to credit facilities will lead to increased decrease in crop yields in the near future. There is need therefore to increase the capacity of the community to better cope and adapt to the ever increasing climate variability. There is a need to introduce effective coping and adaptation strategies such as the use of Decision Support Tools (DST,S) that will assist farmers to be more prepared in view of the expected climate variability. To achieve this, there is need for researchers and the communities to work hand in hand through trainings and seminars involving the farmers to sensitize the farmers on climate change as well as participation in community based projects.

CHAPTER FIVE

ASSESSMENT OF TRENDS IN LAND COVER AND CROP TYPE CHANGE OVER TWO DECADES IN YATTA SUB - COUNTY

5.1 ABSTRACT

Assessment of the distribution and dynamics of vegetation is becoming increasingly important in predicting the effects of climate change especially in the ASALs. The current study assessed the changes in crop type between 1986 – 2000 and 2000 – 2012 in Yatta District, Kenya. The Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM) and Enhanced Thematic Mapper Plus (ETM+) satellite images of the years 1986, 2000 and 2012 in Yatta Sub-county classified using ENVI 4.7. The percentage changes of crop types between 1986 – 2000 and 2000 – 2012 were determined using ENVI EX. Questionnaires were administered to establish change detection from traditional to introduced/exotic crops in specific locations within the respondents farms. In 2012, maize and beans covered 72% while traditional crops, shrub land, bare land and riverine forest covered 14, 6, 3 and 5% of the study area, respectively. There was a significant (P=0.000) decline in the area under traditional crops (28.4 and 45.33%), and a significant (P=0.000) increase in maize (41.14 and 140.93%), beans (363.56 and 8.57%) and bare land (1874.54 and 28.55%) between the years 1986 – 2000 and 2000 – 2012 respectively. However, there was a significant (P=0.006) decrease in riverine vegetation (29.5 and 48.59%) as well significant (P=0.000) decrease in shrub land (52.34 and 65.99%) between the years 1986 – 2000 and 2000 – 2012 respectively. The observed trends can be used by planners and capacity builders to sensitize the community on the changes in crop type and help in development of strategies for reintroduction of traditional crops in view of climate change and dwindling land resources as well as inform policies that will promote their reintroduction to achieve food security.

Keywords: Crop type change, climate change, traditional crops, introduced crops, LANDSAT images.

5.2 INTRODUCTION

Climate change is predicted by scientists to have a major negative impact on agriculture, economy and livelihood of the populations of under-developed world and mainly in sub-Saharan Africa (Kandji *et al*., 2006). Changes in land cover and land use have become recognized as important global environmental changes in their own right (Turner, 2002). To understand how these changes affect and interact with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur and the social and physical forces that drive these changes (Lambin *et al*., 2003). Comprehensive information on the spatial distribution of the land use/land cover categories and the pattern of their change is a prerequisite for planning, utilization and management of the land resources.

The land use/land cover pattern of a region is an outcome of natural and socioeconomic factors and their utilization by human beings in time and space. Information on land use /land cover and possibilities for their optimal use is hence, essential for the selection, planning and implementation of land use schemes to meet the increasing demands for basic human needs and welfare activities. This information is necessary in monitoring the dynamics of land use resulting out of changing demands of an increasing population particularly in the arid and semi-arid lands (ASALs) (Singh and Khanduri, 2011)

Over 80% of Kenya's landmass is classified as ASALs (Oshahr and Viner 2006). Farmers in the ASALs cultivate a variety of economically important crops such as maize, sorghum, green grams, beans and cowpeas under rain-fed agriculture as well as horticultural crops such as mangoes, bananas, tomato, onions, kale, capsicum, pawpaw and citrus. This is however not the case for the farmers in Yatta sub - County who mostly cultivate exotic/introduced crops such as maize and beans that are however not adaptable to the harsh climate conditions of the area (Ministry of Agriculture, 2007).

The change in land area under introduced crops from traditional crops can be attributed to many of the landraces being lost with the "green revolution" which sought to increase food production through introduction of high-yielding varieties of crops to boost food self-sufficiency in famine-prone countries. The high-yield crop varieties were widely distributed, often with government subsidies to encourage their adoption, and they displaced local traditional crops from many farmland areas (Padulosi *et al*., 2000; IPGRI., 1998). The "pushing forward" of high-yielding crops in developing countries through subsidies in the widest sense has quite often appealed to farmers' economic rationale. Now, there is an increasing endorsement at national and international level of the important role in sustainable farming systems and human well-being of less-used (abandoned or orphaned) crops and species, particularly in less favorable and marginal lands" (Padulosi *et al*., 2000; IPGRI 1998). It is therefore important to establish a trend leading to the abandonment of these crops as well as the reasons for abandonment forming a basis for reintroduction.

It has been widely accepted that land use and land cover change in an area is as a result of the complex interactions between diverse driving forces. Population increase, intensive and extensive agricultural practices, urbanization as well as economic development (Kelarestaghi and Jeluodar, 2009) are among the forces that cause changes in land use land cover change which lead to severe environmental problems such as droughts, floods, landslides (Giri *et al*., 2003). Researchers (Rahman et al., 2005, Rouchdi *et. al*., 2008) have therefore acknowledged the advantages of remote sensing coupled with Geographic Information Systems (GIS) in mapping, monitoring and detecting land use land cover dynamics.

In this study, an effort was made to map and detect vegetation cover and crop type changes over two time periods, 1986 – 2000 and 2000 – 2012 in Yatta sub- County using Landsat remote sensed data and GIS technology to examine an establish the trend in the change of crop cover over the years from traditional crops to introduced crops.

5.3 MATERIALS AND METHODS

5.3.1 Study site

The study was conducted in Yatta sub – County as described in chapter two of this thesis.

5.3.2 Data collection

One Thematic mapper (TM) for year 1986, one Enhanced Thematic Mapper (ETM) for year 2000 and one Enhanced Thematic Mapper plus (ETM+) for year 2012 were obtained from Regional Centre for Mapping of Resources for Development (RCMRD), Kenya. These LANDSAT imageries were used to assess vegetation/crop type changes in the study area. The selected years of the images were purposively chosen considering the effect of cloud cover especially in the study area and temporal sensitivity.

5.3.3 Land cover and crop type classification

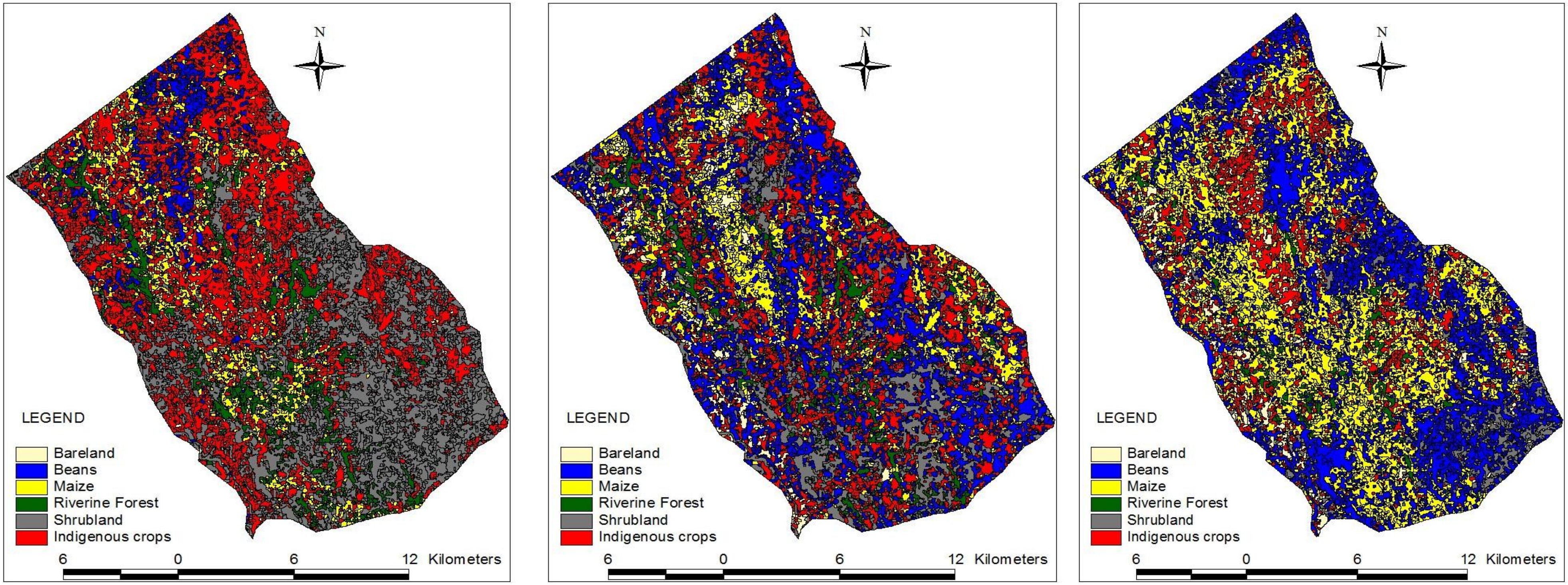
ENVI 4.7 software (ESRI, 2009) was used to process the LANDSAT imagery for the years 1986, 2000 and 2012. Maximum likelihood method of supervised classification was used to get different crop types and land cover. False colour composite using different reflective indices (Bands 4, 3, 2) were used for the visual examination and interpretation of the images. To avoid uncertainties, the selected images were acquired within the same season of the years (December). The images were then classified into different land cover and crop types using supervised classification. Classification of different crops (introduced and traditional crops) was based on the information provided by the farmers regarding their past and current spatial crop production. A total of 60 farmers selected by proportion in line with the population size of the sub-County based on the Cochrane formulae (Cochran, 1977) were interviewed. Specific locations where these crops used to be grown in the year 1986, 2000 and currently 2012 were recorded using a GPS receiver with the guidance of the farmers. False colour composite using different reflective indexes (Bands 4, 3, 2) were used for the visual examination and interpretation of the images and maximum likelihood method of classification (Dutta and Sharma 1998) was used. Six main land cover types were classified according to Anderson (1998) guidelines and selected to carry out statistical analysis. The crop types included; traditional crops (Sorghum, finger millet, cassava, dolichos, sweet potatoes, green grams, cowpeas, pigeon pea, pumpkins), maize and beans while the other types of land cover were riverine forest, shrub land and bare land.

Thematic change detection was established using ENVI EX Software (ESRI, 2009 by comparing two images of different times (1986-2000 and 2000-2012 image changes). The software identified differences between the images with a resultant classification image and statistics. The statistics on image changes were examined and analyzed for land cover and crop type changes and their percentage changes subjected to Chi-square test to establish significance levels.

5.4 RESULTS AND DISCUSSION

5.4.1 Trends in crop type change between the years 1986, 2000 and 2012

Significant (P<0.05) decrease in area under traditional crops (Sorghum, finger millet, cassava, dolichos, sweet potatoes, green grams, cowpeas, pigeon pea, pumpkins) while that under maize and beans increased over the 1986 – 2000 and 200 – 2012 period (Figure 14). The greatest crop type and land cover change occurred after 2000 with rapid increase in introduced/modern crops grown, shrub land and bare land and decrease in traditional crops and riverine forests.



1986 **2000** **2012**

Figure 14: Crop type and land cover change in the years 1986, 2000 and 2012

Shrub land decreased from 35.94% in 1986 to 17.13% in 2000 and 5.83% in 2012 while bare land increased from 0.18% in 1986 to 3.60% in 2000 and to 4.63% in 2012. In contrast, the riverine forest decreased from 9.14% in 1986 to 6.44% in 2000 to 3.31% in 2012. There was significant decrease (Table 9) in cultivation of traditional crops in the years 1986 – 2000 and 2000 – 2012 ($P \geq 0.01$) with corresponding significant increase in the maize crop ($P \geq 0.01$) as well as beans ($P \geq 0.01$). Significant decrease in shrub land ($P \geq 0.01$) and riverine forest ($P \geq 0.01$) and consequent significant increase in bare land ($P \geq 0.01$) were also observed (Table 9).

The change in crop type and vegetation change (from traditional crops to introduced crops, riverine forest and shrub land decrease and bare land increase) is attributed to low unreliable rainfall (92%), population increase (42%), low inputs (42%) and poverty(37%) as per results from the farmer suvey. The decreasing shrub land and riverine forest and increasing bareland is mainly as a result of increased population hence increased human activities such as agricultural activities coupled with the changing climate (Kioko and Okello, 2010; Mutie *et al.,* 2006; Pelikka *et al.,* 2005; Gunlycke and Tamala, 2011; Ochego, 2003). Studies have shown that population growth is the major driver of land use/land cover over time owing to the increasing demand for productive land which is met by clearing more forest and shrub land and increased land degradation hence increased bare land (Barasa *et al.,* 2010; Ramankutty *et al.,* 2002). The rising population especially in developing countries such as Kenya imposes lots of pressure on the land resources in a country where approximately 75% of the populace engages in agriculture but only 20% of its land is arable. As a result, the shortage of arable land has led to expansion of cultivation into the wetter margins of rangelands, felling of forests and the declining savannas and grasslands due to overgrazing, charcoal burning and other unsustainable land use practices (Mwagore, 2002; Campbell et al., 2003).

Table 9: Land cover and crop type changes in Yatta sub - County

	1986		**2000**		**2012**		**Change (1986-2000)**		**Change (2000-2012)**		**(Chi-Square Test)**	
Land use/cover	**Area (km^2)**	**% Area**	**Area (km^2)**	**% Area**	**Area (km^2)**	**% Area**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**X^2**	**P Value**
Traditional Crops	136.80	36.76	97.95	26.32	53.55	14.39	-38.84	-28.40	-44.40	-45.33	35.799	0.000
Maize Crop	42.53	11.43	60.03	16.13	144.62	38.86	17.50	41.14	84.60	140.93	72.250	0.000
Bean Crop	24.39	6.55	113.06	30.38	122.76	32.98	88.67	363.56	9.69	8.57	68.546	0.000
Riverine Forest	34.01	9.14	23.98	6.44	12.33	3.31	-10.03	-29.50	-11.65	-48.59	10.400	0.006
Shrub Land	133.76	35.94	63.75	17.13	21.68	5.83	-70.01	-52.34	-42.06	-65.99	87.309	0.000
Bare Land	0.68	0.18	13.40	3.60	17.23	4.63	12.72	1874.54	3.83	28.55	13.419	0.001
Total	**372.17**	**100**	**372.17**	**100**	**372.17**							

5.4.2 Crop type change over the past two decades

The area in percentage of traditional crops, introduced/exotic crops, riverine forests, shrub land and bare land are as shown in table 8 above. The area in percentages (%) covered by traditional crops and introduced/exotic crops in the year 2012 were; traditional crops (Sorghum, finger millet, cassava, dolichos, sweet potatoes, green grams, cowpeas, pigeon pea, pumpkins) (14%), maize (39%) and beans (33%) with the area under traditional crops decreased significantly from 36.76% in 1986 to 26.32% in 2000 and to 14.39%in 2012 while area covered by maize increased significantly from 11.43% in 1986 to 16.13% in 2000 and 38.86% in 2012. The area covered by beans also increased from 6.55% in 1986 to 30.38% in 2000 to 32.98% in 2012. Traditional crops decreased significantly while the introduced crops (maize and beans) increased significantly in the years 1986, 2000 and 2012, respectively (Figure 15).

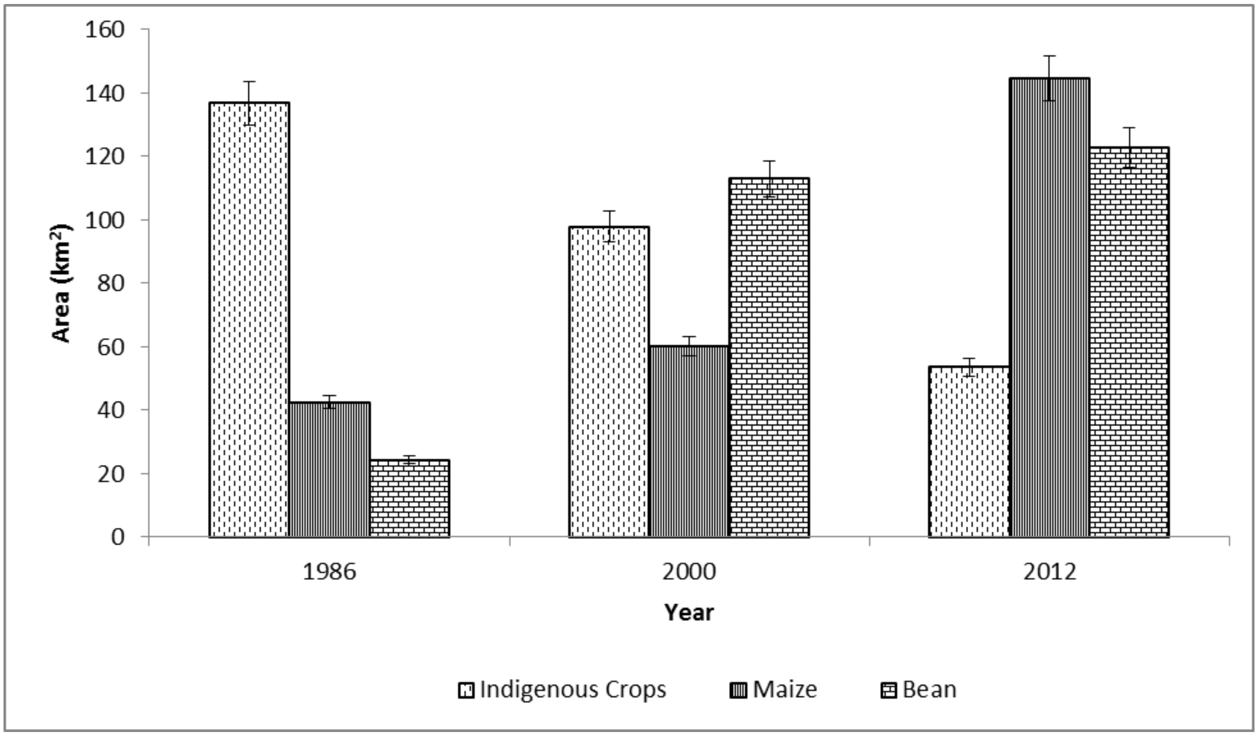


Figure 15: Crop type change in Yatta sub - county

In 1986, the traditional crops mostly grown were pigeon pea (24%), cowpea (21%), green grams (19%), sorghum (16%) and millet (11%) while in 2000 the common traditional crops grown were pigeon pea (21%), sorghum (21%), cowpea (19%) and green grams (19%). In 2012, the common traditional crops were pigeon pea (23%), sorghum (22%), green grams (22%) and cowpea (21%). Other traditional crops grown though not in significant proportions were dolichos, cassava, millet, sweet potatoes, pumpkins and yams. From these observations, pigeon pea, sorghum and cowpea were the most planted traditional crops across the two decades. In Kenya, following the Green Revolution and the push to use modern agriculture to improve food production and security, a high proportion of farmers grow introduced/exotic crops. Traditional crops however offer a huge potential for building resilience and adapting to climate change especially in ASALs. Crop choice is very climate sensitive (IIED, 2011; Kurukulasuriya and Mendelson, 2006).

Change from traditional crops to introduced crops can be attributed to the economic importance attached to introduced crops hence the abandonment of the traditional crops that are more adapted to the local climate of the area. Studies have shown that there is a decrease of area under production of other crops in preference to high value crops of economic importance such as maize. This is as a result of both natural and socio-economic factors and their utilization including population increase and modernisation and commercialization of agriculture (Choudhury and Saha, 2003; Sharma, 2011)

Poverty and population increase are the major drivers behind increased economic importance attached to cash crops and are therefore the major causes for the change resulting in increased land area under agriculture. Research by Agatsiva and Oroda (2001) in Eastern Kenya revealed that the main crops grown in the area were maize and beans usually intercropped while food crops such as sorghum were also grown but at a lower scale. However, most of the farmers were achieving less than 10 bags of maize per acre due to droughts (climate change). Another study by Maeda *et al*. (2010) in Taita Hills showed that maize and beans were the predominant crops grown in the area while crops that are more resistant to drought such as cassava, pigeon peas and cowpeas were grown on a much smaller scale. This can be attributed to the economic importance associated with maize and beans as compared to the drought resistant crops such as cassava, pigeon peas and cowpeas.

Climate variability is another factor contributing to the changing crop type due to the fact that over the years, crop yields have been reducing as a result of climate change translating to reduced economic returns and hence the need for farmers to increase their economic returns by planting modern cash crops even though they are not adapted to the region. De bie et al. (2008) found that disparity between the crop types and the changing crop intensities were attributed to major droughts faced in India during the period of study. A similar study by Punithavathi, *et al*. (2012) to assess agricultural cropping concentration and crop wise changes, showed changes in crop types grown as a result of migration of people and poor climatic conditions due to climatic changes.

5.5 CONCLUSION

From the results, it is clear that there has been a tremendous change in the crop types and land cover within the last two decades in Yatta sub – County mainly as a result of climate variability. A clear trend was established in the shift in crop types grown over the two decades with major significant ($P<0.05$) changes observed from traditional crops that are more adaptable to the regions' local climate to introduced crops that are not but are preferred due to their economic significance. This therefore shows that over the past two decades, farmers in the region have shifted to planting more of introduced crops as opposed to traditional crops even though they are more suited for the local climatic conditions due to their economic importance. The riverine forests and shrub land also significantly ($P<0.05$) reduced while bare land increased. These changes can be majorly attributed to population growth, human activity, poverty and climate change. This study is therefore likely to be used for future generations monitoring methods especially for crop type change. As traditional systems and land husbandry are rapidly being abandoned, an alternative approach is essential in view of the changing climate. This study will inform government policies that will cater for the abandoned crops and encourage their re-adoption especially in the ASALs where they are more adapted as compared to the modern crops. It will also aim to enlighten the community to better understand the crop trends in their region, the reasons for their abandonment and the importance of the abandoned crops as well as their reintroduction thus creating more opportunities for research in these areas.

CHAPTER SIX

MODELLING INFLUENCE OF CLIMATE CHANGE ON GROWTH AND YIELD OF SORGHUM UNDER DIFFERENT CROPPING SYSTEMS AND ORGANIC INPUTS IN SEMI ARID LANDS OF KENYA

6.1 ABSTRACT

A simulation study was carried out using the Agricultural Production Systems sIMulator (APSIM) Model to assess the potential sensitivity of sorghum to likely changes in temperatures and rainfall in semi-arid Yatta sub county Kenya. The APSIM model was calibrated using soil and plant data from field trials, laid out in a randomized complete block design with a split plot arrangement, conducted during the long and short rainy seasons of the years 2010 and 2011. The main plots consisted of cropping systems (monocrop, intercrop and crop rotation) with a legume component (pigeon pea) while the subplots consisted of organic inputs (farm yard manure and compost). Effect of the following future climate change scenarios on performance of sorghum was considered: current temperature (To) and Rainfall (Ro) provided the baseline, To+1.6^{0}C (Tmax), To+1.8^{0}C (Tmin), R_0+10%, R_0-10% and a combination both temperature and rainfall To+10% rainfall increase, To-10% rainfall decrease examined for sorghum. Effect of CO_2 fertilization was not possible because the sorghum module has not been parametized to capture this effect but a baseline CO_2 concentration of 350 ppm was used. The model was evaluated using the Root Mean Square Error (RMSE), Normalized Root Mean Square Error (NRMSE), Coefficient of Efficiency (E*i*), linear regression (R^2) and Range Ratio (RR). Sorghum yields (1.380 t/ha) under rotation cropping system were significantly ($P<0.05$) higher compared to intercropping and monocropping cropping systems as well as yields under farm yard manure were significantly ($P<0.05$) higher as compared to compost and control. There were significant ($P<0.05$) interactions between the treatments with sorghum yields under rotation with farm yard manure having the highest yields (1.380 t/ha) as compared to the other treatments. Among the cropping systems, rotation (1.21 t/ha) yielded the best grain yields while farm yard manure (1.29 t/ha) yielded the best among the organic inputs with compost yielding 1.13t/ha. The short rains (1.16 t/ha) recorded higher yields compared to the long rains (1.12 t/ha). There were no significant differences between the observed and simulated yields with R^2 = 0.96 for the short rains and R^2 = 0.8 for the long rains and RMSE values of 0.87 t/ha and 0.72 t/ha for the short and long rains respectively. Mean differences between the observed and simulated values were averaging to 821 kg/ha for the short rains and 708 kg/ha for the long rains. These results indicated good model performance. The Normalized Root Mean Square Error (NRMSE) was 2.4% for the short rains and 1.48% for the long rains which was low as well as Range Ratio (RR) values of 35.62% and 36% for the short and long rains respectively on the grain yield, both values being low indicating good model performance. Cropping systems and organic input effects on grain and biomass yields were well simulated. Climate change in terms of increased temperatures [To+1.6^0C (Tmax), To+1.8^0C (Tmin)] and reduced rainfall (R_0-10%) had a negative effect on sorghum yields resulting in a mean average biomass yield change of 5% in increased temperature as compared to 1.2% for reduced rainfall while grain yield reduced by 3.8% and 3.4% respectively. Increase in rainfall (R_0+10%), and a combination of increase in both temperature and rainfall predicted an increase in yields across both seasons at 3.6 and 4.7% respectively. Rotation cropping systems and use of farm yard manure results in increased grain and biomass yields of sorghum as well as increased soil fertility. In view of the future climatic predictions, use of cropping systems and organic inputs have been simulated to yield better as compared to the control plots despite the expected negative impacts. Future predictions show a decrease in sorghum yields as a result of reduced rainfall and increased temperatures, however, use of cropping systems and organic inputs helps reduce the negative effects on crop yields. The APSIM model can therefore be used to advice farmers on the best management strategy to undertake to achieve sustainable yields despite the ever changing climate. K**ey words; Abandoned crops, Climate Change, APSIM, cropping systems, organic inputs,**

6.2 INTRODUCTION

While climate change predictions show a potential rise in temperature over the next 50 years bringing a change in the rainfall patterns and distribution, the potential impacts of this in Africa remains widely unknown (IPCC, 2007). However, climate change is expected to make matters worse with increased rainfall variability being predicted especially in the semi-arid tropics (SAT) with consequent reduction in length of growing season, distribution, productivity and ultimately food production in a region that consistently experiences food deficits (Bwalya, 2008). As a result of this, various integrated soil fertility management practices are being promoted in these arid and semi-arid regions having identified declining soil fertility and productivity coupled with climate change as one of the reasons for declining crop productivity in sub-Saharan Africa (McCann, 2005) as opposed to conventional agriculture.

Conventional agriculture often relies on short term solutions such as application of fertilizers to solve nutritional issues whereas organic systems provides long term solutions which are preventive rather than reactive with an example of rotation design of nutrient cycling, use of organic inputs, weed, pest and disease control (Stockdale et al., 2001). Nutrient depletion is a reversible and high agricultural production can be realized through appropriate nutrient managing including integrated use of organic and inorganic sources of nutrients for example through application of organic materials such as litter, crop residues, and manure (Lekasi et al., 2000).

According to Palm et al. (2001) organic fertilizers play a dominant role in soil fertility management through its short term effects of nutrient supply and long term contribution to soil organic matter. Legume integration is also an important component of ISFM technologies with legume-cereal intercropping and rotation being common in Eastern and Southern Africa. Farmers intercrop and rotate to secure food production by averting risk (Giller 2001). Intercropping effectively utilizes available resources and result in higher yields than when crops are grown as pure stands as well as better soil cover, weed control and reduced erosion and nutrient leaching (Fan et al., 2006). Legumes, such as pigeonpea or cowpea have a higher potential to supply N to the cereal as compared to beans (Myaka et al., 2006).

Crop rotation has increased crop productivity and sustainability for the semi-arid regions. Therefore the maintenance and management of soil fertility is the core to development of sustainable food production systems which is through self-sufficient organic farming including fixation of atmospheric nitrogen by legumes, recycling of crop residues and application of natural resources such as farmyard manure, compost and biofertilizer (Ravindra et al., 2007). To achieve this effectively, it is necessary to plant crops suitable for the harsh climatic conditions of the semi arid regions especially the abandoned crops such as sorghum and pigeon pea. Growing of drought tolerant crops provides an opportunity for communities to better cope with climate change in the ASALs (Miano et al., 2010).

Sorghum and pigeon pea are major crops widely grown by the resource poor farmers in the semi-arid parts of Kenya for subsistence and as a source of income (Macharia, 2004). In Kenya, sorghum is ranked as the third among cereals grown. It is grown principally in the often drought prone marginal agricultural areas of Eastern, Nyanza and coast provinces because it stays greener than other crops when water stressed and therefore continues to photosynthesize during drought hence the crop of choice to fight nutritional and food insecurity in Africa (Jones et al., 2001). In view of the expected climate changes, it is therefore necessary to study its potential impact especially on the crops that are adapted to the ASALs.

The application of crop simulation models to study the potential impact of climate change and climate variability provides a direct link between models, agrometeorology and the concerns of the society. (Deressa et al., 2005). As climate change deals with future issues, the use of General Circulation Models (GCMs) and crop simulation models provides a more scientific approach to study the impact of climate change on agricultural production and world food security. In Kenya crop simulation models have been successfully used in the interpretation of research results in complex and highly variable cropping systems (Shisanya, 1996).

The use of crop simulation models such as APSIM will be well received by farmers who in the past have expressed dissatisfaction with research and development aimed at providing “quick fix” solutions and have increasingly become interested in the development of research methodologies that address the long term economic and ecological issues (Carberry et al., 2004; Dimes, 2005). The use of models, with long runs (30 years or more) of daily climatic data such as APSIM thus provides a quick and much less costly opportunity of ‘accelerated learning’ compared with more traditional multi-seasonal and multi-factorial field trials (Carberry et al., 2004).

With this realization, this study will contribute towards assisting farmers to predict the effects of climate change on their yields and advice on the suitable management options to ensure improved crop yields.

6.3 METHODOLOGY

6.3.1 Site Description

The site description is as described in chapter two of this thesis.

6.3.2 Experimental Design and Treatments

A Randomized Complete Block Design (RCBD) with a split plot arrangement replicated three times was set up. The main plots were the cropping systems of sorghum and cassava (monocropping, intercropping and crop rotation) with a legume component (Pigeon Pea and Dolichos) while the sub- plots were incorporated with organic inputs (farm yard manure, compost). The organic inputs were applied at the rate of 10,000 kg/ha applied during planting. The experimental plots were 10m by 10m set in four farms located in two divisions namely Ikombe and Katangi. The experiment had nine treatments replicated three times in all the four farms.

6.3.3 Agronomic Practices

The crops were planted in May and September during the long and short rains of the years 2011 and 2012, respectively. Sorghum seeds were sown at a spacing of 75 cm x 20 cm. Weeding was done every 4 weeks while harvesting was done by hand after 3 months when it had reached physiological maturity i.e when the grain is hard and does not produce milk when crushed. Pigeon pea was planted in intercrops of sorghum as well as in rotation with sorghum. The crops were planted at a spacing of 100 cm by 50cm for pigeon pea and weeding done after every four weeks. Organic inputs both manure and compost were applied at 10t/ha. Crop phenological data as well management data was collected which included sowing date, date of fertilizer emergence, date of flowering, date of grain filling and date of maturity. Harvesting was done after 3 months by plucking the pods. All crop residue was removed after harvesting. For all crops, natural and organic pest and disease management practices were employed.

6.3.4. Soil and plant sampling and analysis

Soil samples were taken randomly from each plot at three depths: 0 – 15 cm, 15 – 30 cm and 30 – 45 cm depths and composited into one sample to get a single composite sample in each plot for physical and chemical analysis. Samples were air-dried by spreading the soil out in a clean, warm, dry area, for two days. The sample were packed, labelled and later taken to the laboratory for both physical and chemical analysis. The parameters analysed for initial soil characterization included soil texture, bulk density, pH, Organic Carbon, Total N, Phosphorous, bases K, Na, Mg, and Ca (Table 10)

Table 10: Soil parameters for the APSIM simulation and methods used for analysis

Parameters	**Method of analysis**
Bulk Density (g/cm3)	Oven dried (105deg. C) to constant weight, after Blake and Hartge (1986)
Saturated water content (cm3/cm3)	Initial Drainage Curve (IDC) as described by Klute (1986)
Field capacity (cm3/cm3)	Initial Drainage Curve (IDC) as described by Klute (1986)
Soil N parameters	
Organic C (g/kg)	Walkley and Black method as described by Nelson and Sommers (1982)
Nitrate N (mg/kg)	
Total N (N)	Kjeldahl procedure, as described by Bremner and Mulvaney (1982)
Soil P parameters	
Labile P (mg/kg)	Olsen method as described by Olsen and Sommers (19820
Other Soil Profile Parameters	
pH	1:2.5 soil KCl I1M), by a standardized pH meter
CEC	Walkley and Black method as described by Nelson and Sommers

	(1982)
Ca	Ammonium acetate method
Mg	Ammonium acetate method
Na	Ammonium acetate method
K	Ammonium acetate method
ESP	Calculated
Texture (Particle size:sand, silt and clay	Hydrometer method (Jones, 1930). Soil texture classes and size classification according to USDA system i.e sand (2000-50 µm), silt (50-2 µm), clay (<2 µm), Gee and Bauder (1986)
Field capacity Saturation capacity Dry upper limit Permanent wilting point	Pressure plate method (Richards, 1948) was used to determine soil water matric potential.

Plant Sampling: Plant sampling of grain and dry yield matter was done where three middle rows were harvested leaving two rows on the sides acting as guard rows during harvesting stage for all the crops (Sorghum and Pigeon pea).

6.3.5 APSIM Data Requirements calibration and evaluation

The Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003; Wang et al., 2003) was used in this study to explore the effects of climate change on sorghum under different cropping systems and organic inputs. APSIM is a component-based simulation framework with various modules such as crop growth and development, soil water, soil nitrogen and crop management. The model runs at a daily time-step using soil data, weather data, crop parameters and management data as input.

Climatic data

Climatic data for modelling consisting of daily rainfall, solar radiation, and minimum and maximum temperature data from 1960 – 2012 were acquired from Makindu weather station. The area has two rainy seasons, the short rains (October – December) and the long rains (March – July).

Table 11: Climate data for October 2010 – October 2011 season

	Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb2011	Mar 2011	Apr 2011	May 2011	Jun 2011	Jul 2011	Aug 2011	Sep 2011	Oct 2011
Rainfall (mm)	32.2	138.1	3.7	8.35	37.9	113.2	119.3	3.6	0	0	0	0	11.9
Max temp (^{0}C)	31.5	27.8	29.4	30.0	33.0	32.1	31.8	27.4	29.2	23.9	26.5	29.1	31.3
Min temp (^{0}C)	20.1	19.8	20.2	17.4	18.6	18.9	20.8	16.2	17.2	12.9	15.3	15.5	17.2

Crop parameters

Crop data was collected through direct observation and registration of crop phenology stages and crop management at sowing, germination, emergence, glowering, grain filling and harvesting/maturity as well as crop management in terms of type of cultivar, crop spacing, plant density, organic inputs (date applied, amount and nutrient content) (table 12). Crop and soil management data was collected (Table 10).

Table 12: Crop phenology stages

		Actual data	
Phenology stage	**Observation notes**	**SRS**	**LRS**
Sowing	Seeding	01/10/2010	01/03/2011
Germination	After 14 days	17/10/2010	18/03/2011
Emergence	Date for 50% emergence	18/10/2010	30/03/2011
end_of_juvenile	Date for 50% emergence	30/11/2010	05/04/2011
floral_initiation	Date for 50% emergence	11/11/2010	07/04/2011
flowering	Date for 50% flowering	12/12/2010	05/05/2011
start_grain_fill	Date for 50% silking	16/12/2010	10/05/2011
end_grain_fill	Date for 50% silking	23/01/2011	11/06/2011
maturity(*)	Date for 50% maturation	26/01/2011	12/06/2011
harvest_ripe	Date for 50% maturation	27/01/2011	15/06/2011
end_crop	Harvesting date	28/01/2011	16/06/2011
Crop Management			

Crop	Type, variety or cultivar	Gadam	Gadam
Seeding	spacing (mm)	750 by 300	750 by 300
	Plant spacing (mm)	750 by 300	750 by 300
	Plant density	7	7
Organic input applied	Date of application, amount and nutrient content	01/10/2010 3500 kg/ha	01/03/2011 3500 kg/ha

6.3.5.3 APSIM Model Calibration and Validation

The Agricultural Production Systems Simulator (APSIM) (Keating et al., 2003; Wang et al., 2003) was used in this study to explore the effects of climate change on sorghum under different cropping systems and organic inputs. APSIM is a component-based simulation framework with various modules such as crop growth and development, soil water, soil nitrogen and crop management. The model runs at a daily time-step using soil data, weather data, crop parameters and management data as input. APSIM has been widely used to simulate cropping systems around the world (Lyon et al., 2003; Ludwig and Asseng, 2006; Heng et al., 2007; Chen et al., 2009).

The phenological parameters of sorghum were derived from observed flowering and maturity dates. Cropping systems simulated included sole cropping of sorghum (with and without organic inputs), intercropping of sorghum and pigeon pea (with and without organic inputs) and rotation of sorghum and pigeon pea (with and without organic inputs). To reflect the seasonal effect, planting window for the short rains and long rains were between 1st to 30th March and 1st to 30th October of every year. The model was set to sow when 25 mm of rain was achieved in any three consecutive days within the sowing window. The calibrated model was then validated using the experimental data during 2010 - 2011. The calibration process aimed at minimizing the root mean square error (RMSE) between observed and simulated parameters.

The early cultivar was selected to use in the simulations since it had similar physiological characteristics as in the trials. Measured soil water parameters from soil profile samples were water content at saturation (sat), at field capacity (dul) and air dry, water content at wilting point (ll15) were derived. Therefore, all these soil water retention parameters were used as initial values and further evaluated and calibrated in the model. Table 13 below presents the calibrated soil properties for the ASPIM model for the trial site

Table 13: Calibrated Soil Properties

Soil water parameters	**Acronym**	**0 - 15**	**15 – 30**	**30 – 60**	**60 – 90**	**90 - 120**
Bulk density (mg/m^3)	**bd**	1.280	1.270	1.340	1.330	1.310
Saturated water content (mm/mm)	**sat**	0.320	0.320	0.340	0.330	0.330
Field capacity (mm/mm)	**dul**	0.280	0.280	0.285	0.270	0.270
Wilting point (mm/mm)	**ll15**	0.150	0.150	0.170	0.170	0.170
Air dry (mm/mm)	**air dry**	0.110	0.120	0.170	0.170	0.170
Drainage coefficient	**SWCon**	0.500	0.500	0.500	0.300	0.300
Soil parameters						
Total carbon (%)	**OC**	1.345	1.280	1.280	0.460	0.430
Inert C fraction	**finert**	0.500	0.750	0.900	0.990	0.990
Initial biomass pool	**fbiom**	0.020	0.015	0.010	0.010	0.010
Sorghum module						
Soil water availability factor	**KL**	0.600	0.600	0.600	0.600	0.600

6.3.6 APSIM Model evaluation

Performance of the APSIM model in simulating grain and biomass yield was statistically evaluated by using the Root Mean Square Error (RMSE). Observed and simulated grain and biomass yield data were used as indicators for establishing the accuracy of climate variability impacts on the yield outputs. The RMSE of a model prediction with respect to the estimated variable X*model* is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}}$$

where X*obs* is observed values and X*model.i* is modelled values at time/place and n is the number of replicates in each planting date experiment.

There are two approaches: normalize the RMSE to the range of the observed data, or normalize to the mean of the observed data.

$$NRMSE = \frac{RMSE}{X_{obs,\max} - X_{obs,\min}}$$

The modified coefficient of efficiency (E1) was also employed to evaluate the model. An efficiency of 1 (E=1) corresponds to a perfect match of modeled data to the observed data and is denoted by;

$$Ei = \frac{\sum^{n}{}_{i=1} |\text{observedi} - \text{Simulatedi}|}{\sum^{n}{}_{i=1} |\text{observedi} - \text{Meanobserved}|}$$

An efficiency of 0 (E=0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (E<0) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Unlike the coefficient of determination, the modified coefficient of internal efficiency is also sensitive to both additive and proportional differences between mode simulations and observations.

Range ratio (RR) which compares the range of outputs between the observed and simulated values was also used. RR only compares the extremes and thus cannot be used alone to check the sensitivity as the rest of the value in the middle are not considered.

$$RR = 100 * \frac{\text{Max}_{\text{observed}} - \text{Minobserved}}{\text{Max}_{\text{simulated}} - \text{Minobserved}}$$

6.3.6 Climate change scenarios - Temperature and rainfall projections

A comparative analysis for CSIRO mk3 data were used to develop climate change scenarios for both near future and far future (2020-2080) period. This data was obtained from the IPCC (2001) database. An average increase in temperature of 1.6^{o}C for the maximum temperatures and 1.8^{o}C for near future and far future respectively was used in the simulation. Rainfall was simulated at a 10% increase and decrease for the near and far future simulations. The sorghum module in APSIM simulations has not been parametized to capture the effect of carbon dioxide fertilization therefore the baseline CO2concentration of 350 pmm was maintained.

***Statistical analysis**:* The data was analyzed for ANOVA and means by Genstat version 13. The variables of measurement included grain and biomass yields and soil nutrients under the different cropping systems and organic inputs.

6.4 RESULTS AND DISCUSSION

6.4.1 Effect of cropping systems and organic inputs on sorghum grain and biomass yields

Cropping systems and organic inputs had a significant ($P<0.05$) effect on sorghum yield in both the short rain season (SR) and the long rain season (LR) with yields under rotation (1.380 t/ha) having the highest yields compared to intercrop and monocrop. Intercrops recorded the lowest yields (0.95 t/ha) during the short rains (Figure 16). The low yields in intercrop systems could be attributed to the fact that there is increased competition of resources and nutrients between the two crops being intercropped. Similarly, adverse effects of intercropping have been attributed to a competition for root development, light, nutrients, and water during the co-growth phase (Herrmann et al., 2014). Even though cereals have been reported to benefit from legume associations, decrease in yields in intercrops have also been reported in several studies (Cattuthers et al., 2000; Li et al., 2001b; Inal et al., 2007). Furthermore, many studies have demonstrated yield increase in rotation cropping systems. Cereal legume crop rotations are considered suitable (Steiner, 2002) with cereals deriving both yield and N benefits from grain legumes compared with cereal monoculture (Kirkegaard *et al.* 2008). The yield advantage may be entirely due to the N fixed by the legumes (Chalk, 1998). According to VAST 2007, crop rotation improves and maintains soil fertility, reduces soil erosion, reduces the buildup of pests and weeds and mitigates risk of weather changes hence increasing crop yields. Alvey et al. (2001) also showed that a cereal legume rotation can enhance P nutrition of cereals through improved soil chemical P availability and microbiologically increased P uptake. Crop rotation with legumes also improved soil physical, chemical and biological conditions (Sileshi et al., 2005; Dawson et al., 2008) and thus yields of cereal crops were generally better in legume cereal rotations than in continuous cereal cultivation (Giller, 2006; Akinnifesi et al., 2006).

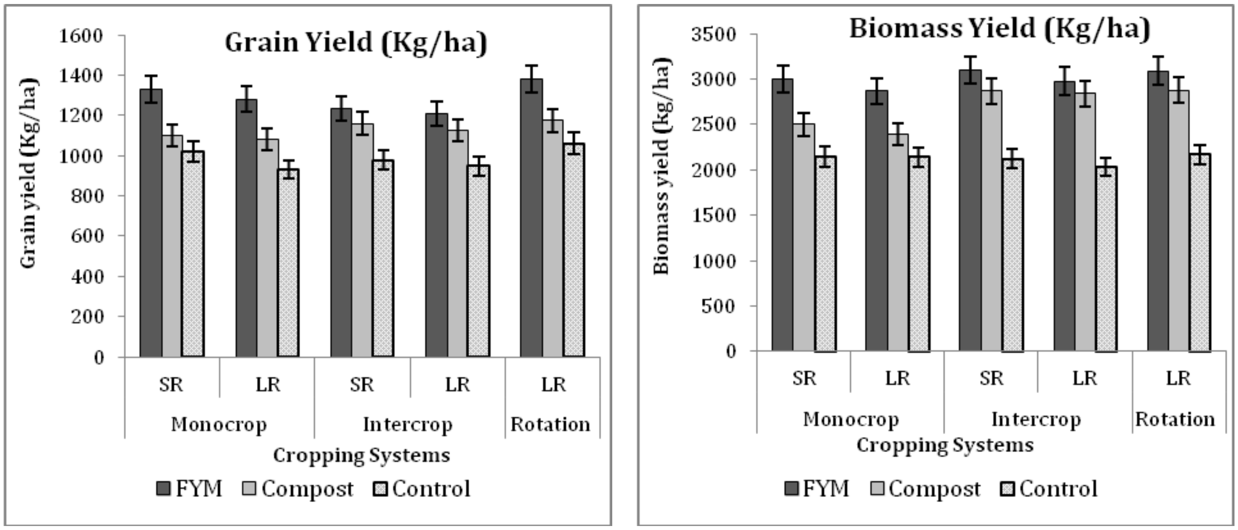


Figure 16: Effect of cropping systems and organic inputs on grain and biomass yield

However, despite the grain increase in rotation systems, intercropping innovation have high potential of being adopted by farmers due to many benefits associated when compared to sole crop stands as demonstrated by Myaka et al. (2006). Application of crop rotation along with increasing soil organic matter increases biodiversity and soil biological community (Kamkar and Mahdavi Damghani, 2009)

FYM had significantly ($P<0.05$) higher yields as compared to compost and control treatments in both seasons with the lowest yields recorded in the control treatment (Figure 16). Organic inputs lead to increased nutrient levels essential for plant growth as well improved water holding capacity and porosity by improving the soil texture and aggregate. Increasing the water holding capacity of soils provides more available water to plants and can also help in resistance to drought (Baziramakenga *et al.* 2001). Gateri et al, (2011) found that FYM generally increased sorghum yields by providing plant nutrients and increasing the soil's capacity to hold those nutrients and also by improving soil physical properties such as the water holding capacity and infiltration rates. Organic inputs (FYM and compost) are a valuable and inexpensive source of nutrients and are acknowledged to play a dominant role in soil fertility management through their short term effects on plants nutrient supply and longer term continuation to maintain soil organic matter and reclaim degraded soils(Palm et al., 2001; Tejada et al., 2008)

6.4.2 Effect of cropping systems and organic inputs on soil organic carbon (OC), Nitrogen (N), Phosphorous (P) and Potassium (K)

Organic Carbon (OC)

There were no significant differences in OC between the two seasons (Figure 17). The soil OC ranged 0.88 – 1.74%. This is because significant differences in OC levels can only be observed after a long period of time as opposed to only two seasons as is in the current study. A recent study from Mexico also showed that significant increases in soil OC occurred after only 2 years when crop rotation was combined with high application of cattle manure (Covaleda et al. 2006). Organic carbon in FYM plots was significantly ($P<0.05$) higher as compared to compost and control treatments regardless of the cropping systems and season. However, the intercrop and rotation cropping systems did not significantly increase the OC levels as compared to the monocrop cropping system (Figure 17). This is due to the fact tha differences in OC levels can only be observed after a long period of time. Combination of FYM under monocrop recorded the highest carbon levels at an average of 1.67% as compared to intercrop and crop rotation. Collins et al. (1992) similarly observed that soil OC and microbial biomass C were significantly greater for annual cereal rotations than cereal - legume rotations. Huggins et al. (2007) also showed that medium to long term (14 years) continuous cereal cropping systems lead to higher soil OC than continuous legume systems. Purakayastha et al. (2008) also concluded that FYM can increase the root biomass and microbial biomass debris which is the main source of percentage organic carbon in the soil.

Soil Nitrogen (N)

Soil N ranged in values between 0.12 – 0.21% with significant ($P<0.05$) differences noted between the two seasons with the long rains recording the highest N levels at an average of 0.17% despite it having received the lowest amount of average rainfall compared to the short rains (Figure 17). The reason for this could be that with reduced precipitation, there was a reduction in N losses due to leaching and soil erosion which are some of the main pathways through which N is lost from the soil. The rate of surface volatilization depends on moisture level, temperature and the surface pH of the soil. If the soil surface is moist, the water evaporates into the air. The N released is picked up in the water vapor and lost. On dry soil surfaces, less N is lost (Vitosh et al., 1995). Cropping systems and organic inputs had a significant ($P<0.05$)

effect on the soil N across the two seasons with rotation recording the highest N levels as compared to intercropping and monocropping with no significant effect between intercropping and monocropping. Food legumes are important sources of protein and fix nitrogen into the soil reducing fertilizer requirements for subsequent crops (Odhiambo and Ariga, 2001). In the semi – arid tropics, research carried out on cropping systems showed that cropping systems based on legumes improves soil N than continuous cropping of cereals (Rao and Mathuva 2000). Machan and Stuelpnagel (2000) also showed that pure stands of legumes planted in rotation with cereal resulted in higher levels of N while mixed stands of legumes resulted in lower residual N after harvest. FYM also recorded the highest N levels (0.17%) as compared to compost and control treatments the lowest being the control (Figure 17). Mutegi et al., (2012) similarly showed that organic inputs let to increased N levels in soils as a result of the fact that organics must undergo microbial de- composition and are therefore released slowly into the soils minimizing losses of N through leaching and denitrification.

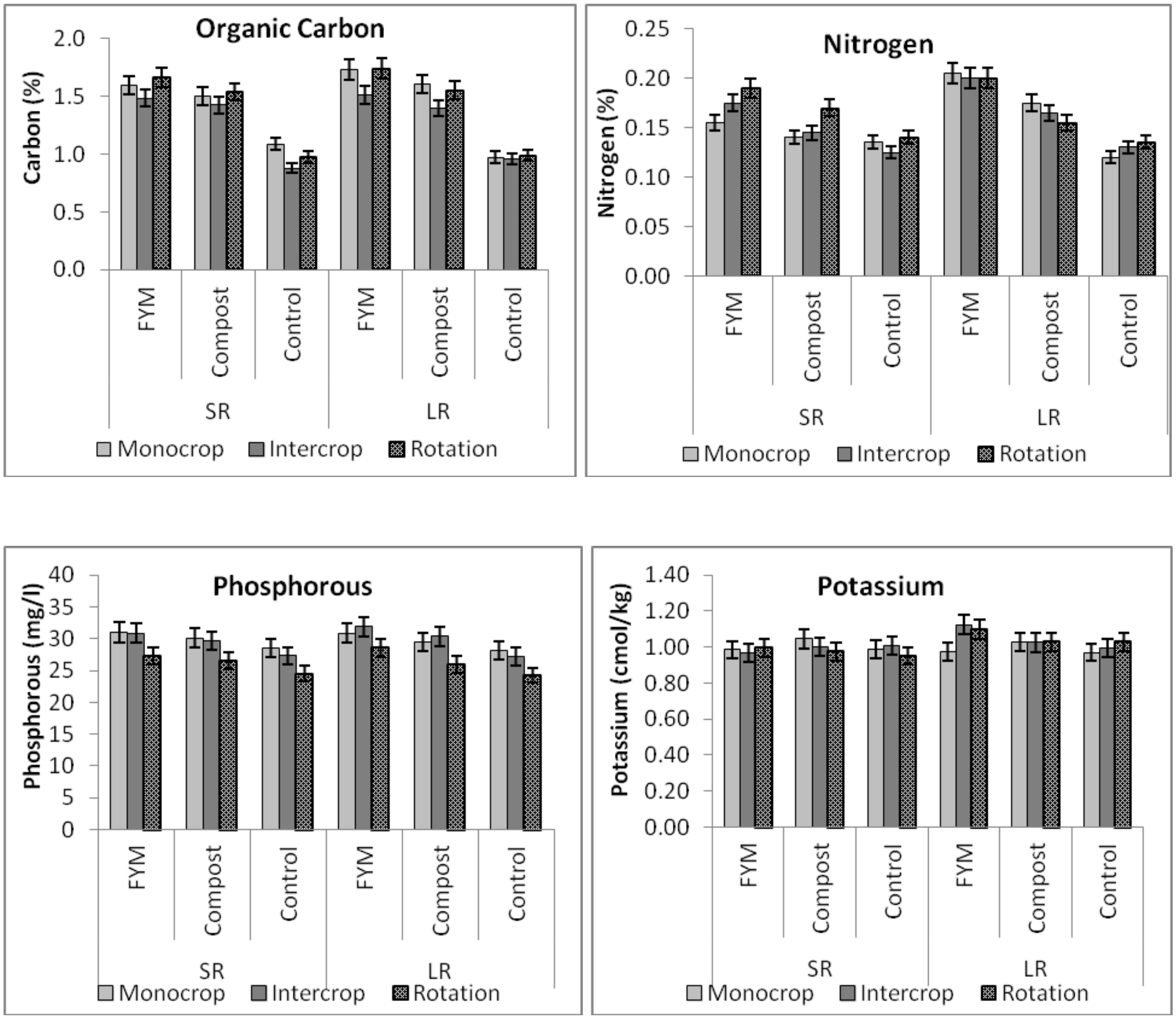


Figure 17: Effects of Cropping Systems (CS) and Organic Inputs (OI) on soil OC, N, P, and K:

OC - No significant (P<0.05) differences between seasons and CS but significant differences in OI; N – Significant differences in CS and OI, no significant differences in interaction CS*OI; P – Significant differences in OI and no significant differences in CS and seasons; K – No significant differences in CS, OI and CS*OI

*Significance (P<0.05)

Soil Phosphorous (P)

Soil P values ranged from 27.2 – 31.9 mg/l with no significant (P<0.05) differences between the seasons though the LR had slightly higher P levels compared to SR. Monocrop treatments had higher P levels (29.68 mg/l) as compared to intercrop and rotation cropping systems though not significant (Figure 17). This is due to P mobilization in the legume systems hence increasing uptake and loss of P in the system as compared to the monocrop cropping system. Legumes have been found to be efficient in mobilizing P from the soil and the stimulation of rhizosphere activity which in turn increases P uptake by other crops in rotation and intercrop cropping systems (Johnston *et al*., 2008). Significant differences ($P<0.05$) were however noted in the organic inputs effect on P with FYM recording the highest levels of P (30.08 mg/l) as compared to compost and control treatments. FYM has been known to provide higher P levels to soil as compared to other organic inputs (Opala et. al., 2012). The increase in P levels with time contrasts with most studies which have reported a decline in P with time, usually ascribed to P sorption by the soil (e.g., Sample et.al., 1980; Sharply, 1983). However, a few studies [Laboski and Lamb 2003; Fabisiak et. al., 2005) have obtained results similar to those of the present study. These authors explained that the increase in P availability with time is likely due to microbially mediated mineralization of soil organic P, to form inorganic P at a faster rate than that of P sorption by the soils of low to moderate P sorption capacity, such as those used in the current study.

Soil Potassium (K)

Soil K values ranged between 0.97 – 1.13 cmol/kg with no significant differences between the two seasons. The cropping systems had no significant ($P<0.05$) effect on the K levels though intercrop and rotation cropping systems recorded higher K levels as compared to the monocrop. FYM and compost recorded higher K levels across the two seasons at an average of 1.02 cmol/kg respectively with the lowest levels recorded in the control treatment though with no significant differences (Figure 17). This could be attributed to the fact that the soils are not K deficient hence little effect could be noticed. However, the high K levels in FYM treatments regardless of cropping systems and season could be as a result of the increased levels of exchangeable bases in the soils. Mutegi et al. (2012) showed that manure resulted in an increase in soil pH which led to increased levels of exchangeable bases (K, Mg and Ca). The significant increase in pH and consequently exchangeable bases also corresponds with findings by Bayu et al., (2005) and Mugendi (2010).

FYM contains more of N, P, K contents as compared to compost even though both have low levels of phosphorous. The effect of compost on crop yields is not as prominent as that of Farm yard manure. Farm yard manures can therefore be regarded as having higher available nutrient levels especially nitrogen and an organic component that is more susceptible to breakdown. This makes it more useful in sustaining crops that have a relatively high nutrient demand (Opala 2011; Ghosh et. al.2003). Farm yard manure and compost therefore improve soil fertility which translates to increased crop yields with FYM being noted for increasing soil fertility as a result of continuous use (Okalebo, 1987)

6.4.3 Meteorological data

The trend in rainfall and maximum and minimum temperatures of the study area over 50 years was declining with an R^2 value of 0.042 (Figure 3). The figure shows a steady decline in rainfall over the years which is significant (R^2=0.042) Rainfall variability compared to the long term average was also evident with some months with more rainfall and others with less rainfall hence water stress is expected during the sorghum growing period (figure 18). The data used in reference was from 1959 - 2012 for the short (October – December) and long (March – May) rainy seasons in the region.

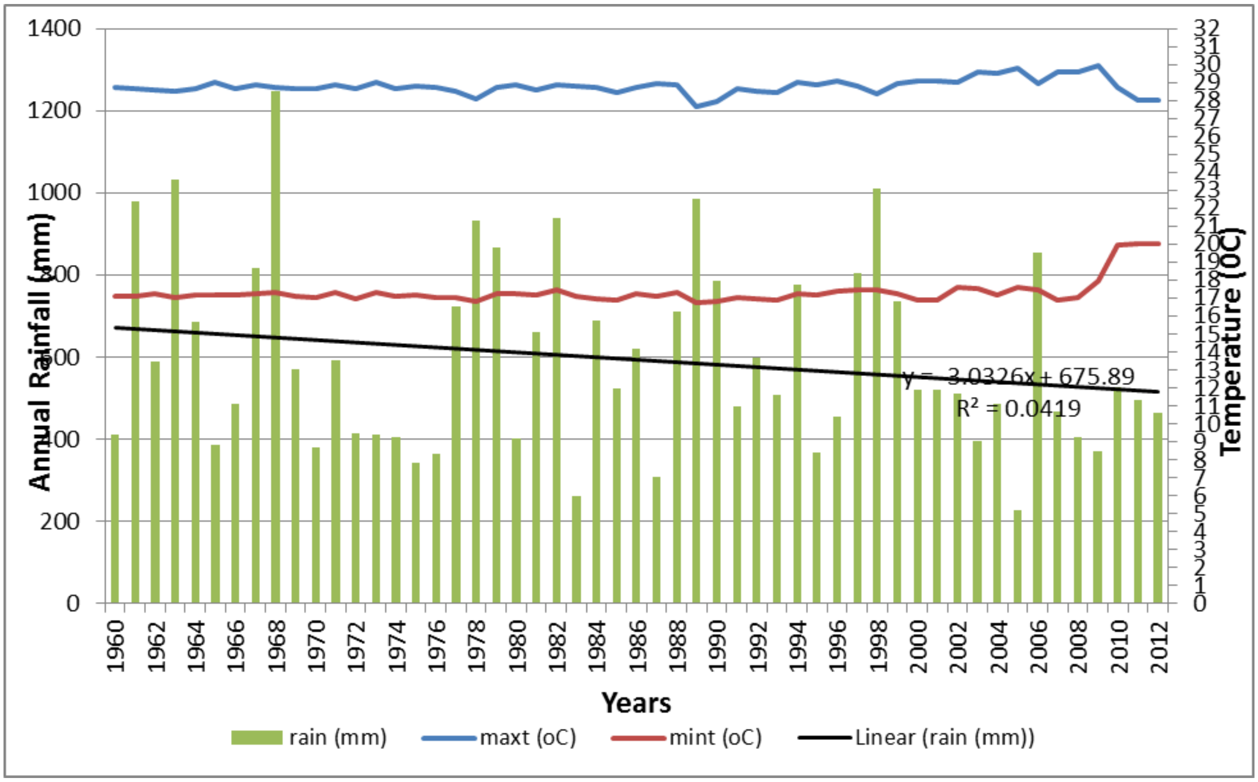


Figure 18: Climate trend of Yatta District over 50 years

The increased temperatures and high solar radiation levels throughout the months over the past 50 years (Figure 19) shows that there is increased evapotranspiration in the study area resulting in increased drought occurances, an aspect of climate change that farmers identified. Climate change poses a serious threat to food security of millions of communities living in the arid and semi-arid lands. Predictions indicates a more severe crop production declines is expected leading to hunger, malnutrition, insecurity and migrations (United Nations, 2000).

The amount and temporal distribution of rainfall is generally the single most important determinant of inter annual fluctuations in national crop production levels (Mulat et al., 2004). According to von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. Rainfall in much of the ASALs is, on the other hand, often erratic and unreliable; and rainfall variability and associated droughts have historically been major causes of food shortages and famines (Wood, 1977; Pankhurst and Johnson, 1988).

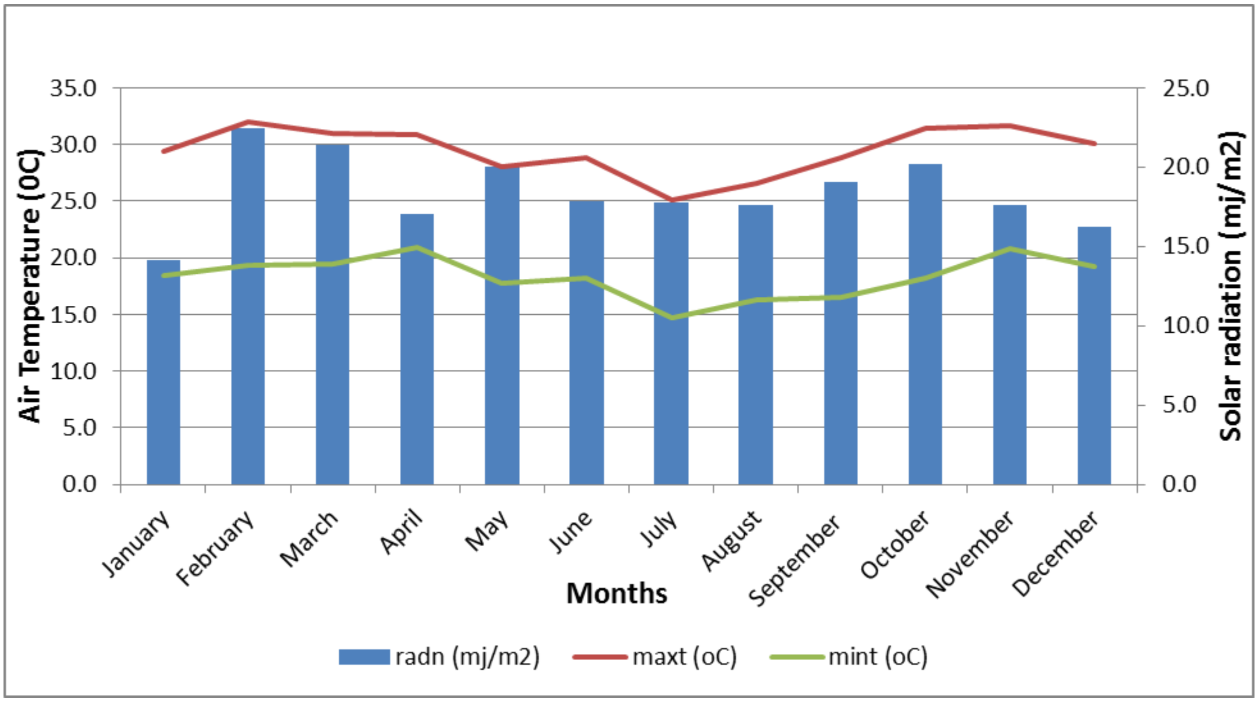


Figure 19: Monthly solar radiation, minimum and maximum temperature for years 2010 – 2012 in Yatta

6.4.2 APSIM Model calibration and validation

Comparative analysis showed that there were no significant differences (P=0.35) in the observed and simulated sorghum yields with good correlation between the observed and simulated grain yields at correlation values of R^2 = 0.96 for the short rains and R^2 = 0.8 for the long rains and biomass yields R2 = 0.98 for the short rains and R2 = 0.54 for the long rains respectively (Figure 20). The model predicted the grain and biomass yields under the different cropping systems and organic inputs well between the two seasons with more accurate predictions observed in the short rains with correlation of determination values closer to 1.

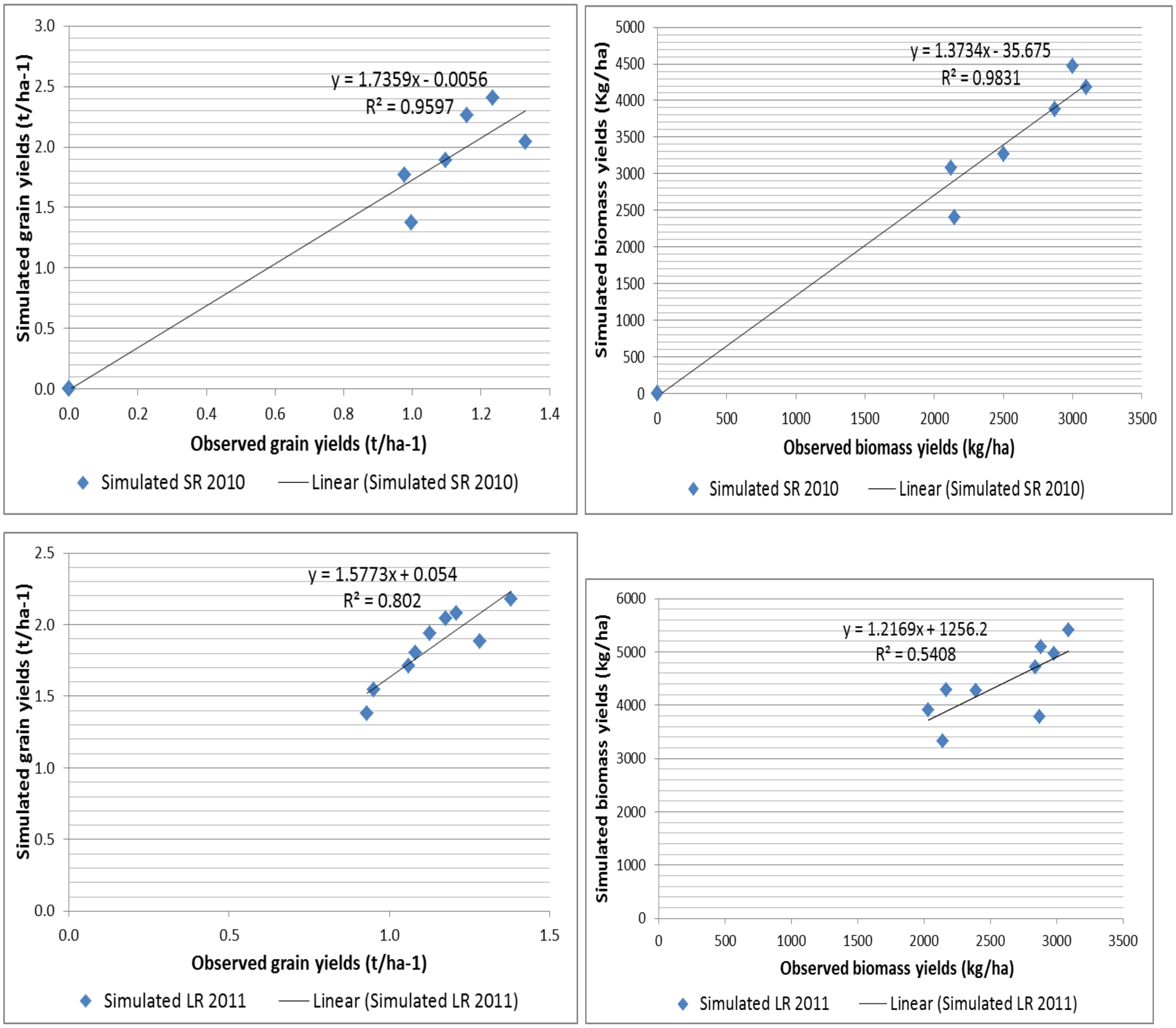


Figure 20: Observed vs. Simulated grain and biomass yield in the SR 2010 and LR 2011

Overall, the APSIM model performed well on sorghum yield under the different cropping systems and organic inputs due to correlation values close to 1 (Figure 20) showing accurate model prediction. Thus it can be used to predict yield responses to climate variability in combination with different management practices in the area. Many studies carried out on sorghum have shown similar good model performance of APSIM in simulating and predicting future climate change effects on the yield (Micheni et. al., 2004; MacCarthy et al., 2009; Dimes et al., 2009). APSIM has the capability to simulate long-term dynamics of soil water, organic matter, nutrients, crop growth and yield (Nelson et al., 1998) in response to management practices and weather conditions.

6.4.3 Sorghum grain and biomass yield simulations for SR 2010 and LR 2011

Grain yield predictions in response to different cropping systems and organic inputs were well predicted and simulated. RMSE values of 0.87 and 0.72 t/ha and NRMSE values of 2.4 and 1.48% were obtained for the short and long rains respectively (Table 14). The low NMRSE values indicated good model performance (Mentaschi et al., 2013). The models' performance in predicting total biomass was good with RMSE values of 0.995 t/ha and 1.87 t/ha for the short and long rains respectively. This can be attributed to the accurate crop and soil data used for callibrating the model which were almost similar to the simulated data.

Table 14: Validated observed and simulated grain yields in the SR 2010 and LR 2011

		Observed SR	**Simulated SR**	**Observed LR**	**Simulated LR**
Monocrop	FYM	1330	2040.2	1282	1880.8
	Compost	1098	1893.9	1080	1803.4
	Control	1021	1373.9	932	1379.7
Intercrop	FYM	1235	2408.9	1210	2079.4
	Compost	1160	2263.8	1125	1937.8
	Control	978	1768.2	950	1549
Rotation	FYM	-	-	1380	2180.6
	Compost	-	-	1175	2041.1
	Control	-	-	1061	1712.4

R^2	0.96	0.80
E*i*	-0.87	-0.7
RR (%)	35.62%	35.98%
RMSE	0.87 t/ha	0.72 t/ha
NMRSE (%)	2.35%	1.60%

E*i* = coefficient of efficiency; R^2 = linear regression; RR = range ratio; RMSE = root mean square error; NMRSE = Normalized root mean square error.

Range ratio values of 35.62 and 36% and modified coefficient of efficiency values of -0.87 and -0.7 for short rains and long rains respectively however indicated that the simulated mean values were better predictors than the observed mean values (Nash and Sutcliffe, 1970). Negative coefficient of efficiency values indicate that the model/simulated values are more accurate while range ratio values below 50% also indicate better model performance as compared to observed results. This is because of external factors that might have affected the crop while in the field such as pest infestation. APSIM has been proven to perform well in simulating crop growth and development and grain yield (Wang et al. 2003).

Simulated yields were higher than observed yields in both the short and long rain seasons (Figure 5). This could be attributed to the bird and pest (termites) infestation of the sorghum grain and dry matter yield while still in the field. One of the reasons identified for low performance of sorghum is the crops' vulnerability to attack by Quelea birds thus need daily scaring of birds which increases production costs (KIRDI 2011). The simulated sorghum biomass yields were 50% higher than the observed yields while the sorghum grain yields were 67% higher which was above 20% considered as high level of model accuracy by Leite and Mendonca (2010) Even though the simulated yields were higher than the observed yields, the difference was not significant (P<0.05). Ibrahim et a., (2011) showed that precipitation related parameters such as rainfall are the most critical factors affecting the yield of sorghum with increased rainfall resulting in increased yields

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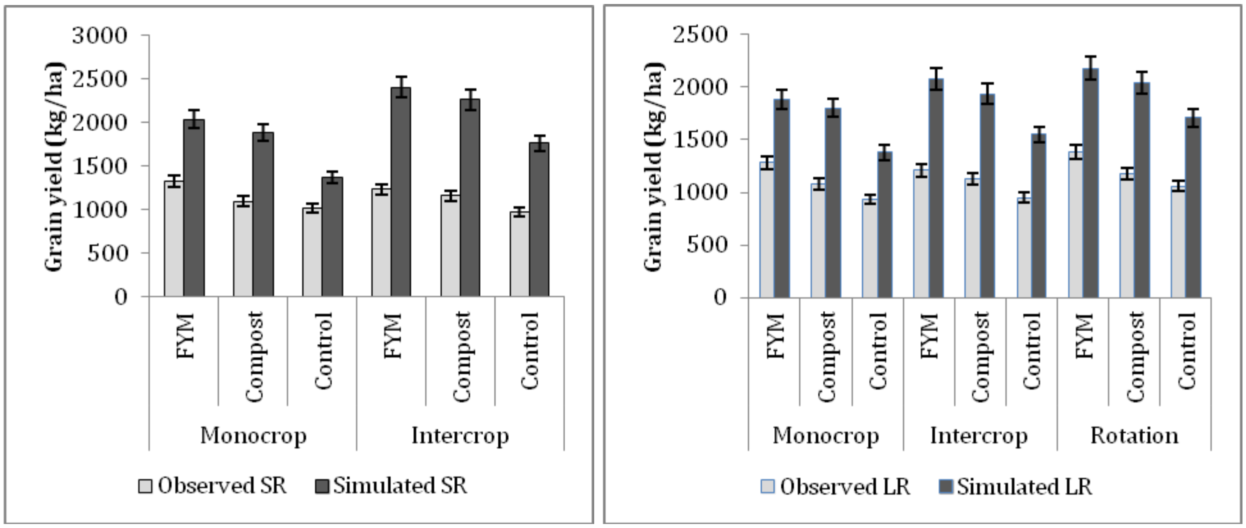

Figure 21: Observed and simulated grain yields during the SR2010 and LR 2011

The sorghum grain and biomass yield for the short rain season were more than for the long season (Figure 21). This can be attributed to the fact that the cumulative rains experienced in the short rainy season was 278.6 mm compared to 118 mmin the long rainy season which was less than that experienced in the short season. This is also in agreement with the farmers perceptions study carried out in the region which indicated that the short rainy season is always more reliable for crop production as compared to the long rainy season. Reproductive stages of sorghum are sensitive to water stress since it leads to delayed anthesis and maturation thereby increasing crop duration and reducing crop yield (Boyer, 1992). Water stress results in reduced sorghum yields due to insufficient capacity of the photosynthetic tissue to provide assimilate needed to fill grain during the reproductive stages (Boyer, 1992) . Basing on other studies done on sorghum, more rainfall increases the variability of sorghum yields resulting in higher yields, which is not surprising given the tolerance of sorghum to dry conditions (Dimes, et al, 2009).

6.4.4 Cropping systems and organic inputs yield simulations

In both seasons, simulated grain and biomass yields responded strongly to the rotation cropping system as compared to the intercrop and monocrop cropping systems. APSIM was able to effectively simulate sorghum performance within the different cropping systems showing higher yields in rotation cropping system (Table 15). The grain yields simulation under monocrop cropping system showed better model performance with low RMSE values of 0.65 and 0.6 t/ha for the long rain and short rains respectively (Table 15). Range ratio values of above 50% indicated good model performance (Robinson et al., 2001) with the biomass yields in the long rainy season having been reproduced quite well by the APSIM model. A similar study by Probert et al. (1998) in using simulations to evaluate strategies involving legumes for improving cropping systems showed realistic APSIM model performance. In both observed and simulated yields, intercrop and rotation cropping systems performed better than the monocrop cropping system. A similar simulation study by Tauro et al., (2013) demonstrated the potential of biological nitrogen fixation to improve the N balance in sorghum legume intercrop and rotation cropping systems particularly in where soil are low in N and crop residues are incorporated resulting in increased crop yields. Despite the grain increase in rotation systems, intercropping innovation have high potential of being adopted by farmers due to many benefits associated when compared to sole crop stands (Myaka et al., 2006).

Table 15: Validated cropping system effect on grain and biomass yields in the SR 2010 and LR 2011

Cropping system	Treatment	Grain Yield (kg/ha)				Biomass Yield (kg/ha)			
		Observed SR 2010	**Simulated SR 2010**	**Observed LR 2011**	**Simulated LR 2011**	**Observed SR 2010**	**Simulated SR 2011**	**Observed LR 2010**	**Simulated LR 2011**
Monocrop	FYM	1330	2040.2	1282	1880.8	3001	4475.2	2872.4	3779.6
	Compost	1098	1893.9	1080	1803.4	2500	3262.9	2390	4267.1
	Control	1021	1373.9	932	1379.7	2145	2402.6	2140	3323.7
	R^2	0.69		0.80		0.99		0.10	
	RR	46.38%		69.85%		41.3%		77.63%	
	RMSE	0.65 t/ha		0.6 t/ha		0.97 t/ha		1.38 t/ha	
Intercrop	FYM	1235	2408.9	1210	2079.4	3100	4184.5	2980	4968.5
	Compost	1160	2263.8	1125	1937.8	2870	3885.5	2840	4711.2
	Control	978	1768.2	950	1549	2120	3080.3	2030	3916.7
	R^2	0.99		0.99		0.99		0.99	
	RR	40.11%		49.02%		88.75%		90.32%	
	RMSE	1.04 t/ha		0.77 t/ha		1.02 t/ha		1.92 t/ha	
Rotation	FYM	0	0	1380	2180.6	0	0	3090	5415.7
	Compost	0	0	1175	2041.1	0	0	2881	5094.6
	Control	0	0	1061	1712.4	0	0	2165	4290
	R^2			0.85				0.99	
	RR			68.13%				82.17%	
	RMSE			0.78 t/ha				2.22 t/ha	

Table 16: Validated organic inputs effects on grain and biomass yields in the SR 2010 and LR 2011

		Grain Yield (kg/ha)				**Biomass Yield (kg/ha)**			
Organic Inputs	**Cropping system**	**Observed SR 2010**	**Simulated SR2010**	**Observed LR 2011**	**Simulated LR 2011**	**Observed SR 2010**	**Simulated SR 2010**	**Observed LR 2011**	**Simulated LR 2011**
FYM	Monocrop	1330	2040.2	1282	1880.8	3001	4475.2	2872.4	3779.6
	Intercrop	1235	2408.9	1210	2079.4	3100	4184.5	2980	4968.5
	Rotation	0	0	1380	2180.6	0	0	3090	5415.7
	R2	0.96		0.17		0.99		0.93	
	RR	25.77%		56.7%		34.06%		13.3%	
	RMSE	0.79 t/ha		0.76 t/ha		1.06 t/ha		1.8 t/ha	
Compost	Monocrop	1098	1893.9	1080	1803.4	2500	3262.9	2390	4267.1
	Intercrop	1160	2263.8	1125	1937.8	2870	3885.5	2840	4711.2
	Rotation	0	0	1175	2041.1	0	0	2881	5094.6
	R2	0.99		0.99		0.99		0.84	
	RR	16.9%		40%		59.43%		59.34%	
	RMSE	0.79 t/ha		0.8 t/ha		0.73 t/ha		1.99 t/ha	
Control	Monocrop	1021	1373.9	932	1379.7	2145	2402.6	2140	3323.7
	Intercrop	978	1768.2	950	1549	2120	3080.3	2030	3916.7
	Rotation	0	0	1061	1712.4	0	0	2165	4290
	R2	0.95		0.85		0.95		0.1	
	RR	46.92%		39.37%		3.7%		13.97%	
	RMSE	0.51 t/ha		0.57 t/ha		0.57 t/ha		1.78 t/ha	

Organic inputs effects on sorghum grain and biomass yields in both seasons were also reasonably simulated with high R^2 values which were closer to 1 (Table 16). The RMSE values were low with grain yields in the control plot during the short rainy season being better predicted at an RMSE value of 0.51 t/ha (Table 16). Most of the Range Ratio values were below 50% and this indicated under prediction by the model. Both observed and simulated yields indicated that FYM produced the best sorghum yields in both seasons as compared to compost and control plots. This is because FYM has a higher nutrient content and lower C:N ratio as compared to compost and control plots and this is calculated in the model. FYM improves the soil texture increasing soil water content hence increased yields. The performance of the model under the different organic inputs is shown in table 5 below. In the past, APSIM has been shown to perform well in simulating mineral N supply following organic inputs and crop response to inorganic and organic N, including legume–cereal rotations (Probert et al. 1998a; Shamudzarira et al. 2000).

6.4.5 Long term simulations of cropping systems and organic inputs

Longterm simulations of grain yields showed that in all the treatments, sorghum grain yield was decreasing over the past 50 years (Figure 22). Comparing the different cropping systems yield trends (Monocrop – R^2= 0.04; Intercrop - R^2=0.06; Rotation - R^2 = 0.19) with the decreasing climatic trend (R^2 = 0.03) over the years showed a decreasing yield trend this trend in sorghum grain yield could be attributed to the declining rainfall in the area. However, despite the declining yields, addition of organic inputs within the cropping systems resulted in increased yields hence assisting in mitigating the negative climate change effects (Figure 22). Trials conducted in Kenya during the short rainy season showed that sorghum had the capacity to produce high yields due to its ability to produce grain even with minimal rainfall (Taylor, 2003).

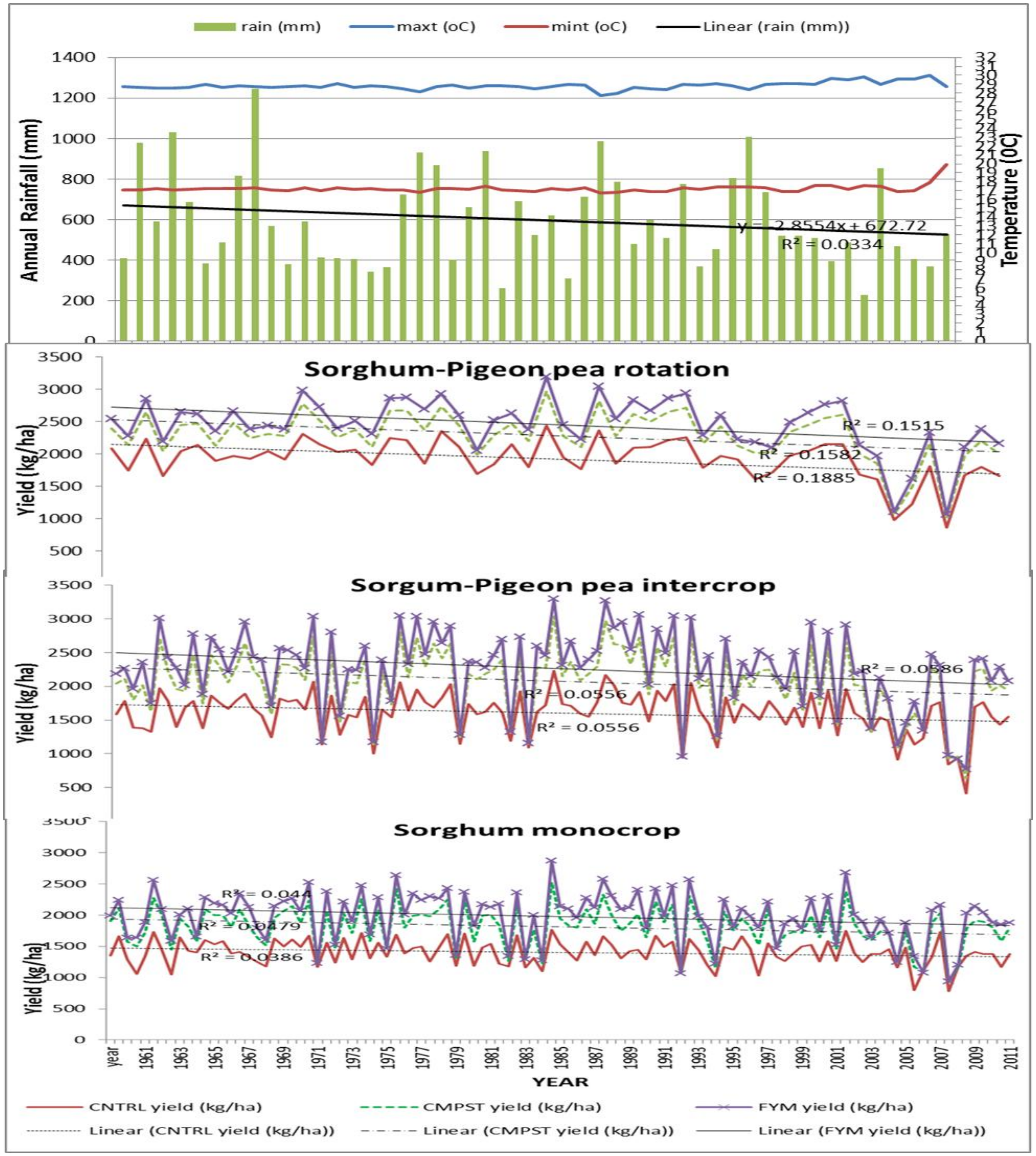

Figure 22: Long term simulations of climate change effects on sorghum grain yield

Sorghum grain and biomass yields and climate variables were found to be highly correlated at a $p<0.05$ significance level suggesting that there is a big influence of climate variables on sorghum yield. Rainfall showed a negative influence on sorghum yield which indicated that when there is reduction in rainfall, yield is reduced. Comparing the declining trend in rainfall and temperature and the sorghum yields, it clearly shows a decrease in rainfall and an increase in temperature results in reduced crop yield. Kurukulasuriya and Mendelsohn, (2006) effectively demonstrated that change in climate directly affects crop yields with declining rainfall resulting in reduced crop yields. This is also in agreement with Abdulhamid (2011) who reported a positive correlation between total seasonal rainfall and yield, though the effect was not significant. Both maximum and minimum temperatures were similar during both the cropping seasons but even these showed no significant effect on yield. Despite this, simulations under crop rotation and farm yard manure simulated higher yields as compared to intercrop and monocrop and compost and control simulations. Even under favorable climatic conditions adequate yields cannot continue to be attained on poor soils (Ogunkunle, 1993) without investment in external inputs particularly organic inputs. In the semi-arid regions of SSA, farmers plant sorghum as sole stands or under sparse intercropping or irregular crop rotations (Ncube et al., 2007). APSIM was developed initially as a farming systems model (e.g crop rotations and intercrops, fallow management, residue management) thereby allowing assessments of short term as well as long term systems dynamics (Holzworth et al., 2006).

6.4.6 Potential influence of climate change - Present and future trends on sorghum yield

Rainfall decrease (R_0-10%), temperature increase [To+1.6^{0}C (Tmax), To+1.8^{0}C (Tmin)] and a combination of both were predicted to result in grain and biomass yield declines across both seasons (Figure 23 & 24). Effects of predicted temperature increase and combined temperature increase and reduced rainfall had the greatest effect on yields as compared to reduced rainfall averaging at 3.8 and 3.4% reduction in yields respectively with the short rainy season recording the highest yield changes at an average 6.2% and 6.4% reduction respectively. This is because a combination of increased temperature and reduced rainfall will result in reduced soil water availability for the plant to carry put crucial plant processes such as photosynthesis resulting in the stunting, drying up and eventual death of the crop. Dimes et al. (2002) also showed that increased temperatures and not reduced rainfall have the most dramatic effect on yields. However, yield under monocrop – control showed a yield increase of 1.3% even with reduced rainfall (R_0-10%). Increase in yield due to low rainfall was also observed by Hazeltine,(1998) who stated that sorghum can survive in low rainfall regions. However, temporal water excess followed by prolonged dry spell events lead to increased risk of soil moisture depletion as excess heating goes toward raising temperatures, increasing evaporation leading to plants wilting.

Similar to this study, Rowhani et al., (2011) demonstrated that increased temperature and rainfall variability would reduce crop yields. Increased rainfall variability during the growing season reduces yields for sorghum and that increased exposure to extreme conditions results in crop damages (Rowhani et al., 2011). Higher temperatures translate into faster crop development and earlier maturation which results in lower crop yields because the plant intercepts less cumulative solar radiation before it reaches maturity and harvest (Brassard and Singh 2008). According to Vara Prasad et al., (2006), temperatures increase alters the photosynthetic mechanism of a sorghum crop by reducing its efficiency in the use of CO2, solar radiation, water and nitrogen. These changes would further lead to poor growth and hence decrease in the final yield. High temperatures also affect pollen viability of sorghum where cell turgidity of the flower is reduced and in some cases die. This causes the crop to become infertile hence reduce grain per panicle.

Increase in rainfall (R_0+10%), and a combination of increase in both temperature and rainfall predicted an increase in yields across both seasons (Figure 7 and 8) at 3.6 and 4.7% respectively. This is because the negative effects of temperature increase have been shown to be reduced by external factors such as rainfall, solar radiation and carbon dioxide which can be attributed to the increase in sorghum yields with increased temperatures and rainfall. Brown and Rosenberg (1997) also showed that generally, reduction in yields as a result of increased temperatures was mitigated by elevated pCO2 and increased precipitation. Folliard, et al., (2004) also mentioned that modeling sorghum in response to temperatures is always problematic, and is often not sufficient to accurately predict the final yields in high temperatures environments. In addition to this, high yields in sorghum depend on the fact that the shoot of the crop maintains its water status and turgor maintenance under drought stress, (Blum, 2005). However, temporal water excess followed by prolonged dry spell events lead to increased risk of soil moisture depletion as excess heating goes toward raising temperatures, increasing evaporation leading to plants wilting which explains the reduced sorghum yields at a combination of increased temperatures and rainfall (Hazeltine, 1998).

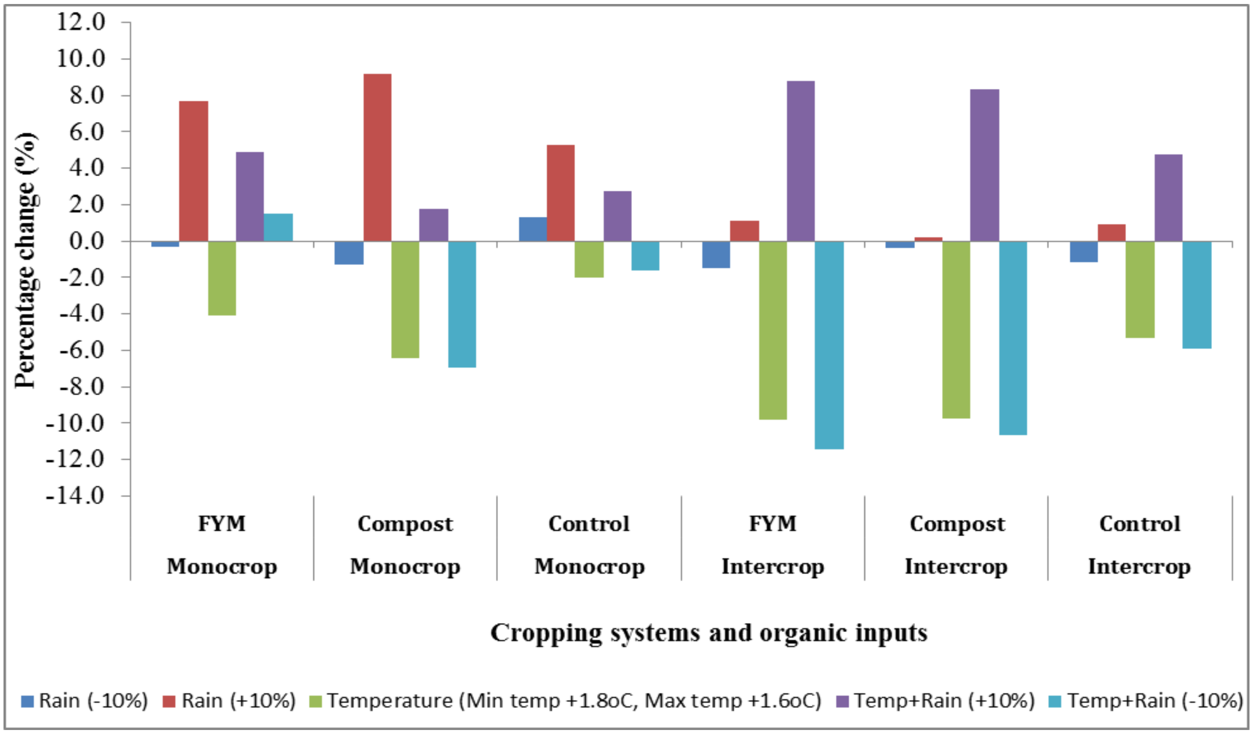

Figure 23: Percentage change in grain yield in SR for the period 2020 - 2080

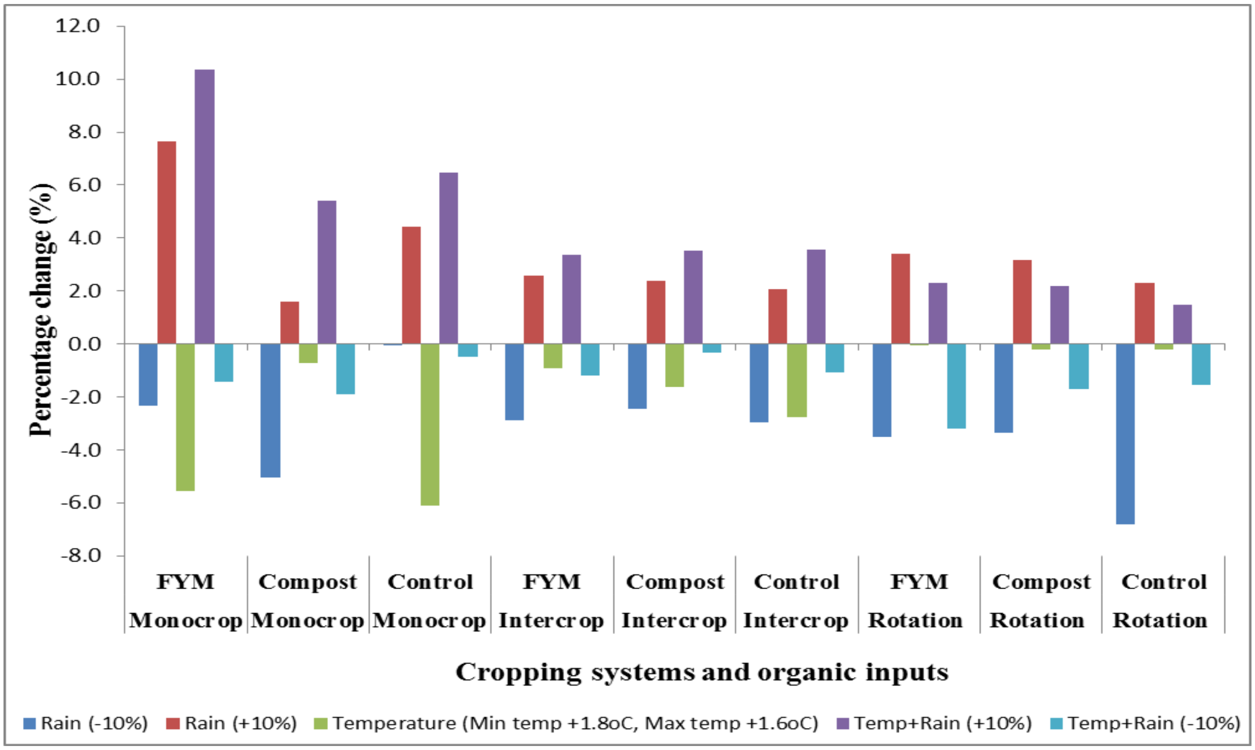

Figure 24: Percentage change in grain yield in LR for the period 2020 - 2080

It was noted that effects of increased temperature resulted in more biomass yield reduction as compared to rainfall decrease at a mean average change of 5% as compared to 1.2% for reduced rainfall (Appendix VI)). Temperatures and rainfall are the largest influential elements in the optimal sorghum production in the area. Thus potential yield for sorghum increased (decreased) with increased (decreased) rainfall. Similarly increased temperatures decreased sorghum yields. This is in line with findings documented by Hupet et al. (2000) and Gong et al. (2006) who indicated that minimum temperatures had a high effect on yield in dry season than during the rainy season since during rainy season there is little temperatures changes than in dry season. According to Hammer et al. (2011) high temperature reduces sorghum yields and increases development rate, leaf number, leaf appearance rate and early flowering, He also observed significant reduction in plant height, pollen viability and seed set when temperatures are high. The significant relationship is contributed by the processes of crop growth that requires temperature and radiation for photosynthesis, water uptake and other metabolism processes.

The short rains recorded the highest yield changes as compared to the long rains (Figure 25). This therefore shows that the variability of rainfall across the region directly influences the availability and variability of surface and groundwater resources which in turn affects sorghum growth in the region. However, it is clear that as increase in temperatures and decrease in rainfall continues, sorghum yield would be severely affected. Future predictions of temperatures and rainfall by models are expected to increase and decrease. With such predictions, sorghum production in the area would experience water stress during the critical period of growing season due to increase in evapotranspiration caused by high temperatures (Rowhani et al., 2011; Semenov, 2009).

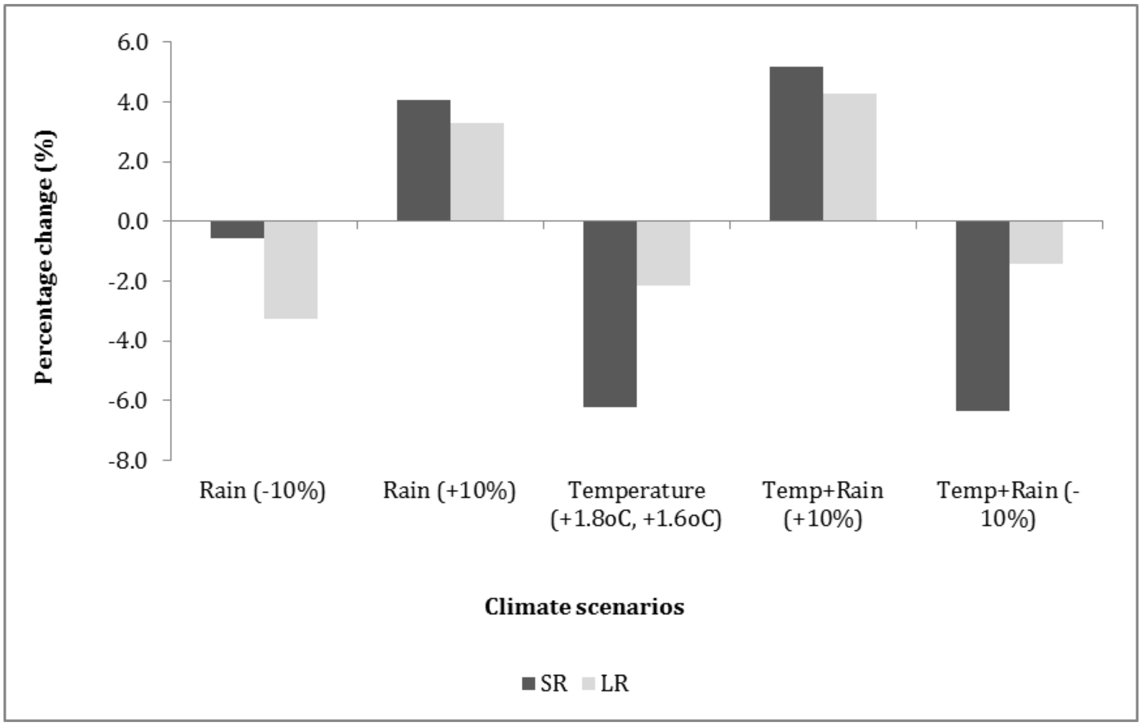

Figure 25: Percentage grain yield change between LR and SR seasons

Luedeling (2011) also confirmed that high rainfall had a strong positive effect at the beginning and end of the short rains. In addition to this moisture effect, high temperatures negatively impacted sorghum yields. The high yield levels, small variation and low susceptibility to climate change make sorghum appear like a recommendable crop, for the present situation as well as for climate change adaptation. The crop model results indicate that particularly during the short rains, sorghum production represents a good option for farmers. In line with this study, Jing Wang et al. (2009) showed that an increase in temperatures shortens the length of the growing season; further increases promote increase of evaporation from soil surface and reduce crop water use. The temperature increment would increase the impact of rainfall changes. Nevertheless, high temperatures would promote vegetative growth in the plant hence giving advantage to industry that uses the crop as feeds. Decrease in rainfall and increase in temperatures also imply increase in the evapotranspiration rate and hence reduction in photosynthesis processes. These events directly affect the crop growth through enhancing weeds growth and promotion of the spread of pests and diseases (Wang et. al, 2009).

Significant effects of high temperatures are always negative. This was particularly the case in this study. Yields were much more susceptible to high minimum high maximum temperatures. Effects of rainfall were mixed, with high rainfall having a positive effect on yields during increased temperatures, and low rainfall having a negative effect combined with increased temperatures. This may reflect sorghum's sensitivity to soil water levels. Water supply must be sufficient, but the crop is also sensitive to waterlogging, which may happen if too much precipitation occurs (Luedeling 2011)

6.4.7 Cropping systems and organic inputs effects in projected climate change

The highest percentage change in yield was registered in a combination of temperature [To+1.6^{0}C (Tmax), To+1.8^{0}C (Tmin)] and rainfall decrease (R_0-10%) resulting in 11.5% decrease in yields under the intercrop - farm yard manure treatment during the short rainy season (Figure 6). Despite the predicted climatic changes, farm yard manure still produced the highest yields as compared to compost and control but had also had the highest recorded yield change at an average of 4.1% as compared to compost (3.8%) and control (2.8%) (Table 16). FYM also recorded the highest increase in yield by 6% as compared to the rest of the treatments (Table 6). This could be attributed to the fact that organic inputs produce optimal yields with optimal climatic conditions but with a change in climate variables, the yields are affected. This is because of competition of nutrients and with no addition of nutrients to the soil, sorghum yields either reduce or remain the same. Adu Gyamfi et al., (2007) showed that soil and crop yields in a pigeon pea intercrop and rotation are only enhanced when fertilized as a result of soil nutrient replenishment, reduced competition and added nutrients from fertilization.

Within the cropping systems, intercropping recorded the highest yield changes at 3.8% while rotation had the lowest at 2.4% yield changes (Table 17). This could be attributed to the high competition of resources by crops planted in an intercrop system while rotation systems provide a cushion against the adverse effects of climate change and the fact that cropping systems are sensitive to climate variability and climate change. This coupled with increase in evapotranspiration due to higher temperatures; Kenya especially the ASALs is expected to experience country wide losses in crop production, economy and livelihoods of the population (Herrero et al. 2010).

Table 17: Change in grain yield with projected climate change

			Yields (kg/ha)						
Season	**Cropping system**	**Organic inputs**	**Base Yield (kg/ha)**	**Rain (-0%)**	**Rain (+10%)**	**Temperature (Min temp +1.8oC, Max temp +1.6oC)**	**Temp+Rain (+10%)**	**Temp+Rain (-10%)**	
SR	Monocrop	FYM	2040.2	-6.6	156.8	-83.2	100.2	30.3	
		Compost	1893.9	-24.2	173.9	-121.3	32.8	-132.2	
		Control	1373.9	18.1	72.6	-27.9	37.3	-22.4	
	Intercrop	FYM	2408.9	-35.3	27.2	-236.0	211.7	-276.0	
		Compost	2263.8	-9.2	5.0	-220.7	187.9	-241.6	
		Control	1768.2	-20.7	16.4	-94.7	83.6	-104.4	
	Rotation	FYM	-	-	-	-	-	-	
		Compost	-	-	-	-	-	-	
		Control	-	-	-	-	-	-	
LR	Monocrop	FYM	1880.8	-44.2	143.7	-104.2	195.1	-27.2	
		Compost	1803.4	-91.2	28.6	-13.3	97.4	-34.4	
		Control	1379.7	-0.5	61.3	-84.3	89.2	-6.9	
	Intercrop	FYM	2079.4	-59.6	53.7	-19.1	70.1	-24.7	
		Compost	1937.8	-47.9	46.1	-31.3	67.9	-6.2	
		Control	1549	-46.0	32.3	-42.6	55.4	-16.7	
	Rotation	FYM	2180.6	-76.6	74.2	-0.6	50.2	-69.5	
		Compost	2041.1	-68.5	64.5	-4.6	44.8	-35.1	
		Control	1712.4	-116.6	39.3	-3.9	25.1	-26.8	
	Total (%)								**Total (%)**
	Cropping system	Monocrop		-1.3	6.0	-4.3	5.3	-2.3	3.4
		Intercrop		-1.9	1.6	-5.2	5.4	-5.1	3.84
		Rotation		-4.6	3.0	-0.1	2.0	-2.2	2.38
	Organic Inputs	FYM		-2.1	4.5	-4.2	6.0	-3.8	4.12
		Compost		-2.5	3.3	-3.9	4.2	-4.3	3.76
		Control		-1.9	3.0	-3.3	3.8	-2.1	2.82

Overall predictions of sorghum yields using models suggest a reduction in areas where temperatures are optimal which is much of SSA and an increase in areas where temperatures are sub optimal. APSIM has been listed as a primary investigating tool in climate change by UNFCCC (2002). For the period up to 2030, alterations in the patterns of extreme events will have much more serious consequences for chronic and transitory food insecurity than shifts in the patterns of average temperature and precipitation. There is evidence that extreme events were already becoming worse towards the end of the 1990s, and there is rising confidence in projections that they will increase in frequency and severity well before 2030 (Easterling *et al*., 2000; IPCC, 2001b, 2001c).

Global average temperatures are projected to rise by about 1°C by 2030 (i.e. well outside the natural range). Consequently, average temperatures in the higher latitudes may rise by 2°C, possibly double the increase in the tropics. (IPCC, 2001b).

6.5 CONCLUSION

Well managed sole sorghum yield ranges from 1.7 to 4.8 t ha-1 but yields have remained below 0.8 t ha-1 in SSA. There is therefore a need to improve the fertility of the soil to improve sorghum yield by the inclusion of legumes and organic inputs to increase the yield as reported in the current study. This combined with modeling to predict climate change effects as demonstrated in the study will provide farmers with better options for mitigating against expected adverse climate change effects.

The APSIM model performed well in modelling the grain and biomass yields under the different cropping systems and organic inputs across the two seasons. The predicted increase in temperatures, decrease in rainfall and combined increase in temperature and decrease in rainfall generally translated to a decrease in sorghum grain and biomass yields while an increase in rainfall and combination of rainfall increase and temperature decrease translated to an increase in yields. This study has therefore demonstrated that yield losses under changing climate will be severe in the near and far future in the ASALs with regard to climate change. However, application of organic inputs and cropping systems showed a positive potential of reversing the effects. It is therefore appropriate to consider management strategies such as incorporating of organic inputs and cropping systems such as rotation to mitigate against negative climatic effects such as reduced rainfall and increased temperatures.

This study will therefore assist farmers in predicting their crop yields in view of the future climatic changes through modelling of different agro intensification techniques that will help farmers mitigate against the adverse climate change effects in the ASALs.

CHAPTER SEVEN

GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 GENERAL CONCLUSION

Climate change is and will continue being a threat to crop productivity especially in the ASALs which are already characterized by harsh climate. This study has shown that farmers are aware of climate change and the effect it has on their agricultural productivity as well as measures to undertake in order to cope and adapt. Despite this, farmers are still being affected adversely by climate change as they are most reliant on rain fed agriculture. Therefore, there is a need to identify most suitable strategies to ensure that they are cushioned against the adverse effects of climate change. One of the ways is through planting of drought tolerant crops. From the study, famers are aware of planting of this strategy but do not practice it due to economic value placed on drought tolerant crops. Most drought tolerant crops are traditional crops that have been abandoned over time with preference to modern crops due to their economic importance. The study has shown that over the past two decades, farmers have been moving from planting traditional crops to planting modern crops the main reasons being poverty, population increase and climate change. There is therefore need to encourage reintroduction of these crops through suitable management practices that will ensure sustainable crop production for the farmer. Sorghum has been identified as one such crop that is most suitable in the ASAL areas. To ensure sustainable crop production of sorghum, there is need to use agro intensification techniques to help mitigate the effects of climate change. These include cropping systems and organic inputs. From the study, crop rotation and use of farm yard manure have resulted in high sorghum yields as compared to farmer practice of no inputs and no cropping systems. To be able to carry out effective farming, there is also need to predict climate change and its effects. The farmers tend to rely mostly on traditional forms of weather prediction which are not reliable and are not able to predict the effect of climate change on crop production. Use of DSTs such as APSIM has proved to be a useful tool in predicting long term weather predictions as well effects on the crop yield as compared to the short term traditional methods of weather forecasting. From this study, APSIM has effectively simulated growth and performance of sorghum under the different cropping systems and organic inputs showing clearly that sorghum performs well under rotation cropping system and farm yard manure incorporation despite the predicted climate change. Therefore, emphasis should be put on the use of different cropping systems especially crop rotation as well as use of organic inputs especially FYM as this study has shown them to be produce better yields.

7.2 GENERAL RECOMMENDATIONS

- The coping and adaptation strategies identified by farmers are not sufficient to cushion them against expected future climatic changes. It is therefore important to build their capacity on more resilient adaptation strategies towards climate change such as use of DST's which can be used to provide efficient and immediate advice on how to manage their crops .
- The government should develop policies that invest more into agricultural research using models especially in the ASALs with the current climate change issue that has become an international concern to ensure food security even with the climate changing.
- More research should be carried out in the ASALs testing the performance of traditional crops using to promote widespread re introduction making them more attractive options to the farmers..
- it would be important to look at the economic impact of the crop type change and possibility of producing a multi-year cropping pattern map for use in future spatial crop distribution prediction in view of the current climate changes
- Future research efforts should be put into new crops that are more suitable for the semi - arid regions as well as making the current crops more resilient to the local climate as this would go a long way in improving the farmers economic welfare as well as food security.
- Finally, to increase usage of research results, it is further recommended that the results from this study be translated to user friendly formats and shared through different avenues. It is useful to use research results and decision support tools in assessing, developing and promoting production improvement strategies at policy level.

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Appendices

Appendix 1: Questionnaire on farmers' perceptions, coping and adaptation to climate change

Climate change: farmers' perception, coping and mitigation strategies questionnaire

SECTION A: Background Information

CONSENT: Hello. My name is ………………………………… We are conducting a household survey to gather information on farmers' perception, knowledge, coping and mitigation strategies to climate change. The information gathered will be used to identify information gaps and consequently design and test desired technologies to combat climate change with possible integration of Decision Support Tools as well as identify the trend in change of crop cover from traditional crops to modern crops. Your participation is voluntary and the information provided will be confidential.

1. Location ………………………………….. Village …………………………………..
2. Name …………………………………...Age ………. Sex; Male [ ] Female [ ]
3. How many household members? ……………………………………………………
4. What is the highest education level completed? (Parents F [ ] M [ ]; Children [ ]
   Never went to school [ ]
   Lower primary school [ ]
   Upper primary school [ ]
   Secondary school [ ]
   Certificate [ ]
   Polytechnic [ ]
   Diploma [ ]
   University [ ]
   Others (specify) …………………………
5. What is the size of your farm (Specify units)?………………………………………..
6. What proportion of your farm is used for:
   (i) Crop production ……………… (iii) Livestock production ……………….
   (ii) Homestead …………………… (iv) Others (Specify) ……………………..

SECTION B: Climate Change

1. Have you ever heard of climate change?
   Yes [ ] No [ ]
2. If Yes (in 1 above), what aspects of climate change have you heard of?
   Rising Temperatures [ ] Droughts [ ] Floods [ ] Erratic Rainfall [ ]
   Low rainfall [ ] Strong wind [ ] Cold Spells [ ]
   Others (specify) ………………………
3. How and where do you get information on climate change from?
   Radio [ ] Newspaper [ ] Friends [ ] Extension Officers [ ]
   Internet [ ] Television [ ] Others (Specify) …………………..
4. a) Have you ever experienced/noticed any changes in climate in your locality?
   Yes [ ] No [ ]
   b) If Yes in 4 (a) above, what changes have you experienced/noticed and since when?

Change	From When (Give years e.g 1990 or range of years e.g from 1990 to 1999)
Erratic rainfall [ ]	
Low rainfall [ ]	
Flooding due to heavy rains [ ]	

Prolonged droughts [ ]	
Increasing temperatures [ ]	
Others (specify) ………………….	

5. To what extent have the changes identified in 4 (b) above impacted on agricultural activities?

At your farm/local level	At the national/regional level
Reduced crop yield [ ] Change in planting time [ ] Crop failure [ ] Increased pest and disease infestation [ ] Flooding of crop fields [ ] Reduced soil moisture [ ] Others (specify) ……………………….	Insufficient food [ ] High food prices [ ] Human wildlife conflicts [ ] Competition over resources [ ] Others (specify) ………………………..

6. How are you responding to these changes in 5 above?

____

____

7. What aspects of climate change do you anticipate to notice profound changes and why? E.g rainfall, floods, temperatures e.t.c

Aspect/Change	Why

8. How will you respond to the changes identified in 10 above?

____

____

9. Which of the practices listed below are used in your locality in response to climate change?

Strategy	Approximate % of farmers using
Agro forestry [ ]	
Drought tolerant crops [ ]	
Rain water harvesting [ ]	
Irrigation [ ]	
Soil and water conservation [ ]	
Application of fertilizers and organic inputs [ ]	
Planting appropriate crop varieties [ ]	
Use of different cropping systems [ ]	
Others (specify) ……………………………….	

10. Are you aware of other strategies that can be used in response to current and/or anticipated climate change?

____

____

11. What indigenous/traditional techniques do you use in weather forecasting and in what aspects of your agricultural prediction are they applicable?

12. Using the indigenous techniques in 17 above, are you able to forecast weather changes accurately?
    Yes [ ] No [ ]
13. In a scale of 1 (low) to 5 (high), how do you rate the accuracy of scientific weather forecasting?
    1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ]
14. Between the traditional approach and the scientific approach, which one do you rely on most when making your farm management decisions?
    Traditional approach [ ] Scientific approach [ ]

SECTION C: Crop Production

1. a) What factors determine when to carry out the following agronomic activities?

Activities/Practices	**Determinant in decision making**
Land Preparation	
Planting	
Weeding	
Harvesting	
Others (specify)	

2. What are the major factors affecting crop productivity in your locality?
   Low soil fertility [ ] Low soil moisture [ ]
   Unreliable rainfall [ ] Wrong crop type [ ]
   Drought [ ] Others (specify) ……………………………………
3. How do you enhance crop productivity on your farm?
   Fertilizers [ ] Manures [ ] Minimum tillage [ ]
   Crop varieties [ ] Others (specify) ……………………………………………
4. What problems/challenges do you experience (have you experienced) in crop production?
   Crop pests and diseases [ ] Unpredictable/inadequate rainfall [ ]
   Lack of rain [ ] Labour scarcity [ ]
   Low soil fertility [ ] Lack of inputs [ ]
   Low quality seeds/seedlings [ ] Others (specify) …………………………………
5. How are you addressing the problems in 11 above and how would you like to be assisted?

Problem	**How addressed**	**Assistance required**

SECTION D: Decision Support Tools

1. (i) What assists you in decision making regarding your farm practices with respect to land preparation, planting, weeding and harvesting?
   a) Knowledge of the environment within which you live [ ]
   b) Agricultural Extension Officers in your area [ ]
   c) Indigenous knowledge on weather prediction [ ]
   d) Decision support tools (DST) [ ]
   e) Others (specify) …………………………………………..

(ii) Are the sources in 1 (i) above sufficient to assist you in decision making?
Yes [ ]		No [ ]

Appendix II: Crop type change questionnaire

1. Are the crop types you grew in the past different from the crops you grow now?
   Yes [ ]		No [ ]
2. Which crops did you grow between 1976 and 1986?
   Maize [ ]
   Beans [ ]
   Kales [ ]
   Tomatoes [ ]
   Finger millet [ ]
   Green grams [ ]
   Yams [ ]
   Sorghum [ ]
   Pigeon peas [ ]
   Dolichos [ ]
   Cow peas [ ]
   Others (specify) ……………………………

3. Which crops did you grow between 1987 and 1997?
   Maize [ ]
   Beans [ ]
   Kales [ ]
   Tomatoes [ ]
   Finger millet [ ]
   Green grams [ ]
   Yams [ ]
   Sorghum [ ]
   Pigeon peas [ ]
   Dolichos [ ]
   Cow peas [ ]
   Others (specify) ……………………………

4. Which crops did you grow between 1998 and 2008?
   Maize [ ]
   Beans [ ]
   Kales [ ]
   Tomatoes [ ]
   Finger millet [ ]
   Green grams [ ]
   Yams [ ]
   Sorghum [ ]
   Pigeon peas [ ]
   Dolichos [ ]
   Cow peas [ ]
   Others (specify) ……………………………

5. Which crops do you grow currently?
   Maize [ ]
   Beans [ ]
   Kales [ ]
   Tomatoes [ ]
   Finger millet [ ]
   Green grams [ ]
   Yams [ ]
   Sorghum [ ]
   Pigeon peas [ ]
   Dolichos [ ]
   Cow peas [ ]
   Others (specify) ……………………………

6. What was/is the acreage of the crops grown?

Crop	**1976 - 1986**	**1987 - 1997**	**1998 - 2008**	**Currently**
Maize				
Beans				
Kales				
Tomatoes				
Finger millet				
Green grams				
Yams				

Sorghum				
Pigeon peas				
Dolichos				
Cow peas				
Others (specify)				

7. What do you think is the reason for the trend above?
   - (i) Population increase [ ]
   - (ii) Low unreliable rainfall [ ]
   - (iii) Poverty [ ]
   - (iv) Low inputs [ ]

Others (specify) ………

Appendix III: Soil parameters used for APSIM callibration

Table 1: Soil information used in calibrating sorghum

Soil horizon depth	**0 - 30 cm**	**30 - 90 cm**	**90 - 150 cm**
Soil water parameters			
Bulk density (g/cm3)	1.28	1.34	1.31
Saturated Water content (mm/mm)	0.32	0.34	0.33
Field Capacity (mm/mm)	0.28	0.285	0.27
Permanent wilting point (mm/mm)	0.15	0.17	0.17
Particle size			
Sand (%)	50	45	43
Silt (%)	18	16	15
Clay (%)	32	29	29
Texture			
Soil fertility parameters			
Soil Organic Matter (%)	1.345	1.28	0.46
Total P (ppm)	42.5	30.72	21.3
Total N (%)	0.1	0.06	0.08
pH (in H2O)	6.3	6.1	6.5
CEC (cmol+/kg)	11	10.05	9.01
Na (cmol/kg)	1.12	1.88	1.88
K (cmol/kg)	1.75	1.55	1.25

Ca (cmol+/kg)	3.12	3.24	1.41

Appendix IV: Soil water parameters for APSIM

Table 2: Soil Water

APSIM soil parameter	**Acronym**	**Value**
Unsaturated flow		
Diffusivity constant	**DiffusConst**	88
Diffusivity slope	**DiffusSlope**	32
Run off		
Runoff curve number of bare soil	**CNBare**	87
Soil evaporation		
First stage Soil evaporation coefficient	**U**	3
Second stage soil evaporation coefficient	**CONA**	5
Soil albedo	**Salb**	0.13
Soil organic matter		
Soil C:N ration	**SoilCN**	10

Appendix V: Statistical analysis of observed and simulated biomass yields

Table 3: Observed and simulated biomass yields in the SR and LR

Cropping systems	**Organic inputs**	**Observed SR (kg/ha)**	**Simulated SR (kg/ha)**	**Observed LR (kg/ha)**	**Simulated LR (kg/ha)**
Monocrop	FYM	3001	4475.2	2872	3779.6
	Compost	2500	3262.9	2390	4267.1
	Control	2145	2402.6	2140	3323.7
Intercrop	FYM	3100	4184.5	2980	4968.5
	Compost	2870	3885.5	2840	4711.2
	Control	2120	3080.3	2030	3916.7
Rotation	FYM	0	0	3090	5415.7
	Compost	0	0	2881	5094.6
	Control	0	0	2165	4290
	R2	0.98		0.54	
	Ei	-0.42		-0.79	

RR	47.27%	31.31%
RMSE	0.995	1.87
NMRSE	1.02%	1.77%

Appendix VI: Percentage change of biomass yield with projected climate change

Table 4: Change in biomass yield with projected climate change

Season	Cropping systems	Organic inputs	Rain (-10%)	Rain (+10%)	Temperature (Min temp +1.8oC, Max temp +1.6oC)	Temp+Rain (+10%)	Temp+Rain (-10%)
SR	Monocrop	FYM	-3.6	348.4	-190.1	-6949.8	23.7
		Compost	-37.6	248.1	-190.5	-6592.1	-202.6
		Control	35.7	71.3	-117.6	-4727.5	-2.4
	Intercrop	FYM	-87.1	67.3	-384.7	-8043	-481.1
		Compost	-25.8	19.9	-381.7	-7471.7	-435.8
		Control	-15.3	11.1	-244.2	-5933.5	-257.8
	Rotation	FYM	0	0	0	0	0
		Compost	0	0	0	0	0
		Control	0	0	0	0	0
LR	Monocrop	FYM	-49.2	75.7	-121.2	-9743.8	-165.9
		Compost	-43.6	16.3	-137	-8431.9	-163.1
		Control	-29.5	19.4	-75.4	-6573.2	-73.2
	Intercrop	FYM	-66.1	71.1	-235.2	-9773.2	-274.4
		Compost	-53	60.2	-205.1	-9264.9	-229.2
		Control	-57	28.2	-142.1	-7695.6	-174.4
	Rotation	FYM	-82.7	96.5	-170.6	-10730.9	-236.5
		Compost	-72.7	81.1	-143.2	-10097	-179.5
		Control	-61.7	42.7	-124.7	-8474.8	-154.8