THE ECONOMIC IMPACT OF CLIMATE CHANGE ON MAIZE PRODUCTION IN KENYA

BY

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A RESEARCH PAPER SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN ECONOMICS OF THE UNIVERSITY OF NAIROBI

March 2013

DECLARATION

This Research Paper is my original work and has not been presented for a degree award in any other university.

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DEDICATION

To my late dad Dr. Fred Kiarie Wandaka, for his love, encouragement and support. Your love will always be remembered.

ACKNOWLEDGEMENT

My deepest appreciation goes to my dad the late Fred Kiarie Wandaka who supported me immensely at the start of this study and although not with us, he made it possible to have it completed. I cannot also forget my mum Margaret, for her prayers, love, patience, support and encouragement.

I am grateful to my supervisors Prof Jane Kabubo-Mariara and Prof Peter Kimuyu on their invaluable advice, tips, guidance, availing research materials and constructive critique of my research project work.

My heartfelt gratitude goes to Tegemeo Institute of Agricultural Policy and Development who provided me with Rural Household Survey data used in this study. My appreciation also goes to Kenya Agricultural Research Institute for provision of secondary data on soils respectively.

I wish to thank my friends and class mates at the University of Nairobi for their support. Special thanks go to Robert Njuguna, Anne Kitonga, Gayline and Murimi for their tremendous support and encouragement during our academic journey at the University.

Last but not least I want to thank Elizabeth Wanjiku, Antony Kimani, Dennis Musyoka and Maureen Mwendwa for their encouragement and constructive criticism during the writing of research paper. To you all mentioned and unmentioned I say thank you again and May God Bless you.

Above all, I thank the almighty God.

ABSTRACT

This study investigates the economic impact of climate change on maize production in Kenya using the Ricardian approach. The general objective of the study is to conduct an assessment of the potential impacts of climate change on maize production in Kenya and make recommendations for strategies that could be adopted to mitigate the impact of climate change. The study uses climate data drawn from ARTES (African Rainfall and Evaluation system), soil data got from the Kenya Soil Survey conducted by the Kenya Agricultural Research Institute and household data obtained from the Tegemeo Institute of Agricultural Policy and Development. The Results of the study indicate that climate change has an adverse impact on maize production in Kenya. According to the regression results, increase in temperature between March and May and increase in precipitation between June and August will have a negative impact. Increase in precipitation between March and May will have a positive impact on maize production in Kenya. Overall, the study found that temperatures have a larger effect on maize production compared to precipitation. Predictions from nine out of the ten climate change scenarios used in the study indicate that maize output will decrease by up to 23% by year 2100. In line with the results, the study recommends that urgent measures be undertaken to mitigate the impact of climate change on maize production. These measures include: research and development of agricultural technologies, investment in irrigation infrastructure and dissemination of information to farmers on climate change and possible impacts.

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ACRONYMS

CCC	Canadian Climate Centre
DFID	Department for International Development
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GDP	Gross Domestic Product
MEMR	Ministry Of Environment and Mineral Resources
NCPB	National Cereals and Produce Board
UNDP	United Nations Development Program
USA	United States of America
ECHAM	European Center Coupled Models
HADCM	Hadley Center Coupled Models
PCM	Parallel Climate Model
CGCM	Coupled General Circulation Model
CSIROM	Common Wealth Scientific and Industrial Research Organization Model

CHAPTER ONE

INTRODUCTION

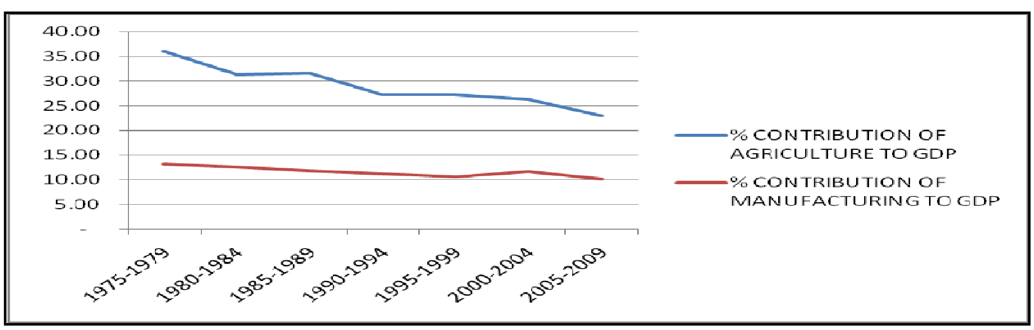
1.1 Background of the Study

1.1.1 Importance of Agriculture to the Kenyan Economy

The Kenyan economy is heavily reliant on agriculture. In the period 1975-1979, the agricultural sector contributed an average of 36% to the Kenyan Gross Domestic Product (GDP), 31.66% between 1980-1984 and 1985-1989 and 27.22% between 1990 and 1994. In the periods 1995-1999 and 2000-2004, the sector contributed an average of 27.18% and 26.33% respectively. Between 2005 and 2009, the sector contributed an average of 22.94% while between 2009 and 2011, the contribution averaged of 22.7%. In the same periods the manufacturing sector, a crucial sector of the Kenyan economy, contributed an average of 13.24%, 12.64%, 11.80%, 11.26%, 10.61%, 11.61%, 10.10% and 9.65% respectively (Economic surveys, 1975-2012*)*.The country has therefore witnessed a decline in the agricultural sector's contribution to the Kenyan Economy as the manufacturing sector has more or less remained constant (Figure 1.1).

In addition to its contribution to the Kenyan GDP, the agricultural sector is the largest employer, accounting for more than 70% of employment in the informal sector and a further 18% in the formal sector. The sector also is a large source of foreign exchange for the country accounting for about 65% of Kenya's total export earnings (Ministry of Agriculture, 2009).

Figure 1 1. The Contribution of Agricultural and Manufacturing Sectors to GDP (%)



SOURCE: KNBS, various issues

1.1.2 Structure of the Agricultural Sector in Kenya

According to the Ministry of Agriculture (2009), the agricultural sector can be divided into six sub-sectors namely industrial crops, food crops, horticulture, fisheries and forestry. In terms of their contribution to agricultural output, food crops such as maize, wheat and bean among others contribute the highest while livestock and fisheries contribute the least. Industrial crops such as tea, coffee and sunflower among others make the highest contribution to agricultural exports followed by horticulture. Fisheries and forestry contribute an insignificant amount to agricultural sector exports (Table 1.1).

Table 1.1: Agricultural Sub-Sectors Contribution to Agricultural Gross Domestic Product and Exports

Agricultural Sub-Sectors	% Contribution to agricultural GDP	% Contribution to agricultural exports
Industrial crops (tea, coffee, sugarcane, sunflower, tobacco e.t.c)	17	55
Food crops (maize, wheat, rice ,beans e.t.c)	32	0.5
Horticulture (cut flowers, vegetables, fruits, nuts e.t.c	33	38
Livestock	17	7
Fisheries and livestock	1	-

Source: Ministry of Agriculture, 2009

Among the food crops sub-sector, maize is the most important since it is Kenya's principal staple food crop. It is the largest source of calorie intake, contributing about a third of calorie intake, for Kenya's population (Kirimi et al., 2011). In terms of area under cultivation, about 1.4-1.6 million hectares are set aside for growing of maize making it the biggest crop grown in terms of area under cultivation. Most maize in Kenya is grown by small scale farmers who produce about 75% of the total production (Guantai et al., 2010). Maize plays an important role in the production patterns of small scale farmers, accounting for 28% of their gross output (Mathenge and Tschirley, 2009).

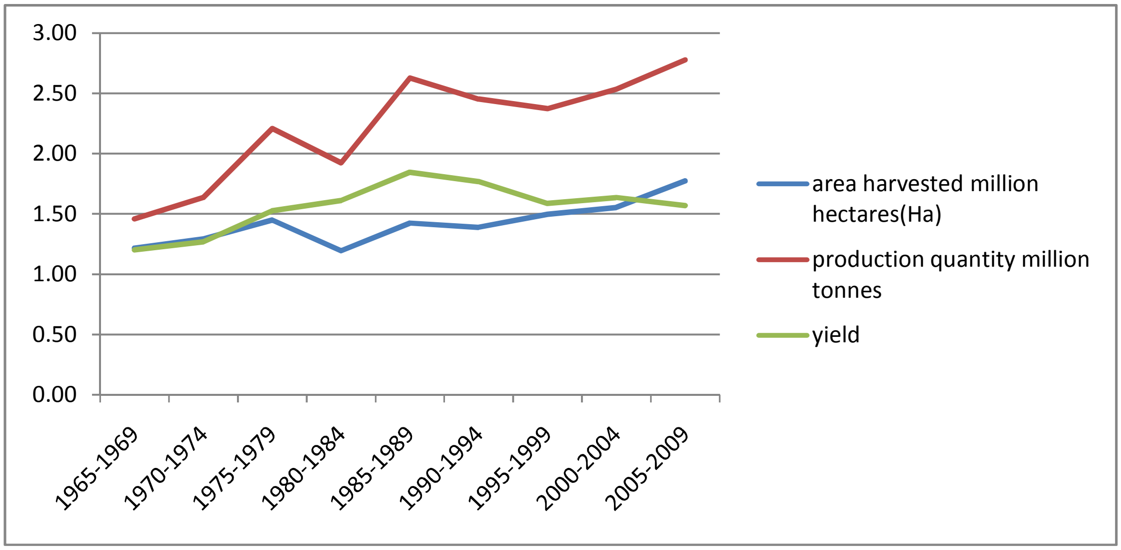
1.1.3 Trends in Maize Production in Kenya

Food security and maize supply in Kenya are closely linked, given that maize is the country's most important staple crop. Kenya's food security depends on the availability of domestically grown maize. This is also true at the household level more so in the rural areas. The availability of maize in the household stores may determine the food security of the household (World Bank, 2010). In addition, maize is an important source of income for farmers especially in maize surplus regions such as the North Rift. Nationally, maize accounts for about 14% of farm household incomes although in maize surplus areas this is higher (Nyoro et al., 2004).

Although maize is undoubtedly one of the most important crops grown in the country, maize yields especially in the period 1990 to 2009 have been poor. This is evidenced by the falling maize yields witnessed over the period 1990 to 2009. As illustrated by figure 1.2, maize yields increased rapidly from independence in 1963, peaking in the period 1985-1989 and finally dropping ever since. The declining maize yields have occurred despite the increase in maize production and area under cultivation. However, World Bank (2010) asserts that the widely noted trend of declining maize yields may not necessarily be true and such results need to be treated with caution.

The increase in yield witnessed between 1963 and 1989 has been attributed to the adaptation of hybrid seeds and related technologies (Karanja, 1996). Another reason that may explain this rapid increase in yield would be the increase in area under cultivation. Area under cultivation increased by nearly 40% from independence that is, from 1,000,000 hectares in 1963 to an average of 1.4 million hectares in the 1984-1989 period. The quantity of maize produced has also experienced growth during that period.

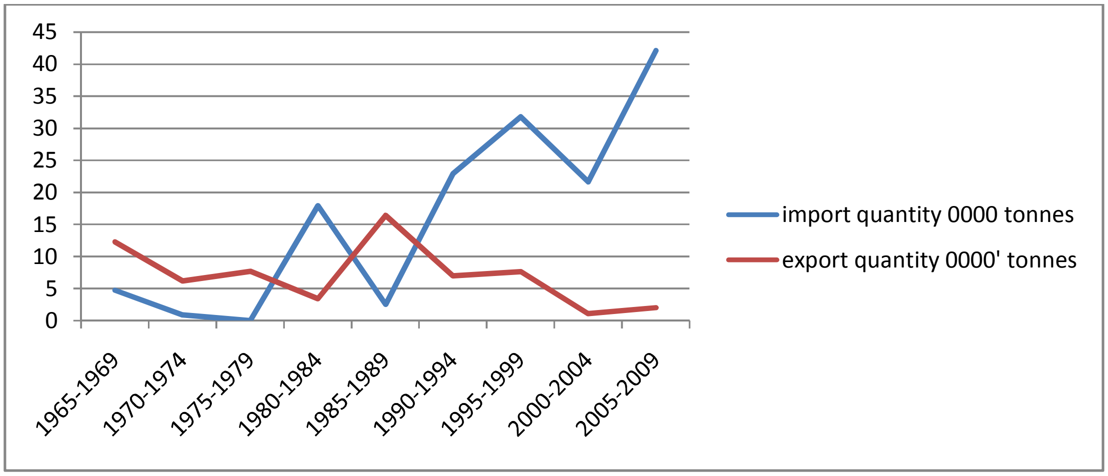
Figure 1. 2: Maize Production Trends



Source: FAO (2010) and World Bank (2010)

Kenya is currently a net importer of maize as a result of domestic demand outstripping local supply. However, this was not always the case. From 1963 to around 1990, Kenya was self sufficient in maize production and was a net maize exporter. The only exception to this was the period 1980-1984, where a major drought affected production. The transition from being a net exporter to net importer began in earnest in the period 1990-94 (figure 1.3). This was also the same period that maize yields began declining (figure 1.2). From 1990-1994 period onwards, imports have been increasing rapidly implying that Kenya is increasingly dependent on maize imports to feed its population. The increased importation of maize is a worrying trend as it implies that the country is diverting more and more of its scarce foreign reserves meant for development to food importation.

Figure 1. 3: Maize Importation and Exportation Trends



Source: FAO (2010)

The falling maize yields witnessed from the early 1990’s (see figure 1.2) could be attributed to such factors as shrinking land sizes and high cost and increased adulteration of inputs. Other factors also include limited access to affordable credit, low and declining soil fertility, limited absorption of modern agricultural technology, pre and post harvest crop losses (Ministry of Agriculture, 2009).

In addition to the above factors, policymakers have begun to recognize the adverse role being played by climate change. Drought and unpredictable weather conditions have led to a succession of crop failures. Climate change is probably the most complex and challenging environmental problem facing the country today. The problem posed by climate change is further compounded by the increasing human population and demand for more agricultural land for food production. This has resulted in the destruction of the vegetation cover and subsequently rampant environmental degradation. Climate change is expected to cause poor crop productivity, outbreaks of diseases and vectors and rampant soil erosion. Yields from rain fed crops in Kenya are expected to fall by half by the year 2020 (Ojwang et al., 2010). This raises serious questions about Kenya’s ability to feed its population as Kenyan agriculture is rainfall dependant.

1.1.4 Policy on Maize Production in Kenya

Kenya's main policy goal in the maize sub-sector has always been to achieve self sufficiency or self reliance in maize production. In order to achieve this, the government has pursued a number of policies. One such policy has been to set the price floors of National Cereals and Produce Board buying prices (NCPB) as an incentive to farmers to produce more. Another policy the Kenyan government has pursued to encourage high maize production, has been the provision of subsidies to maize farmers. The Kenyan government has subsidized the cost of such inputs as fertilizer and seeds. Apart from these policies, the government has also pursued a trade policy on maize that highly discourages the importation of maize by imposing a high import duty (Nyoro et al., 2007).

However, in the pursuit of self reliance in maize production, policy makers have been confronted by the classic food price dilemma. On the one hand, the policy makers want high prices for the farmers hence raising farm incomes and on the other hand, they want tolerable prices for the maize consumers especially in the urban areas. Reconciling these two policy objectives has been a difficult challenge. The result of this dilemma is that consumers of maize and related products have paid a higher price than it would have been if the government didn't intervene in the market. This includes the very farmers the government sets out to assist by setting high prices for maize output through the National Cereals and Produce Board (Sarris and Morrison, 2010).

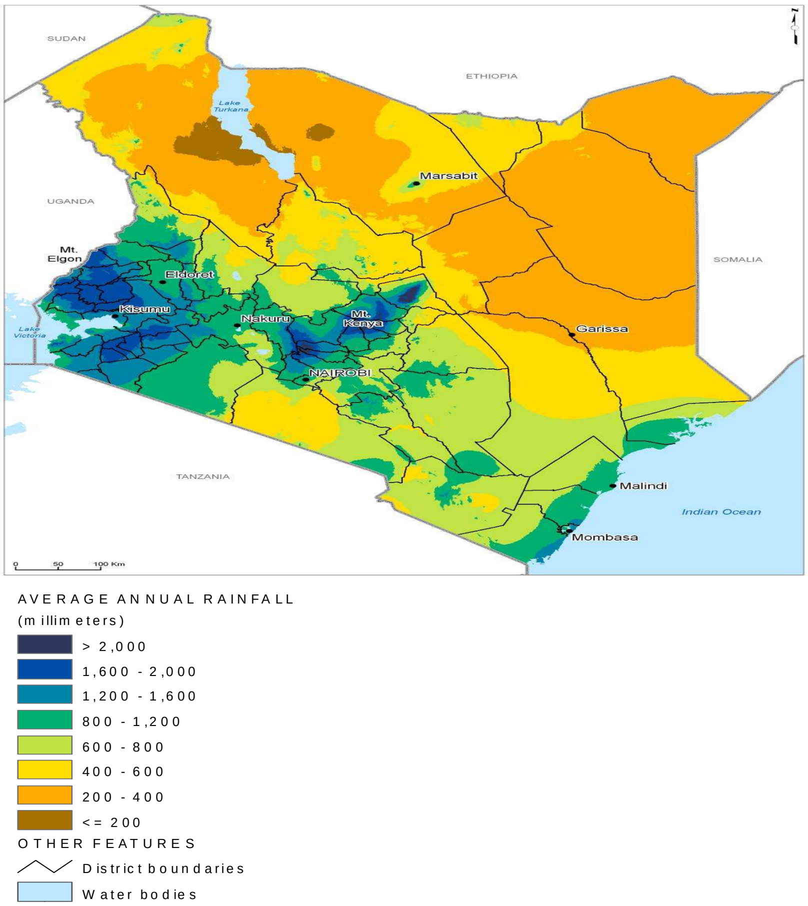
The increase in maize production witnessed from the mid 1990s could be attributed to the policies pursued by the Kenyan Government. However, these policies have failed to address the problem of falling maize yields that has been experienced in the last two decades (see figure 1.2).

1.1.5 The Climatic Conditions and Agro-Ecological Zones of Kenya

Kenya has a complex climate with wide variations across the country. At the coastal region, there exists a narrow belt which is relatively hot and wet. Behind this, lies a large area of hot and dry arid and semi arid region. Thereafter, the land rises to form the temperate highlands (DFID, 2008). Kenya's complex climate is influenced by such factors as topography, its proximity to Indian Ocean and Lake Victoria and the equator (Ojwang et al., 2010).

Kenya has two rainy seasons namely: the long rainy season that runs from March to May and the short rainy season that runs from October to December (McSweeney et al., 2008). The highest amount of rainfall in Kenya is received in the highlands and a narrow coastal belt along the Indian Ocean while the least amount is received in the North eastern parts of the country and around the Lake Turkana (figure 1.4).

Figure 1. 4: Rainfall Distribution in Kenya

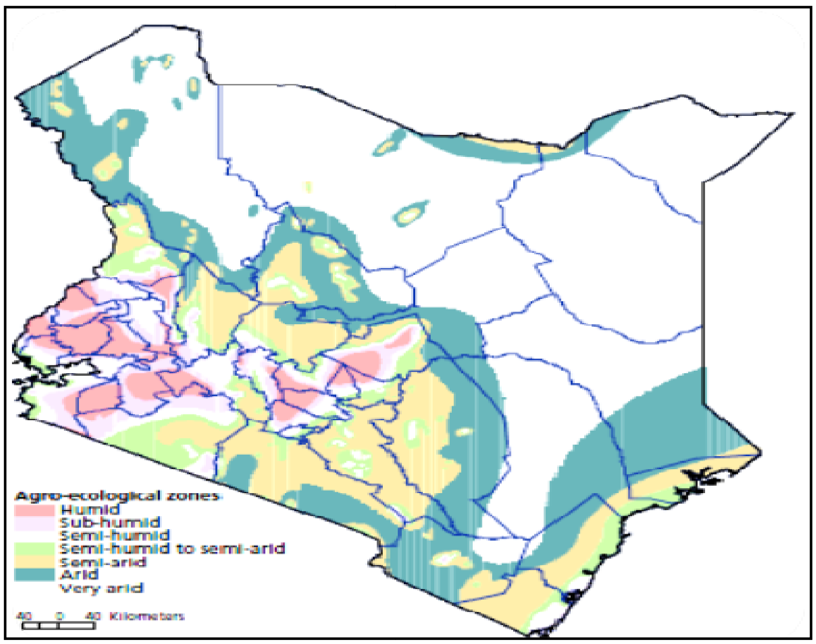


Source: World Resource Institute (2007)

The mean annual temperatures for Kenya range from 10^{0}C to 40^{0}C. Temperature, like rainfall is also dependant on altitude. High altitude areas have the coolest temperatures while low lying coastal belt and arid and semi arid areas have the highest temperatures (Kabubo-Mariara and Karanja, 2007).

The country can be divided into seven agro-ecological zones on the basis of vegetation characteristics, amount and reliability of rainfall and land ecological potential (figure 1.5). These zones are the humid, sub humid, semi humid, semi humid to semi arid, semi arid, arid and very arid. The high to medium potential areas of the country comprise of humid, sub humid and semi humid zones and make up 20% of the Kenyan land area. The largest part of the Kenyan population, about 80%, is located in these zones. In addition, most of the crop agriculture practiced in Kenya is undertaken in these zones. The remaining agro-ecological zones account for 80% of the Kenya's land area. The main economic activity here is livestock keeping and tourism. Most of Kenya's national parks and reserves are located in these zones (Ojwang et al., 2010).

Figure 1. 5: Kenya's Agro-Ecological Zones



Source: Ojwang et al., (2010)

1.1.6 Climate Change in Kenya

The Kenyan climatic conditions have been undergoing some change. According to McSweeney et al. (2008), the average temperatures in Kenya have increased by 1^0C since 1960 which translates to about 0.21^0C per decade.

The variability of annual rainfall has increased. Rainfall between March and May (long rains season) has shown a decline while rainfall between October and December (short rainy season) has shown an increase (MEMR, 2009). Furthermore, increasing temperatures and changing rainfall patterns, extreme weather conditions such as drought and floods have become frequent.

This change in climatic conditions is projected to continue in the future. Downing C et al.(2008) projects that Kenya will experience an increase in temperature by between 1^0C and 5^0C by year 2050 while mean annual rainfall is also going to increase particularly in the short rainy season in the high to medium potential areas. Arid and semi arid areas will likely experience depressed rainfall thereby exacerbating the drought conditions being experienced in those regions.

1.2 Statement of the Problem

The Kenyan economy is highly reliant on agriculture. Agriculture contributes a significant share to the Country's GDP, total employment and export earnings and provides a source of livelihood for a large part of the population especially in the rural areas. Maize is a key sub-sector in the agricultural sector. Maize is the most widely grown in the country in terms of area under cultivation. It provides the Kenyan population with a third of their calorie intake and a key source of farm incomes especially in the maize surplus areas. Food security in Kenya and maize production are closely interlinked. At the country level, the availability of maize determines whether the country is food secure or not (Nyoro et al., 2007). This is also true at the households level, more so in the rural areas.

However, despite the importance of maize to the country, production especially in the last decade has been poor. The reasons for this include the high cost and increased adulteration of inputs, low and declining soil fertility, decreasing land sizes, limited access to affordable capital and low absorption of modern technology (Ministry of Agriculture, 2009). Besides the above factors, policymakers have begun to recognize the increasingly adverse role being played by climate change on maize production. Erratic weather conditions have been blamed for a succession of maize crop failures forcing the Kenyan government to import maize to feed its population.

Most studies[1] conducted on the impact of climate change on agricultural sector in Kenya have analyzed the impact of climate on general agriculture. Mati (2002) and Karanja (2006) attempted to analyze the impact of climate change on individual crops. However, results by Mati (2002) were inadequate as they only addressed two ecological zones, yet maize is grown in nearly all seven agro-ecological zones while the study by Karanja (2006) mainly focused

[1] Kabubo-Mariara and Karanja, 2007; Downing, 1992; Fischer and Velthuizen, 1996 and Kabubo-Mariara, 2009; Mati, 2002 and Karanja, 2006.

on the impact of temperature on production but failed to include the precipitation component. It is important to analyze the impact of climate change at individual crop or animal level so as to be able to get a better understanding of how climate change will affect agriculture production in Kenya. This study sought to address this gap in knowledge by providing insights on how climate change affects maize production.

1.3 Objectives of the Study

The general objective of the study `was to assess the potential impacts of climate change on maize production in Kenya and make recommendations to mitigate the impact of climate change on maize production. The specific objectives of the study were;

1. To investigate the economic impact of climate change on maize production in Kenya.

2. To predict the impact of climate change on Kenyan maize production by the year 2100.

3. To make policy recommendations based on the research findings.

1.4 Significance of the Study

This study sought to provide important insights for policy makers in the agricultural sector on the effects of climate change on maize production and food security in Kenya. Maize availability and food security in Kenya are closely intertwined. Lack of maize at the National Silos and the household granary implies both the country and the households are food insecure. With this close link between food security of the country and maize production, it is important for policy makers to get a clear understanding of the effects of climate change on maize production. The study also sought to propose adaptation options that could be taken up to mitigate the impact of climate change on maize production in Kenya. Finally, the study contributes to the growing literature on climate change in Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

As stated in chapter one, climate change is one of the most complicated challenges facing mankind today. Over the last two decades, there have been a growing number of studies on the impact of climate change on various human activities. This chapter provides a survey of literature related to the economic impact of climate change on agriculture. The chapter describes the theoretical approaches used in assessing the economic impact of climate change on agriculture in section 2.2. In section 2.3, empirical studies are presented and in the final section (2.5), an overview of the literature is provided.

2.2 Theoretical Literature

2.2.1. The Production Function Approach

The production function approach was the pioneering approach used to analyze the impact of climate change on agriculture. The approach is based upon experimental or empirical production functions where environmental variables such as precipitation or temperature are inputs. These environmental variables in the production function are varied so as to estimate the impacts of climate change on yields These changes in yields are then incorporated in economic models so as to predicate the changes in welfare as a result of climate change (Mendelsohn et al., 1994).

Production function approach has the advantage of providing estimates of impact of climate that are free of bias as a result of the determinants of agricultural production that are beyond a farmer's control such as soil quality (Deschenes and Greenstone, 2006). In addition, the approach provides better predictions of the impact of climate change on agricultural yields because of its use of controlled experiments (Mendelsohn et al., 1994; Deschenes and Greenstone, 2006).

Despite this, the approach suffers from some limitations. First, the approach doesn't incorporate adaptation measures adopted by farmers in the face of climate change. This is unlikely since farmers will respond to the changing climate conditions. They may introduce new crops or replace crops with livestock. The lack of incorporation of adaptation measures results in an overestimation of damages as a result of climate change (Mendelsohn et al., 1994). Secondly, the approach is very expensive because of the controlled experimentation required (Deressa, 2007). This may explains why the approach has been used in few sites around the world and for a few crops mainly grains. Hence, the approach may be of little value for generalizing results.

2.2.2. The Ricardian Approach

This technique was developed by Mendelsohn, Nordhous and Shaw in a study done in 1994 that examined the impact of climate change on USA's agriculture. Mendelsohn et al., (1994) developed this technique so as to correct the bias that the production function approach had of over-estimating damages to agriculture because of climate change. This bias was a result of its failure to incorporate adaptation measures taken up in response to the changing climatic conditions.

According to Mendelsohn et al., (1994), the Ricardian approach estimates the impact of climate change by looking at how climate in different places affects farm revenue or the value of the farmland. They note that by looking at the effect of climate variables such as temperature or precipitation on farm revenues or value of the farmland, the approach is able to incorporate farmer's adaptations to climate change.

This approach has gained popularity over the production function approach in the recent past because of the various advantages it has over production function approach. First, it's ability to automatically take into account the farmer's adaptation responses and secondly, it is cost effectiveness. This is because the Ricardian approach can rely on secondary data whereas the production function approach would require extensive experimentation which is expensive (Deressa, 2007*)*.

However, the approach suffers from some limitations. One limitation is that the Ricardian approach fails to incorporate the transition costs a farmer may bear as a result of moving from one adaptation option to another as a result of climate change. For example, if a farmer introduces a new crop because of changing weather conditions, the approach assumes the costs associated with new crop will be borne by the farmer. However, if that new crop fails and the farmer introduces another new crop, the approach fails to capture costs associated with moving to other new crop. The transition costs could be quite high especially in agricultural subsectors where there is extensive capital used which can't be easily changed. Another limitation is that the approach fails to measure the effect of variables that don't vary across space. For example, the effect of carbon dioxide levels which are generally the same across the world (Kurukulasuriya and Mendelsohn, 2008). Another weakness of the approach is that it affected by aggregation bias. However, this weakness also affects other hedonic models and is not restricted to the Ricardian model only (Fezzi et al., 2010). Finally, the approach doesn't fully control for the impact of important variables other than climatic factors that could explain the variation in land values or farm revenues (Kurukulasuriya and Rosenthal, 2003).

2.3 Empirical Studies

This section presents a survey of empirical studies conducted on the economic impact of climate change on agriculture. In Section 2.3.1, production function studies are presented while in section 2.3.2, Ricardian approach studies are presented.

2.3.1 Production Function Studies

Developed and emerging economies

Rosenzweig et al., (1994) investigated the potential impact of global climate change on world food supply. The study used data drawn from other individual studies so as to obtain the world picture of the simulated change in crop yield associated with different climate change scenarios. To simulate the economic consequences associated with the different changes in yield associated with different climate scenarios, the study used a world food trade model. The study found out that developing countries were more vulnerable to climate change than the developed countries. The study also found out that adaptation options taken up at the farm level in developing countries didn't reduce this gap in vulnerability.

The findings by Rosenzweig et al., (1994) were supported by findings of another study by Parry et al., (1999). Parry et al., (1999) investigated the potential impact of climate change on world food security using crop growth models for wheat, rice, maize and soybeans and simulated the changes of crop yields as a result of climate change. They found out that climate change will affect agricultural production more in developing countries than in developed countries particularly those located in Africa. It further noted that, agricultural production in mid and high latitudes will benefit from climate change while agricultural production in low latitudes will suffer.

Chang (2002) used the production function approach to analyze the impact of climate change on Taiwan agricultural sector. He used yield regression models and factored in farmer's adaptation responses. The study focused on 60 crops including rice, corn, wheat, sorghum, soybeans, carrots, tea and sesame among others. Chang (2002) noted that temperature and precipitation have significant impact of crop yields in Taiwan. He also found that climate change will have an overall positive impact on Taiwan society welfare.

ASIA

Basak et al., (2009) analyzed the impact of climate change on Boro rice production in Bangladesh. Their study used a DSSAT model to analyze the impact for the years 2008, 2030, 2050 and 2070 for 12 locations in Bangladesh. Their study also used weather data from the regional climate model PRECIS, soil and hydrologic characteristics. The study found out that Boro rice production will reduce by over 20% and 50 % for the years 2050 and 2070 respectively as a result of climate change. The study also found out that temperature increase is primary responsible for the decrease in production.

Saseendran et al., (2000) investigated the impact of climate change on rice production in Kerala state in India. The study used a CERES-RICE model to investigate the impact of climate change on rice production. The study used climate change scenarios from ECHAM3 climate model. The study found out that an increase in CO_2 concentration will lead to an increase in rice production in the Kerala state due to the fertilization effect. In addition, the study found out that an increase in temperature will have an adverse effect of reducing yields by 6% for every one degree increase in temperature.

Africa

A number of studies on the impact of climate change on agriculture have been conducted using the production function approach. One such study was by Makadho (1996) who investigated the potential effects of climate change on corn production in Zimbabwe using two global climate models namely the GFDL and CCC models. In addition, the author used CERES- maize model to simulate the changes in crop yield associated with the different climate change scenarios. The study found that corn production is expected to decrease as a result of the increase in temperature. This is because increase in temperature will result in a shortening of crop growth period..

Onyeji and Fischer (1994) investigated the potential impact of climate change on Egyptian agriculture and its economy wide implications. They focused on maize and wheat in their study. The authors used IBSNAT crop model to simulate the changes in crop yields associated with the different climate change scenarios. The study found out that climate changes will a result in a reduction in agricultural production and that the decrease in agricultural production will have other negative economic wide implications.

Jones and Thornton (2003) evaluated the potential effects of climate change on small holder maize production Africa and Latin America. Jones and Thornton (2003) used the Global Circulation Model (GCM) to provide the climate change scenarios up to the year 2055. The author then used a CERES- maize model to simulate the changes in maize yield associated with the different climate change scenarios as produced by the GCM model. The study found out the impact by climate change on aggregate smallholder maize production is modest. Aggregate Smallholder maize production according to the authors will fall by 10% by 2055. According to Jones and Thornton (2003), this modest fall in production could be easily compensated for by better plant breeding and technological interventions in the intervening period. .

Kenya

Karanja (2006) investigated crop responses to climate change and climate variability through an analysis of crop water requirements. The study was conducted in six agricultural districts namely Kiambu, Makueni, Kwale, laikipia, Vihiga and Migori. The study focused on a variety of crops such as maize, wheat, sorghum, sugarcane, beans, bananas, millet and pigeon peas among others. The study used the FAO Penman-Monteith model to investigate the impact of climate change on crop water requirements and found out that climate change does affect crop water usage. The study showed that there is an increase in crop water use as a result of a increase in temperatures.

Mati (2002) investigated the potential effects of climate change on maize production in two agro-ecological zones in the Western, Eastern and Central regions Kenya. Mati (2002) used two global climate models namely the GFDL and CCC models to provide the climate change scenarios. The author also used CERES- maize model to simulate the changes in crop yield associated with the different climate change scenarios. The study found out that climate change affected maize production in the two agro-ecological zones. In semi arid ecological zone the study found climate change may cause a decrease in maize production while semi humid, it may cause production to increase. The study proposed growing early maturing varieties, early planting and the growing of maize in the short rainy season in Eastern Kenya as some of the adaptation measures that can be taken up.

Downing (1992) investigated the vulnerability of Kenyan agriculture to climate change. The study used a land use model. Downing (1992) found out that an increase in temperature may be beneficial to agriculture in Highland areas but detrimental to it in arid and semi arid areas. The study also found that in an increase in temperature may increase Kenya's food production potential but if accompanied by an increase in precipitation. These findings were supported by another study by Fischer and Velthuizen (1996). Fischer and Velthuizen (1996) also found out that an increase in temperature would be beneficial to agricultural production potential in highlands but harmful in arid areas if not accompanied by an increase in precipitation..

Kabara (2009) analyzed the economic impact of climate change on agriculture production in Kenya using a translog model. The study used weather data from the Kenya Metrological department (KMD) and agricultural and economic data from FAO, the Ministry of agriculture (MOA) and Kenya National Bureau of Statistics (KNBS). The study found out that increase in precipitation and temperature negatively affects agriculture production in Kenya. According to the study, agriculture production will fall by 23% by the year 2100. The study by Kabara (2009) however, suffers from some limitations. First, the study didn't include farmer adaptations in the face of climate change hence may have overestimated the impacts of climate change. Secondly, the study noted that increase in precipitation and temperature will be harmful for agriculture production in Kenya. However, this may not the case since increase in precipitation in some areas may actually agricultural production for example in the arid and semi arid areas.

The current study differs from the above production function studies in terms of approach used to analyze the impact of climate change. The above studies used the production function approach while the current study used the Ricardian approach. In addition, the current study differs those studies in that they ignored farmer's adaptation measures hence their results may over estimate the impact of climate change on agricultural production. The Ricardian approach used by the current study automatically incorporates farmer's adaptation measures in the face of climate change in its analysis. Thus it is able to give a much more accurate picture of the impact of climate change on agricultural production.

2.3.2 Ricardian Approach Studies

Developed and emerging economies

Mendelsohn et al., (1994) investigated the impact of global warming on US agriculture by measuring the impact of climate change on land prices. The study used a Ricardian model and cross sectional data on climate, farmland prices and other economic data for about 3000 counties in the United States. The study found that higher temperature in winter, spring and summer have an adverse effect on farm values while higher precipitation in all seasons except autumn increases farm values. It also found out that that higher winter and summer temperatures are harmful to crops while higher precipitation in spring and winter is beneficial. The study suggests that the impact of climate change may be greatly overstated if analysis is limited to major grains**.**

Seo and Mendelsohn (2007) analyzed the impact of climate change on South American agriculture taking into account farmer's adaptation by measuring the sensitivity of land values per hectare to seasonal temperatures and precipitation. Seo and Mendelsohn (2007) used a Ricardian model on data on climate, farmland prices and other economic data for about 2300 farms in South America. The study used climate change scenarios as predicted by three models namely the Atmospheric General Circulation Model, Canadian Climate Centre model and Parallel Climate model. The study found that that South American agriculture is vulnerable to climate change. Seo and Mendelsohn (2007) argue in their study that farm land values will decrease as temperature rises as well as when rainfall rises expect in the case of irrigation. The authors further argue in their study that large farms are highly vulnerable to rainfall increases while small farms to increase in temperatures.

Deschenes and Greenstone (2006) investigated the economic impact of climate change on US agriculture .They used both a Ricardian model and also new strategy which they proposed where they estimated the impact of year to year changes in temperature and precipitation on US agricultural profits. The study used weather data drawn from the PRISM climate model, agricultural production data drawn from Census of Agriculture and soil data. The study found out that climate change will have a positive impact on US agriculture and will agricultural profits by 4%. The study suggested that the Ricardian approach is unreliable since it results can be easily be affected by small changes in control variables, sample or weighting.

Fezzi et al., (2010) investigated the impact of aggregation on the Ricardian model. The study used a ten year panel data set of 3000 farms covering the whole of Great Britain. The study found out that aggregation affects the climatic coefficients. The study suggested that predictions of climate change impacts based on the Ricardian model results may be wrong due to aggregation bias. The study also found out that increase in temperature will have an adverse impact on land values if not accompanied by an increase in precipitation.

Although the current study used the same approach as the studies by Mendelsohn et al., (1994), Seo and Mendelsohn (2007), Deschenes and Greenstone (2006) and Fezzi et al., (2010) it has a number of differences from those studies. First, those studies analyzed the impact of climate change on general agriculture production while the current study looked at the impact on maize production. Secondly, those studies used farm land values as the dependent variable while the current study used net revenue per hectare as the dependant variable due to lack of data on farm values in Kenya.

Africa

Molua and Lambi (2007) investigated the impact of climate change on crop farming in Cameroon based on a cross-sectional survey of over 800 households. Climate data was sourced from secondary sources. In their analysis, the authors used the Ricardian approach and their results indicated that temperature and precipitation had significant impact on Cameroonian crop farming. Increase in temperatures according to their study had a negative impact on net farm revenues while increase in precipitation had the opposite effect on farm net revenues.

Gbetibouo and Hassan (2005) investigated the impact of climate change on major field crops in South Africa using a Ricardian model. In their study, the authors regressed farm revenues on climate, soil and other socio-economic variables from 300 districts in South Africa. Gbetibouo and Hassan (2005) found out in their study that temperature increase may have a positive impact while a reduction in rainfall may have a negative impact. The authors also suggest in their study that a shift in growing patterns and farming practices may occur.

Maddison et al. (2007) used a Ricardian model to assess how farmers in 11 African countries have adapted to existing climatic conditions. The authors then estimate the impact climate change on agriculture in those 11 countries while accounting for farmer adaptations that might occur. The authors found out that African agriculture is vulnerable to climate change. The authors suggest in the study that even with perfect adaptation some losses will be experienced in the agricultural sector. However, the size of losses will be minimal in such countries as South Africa and Ethiopia but significant for such countries as Niger and Burkina Faso.

Kurukulasuriya and Mendelsohn (2008) investigated the impact of climate change on African cropland using a Ricardian model. The study used farm data drawn from a survey of over 9500 farmers in eleven countries. The study found out that farm revenue are sensitive to climate especially temperature. The study found out that increases in temperature will have an adverse effect on African agriculture especially in the hot and dry regions. The study suggested that African governments should come up with policies to mitigate the impact of climate change on African farmers.

Deressa (2007) investigated the economic impact of climate Ethiopian agriculture. The study used farm data based on a cross –sectional survey of 1000 households in 50 districts covering 11 agro-ecological zones. The author found that climate change affects agricultural production in Ethiopia. According to the study, increased temperature not accompanied by an increase in precipitation will be damaging to Ethiopian agriculture.

Kenya

Kabubo-Mariara and Karanja (2007) investigated the economic impact of climate on Kenyan crop agriculture based on a cross –sectional survey of 816 households. The authors used a Ricardian approach to analyze the impact of climate variables on net revenue per hectare. They found out that climate change affects agricultural productivity. The study found that high temperatures negatively affect crop production while high precipitation had a positive effect. Their results indicated that medium and low potential agro-ecological zones will be the most affected by climate change while high potential zones may actually gain from climate change. The study also found out that farmers were aware of the changing climate conditions and had started taking up measures to mitigate its effects.

The results of above study were supported by another study by Kabubo-Mariara (2008) which investigated the impact of climate change on crop selection and the adaptation measures taken up by farmers. The study used a probit model based on cross-sectional data to analyze the impact of climate change on crop selection and descriptive analysis to evaluate the adaptation measures being taken up by farmers. To analyze the impact of climate change on crop selection using the probit model, the crops were divided into major food crops, minor food crops and cash crops. The results of the study indicated the choice to grow a crop or a group of crops is affected by climate change. The results also showed that temperature has a bigger influence on the choice than precipitation. The study found out that for major food crops such as maize, the decision whether to grow or not was affected by both temperature and precipitation. Both temperature and precipitation also had a significant influence on decision to grow either tea or coffee, two major cash crops.

Kabubo-Mariara (2009) also examined the impact of climate change on livestock production in Kenya. The author used a Ricardian model and found that livestock production in Kenya is highly sensitive to climate change. The results of the study indicated that livestock incomes exhibit a non linear relationship with climate. The study found that a small increase in temperature may actually be beneficial to livestock productivity while increase in precipitation may have an adverse effect on it. According to the study, this was because high precipitation may result in farmers choosing to grow crops instead of keeping livestock.

Although the current study used the same approach as the Ricardian studies[2] , it differs in that it analyzes the impact of climate change on a singular crop, maize, while the rest of the studies either focused on the impact either at whole agricultural sector, the crop agriculture sector or the livestock sector.

2.4 Overview of the Literature Review

The general consensus that emerges from the review of literature is that climate change will have a negative impact of agricultural production and this impact will be felt more in developing countries than in the developed countries (Rosenzweig et al.., 1994). The above review also showed that production function approach and the Ricardian approach concur with each other with respect to the impact of climate change. However, they differ substantially on the magnitude of impact. The Ricardian approach has recently become more attractive than production function approach in the analysis of economic impacts of climate change on agriculture. This is because of its ability to automatically capture farmer's adaptations thus correcting the inherent bias of the production function approach of overestimating damages as a result of agriculture.

The various studies on the impact of climate change in indicate that precipitation and temperature were the most important climatic factors affecting agriculture production. Most studies indicate that an increase in temperature will have a negative effect on agriculture while precipitation will have a positive effect (Molua and Lambi, 2007; Mendelsohn and Seo 2008; Mendelsohn et al., 1994 and Makadho (1996). Other studies however, have found out that temperature increases could be beneficial to agriculture while an increase in precipitation could be harmful (Kabubo-Mariara (2009), Gbetibouo and Hassan (2005), Downing (1992) and Fischer and Velthuizen (1996).

The earlier studies in Kenya used the production function approach in analyzing the impact of climate change on agriculture while later studies used the Ricardian approach. In addition, most studies in Kenya have analyzed the impact of climate change either at an aggregrate

[2] Mendelsohn et al., (1994) Deressa (2007), Maddison et al., (2007), Molua and Lambi (2007), Kurukulasuriya and Mendelsohn (2008) , Gbetibouo and Hassan (2005), Kabubo-Mariara and Karanja (2007), Kabubo-Mariara (2008) and Kabubo-Mariara (2009) Deschenes and Greenstone (2006)

crop level[3] or livestock level. Few studies have attempted to analyze the impact at a single crop or animal level. Yet to fully understand the impact of climate change especially in the semi arid and arid areas, an assessment of the impact of climate at individual crop is necessary. One study that attempted to analysis at an individual crop level was by Mati (2002). However, the study focused on only two agro-ecological zones though maize is grown in nearly all seven agro-ecological zones in the country. The study further failed to project how maize production will respond to future climate changes scenarios. The current study attempted to fill this gap by analyzing the impact of climate change on maize production in Kenya. The study also projects maize production responses to various climate change scenarios

[3] Kabubo-Mariara and Karanja, 2007; Downing, 1992; Fischer and Velthuizen, 1996 and Kabubo-Mariara, 2008; Kabara,2009

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the framework that was used to analyze the impact of climate change on maize production in Kenya. It begins by describing the empirical model that was used in the analysis and a definition of the variables in section 3.2. In section 3.3, a discussion of the variables is presented. In section 3.5, a discussion on marginal effects and elasticities is presented while in section 3.6, future climate scenarios are discussed. Data and the sources of the data are described in section 3.6.

3.2 Empirical Model

This study uses the Ricardian Approach to investigate the impact of climate change on maize production in Kenya. The Ricardian model is a cross sectional model that is used to evaluated the long term impacts of climate change on agriculture. The Ricardian model estimates the impact of climate change by looking at how climate affects farm revenue or the value of farmland. The model is based on Ricardo's idea that the land rent under competitive markets is the highest net income expected from it (Mendelsohn et al., 1994).

The model assumes that the value of farmland or the net farm revenue is the present value of future net revenue from farm related activities. Net farm revenue measures the net productivity and costs associated with individual crop or livestock (Kurukulasuriya et al., 2007). Gross revenue values are ignored since empirical literature argues that they exaggerate the effect of climate (Mendelsohn et al., 1994).

The Ricardian function following Mendelsohn et al. (1994) can be presented as;

$$R = \left(\sum P_m Q_m (X, C, Z, S) - \sum P_x X\right) \quad (1)$$

Where R is net farm revenue per hectare, P_m is the market price of maize, Q_m is maize output, X is a vector of purchased inputs other than land, C is a vector of climate variables, Z is a vector of soil variables, S is the vector of the socio-economic variables and P_x is the vector of input prices. The farmer is assumed to choose X to maximize the net farm revenue (R) given soil, climate and socio-economic variables.

Maximizing net revenue in equation (1) subject to inputs leads to a reduced form Ricardian model where net revenue (R) is a function of exogenous variables. These exogenous variables are C (climate variables), Z (soil variables) and S (the vector of the socio–economic variables). The reduced form Ricardian model takes up the general form:

$$R = f(C, Z, S) \qquad (2)$$

Equation 2 is said to follow a quadratic function with the climatic factors having squares in order to capture the nonlinear relationship between net revenue and climatic factors (Mendelsohn et al., 1994). Therefore the equation to be estimated becomes;

$$R = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 Z + \beta_4 S + \mu \qquad (3)$$

3.3 Definition and Measurement of Variables

The definition and measurement of independent variables used in the analysis are presented in table 3.1 below. The dependent variable is this study is net maize revenue per hectare computed by removing variable costs from the gross maize revenue. The variable costs represent the cost of the purchased inputs such as fertilizer and seeds, the cost of labour and the cost of land preparation.

In the table 3.1, column one represents the variable name, column two the definition and measurement of each variable and third column, the hypothesized relationship between the dependent variable and each independent variable.

Table 3. 1: Definition and Measurement of Variables

VARIABLE	MEASUREMENT	EXPECTED SIGN
Precipitation	Climate normal monthly mean	+
Temperature	Climate normal monthly mean	-
Farm size	Size of the farm in acres	+
Household size	The number of people in the household	+
Average years of education	The average years of education of total household members	+
Distance to the extension services	The distance to the nearest extension service provider	-
Soil variable	The dominant soil in the district	+

3.4 Marginal impacts and Elasticities

After estimating the Ricardian model, marginal impacts and elasticities are computed so as to assess the impact of climate change on maize production in Kenya. Marginal impacts show the change in net farm revenue as a result of unit change in the climate variables; temperature or precipitations (Mendelsohn et al., 1994) Marginal impacts for each climate variable are computed by differentiating equation (3) with respect to each climate variable; temperature and precipitation. The expected marginal impacts are :

$$E(\frac{\delta R}{\delta C}) = \beta_1 + 2\beta_2 * E(C) \qquad (4)$$

Where R is the net farm revenue per hectare and C is the climate variable.

Elasticities are calculated so as to assess the relative change in net farm revenue per hectare associated with a unit change in temperature and precipitation. Elasticities are computed as follows;

$$elasticity = \frac{C}{R}(\beta_1 + \beta_2 C) \text{ where} \qquad (5)$$

Where R is the net farm revenue per hectare and C is the climate variable. β_1 and β_2 represent the coefficient for the linear and squared term of the climate variables

3.5 Climate change Simulations

After estimating the impact of climate change on maize production, the study examines how future changes in climate will affect net maize revenues. The study uses two climate change scenarios namely; Uniform Change Scenarios and Global Circulation Models Scenarios.

Uniform Change Scenarios

Under this scenario, the impact of climate change on maize production is analyzed by using uniformly changing temperature and precipitation. The study assumed uniform change scenarios of an increase in temperature by 2^0C and 5^0C and a decrease in precipitation by 10% and 20%.

Global Circulation Models Scenarios

The study also analyzes the likely impact of climate change on maize production using the predicted changes of temperature and rainfall from Atmosphere–Ocean Global circulation models. These models are; European Center Coupled Models (ECHAM), Hadley Center Coupled Models (HADCM), Parallel Climate Model (PCM), Coupled General Circulation

Model (CGCM) and Common Wealth Scientific and Industrial Research Organization Model (CSIRO). The predicted changes of temperature and rainfall presented in Table 3.2 are for the year 2100 relative to the year 2000. The figures were adapted from Kabubo-Mariara (2009). The predicted change in temperature is measured in degree Celsius while the predicted change in precipitation is the percentage change. To get the future value of precipitation in year 2100 we multiply the current precipitation values by the percent change in precipitation. To obtain the value of temperature in year 2100, we add the predicted change in temperature to the current temperature value.

Table 3. 2: Predicted Changes in Annual value of Climate Variables by 2100

	Precipitation (Percentage change)				
	CGCM2	CSIRO2	ECHAM	HADCM3	PCM
A2-Scenarios	116	123	134	124	115
B2-Scenarios	109	109	129	115	110
	Temperature (Increases in degrees Celsius)				
A2-Scenarios	7.4	8.2	7.2	8.7	5.4
B2-Scenarios	4.7	6.3	4.9	6.3	3.8

Source: Kabubo-Mariara, 2009

3.5 Data Type and Data Sources

Household Data

The household data for this study is based on a sample of 1446 households. The household data was collected by Tegemeo Institute of Agricultural Policy and Development through interviews of farmers in the year 2000. The data coverage was 22 districts spanning over 6 provinces[4] (see appendix for the list of districts and distribution of households' in each district). The agro ecological zones covered are also presented at the appendix.

[4] The provinces were Central, Rift valley, Coast, Eastern, Western, and Nyanza.

The household data from the survey that is of interest to the study included the amount and cost of fertilizer used, the cost of seeds, the cost of labour, land preparation costs, amount of maize harvested, the price per 90kg of maize, the size of the farm in acres, the gender of the household head, years of education of household members and distance to extension services.

Net farm revenue associated with maize production was computed by taking the gross revenue from maize production minus variable costs associated with maize production. The specific costs were; cost of fertilizer, cost of labour, land prep costs and cost of seeds.

Climate Data

The district temperature data that is used in the study is from Satellite climate data while the district precipitation data is from ARTES (African Rainfall and Evaluation System) climate data. Monthly temperature averages for 14 years (1988-2003) were calculated. Meanwhile, monthly precipitation averages for 30yrs (1960-1990) were also calculated. The purpose for this is to be able to analyze the long term impact of climate on agriculture (Mendelsohn et al., 1994). The averages for the following periods March-May, June-August, September – November and December-February were also calculated. The periods of interest to this study are the March-May, June- August and September- November periods as they represent the time maize is grown in Kenya. March- May and June-August represents the long rains growing season and September-December short rains growing season.

To map the climate data to the households, climate for each district is computed and the identical values allocated to each household in a particular district. The soil data for the study is drawn from the Kenya Soil survey at the Kenya Agriculture Research Institute. The soil data represented the dominant soil in the district (see appendix for distribution of soil among the various districts). Soil data was linked to the households through the district the same way climate data is mapped to households.

CHAPTER FOUR

DATA ANALYSIS

4.1 Introduction

The chapter presented the results of the study. The descriptive results are first presented in section 4.2. This is followed by a discussion of the estimation issues in section 4.3, after which, the results of the model are presented in section 4.4. Marginal impacts are then presented in section 4.5. The predictions of global warming on Kenyan maize production are discussed in section 4.6.

4.2 Descriptive Statistics

Descriptive statistics are presented in table 4.1. The results indicate that the average net farm revenue per hectare[5] is Kshs.46, 030.49. The largest amount of net farm revenue per hectare is about Kshs 2,972,958 while the least is about Kshs. 64.97. The average years of education per household are 5.86 years. The descriptive results indicates that 88% of the households were male headed. The results also indicated that the average size of the households is about 6.67 persons per household.

The results also show that the average farm size per household is 5.082 hectare with largest recorded farm size being 204 acres and the least being 0.095 acres. The results also indicate that the average distance to extension services provider is about 5.39 kilometers with the largest distance reported being 62 kilometers with the least being zero kilometers. Only 9% of the households are found in districts where Ferrasols is the dominant soil type.

[5] Net farm revenue per hectare is the total gross revenue per hectare minus the variable costs per hectare

Table 4. 1 Descriptive Statistics

Variables	Mean	Standard deviation	Min	Max
Net Maize farm revenue per hectare (Ksh/Ha)	46,030.49	126,700.00	64.94	2,972,958.00
Size of the household (units)	6.67	2.90	1	21
Average years of education of household members (years)	5.86	2.37	0.17	15.50
Gender of the household Head (Male=1, Female=0)	0.88	. .32	-	1
Distance to the extension services (KM)	5.39	5.67	0	62.00
Soil type (Ferrasols=1, Others=0)	0.10	0.30	0	1
Farm size (hectares)	5.08	8.94	0.10	204.27
N	1288			

Source: Tegemeo Institute of Agricultural Policy and Development (2000)

Climate

The results indicate that the average temperature between March and May is 18.10^{0}C while between June and August is 17.67^{0}C. The average temperature between September and November is 18.53^{0}C. The district with the highest temperature is Kilifi district with 25.81^{0}C while Kisii district has the lowest temperature of about 15.72^{0}C.

The average precipitation for the months of March to May is 123.686 mm while for the months of June to August is 72.354 mm. The average precipitation between September and November is 78.74mm. The districts that receive the highest rainfall are Kisii, Kisumu and Siaya districts while Mwingi and Makueni receive the least rainfall.

Table 4. 2 Climate Descriptive Statistics

Variable name	Mean	Std. deviation	Min	Max
March –May Temperature (degree Celsius)	18.10	2.40	15.72	25.81
June-August Temperature (degree Celsius)	17.67	2.15	15.38	23.68
September-November Temperature (degree Celsius)	18.53	2.76	15.89	25.74
March-May Precipitation(mm)	123.69	33.34	78.53	166.49
June-August Precipitation (mm)	72.35	41.39	78.53	166.49
September- November Precipitation(mm)	78.74	27.74	29.88	106.96

Source: Satellite and ARTES Climate Data

4.3. Normality of Data

The 2000 Tegemeo household data set consisted of 1446 households of which 1357 grew maize. Normality tests are then undertaken to inspect if the variables were normally distributed. As shown in Table 4.3, some of the variables are normally distributed. The rule of the thumb about normal distribution of data is that the variables should have a kurtosis of below three and a skewness of zero.

Table 4. 3 Initial Normality Results

Variable name	Mean	Std. deviation	skewness	Kurtosis
Net farm revenue per hectare	46030.49	126700	13.05	250.45
Average years of education	5.86	2.64	.273	2.63*
Size of the household	6.671584	2.90	.49	3.57
Distance to the extension services	5.25	5.36	3.39	24.56
Gender of the Household head	.876	.330	-2.28	6.19
Soil type	.054	.23	3.93	16.46
Farm Size (hectares)	5.08	8.94	14.48	289.97
March-May temperature average	18.10	2.4	1.74	5.73
June-August temperature average	17.67	2.15	1.26	3.93
September-November temperature average	18.53	2.76	1.25	3.51
March-May average precipitation	123.67	33.34	.12	1.39*
June-August average precipitation	72.35	41.39	-.44	1.81*
September-November average precipitation	78.74	27.74	-.54	2.06*

Source: Authors computation

A log transformation was done to variables with the exception of gender of the household and soil type that weren't normally distributed to make them satisfy the normality assumption. However, this did not improve much the normality of these variables.

Table 4. 4 Normality Test Results after log Transformation

Variable name	Mean	Std. deviation	skewness	Kurtosis
Net farm revenue per hectare	4.27	.58	-.29	4.23
Size of the household	.77	.22	-1.03	4.36
Distance to the extension services	.51	.48	-.87	4.72
Farm Size (hectares)	.53	.38	.002	4.34
March-May temperature average	1.25	.053	1.44	4.74
June-August temperature average	1.24	.05	1.042	3.34
September-November temperature average	1.26	.06	1.06	3.03

Source: Authors computation

However, the most important basis for testing the normality assumption is through checking the distribution of the residuals. For OLS estimation to be used, the residuals must be normally distributed (Gujarati, 1995). Results in appendix I indicate that the residuals are normally distributed which implies that OLS may be used.

4.4 Model Results

Estimation Issues

The study considers the following estimation issues that may affect the regressions results.

A) Heteroscedasticity

This is dealt with by estimating White heteroscedasticity–consistent variances and standard errors. It is the most recommended way of dealing with heteroscedasticity (Gujarati, 1995).

B) Multicollinearity

Due to the quadratic nature of the climate variables a certain degree of, Multicollinearity is expected. It is expected that the squared climate values are highly correlated to the non squared values which introduces an element of Multicollinearity. Another element of Multicollinearity may exist between climatic values of different seasons. However, this study ensures that the extent of this problem is reduced as far as possible by dropping some of the troublesome variables and demeaning the climatic data (subtracting the mean from the data). According to Amiraslany (2010), demeaning reduces Multicollinearity among independent variables. The troublesome variables the study drops include the average temperature and precipitation between the months of September and November and the average temperature between the months of June and August.

The model results are presented in Table 4.5. Model 1 consists of climate variables only. Model 2 consists of climate variables and soil variables. Model 3 includes household characteristics in addition to climate and soil variables.

The results indicate that there exists a significant non-linear relationship between climate variables and net farm revenue per hectare as shown in the three models. According to the results, high temperatures between March and May have an adverse effect on net farm revenue. This may be due to the disruptive role high temperatures during that period may have on the formative growth of the maize crop (formative growth of the maize plant takes place between March and May). The results also indicate that the average temperature between March and May has an inverted U shaped relationship with net maize revenue per hectare. The positive squared term for March-May average temperature indicates that there is a minimum level of temperature during that period required for maize production and that more or less temperature during that period will increase net farm revenue per hectare.

The results also point out that high precipitation between March and May has a positive impact on net farm revenue while high precipitation between June and August has a negative impact. High precipitation during the months of March to May would have a positive impact on the formative growth of the maize crop while high precipitation between the months of June to August would disrupt the maturing and harvesting of the maize plant (Kabubo-Mariara and Karanja, 2007).

According to the results, the precipitation between June and August has an inverted U shaped relationship with net maize revenue per hectare while the average precipitation between March and May has a "U" shaped relationship with the same. The positive squared term for average precipitation between June and August indicates that there is a minimum level of precipitation during that period required for maize production and that more or less precipitation during that period will increase net farm revenue per hectare. The negative coefficient for squared term of the March-May average precipitation indicates that there is an optimal level of precipitation between March and May from which the net farm revenue per hectare will decrease if it increases or decreases (Mendelsohn et al., 1994). The findings with regard to precipitation and temperature agree with those in Kabubo-Mariara and Karanja (2007) and Deressa (2007) who found out that high temperature during the formative period of crops has a negative impact on net farm revenue per hectare while high precipitation has a positive impact.

Introducing the soil variable (Ferrasols) in model two increases the F statistic from 13.93 to 24.22 but increases the R squared statistic from 0.0521 to 0.0922. The soil variable (Ferrasols) has a negative and significant relationship with net maize revenue per hectare. This is in line with the author expectation that ferrasols soils are poor quality soils for maize production.

Results in model three indicate that, all household characteristics with the exception of distance to the extension services have a positive relationship with net farm revenue per hectare. However, only average years of education and farm size have a significant positive relationship with net maize revenue. This implies the higher farm sizes and education levels are associated with high productivity Distance to the extension services has a negative relationship implying that the further the farmer is from the extension service the lower the net farm revenue per hectare. However, the relationship is insignificant. The introduction of the household variables in the third model reduces the F statistic from 24.22 in the second model to 18.05 but improves the R squared to 0.1232.

Table 4. 5 Estimated Results Per Net Farm Revenue Per Hectare

VARIABLES	MODEL ONE	MODEL TWO	MODEL THREE
Constant	4.37	4.52	4.12
March-May temperature	-0.12 *(0.000)	-0.12 *(0.000)	-0.11.* (0.000)
March-May temperature squared	0.011 *(0.001)	0.008.* (0.019)	0.008 * (0.032)
March-May Precipitation	0.003 (0.383)	0.004.(0.264)	0.005 * (0.166)
March-May precipitation squared	-0.0003 *(0.002)	-0.0003 *(0.000)	-0.0004*(0.000)
June-August precipitation	-0.005 *(0.040)	-0.006.*(0.050)	-0.007* (0.004)
June-August precipitation squared	0.0001145*(0.000)	0.0000989.*(0.002)	0.0000916 *(0.003)
Soil type (Ferrasols)		-0.57. *(0.000)	-0.58 * (0.000)
Gender of the household Head			0.097 (0.062)
Size of the household			0.14 (0.070)
Average years of education of the household squared			0.23 *(0.000)
farm size			0.11 (0.010)
Distance to the Extension services			-0.006 (0.892)
Number of Observations	1288	1288	1288
R squared	0.0521	0.0922	0.1232
F statistic	13.93 * (0.000)	24.22 * (0.000)	18.05 *(0.000)

* Significant at 5%,

( ) parenthesis represents the P values

4.5 Marginal Elasticity

The relationship between climate variables and net farm revenue per hectare is further investigated using elasticity analysis. Elasticities are calculated at the mean so as to assess the relative change in net farm revenue per hectare associated with a unit change in temperature and precipitation (Gbetibouo and Hassan, 2005) .

According to the results presented in Table 4.6, increasing temperatures between March and May from the current levels would reduce net farm revenue by 43% while increasing precipitation between March and May from the current levels would increase net farm revenue by 13%. An increase in precipitation from the current levels between June and August would reduce net farm revenue by 12%. The results also indicate that net farm revenue is more sensitive to changes in temperature than changes in precipitation.

Table 4. 6 Estimates of Elasticities to Climatic Factors

	Temperature	Precipitation
March-May	-0.43	0.13
June –August		-0.12

4.6 Predicting the Future Impacts

In this section, the study simulates the expected future impact of climate change on maize production using two climate change scenarios namely Uniform Change Scenario where the study assumes that temperature and precipitation levels shall change uniformly across the country and climate change scenarios produced by the Atmosphere–Ocean Global circulation models (AOGCM). Regression results from model three in column four of table 4.5 are used to analyze the future impact of climate change. To get the impact of future climate change, temperature and precipitation are adjusted to the different climate scenarios. The difference between the old and the new climate variables is then plugged in the regression result from column 4 of table 4.5 so as to calculate the change in net farm revenue. Future Climate change impacts are calculated at the average net farm revenue.

Uniform Change Scenario

Results for impact of climate change under uniform change scenario are presented in table 4.5. Uniform change assumes that only one climate variable changes and such change is uniform across the region. The uniform scenario changes are an increase in temperature by 2 ^{0}C and 5 ^{0}C and a decrease in precipitation by 10% and 20%.

Table 4. 7 Uniform Scenario Impacts

	% Change in mean net maize revenue	Change in mean net maize revenue (in units)
2.^{0}C Increase in temperature	(0.4)	(0.188)
5 ^{0}C increase in temperature	(0.74)	(0.35)
10% decrease in precipitation	*(1.58)*	(0.07)
20% decrease in precipitation	*(5.8)*	(0.25)

The results in table 4.7 indicate that increasing temperature by 2.^{0}C and 5 ^{0}C and decreasing precipitation by 10% and 20% has a marginal adverse impact on net farm revenue per hectare. These results agree with results by Kabubo-Mariara and Karanja (2007) and Deressa (2007) who found that increasing temperature and decreasing precipitation would have an adverse on crop agriculture in Kenya and Ethiopia respectively.

Global Circulation Models Scenarios

The results of the simulated impacts on maize production using climate scenarios derived from Ocean Global circulation models (AOGCM) are presented in table 4.10. According to the results, net farm revenue per hectare will decline in all global circulation model scenarios. ECHAM global circulation model scenario indicates the most adverse future for maize production in Kenya while CGCM2 paints the least. Overall, climate change will have a negative impact on maize production by the year 2100.

These results are in line with other results by Kabara (2009), Deressa (2007), Kurukulasuriya and Mendelsohn (2008), Kabubo-Mariara (2009) and Kabubo-Mariara and Karanja (2007) who found that agriculture production would reduce by the year 2100.

Table 4. 8 Forecasted Impacts for the year 2100

	CGCM2	CSIRO2	ECHAM	HADCM3	PCM
A2- Scenarios (%)	-11.77	-14.91	-23.21	-15.21	-11.03
Change in net maize revenue(units)	-0.50	-0.64	-0.99	-0.65	-0.47
B2- Scenarios (%) change	-8.80	-9.62	-18.47	-11.37	-8.14
Change in net maize revenue (units)	-0.38	-0.41	-0.79	-0.49	-0.35

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

5.1 Summary and Conclusions

This study analyzed the impact of climate change on maize production in Kenya using a Ricardian model. The data for this study was based on a sample of 1357 households. The data was sourced from Tegemeo Institute of Agricultural Policy and Development. The temperature data that was used in the study was from Satellite climate data while precipitation data was from ARTES (African Rainfall and Evaluation System). Soil data was sourced from the Kenya soil survey conducted by the Kenya Agricultural Research Institute.

The general objective of the study was to conduct an assessment of the potential impact of climate change on maize production in Kenya. Another objective was to simulate future impacts of climate change on maize production in Kenya and make recommendations for strategies that could be adopted to mitigate the impact of climate change on maize production. Five Global Circulation Models were used to produce ten scenarios that were used to analyze the impact of climate change on maize production in Kenya by the year 2100.

The regressions results suggest that climate has a significant impact on maize production. Increase in March-May temperature and June –August precipitation was found to have an adverse impact on maize production while increase in March-May precipitation was found to have a positive impact. The results are in line with findings by Kabubo-Mariara and Karanja (2007), Kabara (2009) and Kabubo-Mariara (2009) who found out that climate change will have an adverse impact on agriculture in Kenya. The study found out that temperature has a bigger impact on maize production as compared to precipitation .This is evidenced by the elasticity of temperature and precipitation. This result supports findings by Kabubo-Mariara and Karanja (2007) and Kabara (2009) who found a larger elasticity for temperature than for precipitation indicating that agriculture in Kenya is more sensitize to temperature than precipitation.

Simulations from the climate scenarios indicate that maize production could fall by up to 23% by the year 2100. ECHAM scenario paints the bleakest picture, predicting that maize production could fall by 23% by the year 2100. Overall, all scenarios indicate a decrease in maize production by the year 2100. These results are in line with expectation that climate change will negatively affect agricultural production in Africa.

5.2 Policy Implications and Recommendations

The results indicate that overall climate change will have an adverse effect on maize production in Kenya and hence may also have an adverse effect on food security. This is noted because of the close relationship between maize availability and food security as maize is the country principal food crop. Therefore, policy efforts should be directed at addressing the impact of climate change on maize production.

One critical policy intervention would be raising awareness among maize farmers on climate change by providing climate change related information. It is estimated that only about 50% of farmers in Africa (including Kenya) are aware of climate change and its impact on agriculture. Increasing awareness would require that the government actively monitors climate change, encourages research into climate change and sets up information dissemination channels to farmers (Kabubo-Mariara, 2009).

Another policy intervention would be raising the country's forest cover. Through the carbon cycle, forests help reduce the amount of carbon in the atmosphere, a gas that is the primarily driver of climate change. The government should ensure forests are protected from destruction and that it implements it policy of planting more than a billion trees by the year 2030. Communities living around forests should be made aware of the need to protect forests and use forest resources sustainable.

Kenya is fresh water scarce country and climate change is expected to further reduce the availability of fresh water in the country. Given this, there is a need for proper management of the few fresh water resources available. The government should construct water pans and dams, protect water towers and encourage rainfall harvesting. In addition, the government should construct water recycling facilities and raising awareness on the need to use water sustainable.

Irrigation is another policy option that could be considered to mitigate the impact of climate change. Maize production is largely dependent on rainfall and a paradigm shift from rain fed to irrigation based maize production may not only increase production but make it resilient to climate change. Finally, effective dissemination of climate related information to maize farmers should be urgently undertaken. Farmers should be informed on climate change and its likely impacts on maize production. This requires that government sets up effective extension service programs (Gbetibouo and Hassan, 2005).

5.3 Limitations of the Study and Areas of Further Research

Although this study makes a contribution to literature on the impact of climate change in Kenya, the study has some limitations. First, the data used in the study did not include information on farmer's perceptions of climate change and what adaptation measures they are taking up. This information would have facilitated the analysis and modeling of the impacts of climate change on maize production in Kenya with and without adaptations and compare the difference. The study recommends that future studies on impact of climate change on agriculture should take into consideration the adaptation measures of farmers. Another limitation of the study is that the study uses data for one time period. As Kabubo-Mariara and Karanja (2007) argue, a better analysis of the full impact of climate change on maize production can be achieved using time series information. This study therefore recommends that future studies use time series data or panel data when assessing the impact of climate change on maize production.

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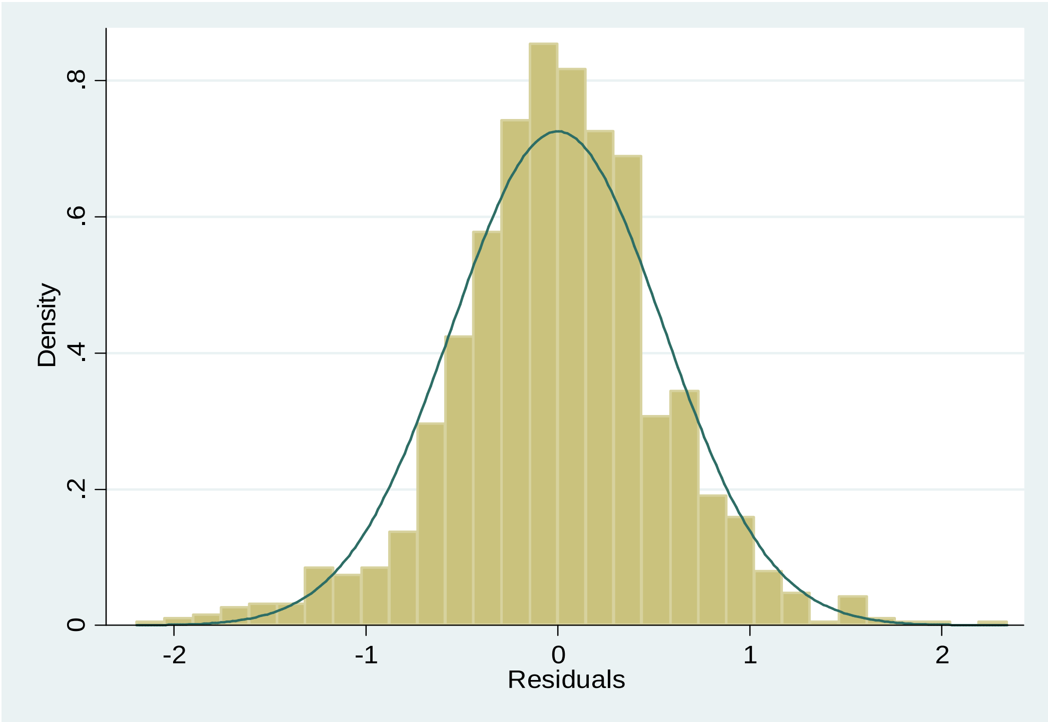
Appendix I: Normality of Residuals



Appendix II: Distribution of Households

Province	District	Households	Agro-ecological zone	Soil type
Central	Murang'a	72	UM0-1 - Upper midland 0-1 UM2-6 - Upper midland 2-6	Nitisols
	Nyeri	102	LH-Lower Highland UM2-6 - Upper midland 2-6	Nitisols
Coast	Kilifi	54	CL- Coastal Lowland	Luvisols
	Kwale	25	CL- Coastal Lowlands	Luvisols
	Taita Taveta		CL- Coastal Lowlands	Ferralsols
Eastern	Kitui	19	LM3-6 - Lower midland 3-6	Ferralsols
	Machakos	22	LM3-6 - Lower midland 3-6	Acrisols
	Makueni	75	LM3-6 - Lower midland 3-6	Luvisols
	Meru	85	UM0-1 - Upper midland 0-1	Nitisols
	Mwingi	34	LM3-6 - Lower midland 3-6	Acrisols
Nyanza	Kisii	91	UM0-1 - Upper midland 0-1	Nitisols
	Kisumu	103	LM3-6 - Lower midland 3-6	Cambisols
	Siaya	74	LM3-6 - Lower midland 3-6	Acrisols
Rift Valley	Bomet	41	LH - Lower highland	Nitisols
	Laikipia	54	L - Lowland	Phaeozems
	Nakuru	108	LH - Lower highland UM2-6 - Upper midland 2-6	Andosols
	Narok	25	LH - Lower highland	Cambisols
	Trans Nzoia	61	UM2-6 - Upper midland 2-6	Gleysols