EFFECT OF CLIMATE VARIABILITY ON CROP DIVERSITY AND HOUSEHOLD NUTRITION IN KENYA

MERCY TAABU MUMO

X50/85538/2016

A RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ARTS IN ECONOMICS TO THE SCHOOL OF ECONOMICS,

UNIVERSITY OF NAIROBI

2020

DECLARATION

I declare that this is my original work and has not been submitted for the award of a degree in any other university or institution.

MERCY TAABU MUMO

SIGNATURE ………………………………. DATE ……………………………………….

This project is submitted for the award of the degree of Master of Arts in Economics with our approval as university supervisors.

PROF. RICHARD MULWA

SIGNATURE ………………………………. DATE …………17th Nov. 2020….

DEDICATION

I dedicate my work to my family and many friends. A special feeling of gratitude goes to my loving parents, Mumo Mueke and Edith Mwende Kiema whose words of encouragement let to the completion of my research paper.

ACKNOWLEDGMENTS

A special thanks to Professor Richard Mulwa for his countless hours of reading, encouraging, and most of all readiness to offer feedback which made the completion of this research an enjoyable experience. I would like to thank the school of Economics for allowing me to conduct my research and providing any assistance requested. Finally, special thanks go to the staff members of Environment for Development (EfD) Kenya that assisted me with this project.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Agriculture is one of the leading sectors in the Kenyan economy and central to the country's development strategy. The sector hires over 40 percent of the total Kenyan population, contributes to a quarter of the country's GDP, and provides nutrition to a larger proportion of the population. However, the agriculture sector in the country has suffered due to frequent droughts, floods, and climate variability. Climate variability, have in part, contributed to poor nutritional status and severe food insecurity problems. Based on the foregoing, this paper aimed to examine the effects of climate variability on the household nutrition situation as well as crop diversity. Household nutrition status was proxied by the production of kilocalories (Kcal) while the Ogive index was used to calculate crop diversity. The study used the 2010 Tegemeo dataset and employed the OLS estimation technique to achieve the study objectives. Results showed that climate variables (temperature and rainfall) had varied and mixed effects on household nutrition status. Increase in temperature during the spring season (March-May) and precipitation in the fall season (September-November) significantly reduced production of kilocalories. Despite this, rainfall in the spring season had an enhancing effect on the production of kilocalories. The effect of other variables on Kcal is mixed, as increase in farm labour and the amount spent on both fertilizer and seeds increased production of kilocalories. Results on the second objective similarly showed a mixed effect of climate variables on crop diversity in Kenya. More specifically, increase in temperatures during both winter (December-February) and spring seasons had a reducing effect on crop diversity while rising temperatures in the summer season (June-August) have an enhancing effect on crop diversity. Findings on the other control variables showed that increase in household head level of schooling, as well as age, increased crop diversity. Taken together, these results demonstrated that climate influences both household nutrition status and crop diversity differently depending on the season of the year. This finding implies that policymakers should implement adaptation strategies and interventions to cushion small-scale farmers from the adverse effects of climate variability on household nutrition status and crop diversity.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Over the years, agriculture has been a critical foundation of both social and economic progress for both developed and developing countries. According to FAO (2013), an approximately 2.5 billion people globally who live in rural localities obtain their economic living from agriculture. In Sub-Saharan Africa (SSA), agriculture hires 62% of the population (Livingstone et al., 2011) contributes to 90% of all production in some economies, 80% of all these coming from smallholder farms (Wiggins, 2009). According to Barrios et al. (2008), agricultural sector in SSA countries is a key contributor to the growth of economies. It contributes to approximately 40% of the real GDP and hires over half of the total labour force.

In Kenya, agriculture is among the major sectors in the Kenyan economy and significantly contributes to the country's GDP, employment levels, nutrition and food security, and foreign exchange earnings. In particular, the KNBS (2018) estimates that agriculture alone accounts for 25.5 percent of Kenya's GDP and 27 percent via important inter-interdependence with other sectors. The sector hires over 40 percent of the entire population and more than 70 percent of those living in rural areas. The sector accounts for over 65 percent of incomes from exports, providing nutrition to more than 80 percent of the population (FAO, 2018).

However, despite the positive contribution of agriculture to economic development, climate change is among the foremost bottlenecks in agricultural production (Kang et. al., 2009). The Intergovernmental Panel on Climate Change (IPCC) (2007) serves that many countries, especially in SSA, will continue to be faced with rising average temperature, regular heatwaves, declining water resources, desertification, and durations of heavy and unpredictable rainfall. The UNEP (2009) also notes that there has been an increase in temperatures globally, warming seas, changing rainfall patterns as well as occurrences of the melting icecaps across the world and that if this is not well managed, it will contribute to a rise in global average temperatures from 1.4^{o}celsius to 6.4^{o}celsius by the year 2100.

Evidence indicates that climate changes have reduced water resources, hydropower, human health, food security and nutrition, employment particularly in African countries. According to Sylla et al., (2016) it is estimated that African economies will continue to experience adverse climatic change and that the effects of the climate variability will be dire especially for agricultural sectors across Africa, due to the reliance on rain-fed agriculture and the increased drying and warming in most sub-tropical regions. Zake and Hauser (2014), in particular, argue that an estimated 95 percent of the agricultural production in SSA solely relies on rainfall, thereby jeopardizing economies of the region due to the high variability of precipitation in Africa. According to Schlenker and Lobell (2010), climate change variability in African has a high likelihood of resulting in the reduction in yields of critical staple crops in the range of 8 and 22 percent by the year ending 2050 if critical investments are no made to enhance the productivity of the agricultural sector. Due to the adverse effect of climate change on calorie production and nutrition, agricultural households have adopted several interventions to mitigate the impact of climate change, including crop diversification. According to FAO (2012), crop diversification relates to the addition of new crops aiming to increase crop diversity through, crop rotation, intercropping, or multiple cropping. In economic literature, crop diversity is measured by the Ogive index which shows the presence and abundance of different crop species under a given cultivation area.

In Kenya, variations in the nature and patterns of rainfall have been recorded in recent years. Evidence shows that greater rainfall has been recorded in the periods of the short rainfall season of October to December. However, the long rainfall of the period of March to April has become progressively undependable (Parry et al., 2012). According to Mutimba (2010), there has been an increase in temperature in Kenya from approximately 0.7–2.0 degrees Celsius during the last 40 years together with uneven and irregular rainfall patterns, which has not only affected crop productivity but also increased water shortage together with deprivation of lakes and water catchment areas. The decline in the crop productivity in the country has in part contributed to poor household nutritional status and food insecurity.

Notwithstanding the acknowledgment of how climate variability affects crop production, especially household nutrition production, little research has been undertaken in Kenya to empirically analyse the effect of climate variability on household nutritional status. In Kenya, except for the studies by Kabubo-Mariara et al. (2016) on the effects of climate change on the production of food calories and nutritional status in Kenya and that by Kabubo-Mariara and Kabara (2015) on the role of changing climate on food security in Kenya, most studies on this subject have delved into looking at the effects of changing climate on the household revenue from agriculture. As such this study, seeks to add evidence on this subject by delving into the linkage between climate change variability and household nutritional status in Kenya.

1.2 Statement of the Problem

Agriculture is one of the critical sectors of the Kenyan economy and central to the country's development strategy. The sector accounts for an estimated 25.5 percent of Kenya's GDP, hires over 40 percent of the total Kenyan population, and more than 70 percent of those living in rural areas. The sector accounts for over 65 percent of incomes from exports, providing nutrition to over 80 percent of the population. However, Kenya's agricultural productivity has suffered from frequent droughts, floods, and climate variability. The declining agricultural productivity in the country, attributed in part to the climate variability, frequent droughts, and floods has contributed to poor nutritional status and severe food insecurity problems. In particular, it is estimated that each year, an estimated 2-4 million Kenyans need external food aid. The 2015/16 KHIBS indicates that at the national level, an estimated 29.9 percent of under-five children are moderately stunted with the higher proportion of them being in rural areas. Similarly, the 2014 Kenya Demographic Health Survey (KDHS), an estimated 26 percent of the children below five years are stunted with an estimated 8 percent of them being severely stunted. To overcome this effect, agricultural households have adopted crop diversification as an adaptation approach to spread the risk from crop failure and curb the declining nutritional status. Hitherto, however, the impact of climate variability on crop diversity and household food nutrition, as proxied by production of kilocalories in this study is not well understood. This study, therefore, sought to examine the effects of variability of climate on crop diversity and household nutritional status and crop diversity in Kenya.

1.3 Research Questions

i. What is the effect of climate variability on crop diversity in Kenya?

ii. What is the effect of climate variability on household nutritional status in Kenya?

iii. What policy insights and recommendations can be drawn from the study findings?

1.4 Research Objectives

The main objective of this study is to investigate the effect of climate variability on crop diversity and household nutritional status in Kenya. Specifically, the study aims to:

i. To determine the effect of rainfall and temperature variability on household nutritional status in Kenya
ii. To establish the effects of rainfall and temperature variability on crop diversity in Kenya
iii. To draw policy insights and recommendations on agricultural household adaptation measures to climate variability

1.5 The Significance of the Study

The outcome of this paper is expected to inform to several stakeholders including farmers, Kenya Meteorological Services, Ministry of Agriculture, policymakers, and general public. Farmers will mostly benefit from the study findings as they will be equipped with first-hand knowledge and evidence on the linkage between climate variability and the agricultural output and by extension their nutritional status. The management of the Kenya Meteorological Services, and policymakers benefit from this study because they will be informed on how climate variability affects the agricultural output. Policymakers will be empowered to adequately make policies for creating awareness on changing atmospheric conditions and come with the most proficient methods to adjust farming activities during atmosphere inconstancy.

Secondly, this study tries to take the discussion further and examine the effects of climate variability on household nutritional status. Examining this relationship is particularly important because numerous studies on this subject have focused on agricultural productivity and not directly examining elements on nutrition and food security. In Kenya, except for the 2015 and 2016 studies Kabubo-Mariara, Mulwa, and DiFalco, numerous papers have focused on the impact of changing climate on agricultural productivity and agricultural revenue (see for example Mariara, Ochieng et al., 2016).

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter reviews pertinent literature on climatic change variability, crop diversification, and household nutritional status in Kenya. The chapter starts with the examination of theoretical literature on the theories linking changes in climate to agriculture production and household nutrition. The empirical literature section reviews past studies on the research topic and an overview of the literature will close the chapter.

2.2 Theoretical Literature Review

2.2.1 The Ricardian Approach

Mendelsohn, Nordhaus, and Shaw (1994) developed the Ricardian methodology to examine the sensitivity of agricultural productivity to climate change. The Ricardian approach, named after one of the most influential classical economists, David Ricardo, uses the arguments of the Ricardian theory that provides that rents paid to the land would be a good reflector of the net productivity of farms under perfect completion. Mendelsohn applied the Ricardian approach et al. (1994) to estimate the effect of changes in climate on agricultural productivity in the USA. The model looked at the effects of climatic change on different yields of varying crops by examining how the climate in different parts influences agricultural revenue. The authors observed that by looking at the effect of climatic conditions like rainfall and temperature on agricultural productivity of the farmland, the methodology allows the inclusion of the farmers' adaptations to variability in climate.

Ricardian approach forms one of the cross-sectional models relying on the production function model that provides the response of farmers and crops to changing climatic conditions as observations of agricultural output is used in various agro-climatic areas (Mendelsohn et. al., 1992). Recently, the model has gained popularity over other models such as the production function. This is due to its ability to take into to factor in farmers' adaptation responses as well as its cost-effectiveness. The model can also rely on secondary data and does not require extensive experimentation which is costly (Duress, 2007).

Despite its nobility, the Ricardian model has several limitations. For instance, its failure to integrate the transition costs that a farmer may put up with due to the practice of moving from different adaptation options to others due to variations in climatic conditions. This can occur when farmers introduce new crops as a result of changing climatic patterns in each region. The methodology assumes that the costs incurred with new crops will be covered by the farmers. However, if those new crops fail and the farmers introduce other crops, the model fails to include the costs linked with shifting to new crops. Duress (2007) observed that the transitioning expenses tend to be high particularly in agricultural sectors characterized by extensive costs that are hard to change.

Moreover, the model does not adequately determine the effect of variables that do not differ across space. As an example, the impact of the levels of Carbon IV Oxide, on average, tend to be the same globally. The model is also affected by aggregation bias. The model also has a weakness in fully controlling for the contributions of non-climatic factors which would explain the variability in land values or agricultural yields (Fezzi, 2010).

2.2.2 Profit Maximization Theory

This theory asserts that the motive of every firm or business is to maximize profits. However, making a profit is subject to constraints that a firm must factor in. Firms endeavor to make the largest amount of profits bearing the costs of production. The cost of production may include costs of factors of production like labor and machinery and the costs of farm inputs like fertilizers. Other constraints include technology and market (Kariuki, 2016). Profit maximization entails the process of producing the maximum level of outputs subject to the budget constraints arising from the use of production inputs. In this approach, it is assumed that markets are competitive, which is the case for a cost-minimization approach. For a firm to make maximum profits, the output should be chosen where the marginal revenue is equated to the marginal cost.

In the market situation where firms and producers are price takers, then the firms must consider what levels of output maximize output, optimizes the inputs, and minimizes the cost of production. Hence, a firm must have the minimum combinations that maximize the profits and minimize the costs, all other factors constant (Abdulai et. al., 2017).

The approach could also be employed in the realms of the output of maize, coffee, tea, and potatoes. This would entail looking at the output of each of the individual outputs and how variations in climate affect their production. This theory would be plausible when an assumption is made, that optimization has been achieved. Furthermore, it is assumed that farmers aim at maximizing profits in the absence of risk and uncertainty. It also assumes that inputs and outputs change simultaneously.

This instantaneous change in both inputs and outputs may not always be possible due to factors such as time differences between planting and harvesting, changes in technology, institutional factors that impede farmers' decisions to produce, market asymmetries in information, dynamism in technical rules of the production function in the process of production, and the fact that producers could be farming to ensure they are food secure and not necessary for the maximization of profits (Mendola, 2007).

Climate change is a big threat to farmers who are solely focused on profits. The variations in temperature and rainfall greatly affect agricultural output. In dry periods, agricultural production decline, and profits to farmers are in jeopardy. In such spells, farmers maybe just focused on maximizing their utility and not necessarily profits. In a nutshell, this theory could be applied in assessing agricultural production subject to climate change, with some limitations, highlighted above.

2.2.3 Utility Maximization Theory

Utility is the ability of a good or service to satisfy human wants. This has evolved many utility theories that focus on explaining the utility derived by a consumer from a space of many consumption bundles. Approach for the utility maximization brings together the dual concept of the agricultural households as both consumption units and businesses.

Each consumer engages in economic activity to make profits. Not always that profit will always be the main goal. Some firms or households may engage in economic activities like agriculture as a hobby or to satisfy a certain need, based on the benefits derived. In this case, utility becomes the object against which they seek gratification. The household's goal is to maximize utility from consumption of commodities. Those commodities could be produced from farms like potatoes, coffee, tea, rice, etc. Bearing in mind that the sale of these can earn profits, then a model that would merge utility and profits would suffice. This would mean that maximization of utility would be subject to the costs expended on these goods. The maximum utility would thus be achieved when changes in utility do not elicit high costs.

Picking individual households in Kenya, it would be easier to characterize agricultural production in Kenya. They devote their labor and inputs to produce agricultural goods that they can individually consume or sell. Production of these is subject to climatic variations, and hence at no time, will there be constancy in utility gained profits. This theory is feasible to explain the agricultural output variation caused by climate change but it's best applicable when consumers and producers are rational, have clearly stated preferences, and every output has a price tag.

2.2.4 The Production Function Approach

The production function theory was developed by Hans in the years 1968. The theory avers the association between quantities of the observable produced output and the quantities of observable inputs (Heathfield, 1971). The approach is grounded on the production functions that incorporate environmental variables, for example, rainfall or temperature as factor inputs (Deressa, 2007).

The production function model may also be employed in analyzing the effect of climate variability on agriculture output. This is because environmental factors like rainfall/precipitation, temperature, and concentration of carbon dioxide can be integrated into the production function to establish the effect of climate variability on agricultural output. Changes in crop production will then be incorporated into economic models to estimate the changes in welfare due to changes in climatic factors.

Although the production function model is widely used and effective in assessing the role of climate variability on agricultural output, it, however, has several limitations. These include ranges, first the inadequacies in incorporating adaptation strategies used by farmers resulting in climate change/variability. Second, the production function approach tends to be costly because of the controlled trials needed although this might not be seen when farmers act to the varying climatic conditions.

This study may also employ this theory because it provides evidence of the role of climate that is unbiased since it is possible to control for the other determinants of agricultural production (Deschenes and Greenstone, 2006). Additionally, due to the potential benefits of the adoption of controlled experimentation, this approach is known for yielding better results of the impact of climate change on agricultural production.

2.3 Empirical Literature Review

The earliest study on climate change and agriculture was conducted in the USA by Mendelsohn et al. (1994). The authors measured the impact of climate on land prices using the Ricardian approach. They preferred this approach because county-level data was readily available and the determination of how changes in climate conditions would affect production. Furthermore, the approach can factor in changes in precipitation, temperature, and carbon dioxide concentration as climatic variables. A cross-sectionally design survey was adopted by the authors where data on climate, farm prices, and other variables were collected in 3000 counties in the USA. Using a linear regression model, they found that temperature, carbon dioxide concentration, and precipitation highly determined corn and wheat output.

In Sri-Lanka, Seo et al. (2005) investigated the impacts of climate variation on agricultural sector output by applying the Ricardian method. The study focused on temperature and precipitation what effects they had on net income from coconut, rubber, rice and tea. The paper established that precipitation is useful to produce all the crops under examination. The temperature was shown to be damaging with an associated loss of 18-50% of income from the crops. The study by Naylor et al. (2007) in Indonesia also examined the risks of variability in climate to produce Indonesian rice in Java and Bali regions. The authors adopted the least-squares regression approaches to link agricultural production variables to observed rainfall from 1979 to 2004. The results showed that increased precipitation escalated rice production output while reduced precipitation reduced rice production. The researchers suggested the need for adapting rice production for climate change in Indonesia if food security by 2050 is a goal to go by. They suggested adaptation measures such as investing in water storage, growing drought-resistant crops, diversifying crop growing, and investing in early warning systems.

In examining the climate change adaptation strategies and its effects on food security in Pakistan, Ali and Erenstein (2017) adopted a probit model in their study. The study focused on three key adaptation strategies; altering the sowing time, growing drought-tolerant crops, and moving to new crops. These adaptation methods were more salient to young and educated farmers as well as wealthy farmers. The study found farmers who adapted had up to 13% chances of being food secure but those who did not have a 6% chance of being poor and food insecure. This study underscored the fact that climate change adaptation practices help farmers reduce their exposure to weather risks.

In the African countries, the study by Kurukulasuriya *et al*., (2006) analyzed the economic effects of temperature and rainfall on agriculture by examining data collected for more than 9,000 farmers in 11 African economies, found that livestock is highly susceptible to increasing temperature as compared to crops. In particular, the study found that increases in rainfall were found to have a beneficial effect on African farming, while reduced rainfall levels had harmful effects. Their study emphasized the need for investing in the development of rural agricultural strategies to support farmers in adapting to climatic changes for long-term growth.

In Kenya, Lagat and Nyangena (2018) examined the effects of climate variability on net revenue from livestock production. Their sample included 1871 livestock farming households in Kenya. They use a regression analysis model where socio-economic and climate variables were assessed based on their effect on net livestock revenues. The researchers found that temperature and precipitation greatly and negatively affect livestock revenues in Kenya. Their study proposed the need for escalated use of extension services to ensure that farmers are informed of the effects of climate change. Similarly, Brain et. al., (2013) evaluated household strategies and determinants that would help adapt agriculture to climate change using farm household data collected from 7 districts and across ecological zones in Kenya. By examining farmers' perceptions of climate change, the paper established that Kenyan farmers face substantial bottlenecking adapting to climate change and this hampers their agricultural productivity while threatening the country's food security.

In yet another study by Kariuki (2016) investigated the effects of climatic variability on output and yields of coffee, tea and maize. The author considered precipitation and temperature as two climatic variables that affect agricultural production in Kenya. Using secondary data from the meteorological department and Food and Agriculture Organization Statistics (FAOSTAT) for the period 1970-2014, the author used a time series approach using autoregressive-Distributed Lag (ARDL) to be able to run a Cobb-Douglas production function while assuming a utility maximization model. The results indicated the absence of linear linkage between rainfall and temperature. Overall, the results established an adverse effect of variability effect of temperature on both the yield and output levels. The study proposed the use of irrigation to grow crops other than depending on rain and the need for government to help the agricultural sector in mitigating and adapting to climatic change variations.

In Kenya, a number of studies link climate variability and agricultural revenue in Kenya. For instance, Ochieng et al. (2016) also examined the effects of variability of climate on the total agricultural revenue and revenues from tea and maize from small-scale agricultural producers. The study found that climate variability had differential effects on agricultural production since it can raise or decrease crop revenues. In particular, the paper established that temperature rises have reducing effects on agricultural household crop and revenue from maize but have an enhancing effect on revenue from tea. In further analyzing the effects of temperature on the crop, maize, and tea revenue, the study found that temperature has long-term than short-term effects on agricultural production. Concerning the effects of rainfall variability on agricultural production, the study found that rainfall had revenue-enhancing effects on crop and maize but a reducing effect on the maize revenues. The study used a fixed-effects model applied to Tegemeo CIMMYT data merged with climate data obtained from Kenya Meteorological Services (KMS). Ochieng et al., (2016) used the Ricardian framework in their analysis.

In yet another study on the effects of variability of climate on crop revenue, Kabubo-Mariara and Karanja (2007) examined the effects of climate change on net crop revenue per acre using a Ricardian framework. The study established that a rise in winter temperatures and precipitation improved revenues obtained from the crops. The paper used both climate and agricultural household data and which was gotten from US Department of State and Africa Rainfall and Temperature Evaluation System.

Regarding studies linking climate variability and household nutrition levels, the study by Kabubo-Mariara, Mulwa, and DiFalco (2016) examined the effects of climate change on the production of food calorie and nutritional status in Kenya. The study found that increased moisture increases household calorie production but too much of the moisture tends to reduce calorie production. The study used panel data estimation techniques on the Tegemeo Institute data for the years, 2004, 2007, and 2010. On climate change and nutrition, Kabubo-Mariara, Mulwa, and DiFalco (2015) examined the effects of climate change on household nutrition in Kenya. The authors estimated household nutrition levels using kilocalories produced by the household from main crops that include maize, beans, sorghum, millet, wheat, and banana. The study established that climate change adaptation rises the production of household nutrition and that adapting households produced more calories than those who did not adapt to climate change. In particular, the study found that those farmers who adapted to climate variability produced 740, 625 kilocalories more than those who failed to adapt.

In a slightly similar study, Kabubo-Mariara and Kaberia (2015), used the county-level data running from 1975 to 2012 to examine the effects of climate change on food security in Kenya. In this study, food security was proxied by crop productivity measured as crop yields i.e. production per acre. The paper found that climate variability affects food security in Kenya. Kabubo-Mariara and Kaberia (2015) established that variability in climate increases food insecurity particularly on maize and sorghum crops and while yields from millet and beans tend to be unresponsive to changes in climate.

2.4 Chapter Summary

From the reviewed empirical literature, it is evident that climatic change affects farmers and household's nutritional levels. The studies indicate that there's a need for economies need to adopt interventions to fight the side-effects of the variability of climate on production and nutrition. Such practices include seasonal sowing, planting drought-resistant crops, investing in irrigation schemes, and diversifying agriculture. This will ensure that no matter the prevailing climatic conditions, variation in agricultural output will be within check. The literature also highlights that precipitation and temperature are key climatic conditions that researchers have used in this subject. Concerning nutrition, the reviewed literature suggests that kilocalories produced from key crops such as maize, beans, wheat, sorghum, and bananas can be used as an appropriate proxy for nutrition as well as agricultural productivity (See for example; Kabubo-Mariara, Mulwa and Di Franco, 2016). In this study, we will, therefore, use rainfall and temperature variables as proxies for climate change and kilocalories produced from maize, beans, wheat, sorghum, and bananas as proxies for household nutrition, in establishing the evidence of the effects of changing climate on household nutrition in Kenya.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Overview

This chapter gives a description of the research design and methodologies that as employed in this paper. It highlights the theoretical framework, an empirical model to be used for estimation, data types, and diagnostic tests.

3.2 Theoretical Framework

The theoretical modeling of this study slightly modifies the approach by Greenstone and Deschenes (2006). According to Greenstone and Deschenes (2006), the production function framework is adopted on this subject because it tends to provide a more straightforward and direct measure of a given variation in rainfall or temperature on agricultural productivity and allowing for the estimating of the effects of weather on agricultural productivity of a specific crop that are affected by biases that are beyond producers control and ability, for instance, soil quality. The Greenstone and Deschenes (2006) model, therefore, take the form:

$$y_i = A\left(\prod_{i=1}^{n} \boldsymbol{x}_i^{\alpha_i}\right)\boldsymbol{z}_i^{\alpha_i} \qquad (1)$$

Where y_i is land's value of farmer i, $\boldsymbol{x}_i$ is a vector of observable farm factors of production such as farm size, capital, land and, labour; $\boldsymbol{z}_i$ is a set of climate change variables that in our study it includes temperature and rainfall. We can now parameterize equation (1) to obtain:

$$y_i = f\left(Ak_i^{\alpha_i}, l_i^{\alpha_i}, h_i^{\alpha_i}, t_i^{\alpha_i}, r_i^{\alpha_i}\right) \qquad (2)$$

Where A captures the effects of technological progress as well as policy-relevant factors, y_i relating to the farmers' maize revenue, k_i is the capital employed by farm i, l_i denotes the farm size under maize cultivation. In this study, we restrict our analysis to small-scale production since farmers who produce for household nutrition are subsistence. The variable h_i denotes human capital, t_i is the temperature, r_i is the rainfall and α_s stands for the parameters to be estimated.

3.3 Empirical Model

Since our study focuses on the effects of climate variability on household nutritional status, we slightly modify the dependent variable from agricultural profits to household's kilocalories. This modification is anchored on the fact that in Kenya, just like other developing countries, market imperfections exist and that agricultural profit as a variable is prone to measurement errors. Kabubo-Mariara, et al., (2016) also argue that the use of household's kilocalories is in order since calories indicator offers an actual food situation in the household and therefore offers a better proxy for household's nutrition status and productivity levels.

We can, therefore, rewrite equation 2 by expressing our dependent variable as household's kilocalories and including other variables that affect household calories production, for example, application of fertilizer and quality seeds in the form:

$$Kc_i = f\left(Ak_i^{\alpha_i}, l_i^{\alpha_i}, h_i^{\alpha_i}, f_i^{\alpha_i}, s_i^{\alpha_i}, p_i^{\alpha_i}, t_i^{\alpha_i}, r_i^{\alpha_i}\right) \quad (3)$$

Where Kc_i is the household *i* calories produced, f_i is the use of fertilizers, p_i is the use of pesticides, and s_i is the use of quality seeds. We include the amount spent on fertilizer and crop seeds because it is considered to be a strong predictor of kilocalories produced by households. We can now transform equation 3 by introducing the natural logarithm operator as:

$$ln\, Kc_i = \alpha_0 + \sum_{i=1}^{n} \alpha_i\, ln\boldsymbol{x}_i + \beta_i\, In\, \boldsymbol{z}_i\, + \varepsilon_i; \quad with\;\; \alpha_0 = lnA \qquad (4)$$

The vector $\boldsymbol{x}_i$ represents or the conventional factors used in the production of the kilocalories as shown in equation 3 i.e. capital, land, labour, fertilizer and seeds and; while vector $\boldsymbol{z}_i$ represents climate variability factors of rainfall and temperature, and ε_i is the error term. The other variables as defined earlier.

To achieve the second objective of the effects of climate variability on crop diversity, this study adopted the Ogive index (OI) which proxied crop diversity. OI is a concentration index that is commonly adopted to examine the concentration of industry. The index reduces gradually with the increase in the level of diversification. OI takes the value of 1 for the case of total concentration and a value of 0 for the increase in the diversification. This used as a proxy measure for crop diversity

$$OI = \sum_{i=1}^{N} [P_i - \left(\frac{1}{N}\right)]^2 \Big/ \frac{1}{N} \qquad (5)$$

N is the total number of crops cultivated and P_i proportion area of the ith crop. Based on this, therefore, the equation to be estimated to achieve the second objective can be expressed as follows:

$$OI_i = A\left(\prod_{i=1}^{n} \boldsymbol{m}_i^{\alpha_i}\right)\boldsymbol{z}_i^{\alpha_i} \qquad (6)$$

Where OI_i is the Ogive index measuring crop diversity and the presence and abundance of different crop species under a given cultivation area. The vector $\boldsymbol{m}_i$ represents household characteristics which are thought to influence crop diversity e.g. age and education of the household head; while vector $\boldsymbol{z}_i$ represents climate variability factors of rainfall and temperature. The equation to be estimated can therefore be written as:

$$OI_i = \alpha_0 + \sum_{i=1}^{n} \alpha_i \boldsymbol{m}_i + \beta_i \boldsymbol{z}_i + \varepsilon_i; \quad with \;\; \alpha_0 = A \qquad (7)$$

where vector $\boldsymbol{m}_i$ represents household characteristics that are considered to influence crop diversity e.g. age and level of schooling household head and the vector $\boldsymbol{z}_i$ represents climate variability factors of rainfall and temperature.

3.4 Data Type and Sources and variable measurement

This study would use the 2010 household survey for Kenya data funded by the USAID and collected by the Tegemeo, Kenya and Michigan State University to measure the agricultural production variables such as kilocalories produced by the households from main crops i.e maize, beans, sorghum, millet, wheat and banana, size of land under maize cultivation among others. In particular, the data for all the waves contain information on agricultural produce, household size, head of the agricultural household, household size among other covariates used in estimating maize production function. Concerning the climate variability factors, this study would use rainfall and temperature sourced from Kenya Meteorological Services (KMS) which was assigned to the households in different locations in the main dataset from Tegemeo Institute.

Table 1: Variable measurements and expected signs of the coefficients

Variable	Measurement	*A priori* Coefficients
Dependent variable		
Household's kilocalories	This measures the household production of kilocalories for main crops i.e. maize, beans, sorghum, millet, wheat, and banana.	1st Objective
Crop diversity	Crop diversity was measured by the Ogive index (OI) which shows the presence and abundance of different crop species under a given cultivation area.	2nd Objective
Independent variables		
Temperature	A continuous variable that measures temperature in different seasons of the year.	Uncertain
Rainfall	A continuous variable that measures rainfall in different seasons of the year.	Uncertain
Fertilizer value	The value of fertilizer that is household expenditure on the purchase of fertilizer for crops cultivation	Positive
Seeds value	The value of seeds that is the household expenditure on the purchase of crop seeds	Positive
Farm size	It is measured by the logarithm of the area put under cultivation. Farm size is restricted in our analysis of small-scale production since farmers who produce for household nutrition are subsistence.	Uncertain
Education of HH	Education was captured by taking the head's highest level of schooling	Positive
Age of HH	Age in years of the household head	Uncertain
Age of HH squared	This is the square age of the household head	Uncertain

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter presents the empirical results of the effect of climate variability on crop diversity as well as on household nutritional status in Kenya. In the chapter, we also provide the summary statistics as well as the estimates of our model.

4.1 Descriptive Statistics

Descriptive statistics of the variables in this study have been categorized into household production and production variables, climate variables, and household characteristics. Household production for individual households was proxied by Kcal which were estimated by multiplying the respective quantities (in kgs) of each crop produced by farmers by the Kcal/kg parameters as indicated in Table 2 . In order to carry out regression analysis, we converted the Kcal to logarithms.

Table 2: Kcal/kg conversion Table

Crop	Kcal/kg	Crop	Kcal/kg	Crop	Kcal/kg
Beans	3,330	Sorghum	3,390	Millet	3,280
Banana	890	Maize	3,620	Wheat	3,390

Source: FAO Food balance sheets: A handbook (2001); Tanzania Food Composition Tables (2008)

4.1.1 Household production and production Variables

To achieve objective one, the study presents the summary statistics in Table 3. The descriptive statistics show that, small scale farmers, on average, produced 567,870 kilocalories per hectare from the selected five main crops that includes; maize, beans, bananas, millet, sorghum and wheat. The high values of kilocalories produced by these crops are in line with the theoretical proposition that the analyzed crops are critical staple foods in Kenya that contribute the most to households nutrition status in the country. Additionally, bean crop is highly considered to be a critical source of proteins. In this study, kilocalories produced per hectare, which is the dependent variable proxy's for households nutrition status was generated by converting the quantity harvested from the selected five crops into their respective kilocalories equivalent per hectare.

Table 3: Household production and production variables

Variable	N	Mean	Std. Dev.	Min	Max
Kilocalories per hectare	310	567,870	1573,489	4937	2471,8948
Total farm labour	310	152.4	97.42	9	550
Total fertilizer value	242	5991	5238	180	28500
Total seed value	309	4096	3567	7.500	25800
Total farm size	310	1.245	0.544	0.100	2.100

Results indicate that labour used in the cultivation of the crops by small-scale farmers on average, expended 152 hours in farming activities that includes; land preparation, planting of crops, application of fertilizer and pesticides, weeding, harvest and post-harvest crop maintenance and storage. As regards the application of fertilizer, the statistics show that small scale farmers on average used almost Kshs 6,000 on the purchase of fertilizer for crop production, with the maximum amount spent by farmers being Kshs 28,500. Similarly, the results indicate that small-scale farmers spent on average Kshs 4,096 to purchase seeds for cultivation.

The results show that farm size, on average, small-scale farmers cultivated 1.245 hectares of land, which is equivalent to 3.076 acres. Further, the minimum and maximum land that was put under cultivation were 0.544Ha and 2.1Ha respectively. Notably, 2.1Ha is the equivalent of 5 acres that is considered the topmost threshold for a farmer to be considered a small-scale farmer. This is in line with the interest of this study that analyses the households' nutrition situation amongst small-scale farmers.

4.1.2 Climate Variables

The results indicate marked variations in both rainfall and temperature variables. As regards temperature, the result in Table 4 shows the average temperature was 23^0C, 20^0C, 19^0C and 22^0C during winter (December to February), spring (March to May), summer (June to August) and fall (September to November) seasons respectively. Further, the lowest and highest ever recorded temperature during this period was 17^0C and 27^0C respectively. The results further show that the average precipitation throughout the season was 2.8 mm, 3.4mm, 2.8mm and 3.3mm during winter, spring, summer and fall seasons respectively.

Table 4 Climate variables

Variable	N	Mean	Std. Dev.	Min	Max
Winter temperature	310	23.07	1.252	22.09	26.68
Spring temperature	310	20.44	1.940	18.02	25.20
Summer temperature	310	19.92	1.720	17.62	23.69
Fall temperature	310	21.91	1.265	20.77	25.73
Winter precipitation	310	2.836	2.032	1.062	7.191
Spring precipitation	310	3.406	2.064	1.411	7.558
Summer precipitation	310	2.843	1.848	0.810	6.776
Fall precipitation	310	3.323	1.927	1.348	7.355

4.1.3 Crop diversification and household characteristics

The summary statistics of the variables employed to achieve the study's second objective are represented in. Table 5 Crop diversity in this study was generated by computing the Ogive index. The index ranges between 1 and 0, where the value of 1 indicates the case of total concentration and the value of 0 for the increase in the diversification. The results show that average crop diversity was 0.318. This result implies that small-scale farmers do not undertake much crop diversity as the index is not near-total concentration and diversity of crops.

On household head demographic information, the results show that household heads had attained an average of 10 years of schooling. The implication of this is that most household heads had completed primary education, which totals eight years, and had entered secondary level of schooling. Additionally, the minimum and maximum level of education of the heads of households were 1 and 23 years respectively. The 23 years of schooling indicates that some of the household heads had attained a tertiary level of education. Concerning the age of the household head, the results show the average age of household heads was 50 years. Additionally, the youngest and oldest head of the household was aged 11 and 93 years respectively.

Table 5: Crop diversification and household characteristics

Variable	Obs	Mean	Std.Dev.	Min	Max
Average Ogive Index	282	0.318	0.248	0	1
Education of HH	283	9.827	3.752	1	23
Age of HH	308	49.74	12.31	11	93
Age of HH squared	308	2625	1221	121	8649

4.2 Econometric Results

4.2.1 Climate variability and households nutrition status

Households' nutrition is proxied by kilocalories produced by the farming households for selected five main crops including maize, beans, bananas, millet, sorghum, and wheat. These crops were selected because they are critical staple foods in Kenya that contribute the most to household nutrition status in the country. Table 6 presents the OLS results for the effects of climate change on households' nutrition status in Kenya. From the results, the joint test for the significance of all variables used in the estimation indicates that all variables used in the regression are jointly significant at all levels and that the estimable model has not excluded an important variable that explains household nutrition. In particular, the result presents an F calculated value F (12,228) of

3.20 with Probability F of 0.0003. Consequently, the model specification test by Ramsey Rest indicates that the estimable model is well specified and no critical variable has been omitted from the study. More specifically, the test which is conducted under the null hypothesis that the model has no omitted variable is not rejected since the calculated F statistics is F (3, 225) =1.05 and has a Probability value of 0.3701 which is greater than all levels of significance.

Table 6: Effect of climate variability on household nutrition status

Dependent Variable: Kilocalories per hectare	
Variables	**Coefficients**
Log farm labour	0.205*
	(0.114)
Log fertilizer value	0.230**
	(0.0966)
Log seed value	0.198**
	(0.0976)
Log farm size	-0.421**
	(0.164)
Log winter temperature	25.47
	(16.86)
Log spring temperature	-67.67*
	(39.75)
Log summer temperature	68.53
	(41.68)
Log fall temperature	-8.915
	(10.95)
Log winter p recipitation	-0.289
	(1.561)
Log spring precipitation	2.786*
	(1.629)
Log summer precipitation	0.420
	(1.061)
Log fall precipitation	-3.032*
	(1.566)
Constant	-45.25
	(29.88)
Observations	241
R-squared	0.126
F(12, 228)	3.20***
Root MSE	1.2943

*Notes: (i) log kilocalories per hectare is the dependent variable (ii) robust standard errors in parentheses (iii) * p < 0.10, ** p < 0.05, *** p < 0.01*

The econometric results indicate the varied effects of climate variables on household nutrition status. Results on temperature variables, the result shows that variations of temperature during the spring period significantly affect kilocalories per hectare produced by the small-scale farmers. More specifically, the results show that a one percent increase in temperature during spring seasons reduces kilocalories produced by small-scale farmers by an estimated 68%. This result implies that increments in temperature during the spring season have a devastating effect on the ability of maize, beans, bananas, millet, sorghum, and wheat to yield more kilocalories.

Regarding the effect of rainfall variables, the economic result shows that precipitation during the spring and fall seasons have significant effects on the production of kilocalories. In particular, the result shows that a one percent rise in precipitation in the spring season enhances kilocalories produced by 2.876 percent. Conversely, the result demonstrates that an increase in precipitation during the fall season significantly reduces the production of kilocalorie. A one percent increase in precipitation during the fall season reduces kilocalories produced by 3 percent. Taken together, this finding is similar to those of Kabubo-Mariara, Mulwa, and DiFalco (2016) who established that increase in moisture increases household calorie production but too much of the moisture tends to reduce calorie production.

Regarding other variables included in the estimable model as controls, the results show that labour used on land preparation, planting, application of fertilizer and pesticides, weeding, harvest and post-harvest crop maintenance and storage significantly enhances production of household nutrition as proxied by kilocalories produced. The result indicates that a one percent increase in labour hours increases the production of kilocalories by an estimated 0.205 percent. This result is indicative of the fact that engaging more in crop cultivation increases the yield and nutrients in the crops cultivated.

A closer look at the econometric results indicates that other farm inputs such as fertilizer and seeds are a significant predictor of the production of kilocalories. Concerning fertilizer, the results show that a one percent increase in the amount spent on fertilizer increases the production of kilocalories by small scale farmers by an estimated 0.23 percent. Similarly, it is observed that a one percent increase in the amount spent on the acquisition of crop seeds increases the production of kilocalories by an estimated 0.2 percent. Taken together, this result shows that investing in essential farming inputs such as fertilizers and seeds is critical in enhancing household nutrition status.

Concerning the size of land put under crop cultivation, the result shows that farm size has a reducing effect on the production of kilocalories. More specifically, the results show that a one percent increase in farm size reduces the production of kilocalories by an estimated 0.421 percent. This rather surprising result could be explained by the fact that an increase in farm size could mean a reduction in attention paid to crop cultivation largely due to the constrained abilities of small-scale farmers.

4.2.2 Effects of climate variability on crop diversity in Kenya

Table 7 shows the OLS regression results of crop diversity and climate variability. The dependent variable is the crop diversity measured by the Ogive index. The index ranges between 1 and 0, where the value of 1 indicates the case of total concentration and the value of 0 for the increase in the diversification. The joint test for the global significance of all variables used in the estimation indicates that all variables added in the regression are jointly significant at all levels. The result shows that F calculated value is F (13, 242) of 5.52 with Probability > F of 0.0000, implying that all variable employed in the regression equations are jointly significant.

Further, the Ramsey model specification test establishes the estimated model is correctly specified and that no important variable has been omitted from the analysis. In particular, the test that is carried out under the null hypothesis the estimable model has not omitted variable is not rejected since the calculated F statistics is F (3, 239) = 1.45 and has a Probability value of 0.2290 which is greater than all levels of significance.

Table 7: Effects of climate variability on crop diversity in Kenya

Variables	**Crop diversity**
Log farm labour	0.0341
	(0.0233)
Log farm size	0.0270
	(0.0296)
Log education of household head	0.0469*
	(0.0269)
Household head age	0.0120**
	(0.00477)
Household head age squared	-0.000112**
	(4.65e-05)
Winter temperature	-0.207**
	(0.0904)
Spring temperature	-0.730**
	(0.316)
Summer temperature	0.749**
	(0.337)
Fall temperature	0.366***
	(0.0759)
Winter precipitation	-0.246**
	(0.124)
Spring precipitation	0.0896
	(0.128)
Summer precipitation	0.152
	(0.108)
Fall precipitation	-0.0398
	(0.102)
Constant	-3.415**
	(1.561)
Observations	256
R-squared	0.142
F (13, 242)	5.52***

*Notes: (i) Crop diversity is the dependent variable (ii) * p < 0.10, ** p < 0.05, *** p < 0.01 (iii) robust standard errors in brackets*

The econometric results show a mixed effect of climate variables on crop diversity in Kenya. As regards temperature variables, the results show that an increase in temperatures during both winter and spring seasons have a reducing effect on crop diversity while rising temperatures in the summer and fall seasons have an enhancing effect on crop diversity. More specifically, the results show that additional temperature during winter and spring seasons reduces crop diversity by 0.207 and 0.73 respectively. Conversely, the results show that additional temperature during the summer and fall periods increases crop diversity by 0.749 and 0.366 respectively. On the other hand, an increase in precipitation in winter had a reducing effect on crop diversity by 0.246.

The results further demonstrate that other factors also affect crop diversity among small-scale farmers. It is observed that an increase in farmers' educational level increases crop diversity. Specifically, a one percent increase in the household head's education enhances crop diversity by 0.0469. One possible explanation for this finding is that education impacts small-scale farmers with critical knowledge that is required for better farming and the diversity of crops in farmland.

Similarly, the results establish that the age of the household head matters in promoting crop diversity. The results demonstrate the existence of an inverted U-shape relationship between crop diversity and the age of the household head. An inverted U-shape relationship implies that an increase in age of the head of household increase crop diversity up to a threshold where an additional year has a reducing effect on crop diversity. For clarity, the econometric results establish an increase in the age of the household head by one year, increases crop diversity by 0.012 all factors held constant.

One plausible explanation for this relationship is that younger household heads could be more willing to learn and embrace crop diversity, however as they progress in age, they are reluctant to adopt crop diversity and rather prefer cultivation of single or limited crops in the farmland.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND POLICY RECOMMENDATIONS

5.0 Overview

This chapter begins by presenting a summary study and then goes ahead to give the conclusions drawn. The summary and conclusion section is then followed by the policy implications of the study. Lastly, we present the limitations of the study.

5.1 Summary and Conclusion

The main objective of this paper was to analyze the effects of climate change on household nutrition among small scale farmers. Specifically, the study sought to examine the effects of climate change on household nutrition status proxied by kilocalories produced per hectare as well as crop diversity. The study used the 2010 household survey for Kenya data funded by the USAID and collected by the Tegemeo, Kenya, and Michigan State University to collect data on agricultural production such as crops cultivated, quantity harvest, farming inputs, household demographic information among other information. OLS technique was used to analyze the questions to achieve the study objectives.

Concerning the first specific objective, the study proxied household nutrition status by kilocalories produced per hectare from a select five main crops that includes; maize, beans, bananas, millet, sorghum and wheat. These crops were selected because they are assessed to be the critical staple foods in Kenya and that contribute the most to households' nutrition in the country. The regression result showed that climate variables had varied and mixed effects on household nutrition status. Increase in temperature during spring season and precipitation in the fall season significantly reduced production of kilocalories. Despite this, rainfall in the spring season had an enhancing effect on the production of kilocalories. Concerning the effect of other variables, the study established that an increase in farm labour and amount spent on both fertilizer and seeds increased production of kilocalories.

With regards to the second objective, the result similarly shows a mixed effect of climate variables on crop diversity in Kenya. More specifically, increase in temperatures during both winter and spring seasons had a reducing effect on crop diversity while rising temperatures in the summer and fall seasons had an enhancing effect on crop diversity. On other control variables, the findings showed that an increase in the household head level of schooling and age increased crop diversity.

5.2 Policy Implications

Study findings indicate varied and mixed effects of climate variables on both household nutrition status and crop diversity in Kenya. However, the overall effect of climate variations has had the propensity of reducing household nutrition as well as crop diversity. This finding implies that policymakers should implement adaptation strategies and interventions to cushion small-scale farmers from the adverse effects of climate variability on household nutrition status and crop diversity.

REFERENCES

Abdulai, S., Nkegbe, P. K., and Donkor, S. A. (2017). Assessing the Economic Efficiency of Maize Production in Northern Ghana. *Ghana Journal of Development Studies*, 14(1), 123-145.

Adebisi-Adelani, O., and Oyesola, O. B. (2014). Farmers' Perceptions of the Effect of Climate Change on Tomato Production in Nigeria. *International journal of vegetable science*, 20(4), 366-373.

Adimassu, Z., Kessler, A., 2016. Factors affecting farmers' coping and adaptation strategies to perceived trends of declining rainfall and crop productivity in the central Rift valley of Ethiopia. *Environ. Syst. Res*. 5, 1.

Ali, A., and Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, 16, 183-194.

Arndt, C., Farmer, W., Strzepek, K., and Thurlow, J. (2012). *Climate change, agriculture and food security in Tanzania*. The World Bank.

Barrios, S., Ouattara, B., & Strobl, E. (2008). The impact of climatic change on agricultural production: Is it different for Africa? *Food policy*, *33*(4), 287-298.

Bizuneh, A. M. (2013). Climate variability and change in the Rift Valley and Blue Nile Basin, Ethiopia: Local knowledge, impacts, and adaptation (Vol. 62). Berlin: *Logos Verlag Berlin GmbH.*

Brown, M. (2015). *Climate Change, Global Food Security, and the U.S. Food System.* 146 pages.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., and Herrero, M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, 114, 26-35.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., and Battese, G. E. (2005). An introduction to efficiency and productivity analysis. Springer Science and Business Media.

David, R. (1817). On the principles of political economy and taxation. *Publicadoen.*

Deressa, T. (2007). Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. World Bank Policy Research Working Paper4342, World Bank, USA.

Di Falco, S., Veronesi, M., and Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 829-846.

FAO (Food and Agriculture Organization of the United Nations) (2009). Global agriculture towards 2050. *High-Level Expert Forum Issues Paper*. FAO, Rome.

FAO (Food and Agriculture Organization of the United Nations) (2012). Crop Diversification for Sustainable Diets and Nutrition. The Role of FAO's Plant Production and Protection Division. FAO, Rome.

Fezzi, C. (2010). "The Ricardian Approach with Panel Data and Flexible Functional Forms: An Additive Mixed Model applied to England and Wales farmland values." Contributed paper presented at the Fourth World Congress of Environmental and Resource Economists, Montreal Canada.

Fischer, G., Shah, M. M., and Van Velthuizen, H. T. (2002). Climate change and agricultural vulnerability.

Funk, C. (2011). Declining global per capita agricultural production and warming oceans threaten food security: *Food Security*. 1(3), 271–289.

Gatiso, G. and Mulatu, W. (2016). The Impact of CO2 Emissions on Agricultural Productivity and Household Welfare in Ethiopia: A Computable General Equilibrium Analysis.

Gay, L.andAirasian, P. (2000). Windows statistics to accompany Educational research: Competencies for analysis and application (6thEd.). Upper Saddle River, NJ: Prentice-Hall.

Gbetibouo, G. and Hassan, R. (2005). Measuring the economic impact of climate change on major South African field crops: a Ricardian approach. "Global and Planetary Change47, no. 2: 143-152.

Gebreegziabher, Z. and Kassahun, M. (2013). Crop-Livestock Inter-linkages and Climate Change Implications for Ethiopia's Agriculture: A Ricardian.

Gebreegziabher, Z., Mekonnen, A., Deribe, R., Abera, S., and Kassahun, M. M. (2013). Crop-Livestock inter-linkages and climate change implications for Ethiopia's agriculture: A Ricardian approach (No. do-13-14-end).

Gumbo Gatiso, G., Tsegaye, E., Sime, Z. and Mulatu, W.D. (2016). The Impact of CO2 Emissions on Agricultural Productivity and Household Welfare in Ethiopia: A Computable General Equilibrium Analysis.

Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007 Impacts, Adaptation and Vulnerability, Report of Working Group II to the Fourth Assessment Report of the IPCC, Cambridge University Press, Cambridge: the UK and New York, 2007.

Kabubo-Mariara, J., Mulwa, R. M., and DiFalco, S. (2016). The impact of climate change on food calorie production and nutritional poverty: evidence from Kenya. Environment for Development Discussion Paper Series 16–26. The Environment for Development (EfD) initiative.

Kang, Y., Khan, S., and Ma, X. (2009). Climate change impacts on crop yield, crop water productivity, and food security–A review. Progress in Natural Science, 19(12), 1665-1674.

Kariuki, G. M. (2016). Effect of Climate Variability on Output and Yields of Selected Crops in Kenya (Doctoral Dissertation, Kenyatta University).

Kenya National Bureau of Statistics (KNBS), 2013. Economic Survey, Nairobi.

Komba, G. and Muchapondwa, E. (2015). Adaptation to Climate Change by Smallholder Farmers in Tanzania.

Kothari, R. (2008). Research Methodology: Methods and techniques. New Delhi: New Age International Publishers.

Kurukulasuriya, P. (2006). The policy nexus between agriculture and climate change in Africa. A synthesis of the investigation under the GEF / WB Project, Regional Climate, Water and agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa. CEEPA Discussion Paper No39, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Kurukulasuriya, P. and Robert, M. (2008). A Ricardian analysis of the impact of climate change on African cropland.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M. ... and Mahamadou, A. (2006). Will African agriculture survive climate change? The World Bank Economic Review, 20(3), 367-388.

Lagat, P., and Nyangena, J. (2018). The effects of climate variability on livestock production in Kenya. Journal of Agricultural Policy, 1(1), 58-79.

Leggett, J. (1992). Emissions Scenarios for the IPCC: an Update, Climate Change 1992: The Supplementary Report to The IPCC Scientific Assessment, Cambridge University Press, UK, pp. 68-95

Livingstone, G., Schonberger, S., and Delany S., (2011). Sub-Saharan Africa: The state of smallholders in agriculture. International Fund for Agricultural Development, Rome, Italy.

Mendelsohn, R., Nordhaus, W. D., and Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. The American economic review, 753-771.

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. Food policy, 32(3), 372-393.

Mutimba, S., Mayieko, S., Olum, P. and Wanyama, K. (2010). Climate change vulnerability and adaptation preparedness in Kenya. Heinrich Boell Stiftung. East and Horn of Africa, p. 61.

Naylor, R. L., Battisti, D. S., Vimont, D. J., Falcon, W. P., and Burke, M. B. (2007). Assessing risks of climate variability and climate change for Indonesian rice agriculture. Proceedings of the National Academy of Sciences, 104(19), 7752-7757.

O'Loughlin, J., Witmer, F. D., Linke, A. M., Laing, A., Gettelman, A., and Dudhia, J. (2012). Climate variability and conflict risk in East Africa, 1990–2009. Proceedings of the National Academy of Sciences, 201205130.

Overseas Development Institute (ODI). (2007). Climate change, agricultural policy, and poverty reduction how much do we know? Overseas Development Institute, Oxford.

Pal, S., & Kar, S. (2012). Implications of the methods of agricultural diversification in reference with Malda district: Drawback and rationale. *International Journal of Food, Agriculture and Veterinary Sciences*, *2*(2), 97-105.

Parry, J. E., Echeverria, D., Dekens, J., &Maitima, J. (2012). Climate risks, vulnerability, and governance in Kenya: A review. *Commissioned by: Climate Risk Management Technical Assistance Support Project (CRM TASP), a joint initiative of Bureau for Crisis Prevention and Recovery and Bureau for Development Policy of UNDP*.

Porter, J. R., and Semenov, M. A. (2005). Crop responses to climatic variation. Philosophical Transactions of the Royal Society B: Biological Sciences, 214360(1463), 2021-2035.

Rosenzweig, C. (2010). Implications of Climate Change for International Agriculture: Crop Modeling Study, (EPA 230-B-94-003), U.S. Environmental Protection Agency, Washington, D.C.

Schlenker, W., Lobell, D.B., 2010. Robust negative impacts of climate change on African agriculture. Environmental Research Letters 5 (1)

Seo, S. N. N., Mendelsohn, R., and Munasinghe, M. (2005). Climate change and agriculture in Sri Lanka: a Ricardian valuation. Environment and Development Economics, 10(5), 581-596.

Singh, H., Subash, N., Gangwar, B., Valdivia, R., Antle, J., and Baigorria, G. (2015). Assessing Economic Impacts of Climate Change and Adaptation In Indo-Gangetic Basin. Procedia Environmental Sciences, 29, 229-230.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., and Miller, H. L. (2007). The physical science basis. A contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change, 235-337.

Sowunmi, F. A. (2010). Effect of climatic variability on maize production in Nigeria. Research Journal of Environmental and Earth Sciences 2(1), 19-30.

Sylla, M.B., Elguindi, N., Giorgi, F., Wisser, D., 2016. The projected robust shift of climate zones over West Africa in response to anthropogenic climate change for the late 21st century. Clim. Change 134, 241–253.

The Republic of Kenya. (2010). National climate change response strategy. Nairobi: Government Printer.

United Nations Environmental Program (UNEP). (2009). Kenya: Atlas of our changing environment. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme Nairobi, Kenya.

Zake, J., Hauser, M., 2014. Farmers' perceptions of the implementation of climate variability.