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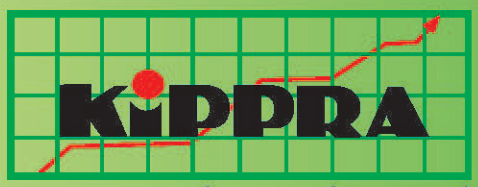

The KENYA INSTITUTE for PUBLIC POLICY RESEARCH and ANALYSIS

Effects of Climate Change on Crop Revenue in Kenya: Implications On Agricultural Production

Joshua Laichena, E. Omosa and K. Musyoka

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THE KENYA INSTITUTE FOR PUBLIC POLICY RESEARCH AND ANALYSIS (KIPPRA)

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Abstract

This study investigated the impact of climate and economic variables on crop production and the effects of climate change variation on crop revenues using a Ricardian model. The study used cross sectional survey data collected by Agriculture Sector Development Support Programme II (ASDSP II) in 2013 of 12,651 households across Kenya and the historical climate data from the Kenya Meteorological Services. Public Expenditure Review and Analysis for climate change adaptations and mitigation in agriculture (PERCC) methodology was used to identify climate relevant public expenditure in agriculture. This was done by using the UN Food and Agriculture Organization's (FAO) Monitoring and Analysing Food and Agricultural Policies (MAFAP) data for the period 2013/14 to 2017/18. The findings of the study provide evidence that climate change significantly impacts crop revenue in Kenya, showing that farming in Kenya is sensitive to temperature and precipitation changes. The study further highlights the need for effective adaptation policies to reduce vulnerability and enhance resilience in the face of a changing climate. These findings are warnings that severe climate scenarios could lead to substantial losses in crop yields, particularly crop revenue, affecting the most vulnerable regions and posing a major threat to the agricultural sector, which is a key contributor to Kenya's Gross Domestic Product (GDP). Based on these findings, it is recommended that the government focuses on various policy measures. First, strengthening climate adaptation measures to safeguard the agricultural sector by ensuring allocation and tracking of the funding for adaptation in the sector, since the sector is vital for Kenya's GDP. Secondly, to mitigate the potential adverse effects of climate change, it is imperative to design and implement robust climate adaptation policies that prioritize enhancement of agricultural resilience through adoption of improved farming inputs, advanced technologies, and comprehensive training and extension services. Lastly, to improve the management and tracking of climate financing in the agriculture sector, the government needs to ensure that funds are effectively used for their intended purposes in both adaptation and mitigation efforts to achieve food and nutrition security, as outlined in the Bottom-up Economic Transformation Agenda (BETA) plan and the 4th Medium Term Plan (MTP IV).

Abbreviations and Acronyms

AEZs	Agro-ecological Zones
APSIM	Agricultural Production Systems sIMulator
ASDSP II	Agriculture Sector Development Support Programme II
ASTGS	Agricultural Sector Transformation Growth Strategy
BETA	Bottom-up Economic Transformation Agenda
CCCF	County Climate Change Fund
CCM	Canadian Climate Model
CPI	Climate Policy Initiative
DSSAT	Decision Support System for Agrotechnology Transfer
EDE	Ending Drought Emergencies
FAO	Food and Agricultural Organization
GCF	Green Climate Fund
GCM	Global Circulation Model
GDP	Gross National Product
GEF	Global Environmental Facility
GFDL	Geophysical Fluid Dynamics Laboratory Model
GHGs	Green House Gases
GoK	Government of Kenya
IPCC	Intergovernmental Panel on Climate Change
KALRO	Kenya Agricultural and Livestock Research Organization
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KMS	Kenya Meteorological Services
KNBS	Kenya National Bureau of Statistics
LDCF	Least Developed Country Fund
LULUCF	Land Use Land Use Change and Forestry
MAFAP	Monitoring and Analysing Food and Agricultural Policies
MAM	March April May
MTP	Medium Term Plan
MRV	Monitoring Reporting and Verification
NAP	National Adaptation Plan
NAPA	National Adaptation Plan of Action
NASA	National Aeronautics and Space Administration
NCCAP	National Climate Change Action Plan
NCCRS	National Climate Change Response Strategy
NDC	Nationally Determined Contribution
OECD	Organization for Economic Cooperation and Development
OND	October November December
PEA	Public Expenditure Analysis
PERCC	Public Expenditure Review for climate change adaptations and mitigation in agriculture
SAPs	Sustainable Agricultural Practices
SCCF	Special Climate Change Fund
SEI	Stockholm Environment Institute
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization
WOFOST	World Food Studies simulation model

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1. Introduction

Many climate models indicate that climate change is expected to negatively impact crop yields, revenue, and agricultural production in Africa by up to 50 per cent by 2020 (Mendelsohn and Seo, 2007). A range of Global Circulation Models predicts a warming of above 2°C in most of East Africa and an increase in precipitation of 6.3 per cent, coupled with large regional variations in precipitation. Given a temperature rise of 2.5°C the biophysical impacts of climate change will reduce food availability, undermine food security and expose between 55 and 65 million extra people to the risk of hunger by the year 2080 (Shi Zhen et al., 2020). The disastrous effects of global climate change are becoming more severe, and most of the damage is expected to occur in underdeveloped countries. Compared to developed and other developing nations, African nations are more vulnerable to the effects of climate change, because they are highly dependent on rain-fed agriculture and their limited institutional, financial, and technical capabilities for adaptation makes them less able to withstand adverse effects of climatic changes (Bruckner, 2012; Dessalegn and Akalu, 2015; Gemeda and Debela Hunde Feyssa, 2015).

Climate change has a profound impact on agriculture, influencing crop revenue. As global temperatures rise, the frequency of extreme and unexpected weather events such as heatwaves, droughts, and floods increase, posing significant challenges to agricultural production, and therefore crop revenue (Jenkins et al., 2021). While some regions may experience marginal benefits in crop yields due to factors such as increased CO_2 levels, which can enhance photosynthesis, these benefits are often offset by the negative effects of higher temperatures and altered precipitation patterns (Ibid; McLachlan and Zheng, 2020). For instance, studies have shown that in countries like China, India, Brazil, Egypt, Ghana, and Ethiopia, climate-induced changes in crop yields, and therefore crop revenue ,can result in varying economic outcomes (Jenkins et al., 2021). In some scenarios, GDP and welfare indicators may initially experience marginal increases due to improved yields; however, as warming levels rise beyond certain thresholds, these trends begin to reverse, resulting in higher consumer prices and decreased national economic welfare (McLachlan, van, and Zheng, 2020).

It must be noted, however, that the relationship between climate change and crop revenue is complex, as it is influenced by both natural and socio-economic factors, and the overall effect is highly dependent on the specific regional climate impacts and the resilience of the agricultural systems in place (Ibid). Empirical studies have predicted how climate change affects yields, and therefore, crop revenue. In China, for example, a study assessing the economic effects of climate-induced crop yield changes showed that there were marginal benefits on GDP and welfare up to certain levels of warming due to projected increases in rice yields, which lowered domestic consumer rice prices. However, at higher warming levels, these trends began to reverse. In contrast, India faced negative impacts due to declining crop yields, leading to increasing consumer prices of domestic and imported rice and wheat, and declines in GDP and welfare, especially at higher warming levels (Wang, D., et al., 2021). Furthermore, a study by the National Aeronautics and

Space Administration (NASA) predicted that climate change might affect the production of maize (corn) and wheat as early as 2030 under a high greenhouse gas emissions scenario. Maize crop yields are projected to decline by 24 per cent, while wheat could potentially increase by about 17 per cent. The change in yields for maize and wheat is due to projected increases in temperature, shifts in rainfall patterns, and elevated surface carbon dioxide concentrations from human-caused greenhouse gas emissions (Müller et al., 2021). In the United States (US), climate change is boosting maize yields in parts of the US, Latin America, and Asia, but sharply reducing them elsewhere. It is also reducing the US soybean yields in southern and eastern states and expanding them to the north and west (Ray et al., 2019). A study in India and Pakistan, shows that extreme heat may lead to a decline in crop yields, which, combined with the banning of wheat and rice exports in India, posed a threat to international food markets and countries already affected by shortages of staple foods (WMO, 2023). The above studies illustrate the varied and significant ways in which climate change can affect crop revenue, with implications for both local economies and global food security. However, the specific impacts are highly dependent on regional climate conditions and the resilience of agricultural systems.

At a country level, past studies have indicated that temperatures throughout Kenya have generally risen mainly near the large water bodies (King'uyu, Ogallo and Anyamba, 2000; GoK, 2010). Climate projections also show that the country will experience an annual temperature increase ranging from 1°C to 3.5°C by the year 2050 (SEI, 2009). Climate change associated with unpredictable rainfall, reduced soil productivity through erosion, and increased evapo-transpiration is responsible for declining agricultural production (GoK, 2010). Kenya is already experiencing climate-change characterized by more frequent and intense extreme weather events, particularly drought and flood (GoK, 2012). The effects of climate change are frequently discussed in terms of rising temperatures and shifting precipitation patterns whereas it is more crucial how these changes affect agricultural production (Kiremu et al., 2022). Climate change also increases the risk of rural populations who derive majority of their livelihood from agriculture, while at the macro-scale; it increases the vulnerability of the economy, which is dominated by climate sensitive sectors such as agriculture (GoK, 2010).

Due to its significant contribution to the GDP, growth in the agriculture sector is correlated with growth of the overall national economy. For instance, in 2013, the sector accounted for 65 per cent of the country's exports, and more than 70 per cent of total national labour force (KIPPRA, 2014). Declining productivity is mainly attributed to unfavourable climatic weather conditions and high cost of farm input. Further, agriculture is sensitive to climate change due to the close natural link between climatic weather conditions and plant development. The most important climate variables that affect agricultural production are temperature, precipitation, atmospheric pressure and humidity, wind and sunshine and cloud cover. Agricultural production potential is determined by physical factors, primarily soil and climatic conditions, and a complex interaction of socioeconomic, cultural and technological factors. These factors include farm sizes, level of farming and livestock inputs and management practices such as soil

conservation and enhancement, and veterinary services. Furthermore, economic factors like market prices and access to credit, education and extension services also play a role in determining production potential (FAO, 2016).

Under extreme weather conditions, resulting to severe drought in Kenya, the government is forced to allocate funds for emergency food relief, pointing to a close link between climate change, agricultural production and financing for mitigation and adaptation. Addressing climate-related effects require urgent action on a local and national scale. Responding to negative effects of climate change, and preparing for future climate change is estimated to cost US$500 million per annum, with adaptation cost alone increasing to between US$1 to US$2 billion per year by the year 2030 (SEI, 2019).

The Kenya National Adaptation Plan (2015-2030) estimates the cost of adaptation in the agriculture sector alone to cost US$375 million and for all priority sectors in the plan to cost a total of US$36,136 million. These estimates are beyond what the country can mobilize domestically, and hence, leveraging domestic resources with international climate finances is therefore imperative. On the other hand, investments in climate mitigation and adaptation projects were estimated to cost US$2.4 billion in 2018, which came from both domestic and foreign sources. About 42.2 per cent (Ksh 102.7 billion) of the total climate finance tracked, came from domestic sources with domestic private and public sector sources accounting for 14 per cent (Ksh 34 billion) and 28.3 per cent (Ksh 68.8 billion), respectively (Odhengo et al., 2021).

Domestic sources have recently become important as the government allocates more resources to climate activities. However, there are concerns on whether the available resources can address the climate change problem in agriculture. Although public expenditures are an important policy instrument in addressing climate change mitigation and adaptation, the linkages between agricultural production and climate finance in the sector for both mitigation and adaptation are poorly understood. Previous studies have concentrated on assessing the economic cost of climate change, from the demand side ignoring the supply side. This study aimed to bridge this gap by investigating how variations in climate change and other economic variables affect the crop yield and revenue in Kenya. The study aimed to answer the following questions: first, how do variations in climate change and other economic variables affect crop yield and, therefore, crop revenue in Kenya? Secondly, what are the effects of variations in climate change on crop yields in Kenya? Finally, what are the sources and composition of climate financial flows to the agriculture sector in Kenya? The study aimed to address three objectives, namely: examining the relationship between climate change and other economic variables on crop yields and crop revenue in Kenya; forecasting the effects of climate change variation on crop yields and, therefore, crop revenue; and identifying climate financial flows and their composition to the agriculture sector in Kenya.

2. Level and Composition of Spending in Support of Food and Agriculture

2.1 Background

The importance of agriculture in Kenya is re-emphasized through the Kenya Vision 2030, the Bottom-up Economic Transformation Agenda (BETA) and the Fourth Medium Term Plan (MTP IV - 2022/23 to 2027/28) in which agriculture, along with manufacturing, housing and healthcare, are given priority to ensure inclusive growth, job creation and food security for all. In line with this framework, the Agricultural Sector Transformation and Growth Strategy (ASTGS) guides the agriculture sector interventions until 2029. The Strategy identifies three key pillars of improved agricultural performance including, increasing the incomes of small-scale farmers, pastoralists, and fishermen; increasing agricultural production and value-added; and boosting household resilience to food insecurity as well as 'enablers' that are necessary to guarantee reaching the objectives defined within the pillars. The specific actions to be undertaken by the government are specified within 'flagships,' six of which are defined under each of the pillars and three belonging to the groups of enablers. This is further reinforced by MTP IV, which identifies various value chain development and agro-processing for prioritized crops and livestock.

Climate change issues are addressed in economy-wide strategies that specify contributions of individual sectors, including agriculture. Kenya launched the National Climate Change Response Strategy (NCCRS) in 2010 and a National Climate Change Action Plan (NCCAP 2013-2017) in 2013. In 2018, the action plan was renewed into the National Climate Change Action Plan (NCCAP) for 2018-2022. Kenya's third Action Plan on climate change (NCCAP 2023-2027) builds on the previous Action Plans and provides a framework for Kenya to deliver on its Nationally Determined Contribution (NDC) under the Paris Agreement and transition the country into a low carbon climate resilient development pathway. Climate change adaptation was set as a key priority for the country recognizing the adverse socioeconomic impacts related to climate change and the increasing vulnerability of the different sectors. It was also recognized that adaptation and development goals need to complement each other to achieve sustainable development. The National Adaptation Plan (NAP), developed for 2015-2030, builds on the foundations laid out in the NCCRS and the NCCAP. It forms the basis for the adaptation component of Kenya’s Intended Nationally Determined Contribution (INDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat.

The actions proposed in the NAP complement adaptation actions that are ongoing through various projects and programmes already implemented by the public and private sector. Related to the agriculture sector, the NAP proposes to reinforce the land reforms and ensure sustainable land use; protect the environment to secure livelihoods, health and ecosystem services, among others; enhance the resilience of the food crops, industrial crops and horticulture value chains; enhance the

resilience of the livestock value chains; enhance the resilience of the fisheries value chains; and fast track the Common Programme Framework for Ending Drought Emergencies (EDE) 2012-2022. These priority actions related to agriculture are elaborated in Table 2.1.

Table 2.1: Main actions related to agriculture and associated budget for NAP, 2015-2030

Sector	Action in NAP 2015-2030	Budget (US$ m)
Land reforms	Mainstreaming climate change adaptation in land reforms	1.40
Environment	Mainstreaming climate change adaptation in the environment sector	636.10
Crops	Enhance the resilience of crop value chain	375.10
Livestock	Enhance the resilience of livestock value chain	299.80
Fisheries	Enhance the resilience of fisheries value chain	136.90
Common Programming Framework for EDE (2010-2022)	Fast track the implementation of the EDE common programme framework	2,118.30
Total budget allocated to actions related to agriculture		3,567.60

Source: Government of Kenya (2016)

However, it is important to note the amount of funding required for climate proofing on the sectors to achieve the proposed actions for various sectors in the NAP. Building on NAP main actions, it is necessary to track the funding for climate change in the agriculture sector to monitor and track the funding that is directed towards adaptation and mitigation in the agriculture sector. In the next section, climate relevance funding is tracked using the FAO's database on Monitoring and Analysing Food and Agricultural Policies (MAFAP) for the period 2013/14 to 2017/18.

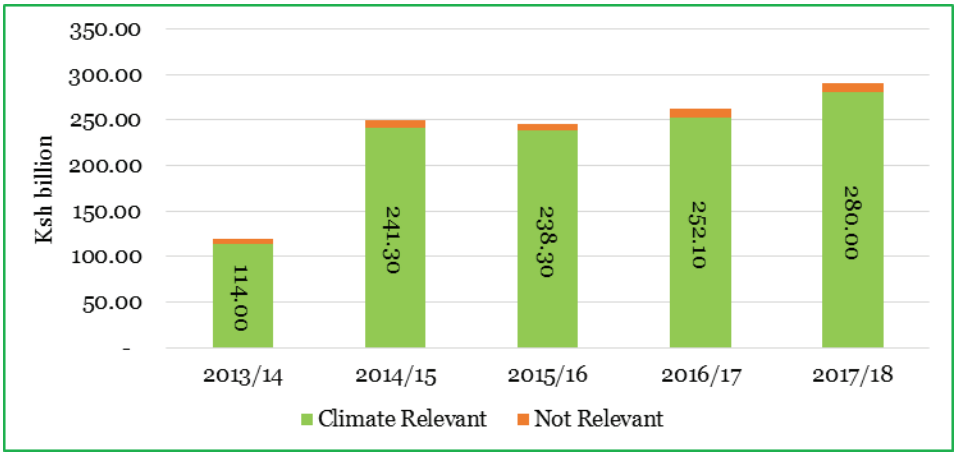
2.2 Climate Change Public Expenditures in Support of Food and Agriculture Sector

The adaptation aspect of climate change has been defined by various studies as the process of adjusting to the current and future effects of climate change (Barnes et al., 2020; Owen, 2020). On the other hand, mitigation measures of climate change has been defined as preventing or reducing the emissions of greenhouse gases into the atmosphere to reduce the adverse effects of climate change (Amelang et al., 2020).

Most of the public expenditures in support of the food and agriculture sector in Kenya affect the sectors capacity to adapt to climate change (Figure 2.1). The

information gathered in the MAFAP database allows for classifying about 99 per cent of public expenditures as relevant to climate change adaptation and mitigation (referred to as climate relevant), on average in the considered period. The amount of climate relevant spending increased throughout the period of analysis from Ksh 114 billion (US$0.912 billion) to nearly Ksh 280 billion (US$2.24 billion), with an average annual growth rate of about 20 per cent. The climate relevant spending in agriculture constitutes, on average, 14 per cent of total government spending in all sectors of the economy.

Figure 2.1: Public expenditures in support of food and agriculture sector and climate change related spending (Ksh billion), 2013/14-2017/18



Source: Calculations based on MAFAP database, 2018

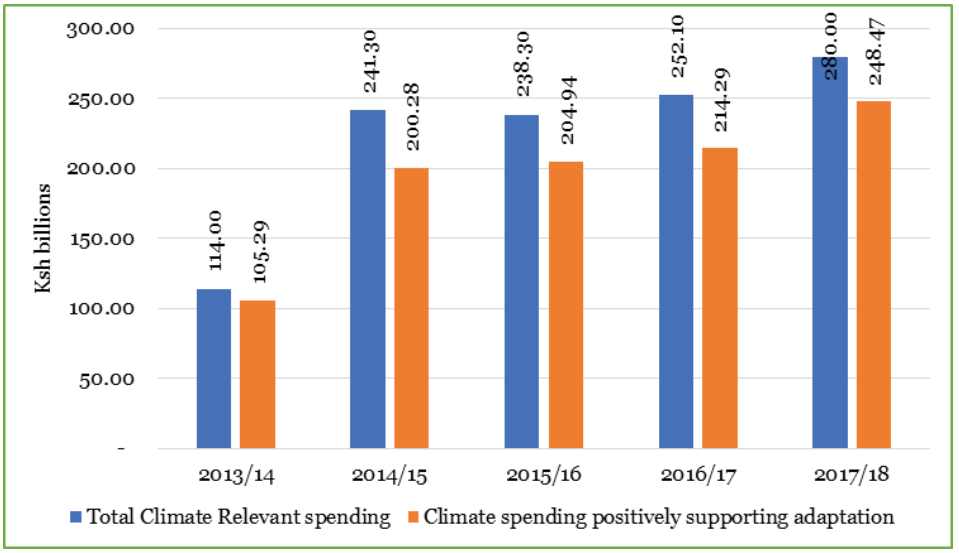
2.2.1 Climate change adaptation and mitigation definitions

The Public Expenditure Review for climate change adaptations and mitigation in agriculture (PERCC) adopts FAO's definitions of adaptation and mitigation. FAO defines adaptation as "the vital response to the adverse effects of climate change and the preparation for future impacts". This includes an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities as noted by the Intergovernmental Panel on Climate Change (IPCC, 2014). In agriculture, adaptation actions encompass technological responses, enhancing smallholder access to credit and other critical production resources, and strengthening institutions at local and regional levels. Specific responses consist of developing new crop varieties adapted to changes in carbon dioxide, temperature and drought, fostering the capacity for climate risk management, offsetting economic impacts of land use change, crop insurance, and information systems to support early warning and proactive planning.

Mitigation, includes all the "human interventions to reduce the emissions of Green House Gases (GHGs) by sources or to enhance their removal from the atmosphere by sinks (for example, forests, vegetation or soils that can reabsorb carbon dioxide (CO_2)." Mitigation measures in agriculture include technological innovation and transfer, crop diversification, climate-smart agricultural practices to increase soil quality and decrease soil erosion (IPCC, 2014).

Within climate-relevant spending, an evaluation of expenditure positively linked to climate adaptation was performed. Figure 2.2 shows that on average, 86 per cent of public expenditures are positively linked to climate change adaptation. This share was relatively stable throughout the years, while the underlying amount increased on average by 24 per cent per year from Ksh 105.3 billion in 2013/14 to Ksh 248.5 billion in 2017/18.

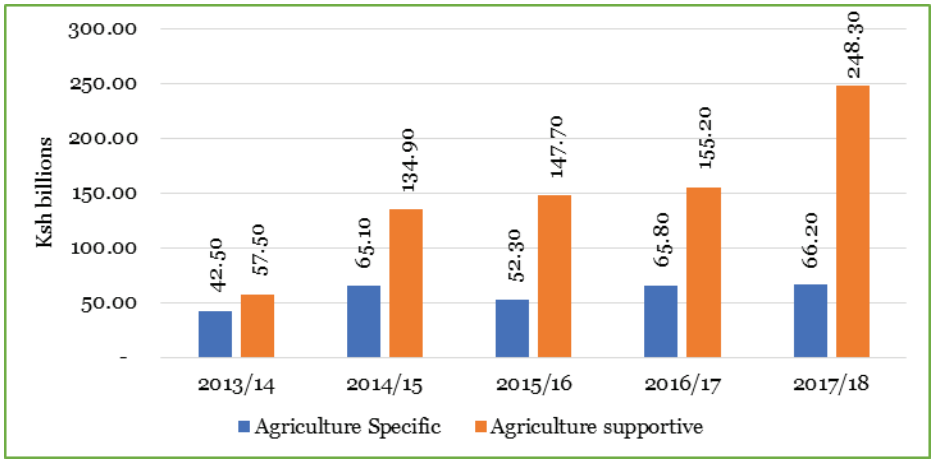
Figure 2.2: Climate-relevant agricultural public expenditure positively supporting adaptation, 2013/14-2017/18 (Ksh billion)



Source: Calculations based on MAFAP database, 2018

The average composition of public expenditures positively supporting adaptation was investigated to determine the type of adaptation-enhancing measures that are employed. First, a broad disaggregation between agriculture-specific and agriculture-supportive measures shows that a higher share of measures in favour of adaptation is spent on agriculture-supportive activities, ranging from 60 to 70 per cent in the periods examined. Agriculture-specific measures enhancing adaptation increased from Ksh 42.5 billion in 2013/14 to Ksh 66.2 billion in 2017/18 (Figure 2.3).

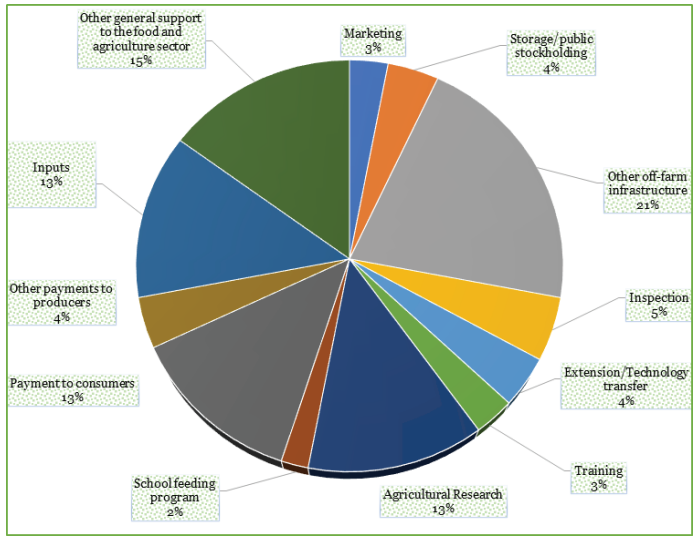
Figure 2.3: Agriculture-specific/ agriculture-supportive public expenditures positively supporting adaptation (Ksh billions) 2013/14-2017/18



Source: Calculations based on MAFAP database, 2018

Further disaggregation focusing on the average composition of agriculture-specific public expenditures positively stimulating the adaptive capacity of the agriculture sector (Figure 2.4) was done, where the largest share, 21 per cent was given to other off-farm infrastructure (including off-farm irrigation, which contributes the most, and feeder roads), followed by spending in other general support to the food and agriculture sector 15 per cent.

Figure 2.4: Average composition of agriculture specific public expenditure positively supporting adaptation (2013/14-2017/18)

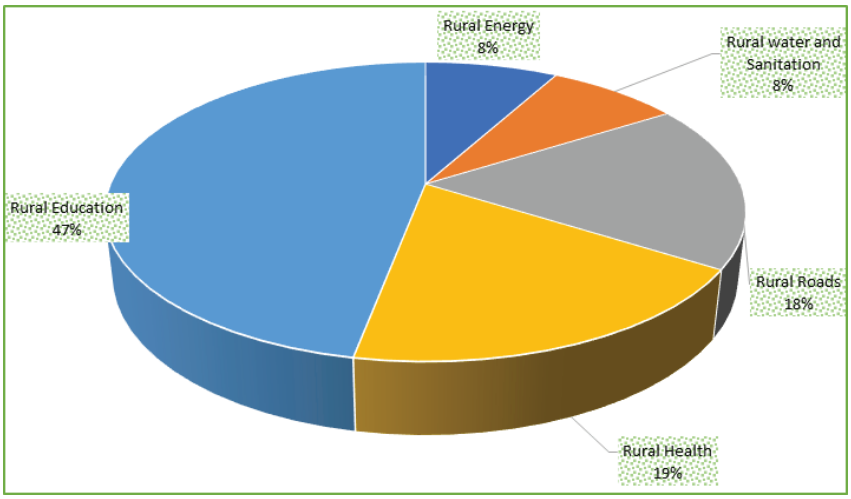


Source: Calculations based on MAFAP database, 2018

The adaptation supportive measures spent 13 per cent on subsidies for improved quality inputs, including variable inputs such as improved seeds or fertilizers, which contributes the most, support to building on-farm capital and on-farm services provision, on agricultural research, and payments to consumers (cash transfers above all). Lastly, inspection, training, extension and technology transfers, other payments to producers, storage, marketing and school feeding programmes contribute smaller shares, generally renging from 2.0 to 5.0 per cent.

The analysis of the average composition of agriculture-supportive public expenditures positively supporting adaptation (Figure 2.5) reveals that rural education takes the largest share (47%), while rural health and rural roads accounts for 19 per cent and 18 per cent, respectively. Rural water and sanitation and rural energy make up the remaining share (8%) each.

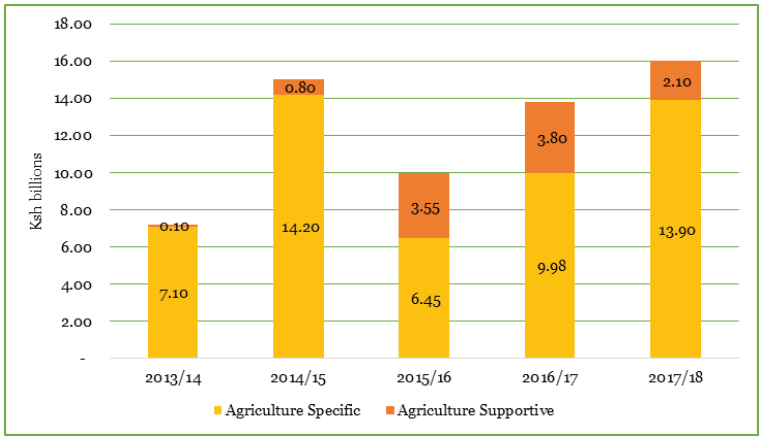
Figure 2.5: Composition of agriculture-supportive public expenditures positively supporting adaptation, 2013/14-2017/18 (average)



Source: Calculations based on MAFAP database, 2018

To examine the average composition of public expenditures linked to climate change mitigation, the agriculture-specific and agriculture-supportive spending are disaggregated. The analysis revealed that mitigation-related spending concerns mainly the agriculture-specific measures, while agriculture supportive measures account for a relatively lower share (Figure 2.6).

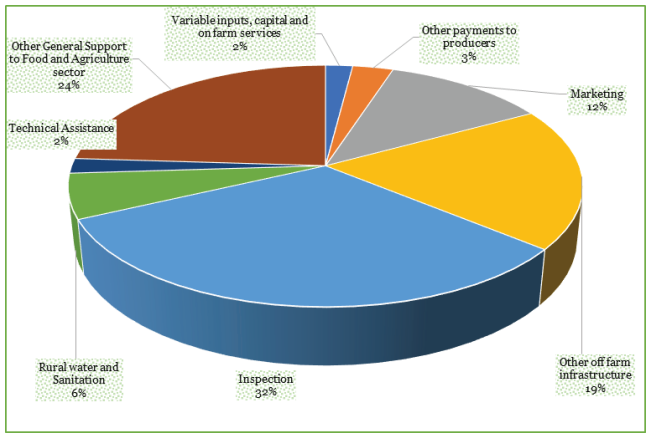
Figure 2.6: Average agriculture specific/agriculture supportive public expenditure with link to mitigation, Ksh billion (2013/14-2017/18)



Source: Calculations based on MAFAP database, 2018

Among the public spending positively supporting climate change mitigation, agriculture-specific measures 70 per cent on average, and the main contribution was 'other general support to the food and agriculture sector' category with a share of 46 per cent, followed by agricultural research with 12 per cent (Figure 2.7). Other off-farm infrastructure, variable inputs, training and capital contribute between 2.0 and 4.0 per cent. Agriculture-supportive measures accounted for the remaining 30 per cent, consisting of spending on rural energy (27%) and rural water and sanitation (3%).

Figure 2.7: Average Composition of public expenditures enhancing mitigation, 2013/14-2017/18

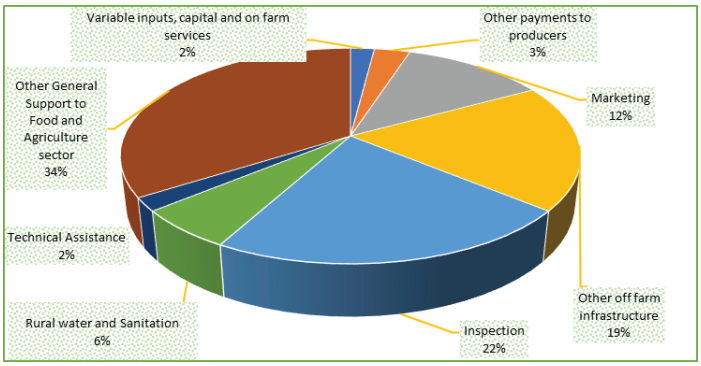


Source: Calculations based on MAFAP database, 2018

Most of the public expenditures with adverse effects on climate change mitigation are agriculture-specific (94% on average) driven by expenditures in the livestock

subsector, and the main spending components are inspection activities, other general support to the food and agriculture sector and other off-farm infrastructure (32%, 24% and 19%, respectively). Marketing accounts for 12 per cent, while other payments to producers, input subsidies and technical assistance contribute 2-3 per cent each (Figure 2.8).

Figure 2.8: Average composition of public expenditures with adverse effects on mitigation, 2013/14-2017/18

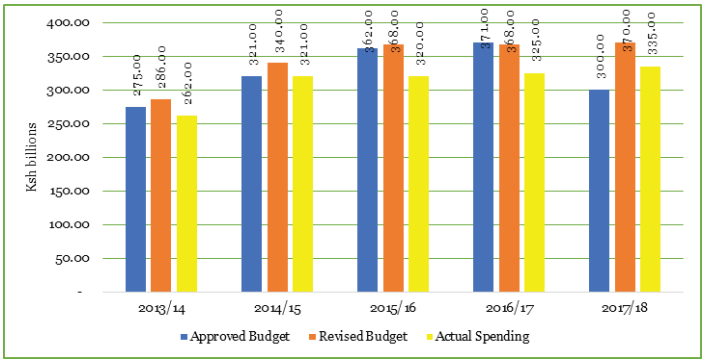


Source: Calculations based on MAFAP database, 2018

2.2.2 Budgeted climate relevant amounts versus actual spending

The budgetary allocations for climate relevant expenditures were higher than actual expenditures in every year considered (Figure 2.9). The budgeted amounts for the climate relevant spending in agriculture were generally lower than revised budget allocations. With an actual average execution rate of about 77 per cent, the spending shows that an important part of the allocations (about 33%) was not disbursed for implementing the planned activities. Adaptation enhancing measures received an average of about 77 per cent of the total allocated fundings.

Figure 2.9: Comparison between budget and actual climate relevant expenditures (2013/14-2017/18)



Source: Government of Kenya, 2021

3. Literature Review

3.1 Theoretical Framework

There are two methods that have been developed during the last few decades to evaluate the impact of climate change on the agricultural sector: the production-function approach (Rosenzweig and Iglesias, 1999), and the Ricardian approach (Mendelsohn et al., 1994). The production-function approach relies on empirical or experimental production functions to predict environmental damage. This approach has been criticized for inherent bias, which tends to overestimate the damage, a bias sometimes referred to as the 'dumb farmers scenario', since it fails to consider the variety of adaptations that farmers might make in response to changing economic and climatic conditions (Mendelsohn et al., 1994). The Ricardian approach is a cross-sectional model used to study agricultural production by measuring climate change damage as a reduction in net crop revenue or land value. In addition, it takes into account the costs and the benefits of different adaptation techniques that farmers apply. The Ricardian approach is based on several assumptions. First, it is assumed that climate shifts the production function for crops. Second, there is perfect competition in both product and input prices (no public intervention in the market and no monopoly). Third, the land values have attained the long run equilibrium associated with each region's climate. Fourth, market prices are unchanged because of the change in environmental conditions. Fifth, adaptation takes place by all means including the adoption of new crops or farming systems. And finally, the adaptation cost is not considered in the analysis.

Conventional approaches to assess the impacts of climate change on agriculture rely on complex crop simulation models that compare crop yields under different climatic conditions (Torriani at al., 2007; Adams et al., 1999; Ochieng et al., 2016). Most models use calibrated crop models from controlled experiments in which crops are grown in a laboratory setting that simulates different climates and levels of carbon dioxide. By adjusting different climate parameters while keeping the farming methods unchanged, the effects of climate change on yields are established. Elbehri and Burfisher (2015) have categorized approaches for analyzing the impacts of climate change and variability on agriculture into two: pathway models and Ricardian models.

Pathway models quantify biophysical effects of changes in temperature, precipitation and carbon dioxide on crop yields. They generate variables used to shock economic models. Two types of crop yield are identified: dynamic crop growth simulation and statistical yields. Dynamic crop growth models simulate incremental plant growth process and yields in response to changes in climate conditions. They include Decision Support System for Agro-technology (DSSAT), which has been applied by studies such as Thornton et al.(2011) and Nyang'au et al. (2014). Other dynamic models include the World Food Studies (WOFOST) simulation model (Alvaro et al., 2010) used for analysing the growth and production of field crops under a wide range of weather and soil conditions. FAO's Aqua Crop (Miller et al., 2008) and the Agricultural Production Systems Simulator (APSIM) a wiki-modelling framework.

Statistical crop yields models describe empirical relations between observed crop yields and projected changes in climate variables. These have advantages over dynamic crop growth models since they take into account farmers adaptive behaviours and can be estimated at different time and spatial scales. These models have been used by Lobell et al. (2007, 2008, 2010) and Rowhani et al. (2011). Crop models are extremely data intensive and often predict severe yield reductions resulting from climate change because of the 'dumb farmer effect' whereby they ignore adaptation actions, which farmers would ordinarily take in response to a changing environment (Mendelsohn et al., 1994).

Economic models have emerged to address this weakness. These are used to predict aggregate crop outputs, prices and net revenue using the yields from the agronomic models (Mendelsohn and Dinar, 1999). The Ricardian model has got its advantages and weaknesses. One of its fundamental advantages is its ability to incorporate private adaptations. Farmers adapt to climate change to maximize profit by adjusting the crop mix, planting and harvesting dates, and various agronomic practices. Another advantage of the model is its cost-effectiveness, as secondary data on cross-sectional sites can be relatively easy to collect regarding climatic, production, and socioeconomic factors.

One of the weaknesses of the Ricardian approach is that it is not based on controlled experiments across farms. Farmers' responses vary across space not only because of climatic factors, but also because of many socioeconomic conditions. Such non-climatic factors are seldom fully included in the model. Attempts have been made to include soil quality, market access and solar radiation to control for such effects (Mendelsohn et al., 1994; Kumar and Parikh, 1998). The other weakness of the Ricardian model is that it does not include price effects (Cline, 1996). It also does not account for price changes as it assumes that prices are implicitly constant (Elbehri and Burfihser, 2015).

3.2 Empirical Review on Climate Change Impact on Agriculture

Despite the weaknesses, the Ricardian model has been used in many studies. (Ali et al., 2021; Hossain et al., 2019) employed the Ricardian model in estimating the economic effects of climate change on the net revenue from crop cultivation in Pakistan and Bangladesh. The findings demonstrated that crop revenue is susceptible to climate change and fluctuation in both countries. Net revenue losses are highly correlated with a rise in the yearly average temperature and a decrease in rainfall. While an increase in temperature is expected to hurt net revenue, an increase in precipitation is seen to have beneficial impacts. In Bangladesh for instance, marginal impact estimates indicate that temperature rise in agro-ecological zones (AEZs) with adequate irrigation systems was shown to be favorably influencing crop revenue. However, the effects will differ greatly depending on cropping season and location. The studies further revealed that not all the zones would be affected equally by expected climatic changes.

In Sub-Saharan Africa, similar studies have been undertaken, some supported by the World Bank (Benhin, 2008; Dessalegn and Akalu, 2015; Gbetibouo and

Hassan, 2005; Gemeda and Debela Hunde Feyssa, 2015; Herrero et al., 2010; Kogo et al., 2021; Mano and Nhemachena, 2007; Molua et al., 2007; Mulwa et al., 2016; Ochieng et al., 2016; Mariara and Karanja, 2007), on estimating economic impacts of climate change on agriculture for various countries. The studies also investigate whether there are any significant differences in the effects between irrigated farms and dryland farms and between large-scale and small-scale farms.

A synthesis of these studies and a similar one in South America by Mendelsohn (2009) concluded that farmers in the tropical and sub-tropical regions suffer greater losses from even marginal changes in climate than those in temperate regions. The studies also conclude that climate change is expected to have mixed impacts with some of the AEZs gaining and others losing. Climatic variables (temperature and precipitation) have significant effects on crop revenues. The analysis indicates that crop revenues are affected negatively by increases in temperature and positively by increases in precipitation.

In South Africa for instance, (Benhin, 2008) found that the differences between the impacts on large-scale farms and small-scale farms were not very clear-cut, because they are overshadowed by the impacts of whether a farm is irrigated or not. The results also revealed seasonal differences in the impacts. An increase in temperature will affect crop net revenues negatively in the summer farming season but positively in the winter season. The studies also conclude that under current conditions, farmers practicing irrigated agriculture experience less damage than dryland farmers showing that seasonality and moisture availability frequently constrain agriculture.

3.3 Climate Financing Mechanisms

There is no internationally agreed definition of climate finance (Bucher et al., 2011) but broadly, it refers to financial support for mitigation and adaptation activities, including capacity-building, research and development, and broader efforts to enable the transition towards low-carbon, and climate-resilient development. In addition, climate financing as defined by the United Nations Framework Convention on Climate Change (UNFCCC) refers to local, national, or transnational money from public, private, and alternative sources aimed at supporting climate change mitigation and adaptation efforts. Furthermore, Climate Policy Initiative (CPI), 2013 defines climate finance as specific capital flows from developed to developing countries with direct or indirect greenhouse gas mitigation or adaptation objectives towards a low-carbon and climate-resilient development pathway.

Climate finance at the international arena emerged following the Copenhagen climate talks in 2009. The Paris Agreement reinforced industrialized countries' commitment from the 2009 Copenhagen Accord to mobilize US$100 billion per year by 2020 to fund climate change mitigation and adaptation in developing countries. Climate finance is still essential to spur mitigation and adaptation efforts in developing nations with severe climate change consequences. Strong financial structures that comprise systems, initiatives, and programmes supporting mitigation and adaptation measures are necessary for an effective response to climate change problem.

As implementation of the Paris Agreement on climate policy gathers momentum worldwide, it is becoming increasingly clear that developing African countries will need efficient and enabling financial and technical help as finance is a key factor in determining a country's response to climate change (Odhengo et al., 2019). Since 2010, many developed countries have channeled climate financial support through bilateral and multilateral agencies, and other international organizations. In the last few years (2010-2018), many funds have emerged to finance climate change activities in developing countries. Some estimates show that annual global climate finance may be as high as US$359 billion (Buchner et al., 2019). Sixty-two per cent (62%) of these funds were from the private sector.

Overall, the climate finance flows are lower than required investment needed to shift global economy to a below 2°C pathway. Climate funds flow through several mechanisms such as multilateral funds and other climate finance initiatives through bilateral institutions. These support low-carbon and climate-resilient projects through diverse economic and financial instruments, including policy incentives; risk management; grants; low-cost debt; and capital instruments, such as project-level market rate debt, project-level equity, and balance sheet financing. Similarly, multiplicity funding avenues complicate the process of accessing the climate finances, while at the same time making the process of monitoring, reporting and verification (MVR) difficult.

Under the UNFCCC, two funds, the Least Developed Country Fund (LDCF) and the Special Climate Change Fund (SCCF), exist to support mitigation and adaptation needs of developing countries. LDCF addresses the special needs of the Least Developed Countries by financing the preparation and implementation of the National Adaptation Programmes of Action (NAPAs). The NAPAs outline country priorities for adaptation actions in sectors and resources that are central to human and socioeconomic development. More than US$10 million is available for NAPAs and countries can apply for full cost funding of up to US$200,000 (World Bank, 2013).

The SCCF was established in 2001 to support activities, programmes and measures under four financing windows namely: adaptation to climate change; technology transfer; mitigation in selected sectors including: energy, transport, industry, agriculture, forestry and waste management; and economic diversification. In addition, the fund supports countries to prepare their (initial) National Communications to the UNFCCC and strengthen implementation of related adaptation activities. The SCCF is characterized by lack of adequate and predictable resources amid a growing demand (GEF, 2013).

Kenya has the potential to access a variety of climate financing tools and windows like different bilateral funds that are outside the framework of the UNFCCC (Odhengo et al., 2019). Other opportunities include those that are part of the UNFCCC multilateral funds framework like the Green Climate Fund (GCF), Global Environment Facility (GEF), and Adaptation Funds. The country could also take advantage of domestic sources of climate finance such as corporate investments and national budgetary allocations.

4. Method and Model Specification

4.1 The Ricardian Method

This study applied the Ricardian method developed by Mendelsohn et al. (1994) to measure the value of climate in US agriculture. This analysis is based on the assumption of a direct cause and effect relationship between climate events and farm value. Ricardian approach is preferred to the traditional estimation methods, given that instead of ad hoc adjustments of parameters that are characteristic of traditional approach, the technique automatically incorporates efficient adaptations by farmers to climate change. Furthermore, Ricardian analysis incorporates the substitution of different inputs and the introduction of alternative activities that each farmer has adopted in light of the existing climate (Kurkurlasuriya et al., 2004). The analysis of climate change impact on agriculture applying the Ricardian approach uses net crop revenue as a dependent variable, a more robust measure given concerns about equilibrium as it measures what the farmer currently receives without any concerns for future returns, discounting, capital or labour markets.

The Ricardian method is superior to other methods as it accounts for changes in management practices and adaptation measures taken by the farmers according to the changing local climatic conditions to maximize their outputs and farm incomes, through pursuit of certain adaptation measures such as crop diversification, mixed cropping, irrigation, different planting dates, water and soil conservation practices (Mariara and Karanja, 2007; Mendelsohn 2014). Furthermore, the Ricardian method relies on cross-sectional data with the flexibility to consider all major enterprise activities. Lastly, the Ricardian method is relatively simple to implement compared to other methods. However, it also has some weaknesses. The first shortcoming is the likelihood of omitted variable bias, which exists in all cross-sectional analyses. It does not account for CO_2 fertilization effects. Moreover, the method cannot capture the transition cost of a sudden adaptation against climate. However, in the real world a swift adaptation to new technology is barely practiced.

The basics of the Ricardian model were built on the simple profit function (V) which is the difference between total revenue (PQ) and total cost (PX). The basic model can be stated as Equation 1 (Mendelsohn et al., 1994, 2014).

$$V = \sum P_i Q_i (F,X,G,M,R) - \sum P_x X \qquad 4.1$$

Where V, is the net crop revenue; P_i is the market price of crop i, Q_i is the output of crop i, F is a vector of climate variables, X is a vector of purchased inputs (other than labour and land), G is a set of socioeconomic variables such as household size, and average education, M is a set of farm characteristics such as farm size, access to credit, and access to extension services, R is a dummy variable representing adaptation measures and P_x is a vector of input prices. Given the characteristics of the farm and market prices, it is assumed that the farmer will select input X that maximizes the net crop revenues (Mendelsohn, 2014).

4.2 Empirical Model Specification

A quadratic formulation of climate is the foundation of the standard Ricardian model (Mendelsohn and Dinar, 2009) and as a result, the net crop revenue can be stated as shown in Equation 2:

$$V=\beta_1+\beta_2 F+\beta_3 X+\beta_4 G+\beta_5 M+\beta_6 R+u \quad 4.2$$

Where V is the net crop revenue, F is a vector of climate variables, X is a vector of purchased inputs (other than labour and land), G is a vector of household socioeconomic variables, M is a vector of farm characteristics such as farm size, access to credit, and access to extension services, R is a dummy variable representing adaptation measures to capture farmers' adaptation to climate change (for example, use of irrigation), β represent the coefficient of the explanatory variables and u is the error term.

The Ricardian model regresses the natural log of net crop revenue per acre against long term climate variables and other control variables. Then, projecting in the future the estimated relationship between economic performance and long run climate variables allows us to account for climate impact (De Salvo et al., 2013; Mendelson et al., 1994). Most of the Ricardian model applications use seasonal climate variables (Mendelsohn and Dinar, 2009) since seasonal differences in temperature and precipitation have a significant impact on farmland productivity. This study used seasonal data, annual average temperature and average monthly precipitations for the cropping seasons and harvesting seasons, like studies by De Salvo et al., 2013; Fleischer et al., 2011. We could not use soil characteristics as a control variable because it was not easily available for each farm included in the sample. We, however, used the use of irrigation to cater for adaptation measures taken by the farmers.

For temperature and precipitation, linear and quadratic terms are introduced to capture the level and non-linearity for climate effects. The temperature and precipitation hot season – defined as the average temperature and precipitation for March to May (long rain) and October to November (short rain) and temperature and precipitation cold season – defined as the average temperature and precipitation for June-August (cold season) because this is the standard specification employed in the pioneering Ricardo study to capture seasonal effects (Mendelsohn et al., 1994). The quadratic term is included in the model to capture the non-linear associations of climate variables and net crop revenue, which will indicate how the marginal effect will change as one moves away from the mean (Mendelsohn, 2014). If a positive coefficient for the quadratic term is obtained, the function assumes a U-shaped form (convex function), whereas if the value is negative, the function assumes a hill-shaped form (concave function). Based on the reviewed literature and previous cross-sectional analyses, it is expected that net crop revenue will have a hill-shaped relationship with temperature, implying that each crop has a known temperature at which it grows best throughout the seasons.

Equation 2 can be re-written as Equation 3, which assumes a quadratic relationship between log of net crop revenue and climate variables to reflect the non-linear relationship that is consistent with other studies.

$$Vlog=\beta_0+\beta_1 Th+\beta_2 T_h^2+\beta_3 Tc+\beta_4 T_c^2+\beta_5 Ph+\beta_6 P_h^2+\beta_7 Pc+\beta_8 Pc2-\beta_9 X+\beta_{10} G+\beta_{11} M++\beta_{12} R+\mu \quad 4.3$$

Where:

Vlog represents logarithm of net crop revenue (acre) – measured as (average price in Ksh of 90kg bag of crop in 2013);

T represents the mean temperature measured in degree Celsius;

P represents the mean precipitation measured in millimetres;

h represents the hot season (January to February, March to May and October to December for 2013);

c represents the cold season (June to August for 2013);

X represents a vector of purchased inputs (other than labour and land);

G represents a vector of household socioeconomic characteristics;

M represents a vector of farm and farmer characteristics;

R represents dummy representing irrigation as an adaptation measure;

β_i are the coefficients of the variables;

β_o is the constant term; and

μ is the error term.

To facilitate interpretation of the climate impact, we calculate the marginal effects of climate variables at sample means. From Equation 3, we can derive the marginal impact of a hot season temperature (Th) and hot season precipitation (Ph) on net crop revenue per acre evaluated at the mean as follows:

$$MI_{Th}=dV/d_{Th} = [\beta_1+2\beta_2 Th] \quad 4.4$$

$$MI_{Ph}=dV/d_{Ph} = [\beta_5+2\beta_6 Ph] \quad 4.5$$

The empirical process begins by estimating the response of crop revenues to climate variables only. The second model adds farm characteristics to the first model to add spatial heterogeneity in net crop revenue while the third model adds social economic variables and adaptation measures to the second model. Econometric analysis with cross-sectional data is usually associated with the problem of multicollinearity, heteroskedasticity, and the effect of outliers in the variables. The study implemented a quantile regression, which reduces the weight of the outliers and correcting for heteroskedasticity. Multicollinearity was reduced by dropping the variables that proved correlated with each other. This method provides a complete picture of the relationships between the outcome of y (Net Crop Revenue/Acre) and the regressors xi (climate variables and control variables). Moreover, quantile regression permits us to study the impact of such variables on both the location and scale parameters of the model, allowing a richer understanding of the data (Cameron and Trivedi, 2005). In our case we ran a regression, choosing the median as a statistical indicator of central tendency since a median regression is more robust to outliers than a mean regression. Finally,

it does not need any assumption about the parametric distribution of regression errors, since median regression is a semi-parametric approach.

4.3 Kenya's Planting Calendar by Region and Crop Stage

Tables 4.1a to 4.1c shows the planting calendar for various crops by region and crop stage. The details for specific crop and season by county and region are presented in Annex 2.8. Tables are important in showing how the four climatic variables (in Table 4.2) used for Ricardian analysis were constructed as indicated in Table 4.3.

Table 4.1a: Kenya planting calendar by region and crop stage (maize)

Region	Crop type	Planting period	Reproductive period	Ripening period	Harvesting period
Long rain season					
Western	Maize	February-March	March-June	July-August	September
Noth Rift	Maize	March-May	May-July	August-October	November
South Rift	Maize	February-May	May-July	July-October	September-December
Central	Maize	March-April	April-June	July-August	September
Eastern	Maize	March-April	April-May	June-July	August
Coast	Maize	March-April	April-June	June-August	September
North Eastern	Maize	March-April	April-May	June-July	August
Short rain season					
Western	Maize	August-September	September-December	January-February	March
Noth Rift	Maize	No short rain season			
South Rift	Maize	August-September	September-December	January-February	March
Central	Maize	October-November	November-December	January-February	March
Eastern	Maize	October-November	November-December	January-February	March
Coast	Maize	October-November	November-December	January-February	March
North Eastern	Maize	October-November	November-December	January-February	March

Table 4.1b: Kenya planting calendar by region and crop stage (beans and other crops)

Region	Crop type	Planting period	Reproductive period	Ripening period	Harvesting period
Long rains season					
Western	Bean Green grams Cowpeas	February-April	March-May	April-June	July
Noth Rift	Beans	April-May	May-June	June-July	August
South Rift	Beans	March-April	April-May	May-June	July
Central	Beans	March-April	April-June	June-August	September
Eastern	Beans Green grams Cowpeas	March-April	April-May	June-July	August
Coast	Beans Green grams Cowpeas	March-April	April-May	June-July	August
North Eastern	Beans	March-April	April-May	May-June	July
Short rains season					
Western	Bean Green grams Cowpeas	August-October	September-November	November-December	January
Noth Rift	Beans	September-October	October-November	November-December	January
South Rift	Beans	September-October	October-November	November-December	January
Central	Beans	October-November	November-December	January-February	March
Eastern	Beans Green grams Cowpeas	October-November	November-December	December-January	February
Coast	Beans Green grams Cowpeas	October-November	November-December	January-February	March
North Eastern	Beans	October-November	November-December	December	January

Table 4.1c: Counties distribution per region

Region	Counties in each region
Western	Nyamira, Kisii, Migori, Homa Bay, Kisumu, Siaya, Kakamega, Bungoma, Busia and Vihiga
Noth Rift	Trans Nzoia, Uasin Gishu, Elgeyo Marakwet, Nandi, West Pokot, Baringo, Samburu and Turkana
South Rift	Kajiado, Narok, Bomet, Kericho and Nakuru
Central	Nyandarua, Nyeri, Laikipia, Kiambu, Murang'a and Kirinyaga
Eastern	Kitui, Machakos, Makueni, Embu, Meru, Tharaka Nithi, Isiolo and Marsabit
Coast	Taita Taveta, Kwale, Mombasa, Kilifi, Tana River and Lamu
North Eastern	Garissa, Wajir and Mandera

4.4 Measurement of Variables

The variables used in the analysis of the impacts of climate change on net crop revenues are defined in Table 4.2.

Table 4.2: Definition and measurement of variables

Ricardian model variables	Variable name	Definition	Measurement	Expected sign
V=V_log	Net crop revenue per acre	Logarithm of net crop revenue per acre	Calculated as the total value of crop (Kgs) less input cost (using 2013 prices of a 90 Kg bag of maize in Ksh (5,000 - approx. 55.5/Kg))	+
F	**Climate variables**			
Th	Temp_Hot season	January-February temperatures	Average degree Celsius	±
Th2	Temp_Hot season sq	January-February temperatures Sq	Average degree Celsius	±
Tc	Temp_Cold season	June-August temperatures	Average degree Celsius	±
Tc2	Temp_Cold season sq	June-August temperatures Sq	Average degree Celsius	±

Ph	Preci_ Hot season	March-May and October-December Precipitation	Average in mm	±
Ph2	Preci_Hot season sq	March - May and October – December Precipitation Sq	Average in mm	±
Pc	Preci_Cold season	June - August Precipitation	Average in mm	±
Pc2	Preci_Cold season sq	June - August precipitation Sq	Average in mm	±
M	**Farm and farmer characteristics**			
M1	Access to Extension Service	Farmers who accessed extension service	Dummy-(Yes=1; No=0)	+
M2	Access to credit	Farmers who accessed agricultural credit facilities	Dummy-(Yes=1; No=0)	+
M3	Livestock_ ownership	Livestock rearing of by H/H	Dummy-(Yes=1; No=0)	+
M4	Priority crops	Main crop grown (Maize)	1 = Maize; 2 = Beans; 3 = Other crops	+
M5	Total area under crop	Land used for farming	Acres	±
G	**Household characteristics**			
G1	Gender	Gender of H/H head	Dummy (M=1; F=0)	+
G2	Age	Age of H/H head	Count (in years)	+
G3	Education level	Average years of education of the H/H head	Count	+
G4	Occupation	Main occupation of H/H head	Categorical	+

G5	Household size	No. of persons in a given household	Count/No	±
G6	Poverty_ index	Population living below poverty index	Percentage (2005), county based	±
R	**Adaptation measure**			
R	Access to irrigation	Irrigation use at any point of the year	Dummy (Yes=1; No=0)	+

Source: Authors' compilation based on the literature review

4.4.1 Dependent variable

The dependent variable for the analysis was the net crop revenue per acre. However, there were negative net crop revenue values derived from several observations. Besides, regression using these values produced large coefficients. To avoid this, we took the smallest value (negative +1) of the net crop revenue per acre and added across all the observations and then took the logarithm of the new net crop revenue value for all the observations. The logarithm of the net crop revenue per acre (V_log) was used as a proxy for the dependent variable (net crop revenue per acre). To arrive at the net crop revenue values, the gross crop revenue was calculated using the average of the 2013 value of maize per 90 kg bag (equivalent to Ksh 55.5 per Kg) and the cost of all inputs derived from the survey. The net crop revenue was then calculated by substracting the cost of all inputs (for example, fertilizer, seeds, and pesticides) used by the farmers in the survey. To obtain the net crop revenue per acre, we divided the new total crop revenue values by the farm size (total area under crop cultivation) for all observations.

4.4.2 Explanatory variables

The relationship between climate change and net crop revenue is complex and is confounded by other factors including social economic and farm characteristics as described below:

(a) Climate Variables

The climate variables used are temperature and precipitation. The two variables were split into hot and cold seasons as described in Table 4.3.

Table 4.3: Description of climate variables

Climate variable	Calendar period	Crop stage and weather condition
Temperature – Hot season	January-February	Ripening and harvesting for the short rains
Temperature – Cold season	June-August	Vegetative and ripening for the long rains Planting for the short rains
Precipitation – Hot season	March-May and October-December	MAM – Planting for the long rains and harvesting for the short rains OND – Planting for the short rains
Precipitation – Cold season	June-August	Vegetative and ripening for the long rains Planting for the short rains

(b) Farm and farmer characteristics

- *Access to extension services:* Agricultural extension services play a crucial role in enhancing farm productivity and income. They are the main conduit for disseminating information on farm technologies, supporting rural adult learning, and assisting farmers in developing their technical and managerial skills. Studies show that access to extension services can have a positive impact on crop revenue through increased productivity, improved farm management, and reduced use of inputs.
- *Access to credit:* Access to agricultural credit can have a significant positive impact on crop revenue by enabling the purchase of better inputs and technologies, improving farm management, and increasing income. Studies have shown that access to agricultural credit increases the yields.
- *Livestock ownership:* Livestock ownership can provide an alternative source of income and serve as a buffer against crop failures due to climate variability. It can also enhance crop revenue by using manure as fertilizer and integrating crop-livestock systems (Waseem et al., 2023; Mzyece, and Ng'ombe, 2020) in the rearing of livestock.
- *Priority crops:* The crops were grouped into three categories; maize, beans and other crops based on the first two choices of priority crops reported by farmers in the survey.
- *Total cropped area:* The total area under cultivation can influence crop revenue, as larger areas may lead to higher production. However, this relationship is also affected by the quality of land, availability of irrigation, and other factors (Matthew, 2022; OECD, 2024; Emran et al., 2021).

(c) Household characteristics

- *Gender of household head:* The gender of the household head can influence agricultural practices and access to resources. Studies have shown that female-headed households may have less access to land, credit, and extension services, which can affect their ability to adapt to climate change and maintain crop revenue. Gender implications of agricultural commercialization can lead

to changes in women's decision-making agency and control over resources, impacting crop revenue (Berhane et al., 2022).

- *Age of household head:* The age of the household head can have a significant impact on crop revenue. However, the relationship is not always straightforward and can depend on various factors as some studies have shown. Some studies have found a negative association between the age of the household head and crop revenue. As the age of the household head increases, the likelihood of crop diversification decreases, which could potentially lead to lower crop revenue. This could be due to older farmers being less likely to adopt to new technologies or practices.
- *Average education of the household head:* Education plays a significant role in the ability to understand and implement adaptation strategies for climate change. Educated farmers are more likely to adopt innovative farming techniques and manage resources efficiently, potentially leading to increased crop revenue (OECD, 2019).
- *Occupation of household head:* The occupation of the household head can significantly impact crop revenue, but the direction and magnitude of this impact can depend on various factors, including the nature of the occupation and the specific circumstances of the household. If for example the household head's primary occupation is farming, they may have more time and resources to devote to farming activities, which could potentially lead to higher crop revenue. If the household head has a non-farming occupation, they might have additional income that can be invested in farming activities, such as purchasing better quality seeds or hiring labour, which could increase crop revenue. However, they might also have less time to devote to farming, which could potentially decrease crop revenue.
- *Household size:* Larger households may have more labour available for farming, but they also have more mouths to feed, which can affect the allocation of resources and crop revenue. The social demographics of households, including size, can influence decisions to adopt sustainable agricultural practices (SAPs), which are crucial for adapting to climate change (Berhane et al., 2022).
- *Poverty index:* Poverty can limit a household's capacity to invest in climate-resilient agricultural practices, affecting crop yields and revenue. Climate-induced crop yield changes can have significant poverty implications, with impoverished households experiencing increased vulnerability (Thomas et al., 2010).

(d) Adaptation measure

Use of irrigation can significantly influence crop revenue in various ways. First, by providing a consistent water supply, irrigation helps crops grow more efficiently, leading to higher yields. This is especially important in regions with irregular rainfall (Olamide et al., 2023). Secondly, adequate irrigation ensures that crops receive the right amount of water at the right times, which can improve the quality of the produce thereby translating to higher market prices. Thirdly, with reliable

irrigation, farmers can grow a wider variety of crops, including those that are more water-intensive but potentially more profitable. Fourthly, irrigation reduces the risk of crop failure due to drought, providing a more stable income for farmers (Ibid). Overall, the use of irrigation can lead to higher productivity, better crop quality, and increased revenue for farmers.

4.5 Data and Data Sources

The primary data were collected through a national survey conducted in 2013 by the Agriculture Sector Development Support Programme (ASDSP) covering a sample of 12,651 farm households randomly selected from all the 47 counties of Kenya. The survey considered the cropping seasons of 2013. The questionnaire was developed to collect detailed information on the socioeconomic characteristics of the sampled households including basic household information (such as gender, farmer's age, education, and household size). The farm characteristics include farm size, access to farm credit, distance to market, access to extension services, and access to irrigation. Furthermore, the questionnaire also collected information relating to crop types, growing seasons of different crops, costs and amounts of inputs used such as seeds, pesticide, and fertilizer.

This study settled on the analysis of maize production to cover the first objective on examining the relationship between net crop revenue and climate change and other economic variables and the second objective on forecasting the effects of climate change variation on net crop revenue. The production values of maize used are as reported by the farmers. To calculate the gross and net revenues, a 90 kg bag of maize was converted into Ksh at the 2013 price of Ksh 5,000. To get the net revenue per acre, the net revenue was divided by the total area under cultivation per each farmer. The climate data is based on average for maximum and minimum temperature and precipitation for the growing seasons; January-February, March-April-May (MAM) and October-November-December (OND) for the hot season and the period June-July-August (JJA) for the cold season for temperature and precipitation. The data was obtained from the Kenya Meteorological Services (KMS). The poverty index used was for 2005, given that the survey data was for 2013 and was obtained from Kenya National Bureau of Statistics (KNBS) survey of 2005. For the third objective on climate financial flows and composition to the agriculture sector in Kenya, we used FAO MAFAP 2013/14 to 2017/18 database. Flow for climate change financing in agriculture covers mitigation and adaptation activities.

A quantile regression was implemented to examine the impact of a set of climate variables and other control variables on the outcome variable, the net crop revenue per acre. This method was chosen because it provides a complete picture of the relationship between the outcome (net crop revenue/acre) and the regressors (climate variables and control variables). Furthermore, quantile regression allowed us to study the impact of these variables on both the location and scale parameters of the model, enabling a deeper understanding of the data (Cameron and Trivedi, 2005). In the case of this study, we ran the regressions choosing the median as a statistical indicator of central tendency since a median

regression is more robust to outliers than a mean regression. It also does not need any assumption about a parametric distribution of regression errors, since median regression is a semi-parametric approach. STATA software was used to implement the analysis in this study.

4.6 Descriptive Statistics

4.6.1 Descriptive statistics for the model variables

Table 4.4 presents the descriptive statistics (mean, standard deviation, minimum, and maximum) for the dummy and continuous socioeconomic and farm variables used in the study. Thus, the mean value of net crop revenue per acre of land is Ksh 41,344.90. The mean age of household heads is approximately 50 years, while the maximum age is 128 years. The average family size is approximately six (6) members in each household. The average total cropped area is approximately 2.56 acres, while the maximum is 58 acres. The average net crop revenue per farmer is Ksh 52,135.19, while the maximum is Ksh 7.48 million. The average quantity of maize harvested by farmers is 1,271.09 kgs. It is important to note that there is wide variation in net revenue, cropped area, age of household heads, size of the household, and amount harvested.

Table 4.4: Descriptive statistics for model variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Net crop revenue per acre	9,663	41,344.90	390,139.40	-97971.15	22800000.00
Temperature – hot season	12,651	29.46	4.49	17.90	42.00
Temperature – Cold season	12,651	14.98	5.41	5.50	30.30
Precipitation – Hot season	12,651	185.54	52.90	66.55	264.87
Precipitations Cold season	12,651	70.79	55.70	1.48	172.77
Access to extension services	12,651	0.19	0.39	0	1
Access to agricultural credit	12,651	0.04	0.19	0	1
Livestock ownership	12,651	0.83	0.37	0	1
Priority crops	9,826	1.56	0.89	1	3
Total area under crop	9,762	2.56	3.95	0.01	58.00

Gender of household head	12,651	0.83	0.37	0	1
Age of household head	12,470	50.01	14.95	19	128
Education of household head	12,477	7.44	5.09	0	18
Main o household ccupation of head	12,414	2.61	1.53	1	7
Household size	12,651	5.63	2.62	1	20
Poverty index	12,651	46.13	17.59	12.10	92.90
Use of irrigation	12,651	0.05	0.21	0	1
County No.	12,651	26.61	13.05	1	47

Source: Authors' calculations based on ASDSP survey data and KNBS

Temperature and rainfall climate variables were calculated based on the dry season (January-February) and the main growing seasons (average of the March-April-May (MAM) for hot season and June-July-August (JJA) for cold season using 2013 climate data from Kenya Meteorological Services). Table 4.4 presents the mean, standard deviation, minimum and maximum values of all the variables used in the analysis. As can be seen from the table, for climate variables, the maximum average temperature recorded for the hot and cold seasons was 42°C and 30°C respectively, whereas the minimum average temperature recorded for the same was 17.9°C and 5.5°C, respectively. The standard deviation values of temperature for all seasons are approximately the same, indicating that the seasonal temperature is evenly distributed. Regarding the rainfall, the minimum average rainfall recorded for the hot and cold seasons were 66.55 mm and 1.48 mm, respectively whereas the maximum average rainfall for the hot and cold seasons were 264.87 mm and 172.77 mm, respectively. As indicated by the standard deviation column, there was no variation in the rainfall distribution across the hot and cold seasons each year.

The total cropped area varied from a low of 0.01 acres to a high of 58 acres. The standard deviation values of the land under crops were large, indicating that there were variations in the land under crops. The mean age of household heads was approximately 50 years, with the youngest being 19 years and the eldest being 128 years. The standard deviation of household heads was large, indicating that there were variations in the age of household heads. There were also variations in the level of poverty across the households as the standard deviation indicates.

5. Results and Discussion

5.1 Results of Estimation of Response of Crop Revenue to Climate

The estimation of the Ricardian function specified in Equation 3 follows six (6) model variations, with results presented in Table 5.1. The six (6) models were estimated to control for various explanatory variables. Models 1 and 4 focus on the climate factors (precipitation and temperature), with Model 1 controlling for use of irrigation (adaptation measure), farm and farmer characteristics as well as socioeconomic variables. In Models 2 and 5, the use of irrigation is introduced with model 2 controlling for farm and farmer characteristics and socioeconomic variables. Lastly in Models 3 and 6, other socioeconomic and farm and farmer characteristics, household size, poverty index, total cropped area, and livestock dummy are added, with Model 3 excluding squared terms for temperature and precipitation. Such an exercise is common in the literature of the Ricardian method (see Seo and Mendelsohn, 2007). The four main climate variables show significant effects on crop revenues in all the six models, as does the square of the temperature and precipitation except for the squared term of the precipitation for the cold season in Models 4 and 5 and the squared term of the temperature for hot season in Models 4, 5 and 6. A test of joint significance suggests that the combined effect of the four main climate factors is significant ($F = 81.93$; $p < 0.00$). This indicates that the estimates are robust across the six models.

Table 5.1: Response of crop revenue to climate variables, adaptation and farmer and socioeconomic variables

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Log net crop revenue/ acre	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**	**Coef.**
Temperature – hot season	-0.021*** (-4.350)	-0.000*** (-4.750)	-0.032*** (-7.280)	0.002*** (3.050)	0.003*** (2.090)	0.047* (1.910)
Temperature – Cold season	0.052*** (13.610)	0.049*** (12.710)	0.023*** (6.070)	0.105*** (5.180)	0.098*** (4.880)	0.085*** (4.510)
Precipitation – Hot season	-0.004*** (-7.830)	-0.004*** (-7.830)	-0.007*** (-12.770)	0.012*** (3.540)	0.009*** (2.830)	0.008** (-2.560)
Precipitation – Cold season	0.007*** (12.600)	0.007*** (13.030)	0.006*** (11.460)	0.005** (2.500)	0.005*** (2.810)	0.012*** (6.510)
Temparature – Hot season Sq				0.000 (-0.590)	0.000 (-0.660)	0.000 (0.380)
Temparature – Cold season Sq				0.002*** (2.720)	0.001** (2.440)	0.002*** (3.220)

Precipitation – Hot season Sq				0.000*** (-5.090)	0.000*** (-4.340)	0.000 (-0.190)
Precipitation – Cold season Sq				0.000 (1.300)	0.000 (1.090)	0.000*** (-3.290)
Access to extension services			0.147*** (3.180)			0.129*** (2.740)
Access to agricultural credit			0.145 (1.440)			0.153 (1.490)
Keep livestock			0.006 (0.130)			0.002 (0.040)
Priority crops			0.247*** (11.210)			0.252*** (11.090)
Total area cropped			-0.113*** (-24.170)			-0.113*** (-23.480)
Gender of household head			0.183*** (3.670)			0.187*** (3.670)
Age of household head			-0.003** (-1.960)			-0.003* (-1.920)
Average education level of household head			0.016*** (3.830)			0.016*** (3.780)
Occupation of household head			-0.046*** (-3.630)			-0.048*** (-3.700)
Household size			-0.009 (-1.220)			-0.010 (-1.360)
Poverty index			-0.011*** (-7.330)			-0.013*** (-7.840)
Use of irrigation		0.842*** (8.990)	0.516*** (6.120)		0.777*** (8.520)	0.486*** (5.610)
Cons	11.155*** (62.380)	11.121*** (61.490)	12.035*** (54.130)	9.989*** (15.600)	10.057*** (15.840)	12.977*** (18.980)
Observations	7,858	7,858	7,452	7,858	7,858	7,452
Pseudo R2	0.033	0.041	0.107	0.038	0.044	0.111

** Significant at ≤ 10% ** Significant ≤ 5% *** Significant ≤ 1%. (t-values in parentheses)*

The coefficients of the linear term of the hot season precipitation in Models 1, 2, 3 and 6 are negative, implying negative effects of increases in precipitation during this season. In Kenya, this can be attributed to the fact that this is the period (MAM) of long rains and any further increase in precipitation during this period could lead to flooding and destruction of crops. The cold season precipitation in all the models has a positive relationship with the crop revenues. This period (June-August) is crucial and is required for ripening and flowering of crops.

The variables for the hot season temperatures are negatively related to crop revenue, while cold season temperature variables in the models are positively associated with crop revenue. High hot season temperatures are harmful to crop production and, therefore, reduce crop revenue while high cold season temperatures are beneficial and positively related to crop revenue. This is because the hot season temperature (March-May) is the planting period followed by formative crop growth in May and June, while cold season (June-August) is the period for ripening and maturity of crops. High hot season temperatures, therefore, slow down or destroy crop growth, while higher cold season temperatures in June-August are crucial for ripening and harvesting.

For the non-linear terms for temperature variable in the hot season in Models 4, 5 and 6 are positive and significant. Furthermore, the squared terms for temperature in cold season in Models 4, 5 and 6 are significant and positive. The results implies that increases in hot season temperatures tend to benefit crop revenue with diminishing marginal benefits up to a maximum turning point after which further increases in temperature lead to negative effects on the crop revenue (Mendelsohn et al., 1994; Seo and Mendelsohn, 2007). Similarly, the non-linear terms for precipitation variable in hot season in Models 4, 5 and 6 are positive and significant, indicating that increases in hot season precipitation tend to benefit crop revenue with diminishing marginal benefits up to a maximum turning point after which further increases in precipitation will have negative effects on crop revenue.

Adding access to irrigation variable in the 2nd and 5th models helped to capture adaptation by the farmers in the face of climate change. The coefficient of irrigation use had a positive impact on crop revenue, implying the importance of adaptations to counter the effects of climate change through irrigation. This conforms to a prior expectation that the use of irrigation helps farmers to cushion themselves by increasing crop production, which increases their crop revenues.

Finally, the impact of farm and farmers characteristics and socioeconomic variables were tested. The introduction of these variables in Models 3 and 6 raised the pseudo R2 from 0.041 to 0.107 for Model 3 and 0.038 to 0.111 for Model 6. Most of the household level variables have a significant impact on crop revenue. The results for Model 3 suggest that among the control variables, the average education level and gender of the household head, access to extension services, access to agricultural credit and priority crops planted are positively associated with crop revenue, while age and occupation of the household head, household size, poverty index and total cropped area are negatively associated with crop revenue. The livestock ownership dummy has a positive impact on crop revenue though not significant, which implies complementarity between crop farming and

livestock keeping. Furthermore, access to agricultural credit, livestock keeping, and farm size variables are however not significant in determining crop revenue in both models.

One interesting result, however, stands out. A significant and negative effect of total cropped area is unexpected. This is because an increase in the area under crop would boost yields and, therefore, crop revenue. However, this is not surprising because several factors can cause an increase in total cropped land to be negatively associated with crop revenue. These may include land degradation, where expanded cropped land often involves using marginal or less fertile land, which can lead to lower yields and, therefore, reduced revenue; resource dilution, where when more land is cultivated, the resources (such as water, fertilizers, and labour) available per unit of land may decrease, leading to less efficient production and lower overall revenue; increased costs related to managing larger areas of land, which can increase operational costs for labour, machinery, and inputs; or climate risks, where larger areas of cropped land may be more exposed to climate risks such as droughts, floods, and pests and diseases. This can substantially reduce yields and revenue (Kaiser, 2021).

5.2 Marginal Effects

In the context of climate and agriculture, the Ricardian model estimates the effects of temperature and precipitation on crop yields per acre by calculating the marginal effects of the climate variables (detailed results are presented in Annex 2.7). This is done by differentiating the crop yield per acre function with respect to each variable (temperature and precipitation). This allows for determination of how a small change in each variable affects crop yield per acre. The marginal effect depends on the region's specific conditions and annual average temperature.

To facilitate interpretation of the climate impact on crop yield per acre, the marginal effects of these variables at sample means were calculated (Table 5.2). The marginal effects for cold season temperatures are positive, but hot season temperatures have larger negative effects on crop yields. The seasonal marginal effects with respect to hot season temperature are statistically significant and thus different from zero confirming that global warming is likely to have devastating effects on agricultural production unless farmers take adaptation measures to counter the impact of climate change (Kurukulasuriya et al., 2004).

Table 5.2 Marginal effects of seasonal temperature and precipitation on crop yield per acre

Seasons	Marginal effect	Std. Err.	P>z
Temperature hot season (January-February)	-29.19	0.004	0.000
Temperature cold season (June-August)	15.21	0.004	0.000
Precipitation hot season (March-May and October-December)	-19.31	0.001	0.000
Precipitation cold season (June-August)	68.58	0.001	0.000

Results on Table 5.2 indicate that the marginal effect of increases in precipitation and temperature in the two seasons are significant. The higher hot season temperatures have negative effects on the crop revenue implying that a further increase in temperatures would be harmful to agricultural production whereby a further increase in hot season temperature by 1°C would lead to a reduction in crop yield by 29.19 kgs per acre. Increases of the cold season temperatures are beneficial to crop yields whereby a further increase in cold season temperature by 1°C will increase the crop yield by 15.21 kgs per acre.

Furthermore, increase in precipitation has positive effects on crop yields in cold season when Kenya experiences short rains, whereby an increase in cold season precipitation by 1°C would lead to an increase in crop yield by 68.58 kgs per acre. The climate conditions in the hot season temperature and precipitation are the main cropping seasons and any change in climate variables affects crop yields and, therefore, crop revenue.

5.3 Forecasted Effects of Climate Change on Crop Revenues

To estimate the changes in crop yields due to changes in climate, two Global Circulation Models (GCM) results were used: The Canadian Climate Model (CCM) and the Geophysical Fluid Dynamics Laboratory Model (GFDL), which predicts 3.5°C and 4°C changes in temperature by the year 2030, respectively, for Kenya. Both models also predict a 20 per cent change in precipitation over the same period (Kabubo-Mariara and Karanja, 2006).

By analyzing variations in temperature and precipitation, it is possible to understand how climatic variables impact crop yields. The study examined the impact of adverse changes in temperature and rainfall on crop yield. Using the estimated marginal effects in Table 5.2, the study calculated the changes in crop yield for each climate scenario throughout Kenya. The change in crop yield per acre was then multiplied by the number of acres of cropland per farmer to get an aggregate national effects of climate change on crop yield. This value was then summed across all the farmers to get the total effects at the national level. The change in crop yield per acre per farmer was derived using the formula:

Aggregate climate effect $F_i = \Delta Y_i * S_i$ *5.1*

Where ΔY_i = Change in crop yield per acre

S_i = Total cropped area per farmer i

F_i = *Farmer i*

GFDL and CCM climate forecast of temperatures and precipitation assumes the changes in climate are uniform across the country. These models show that a 3.5°C increase in temperature will result in a crop yield reduction of 1.13, 90 kgs bags per acre per farmer and 28,318.57, 90 kgs bags for all farms in Kenya, equivalent to Ksh 141.59 million losses for all farms in Kenya (using the 2013 price of Ksh 5,000 for a 90 kgs bag). Furthermore, a 4°C increase in temperatures would result in a reduction of crop yields of 32,364.08, 90 kgs bags for all farms in Kenya while a 20

per cent reduction in rainfall would lead to a crop yield reduction of 109,448.30, 90 kg bags for all farms in Kenya, equivalent to Ksh 547.24 million. The combined effects of a change in adverse climate variables (temperature and rainfall) can be detrimental to crop production (Mendelsohn, 2014; Shrivastava et al., 2011). An increase in temperature of +3.5°C, combined with a 20 per cent reduction in rainfall will cause crop yield reduction of 109,550.28, 90 kgs bags of maize valued at Ksh 1,666.85 million nationally. Similarly, an increase in temperature of 4°C, combined with a 20 per cent reduction in rainfall will cause a crop yield reduction of 340,465.48, 90 kgs bags of maize valued at Ksh 547.75 million.

Table 5.3: Forecasted effects of climate change on crop yields and revenue

	Climate scenario for CCC and GFDL Models	**Impact (No. of 90 kgs bags)**	**Price of a 90 kgs bag in 2013 (Ksh 5,000)**
	Average loss (No. of 90 kgs bags) per farmer	Total loss (No. of 90 kgs bags) - National	Total loss (Ksh million) - National
+3.5°C	1.13	28,318.57	141.59
+4°C	1.29	32,364.08	161.82
20% rain reduction	4.38	109,448.30	547.24
+3.5°C plus 20% reduction	1.13	109,550.28	547.75
+4°C plus 20 % reduction	1.29	109,564.85	547.82

Source: Authors' calculation using Ricardian median regression

Thus, a further reduction in precipitation and an increase in temperature in the country will make farming unproductive. As such, effective adaptation strategies need to be considered early enough by Kenyan farmers. These findings are consistent with the studies by Mulwa et al. (2022) and Owa and Ouda (2007).

6. Conclusion and Policy Implications

6.1 Conclusion

Climate change is widely acknowledged as a global concern due to its significant effects on human life, given its multiple impacts on livelihoods. Therefore, it is a matter of great concern for economists and policymakers. This study aimed to measure the effects of climate change on net crop revenue in Kenya by employing a Ricardian method, using cross-sectional data from 12,651 randomly selected farm households across all 47 counties of Kenya.

The findings show that climate variables have a significant impact on net crop revenue per acre across Kenyan farm households in all the models, indicating both positive and negative effects of precipitation and temperature. Net crop revenue is likely to decrease during cold season temperatures and hot season precipitation, the major harvesting seasons in Kenya. The results are consistent with Ricardian studies in Europe (Van Passel, Massetti and Mendelsohn, 2016; Fabian et al., 2018) and crop studies (Olbrisch et al., 2011). The results highlight the importance of seasonal climate changes when measuring impacts and considering climate adaptation policies. Notably, the seasonal variation will be significant if climate change models predict different effects by season. Climate impacts are also likely to vary considerably across Kenya's regions because the climate is heterogeneous.

The study results provide evidence of the economic impacts of climate change on crop revenue in Kenya and suggest that Kenyan farms are indeed sensitive to climate variables such as temperature and precipitation. Furthermore, the results enhance the understanding of the nature of climate change effects in Kenya. This is crucial for predicting the possible effects of future climate change on agricultural production, which is fundamental to the country's economy. Such knowledge is key to designing adaptation policies, which are vital for climate change preparedness. The results also reveal that since Kenya's agriculture is vulnerable to climate change, if severe scenarios of climate change, as predicted, materialize, farmers in Kenya could greatly lose their crop yields and, therefore, their crop revenue. This would be a stunning blow to the agricultural sector in Kenya, which is the main contributor to GDP. The impact would be even more devastating to Kenya's most vulnerable ASAL regions.

In terms of climate financing for the agriculture sector, the examined expenditure pattern aligns broadly with national adaptation and mitigation objectives. Adaptation-related measures enhance the resilience of the agricultural sector by promoting the use of improved inputs and better technologies, providing training and extension services, conducting agricultural research, and supporting food consumption. The allocated public resources are well-matched with the objectives of the national climate change adaptation plan. However, there is a disparity between the allocated funds and the actual disbursement of climate finance for mitigation and adaptation in the agriculture sector. Furthermore, it was also not possible to establish the role of the fund's measures in climate change adaptation

or mitigation; therefore, the data was marked as "not determined" and was not used for classification.

There are caveats that readers should keep in mind when interpreting the results of this study. First, the cross-sectional analysis is vulnerable to omitted variables. One of the key problems associated with cross-sectional analysis of omitted variables in a Ricardian model is the potential for biased estimates of climate change impacts on agriculture. When important variables affecting crop revenue are omitted from the model, the estimated coefficients on the included variables may be inaccurately attributed effects that are actually due to the omitted variables (Ariel Ortiz-Bobea, 2020). This can lead to incorrect conclusions about the relationship between climate change and net crop revenue.

Lastly, since this study applied only the Ricardian approach to measure the effects of climate change on crop revenue, further research using more advanced models, such as agro-economic and CGE models, to assess these effects is recommended for future analyses. These models integrate agricultural management practices, cropping patterns, and their impacts on biogeochemical cycles, freshwater availability, and soil quality, all influenced by climate variables such as temperature and rainfall patterns (Palatnik and Roson, 2012). The CGE models simulate the simultaneous equilibrium in a set of interdependent markets, offering a global perspective on agricultural markets and land use. They are instrumental in analyzing the non-linear effects of climate change, including changes in average temperature and precipitation, as well as increases in variability, which can significantly impact crop revenues and land value (Benitez et al., 2018).

6.2 Policy Implications

The empirical findings of this study hold important implications for policymakers seeking to identify the most effective strategies and levels of intervention to address climate change, with the goal of enhancing farmers' economic stability and achieving food security. We outline a few policy implications below.

First, the study confirms that climate variables, particularly seasonal precipitation and temperature changes, significantly affect crop revenue in Kenya. Thus, it is crucial for the government to strengthen climate adaptation measures by considering the spatial and temporal distribution of climate change effects to safeguard the agricultural sector, which is a key contributor to Kenya's GDP.

Secondly, to mitigate the potential adverse effects of climate change, it is imperative to design and implement robust climate adaptation policies that prioritize enhancing agricultural resilience through the adoption of improved farming inputs and advanced technologies. Such measures may include establishing advanced research capacity for the development of new farming techniques, developing crop diversification activities, providing weather index-based crop insurance programmes, and reinforcing agricultural extension programmes to broadcast up-to-date climate-resilient adaptation strategies to farmers.

Thirdly, the findings indicate that irrigation, as an adaptation measure, improves crop revenue. Therefore, the government may need to take immediate steps to provide appropriate and timely irrigation facilities for farmers. This should include groundwater management and the harvesting and storage of rainfall water, which can be used to supplement irrigation instead of mainly relying on rainfed agriculture.

Fourth, findings that access to credit and extension services improves crop yields have implications for how extension services are offered in the country and for farmers' access to credit. The government needs to introduce and intensify farmer education programmes, such as financial literacy, and collaborate with the private sector, including banks, to develop and provide a range of financial products tailored to the needs of smallholder farmers. Furthermore, building on ongoing projects related to climate-smart agriculture, the government should consider supporting farmers with inputs such as improved seed varieties and educating farmers about the importance of adopting climate-smart agricultural practices, including improved pest management and the use of climate-resilient crop varieties.

Lastly, to improve the management and tracking of climate financing to agriculture sector, the government should ensure that funds allocated for climate change in agriculture sector are fully disbursed and effectively used for their intended purposes in both adaptation and mitigation efforts to achieve the objective of achieving food and nutrition security as outlined in the BETA plan and in the fourth medium term plan.

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Appendices

Appendix 1: Assessment of climate finance flows to agriculture sector using MAFAP data methodology

The data labelling used the Public Expenditure Review and Analysis for climate change adaptations and mitigation in agriculture (PERCC) methodology, which builds on the public expenditure analysis (PEA) framework developed under the Food and Agriculture Organization of the United Nations' (FAO) project on Monitoring and Analysing Food and Agricultural Policies (MAFAP). PERCC aims at analyzing the level and the composition of public expenditures for climate change adaptation and mitigation in agriculture by adding an additional dimension to the standard MAFAP's PEA analysis with each expenditure measure labelled as related, or not, to climate change adaptation and mitigation (or marked as not determined if information is insufficient to make a proper choice). These are further broken down into measures that are enhancing or constraining climate change adaptation and enhancing or constraining climate change mitigation efforts through decreased or increased GHG emissions, respectively. In cases where it was not possible to establish the role of the measure in climate change adaptation or mitigation, the data is marked as "not determined."

Before labelling expenditures as climate change relevant, all measures supporting the agriculture sector are considered regardless of their financing source, the finance instrument used, objectives or perceived economic impacts. The PEA includes expenditures from the national budget undertaken by either the national or county government (regardless of the ministry or agency that implements the policy), and development aid. The agriculture sector is understood in broad terms, and it includes forestry and fisheries. However, some of the key expenditures for agricultural development more broadly address rural areas and they too are included (for example, rural roads). General expenditure measures that target the entire economy are not considered, even if they generate monetary transfers to the agriculture sector.

Expenditure measures were analyzed and classified according to the way in which they are implemented. The classification makes a broad distinction between expenditures that are agriculture-specific (direct support for the agriculture sector), agriculture-supportive (indirect support for the agriculture sector) and non-agricultural expenditures. Within the agriculture-specific category, the classification made a distinction between support for producers and other agents in the value chain (for example, input subsidies, cash transfers), and general or collective support for the sector (for example, expenditures on research or feeder roads). The agents in the value chain include agricultural producers, input suppliers, processors, consumers, traders and transporters. Agriculture-supportive measures are not strictly specific to the agriculture sector but have a strong influence on agriculture sector development such as investment in rural infrastructure. The detailed classification of support follows the principle of classifying policies according to their economic characteristics (that is, the way

they are implemented), which provides the basis for further policy analysis. This allows us to understand the economic signals that public expenditures provide to the sector and to evaluate the sector's (and agents' operating in the sector) response to them. The PERCC analysis was conducted from the period 2013/14 to 2017/18, for which public expenditure data is available in the 2019 edition of the MAFAP database.

Appendix 2: Ricardian regression results

Appendix 2.1: Model 1

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval
Temparature Hot Season	-0.021	0.005	-4.350	0.000	-0.030	-0.012
Temparature Cold Season	-0.052	0.004	-13.610	0.000	-0.059	-0.044
Precipitation Hot Season	-0.004	0.001	-7.830	0.000	-0.005	-0.003
Precipitation Cold Season	0.007	0.001	12.600	0.000	0.006	0.008
Cons	11.155	0.179	62.380	0.000	10.804	11.505
Observations	7,858					
Pseudo R2	0.033					

Appendix 2.2: Model 2

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Temparature Hot Season	-0.023	0.005	-4.750	0.000	-0.033	-0.014
Temparature Cold Season	-0.049	0.004	-12.710	0.000	-0.057	-0.042
Precipitation Hot Season	-0.004	0.001	-7.830	0.000	-0.005	-0.003
Precipitation Cold Season	0.007	0.001	13.030	0.000	0.006	0.008
Use of Irrigation	0.842	0.094	8.990	0.000	0.659	1.026
Cons	11.121	0.181	61.490	0.000	10.766	11.475
Observations	7,858					
Pseudo R2	0.041					

Appendix 2.3: Model 3

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Temparature Hot Season	-0.032	0.004	-7.280	0.000	-0.041	-0.023
Temparature Cold Season	-0.023	0.004	-6.070	0.000	-0.031	-0.016
Precipitation Hot Season	-0.007	0.001	-12.770	0.000	-0.008	-0.006
Precipitation Cold Season	0.006	0.001	11.460	0.000	0.005	0.007
Access to Extension Services	0.147	0.046	3.180	0.001	0.056	0.237
Access to Agricultural Credit	0.145	0.100	1.440	0.150	-0.052	0.342
Keep Livestock	0.006	0.047	0.130	0.900	-0.087	0.099
Priority Crops	0.247	0.022	11.210	0.000	0.204	0.290
Total Area Cropped	-0.113	0.005	-24.170	0.000	-0.123	-0.104
Gender of Household Head	0.183	0.050	3.670	0.000	0.086	0.281
Age of Household Head	-0.003	0.001	-1.960	0.050	-0.005	0.000
Average Education Level of Household Head	0.016	0.004	3.830	0.000	0.008	0.024
Occupation of Household Head	-0.046	0.013	-3.630	0.000	-0.071	-0.021
Household Size	-0.009	0.007	-1.220	0.223	-0.023	0.005
Poverty Index	-0.011	0.001	-7.330	0.000	-0.014	-0.008
Use of Irrigation	0.516	0.084	6.120	0.000	0.351	0.682
Cons	12.035	0.222	54.130	0.000	11.600	12.471
Observations	7,452					
Pseudo R2	0.107					

Appendix 2.4: Model 4

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Temparature Hot Season	0.002	0.038	3.050	0.002	-0.072	0.075
Temparature Cold Season	-0.105	0.020	-5.180	0.000	-0.145	-0.065
Precipitation Hot Season	0.012	0.003	3.540	0.000	0.005	0.018
Precipitation Cold Season	0.005	0.002	2.500	0.013	0.001	0.008
Temparature Hot Season Sq	0.000	0.001	-0.590	0.552	-0.002	0.001
Temparature mp Cold Season Sq	0.002	0.001	2.720	0.007	0.000	0.003
Precipitation Hot Season Sq	0.000	0.000	-5.090	0.000	0.000	0.000
Precipitation Cold Season Sq	0.000	0.000	1.300	0.192	0.000	0.000
Cons	9.989	0.640	15.600	0.000	8.734	11.244
Observations	7,858					
Pseudo R2	0.038					

Appendix 2.5: Model 5

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Temparature Hot Season	0.003	0.037	20.090	0.003	-0.070	0.076
Temparature Cold Season	-0.098	0.020	4.880	0.000	-0.138	-0.059
Precipitation Hot Season	0.009	0.003	2.830	0.005	0.003	0.016
Precipitation Cold Season	0.005	0.002	2.810	0.005	0.002	0.009
Temparature Hot Season Sq	0.000	0.001	-0.660	0.040	-0.002	0.001
Temparature Cold Season Sq	0.001	0.001	2.440	0.015	0.000	0.003
Precipitation Hot Season Sq	0.000	0.000	-4.340	0.000	0.000	0.000
Precipitation Cold Season Sq	0.000	0.000	1.090	0.275	0.000	0.000
Use of Irrigation	0.777	0.091	8.520	0.000	0.598	0.956
Cons	10.057	0.635	15.840	0.000	8.813	11.301
Observations	7,858					
Pseudo R2	0.044					

Appendix 2.6: Model 6

Log of net crop revenue per acre	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Temparature Hot Season	0.047	0.036	1.910	0.051	-0.117	0.023
Temparature Cold Season	0.085	0.019	4.510	0.000	-0.122	-0.048
Precipitation Hot Season	0.008	0.003	-2.560	0.021	-0.015	-0.002
Precipitation Cold Season	0.012	0.002	6.510	0.000	0.008	0.015
Temparature Hot Season Sq	0.000	0.001	0.380	0.705	-0.001	0.001
Temparature Cold Season Sq	0.002	0.001	3.220	0.001	0.001	0.003
Precipitation Hot Season Sq	0.000	0.000	-0.190	0.852	0.000	0.000
Precipitation Cold Season Sq	0.000	0.000	-3.290	0.001	0.000	0.000
Access to Extension Services	0.129	0.047	2.740	0.006	0.037	0.221
Access to Agricultural Credit	0.153	0.103	1.490	0.135	-0.048	0.354
Keep Livestock	0.002	0.048	0.040	0.966	-0.093	0.097
Priority Crops	0.252	0.023	11.090	0.000	0.208	0.297
Total Area Cropped	-0.113	0.005	-23.480	0.000	-0.122	-0.103
Gender of Household Head	0.187	0.051	3.670	0.000	0.087	0.287
Age of Household Head	-0.003	0.001	-1.920	0.054	-0.005	0.000
Average Education Level of Household Head	0.016	0.004	3.780	0.000	0.008	0.025
Occupation of Household Head	-0.048	0.013	-3.700	0.000	-0.073	-0.022
Household Size	-0.010	0.007	-1.360	0.174	-0.025	0.004
Poverty Index	-0.013	0.002	-7.840	0.000	-0.017	-0.010
Use of Irrigation	0.486	0.087	5.610	0.000	0.316	0.656
Cons	12.977	0.684	18.980	0.000	11.637	14.318
Observations	7,452					
Pseudo R2	0.111					

Annex 2.7: Marginal impact of climate variables on crop yields

Qty of crop harvest/acre	dy/dx	Std. Err.	z	P>z	95% Conf.	Interval
Temparature Hot Season	-29.186	0.004	-7.280	0.000	-0.041	-0.023
Temparature Cold Season	-15.214	0.004	-6.070	0.000	-0.031	-0.016
Precipitation Hot Season	-191.307	0.001	-12.770	0.000	-0.008	-0.006
Precipitation Cold Season	-68.578	0.001	11.460	0.000	0.005	0.007

Appendix 2.8: Kenya planting calendar by region

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize - Counties: Nyamira, Kisii, Migori, Homa Bay, Kisumu, Siaya, Kakamega, Bungoma, Busia, Vihiga													
1.Western – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
1.Western – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Crop Calendar: Beans, Green grams & Cowpeas													
1.Western – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
1.Western – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize and Finger Millet - Counties: Trans Nzoia, Uasin Gishu, Elgeyo Marakwet, Nandi, West Pokot, Baringo, Samburu and Turkana													
2. Noth Rift – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
2. Noth Rift – Short Rains	Planting	The Region does not have Short Rain season											
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Irish potatoes are planted same time with other crops and harvesting is from July. Wheat is planted from June													
Crop Calendar: Beans													
2. Noth Rift – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
2. Noth Rift – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize - Counties: Narok, Kajiado, Bomet, Kericho and Nakuru													
3. South Rift - Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
3. South Rift – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Wheat and irish potatoes are planted with other crops and harvested from late July and August													
Crop Calendar: Beans													
3. South Rift – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
3. South Rift – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize - Counties: Nyandarua, Laikipia, Nyeri, Kiambu, Muranga and Kirinyaga													
4. Central – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
4. Central – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Crop Calendar: Beans													
4. Central – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
4. Central – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize, Sorghum & Millets - Counties: Kitui, Machakos, Makueni, Embu, Meru, Tharaka Nithi, Isiolo and Marsabit													
5. Eastern – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
5. Eastern – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Crop Calendar: Beans, Green grams and Cowpeas													
5. Eastern – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
5. Eastern – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize - Counties: Taita Taveta, Kwale, Mombasa, Kilifi, Tana River and Lamu													
6. Coast – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
6. Coast - Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Crop Calendar: Beans, Cowpeas and Green grams													
6. Coast – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
6. Coast – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

Region/ Season	Crop Stage	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Crop Calendar: Maize - Counties: Garissa, Wajir and Mandera													
7. Northeastern – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
7. Northeastern – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
Crop Calendar: Beans													
7. Northeastern – Long Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												
7. Northeastern – Short Rains	Planting												
	Vegetative-Reproductive												
	Ripening-Harvest												
	End of Harvest												

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