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Containing the Effects of Climate Change on Maize Yield in Kenya

Aldrine Kimtai and Juvenalis Mutiso

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Containing the Effects of Climate Change on Maize Yield in Kenya

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Abstract

Climate change has implications on agricultural production. This study examined the effects of climate change on maize yield in Kenya using annual time series data for the period 1961-2020. The Autoregressive Distributed Lag (ARDL) model was used in the estimations. The key findings from the study indicate that precipitation is one of the most important factors influencing maize production in the country. Water deficit with the combination of high temperature, which is a proxy for climate change, has a negative and significant effect on maize production while high precipitation is positively associated with maize yield. The study recommends a number of interventions to mitigate the effects of climate change on maize yield in Kenya. First, enhanced investment in irrigated agriculture both by the National and County governments with support from the private sector and other stakeholders. This would include completion of the various irrigation schemes in the country, such as the Galana Kulalu, to increase maize production in the arid and semi-arid lands (ASALs). Secondly, enhanced investment in water harvesting and storm water management initiatives are needed, while supporting sustainable and climate-smart agriculture in the country. Thirdly, dedicated efforts towards adoption of improved agricultural technology, including maize seeds and management approaches (such as appropriate tillage, and agricultural water management) to cope with climate change. This, coupled with investment in Early Warning Systems, will enhance the resilience of farmers in adapting and mitigating the effects of climate change in the country. Lastly, intensify extension services and investment in maize research through research institutions such as Kenya Agricultural Livestock and Research Organization (KALRO) in fast-maturing and drought resistant maize varieties.

Abbreviations and Acronyms

AZA	Agro-ecological Zones Analysis
ARDL	Autoregressive Distributed Lag
ASALs	Arid and Semi-Arid Lands
EAC	East African Community
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
KNBS	Kenya National Bureau of Statistics
Ksh	Kenya Shillings
SDGs	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change

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1. Introduction

Maize is among the major staple food crops in Kenya, a country where agriculture has been the backbone of the economy for years. It is not only cultivated by many Kenyans but also a major source of income and employment creation. Maize plays a crucial role in the United Nation's Sustainable Development Goals (SDGs) of reducing poverty and hunger. Integrated Food Security Phase three indicates that 3.1 million Kenyans, most of whom live in the Arid and Semi-Arid Lands (ASALs), are faced with food insecurity in the year 2022 greatly owing to the decline in maize production in 2021.

The Kenya National Bureau of Statistics (KNBS) Economic Survey (2022) indicates that maize production decreased by 12.8 per cent from 42.1 million bags in 2020 to 36.7 million bags in 2021. The imported maize almost doubled from 273,500 metric tonnes to 486,500 metric tonnes in the same period increasing the joint import expenditure on maize, wheat, and rice from Ksh 82.7 billion to Ksh 107.3 billion. Additionally, the value of marketed maize in the country decreased by 16.7 per cent from Ksh 8.2 billion in 2020 to Ksh 6.9 billion in 2021 largely attributed to low production due to unfavourable weather conditions.

Agriculture significantly contributes to the creation of employment in the country, and the Gross Domestic Product (GDP) directly and indirectly. About 70 per cent of the rural population draws their incomes from agriculture and maize contributes about 30 per cent of the total production in the country. Therefore, it is critical to increase maize yield to mitigate the loss of livelihoods and combat food insecurity in the country.

Climate change opens a new frontier of challenges on development, food security and poverty alleviation, which poses pertinent policy questions that both researchers and policy makers must grapple with. This is in light of existing empirical evidence on the impact of climate change on agriculture, particularly in maize production. The Economic Survey 2022 showed that the agriculture sector registered a decline of 0.1 per cent in 2021, compared to a growth of 5.2 per cent in 2020. This was attributed to poorly distributed rainfall. With the effects of climate change in agriculture pointing to severity, this has negative effects on maize yield and overall food security.

Kenya's mean average annual precipitation, average annual maximum temperature, and average annual minimum temperature from 1961 to 2020 were 725.60 mm, 30.67°C, and 18.93°C, respectively (FAO, 2020). Maize yield, annual precipitation, and average maximum temperature have had several spikes over the same period. Suffice to note that the study uses data for the whole country at an aggregate level, despite the fact that maize is grown in different regions of the country with different climatic conditions. In addition, the ideal temperature and precipitation levels differ from region to region.

Further, the average maximum temperature of above 30°C and average precipitation of below 550 mm tend to reduce maize yield. For instance, in 1968, Kenya recorded the lowest maximum temperature (of 29.49°C) for the review period, which was attributable to weather variability recorded that year. Maize yield increased from 1,200 kilogrammes per hectare in 1967 to 1,253.6 kilogrammes in 1968 while average precipitation rose from 900.37 mm to 1,030.88 mm (Figure 2.1). Another spike in maximum temperature occurred in 2009 when it increased from 30.89°C in 2008 to 31.48°C in 2009, maize yield decreased from 1,392.5 kilogrammes per hectare to 1,294.3 in the same period.

Despite concerted efforts to sustainably ensure a steady supply of food, Kenyan agriculture is heavily reliant on rainfall. Erratic weather patterns have in recent times, increased the risk of crop production characterised by regular crop failure in regions with low precipitation and consequently led to a decline in maize yield. The biophysical effects of climate change on the growth of maize have affected the profitability of maize farming in Kenya. The effects of climate change can be observed in an increase in arid and semi-arid lands in the country.

A reduction of maize production has implications on the welfare of households practising maize production. The welfare of the lower social class who majorly practice maize farming to fight hunger is greatly affected by the current persistent change changes. Maize is more susceptible to moisture stress relative to other crops (Nsabimana and Habimana, 2017). Therefore, the high dependence on rain-fed maize production makes the country vulnerable to supply shocks whenever there is unfavourable rainfall. The overreliance on rain-fed agriculture makes the country more susceptible to climate risks.

The consumption of maize continues to increase even as the government rallies the call to diversify the consumption basket. However, Kenya is still a maize-deficient country and to a great extent relies on imports to meet its annual consumption demand. According to Economic Survey 2022, maize production declined by 12.8 per cent from 42.1 million bags in 2020 to 36.7 million bags in 2021. Out of total cereal consumption of 7,185 thousand metric tonnes in 2021, 3,590 thousand metric tonnes which is equivalent to 49.9 per cent was maize. Additionally, out of the 4,215,000 metric tonnes, within our borders, approximately 78 per cent was produced in the country. There is, therefore, a need for policies aimed at reducing the effects of climate change on maize production.

The overall objective of this study was to assess the effects of climate change on maize production in Kenya. In addition, the study aimed to investigate the effects of precipitation variability and change in temperature on maize yield in Kenya. The literature showed that these two climate variables dictate crop yield, especially in countries like Kenya where agriculture is greatly dependent on rainfall.

There are different dimensions one can examine the effects of climate change on crop yield in the country. Among them is the study by Kirui (2014), which took the approach of maize supply response to climate variability using monthly data for the period 2009 to 2012. Whereas the approach is closely related, Kirui (2014) utilizes high frequency data while in our study we employed annual data for climate variables that is informed by the fact that maize yield is realized on an annual basis particularly the highlands maize producing regions. Mulwa et al. (2017) also employed spatial analysis for climate change for East African Community (EAC) but we must point out that our study seeks to investigate the aggregate climate change effects for the whole country taking cognizance that some regions of the country do not produce maize.

Section two of the study presents the literature review, while sections three and four outlines the methodology used to achieve the objectives of the study and empirical results respectively, while section five sums up the conclusion and policy recommendations.

2. Sector Development and Policy and Legal Framework

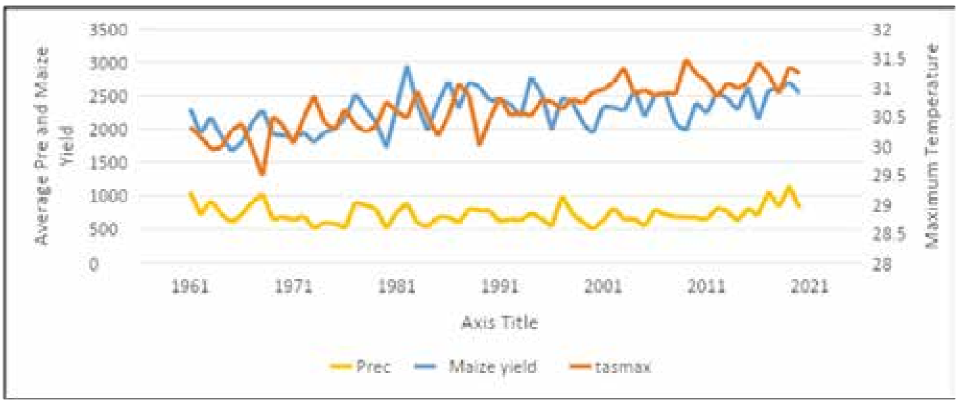
2.1 Maize Sub-Sector Development

Climate change opens a new frontier of challenges on development, food security as well as poverty alleviation. This poses pertinent policy questions that both researchers and policy makers must grapple with considering the empirical evidence of the impact of climate change on agriculture, particularly in maize production. The KNBS Economic Survey 2022 showed that the agriculture sector registered a decline of 0.1 per cent in 2021 compared to a growth of 5.2 per cent in 2020. This was attributed to poorly distributed rainfall. With the effects of climate change in agriculture pointing to severity, maize yield is threatened and in extension overall food security.

Kenya's mean average annual precipitation, average annual maximum temperature, and average annual minimum temperature from 1961 to 2020 were 725.60 mm, 30.67 °C, and 18.93°C, respectively (FAO 2020). Maize yield, annual precipitation, and average maximum temperature have had several spikes over the same period.

Further, an average maximum temperature of above 30°C and average precipitation of below 550 mm tend to reduce maize yield. For instance, in 1968 Kenya recorded the lowest maximum temperature (29.49°C) for the review period which was attributable to weather variability recorded that year. Maize yield increased from 1,200 kilograms per hectare in 1967 to 1,253.6 kilograms in 1968 while average precipitation rose from 900.37 mm to 1,030.88 mm (Figure 2.1). Another spike in maximum temperature occurred in 2009 when it increased from 30.89°C in 2008 to 31.48°C in 2009, maize yield decreased from 1,392.5 kilogrammes per hectare to 1,294.3 in the same period.

Figure 2.1: Maize yield, maximum temperature and precipitation 1961 - 2020



Data Source: Food and Agriculture Organization Statistics

Over the years, climate change has continued to impact the contribution of agriculture to Kenya's GDP growth rate. About 70 per cent of the rural population draw their income from agriculture and maize contributes about 30 per cent of the total production in the country. Therefore, it is critical to increasing maize yield to mitigate the loss of livelihoods and combat food insecurity in the country. Maize yield is highly susceptible to temperature and rainfall variability, and extreme climate events.

Dry weather conditions in 2017 led to a decline in the production of most agricultural commodities KNBS (2017). The real gross value added in the agriculture sector grew at a decelerated rate of 1.6 per cent, from Ksh 879.6 billion in 2016 to Ksh 893.3 billion in 2017 with 6.3 per cent decline in maize production between 2016 from 2017.

The overall Import Dependency Ratio of the Food Balance Sheet increased from 29.4 per cent in 2016 to 42.7 per cent in 2017 because of increased imports of vegetable products, caused by food deficits due to drought (KNBS, 2018). In 2017, the prices of maize, sugar, rice, and milk hit record highs. These high prices particularly impacted the rural areas of Kenya, where households spent more than 60 per cent of their income on food in 2017, compared to 49 per cent by their counterparts in core-urban areas.

Climate change has led to more frequent and intense extreme weather events such as drought, floods, strong winds, hailstorms, and frosts. Droughts led to losses in investments in crop production due to reduced yields or total crop failure as a result of water stress, inhibiting plant nutrient abstraction from the soil and the vital physiological processes of the plant.

2.2 Policy and legal framework

The constitution of Kenya recognizes that climate change is an issue which has implications on overall development goals. Thus at the county level the Fourth Schedule of the Constitution gives the county government the roles and functions of agriculture, soil and conservation among the fourteen functions under the constitution. Climate Change Act, 2016 is the key legislation upon which the country's response is guided. The Act's objectives are to enhance response to climate change mechanisms and to achieve low carbon climate resilient development. This is key in mainstreaming activities into sector functions and the legal foundation for the National Climate Change Action Plan 2018-2022.

Kenya Vision 2030 (2008) the country's development blueprint takes cognizance of climate change as a risk that could slow the country's development, and this is a cross-cutting thematic area. Several other interventions put in place by the government in combating climate change include Climate Change Fund, meant to finance mechanisms for priority climate actions and interventions, and National Climate Change Response Strategy (2010)–the first national policy document on climate change that seeks to integrate climate change adaptation and mitigation into all government planning, budgeting, and development objectives. Additionally, the Kenya National Adaptation Plan 2015-2030 to United Nations

Framework Convention on Climate Change (UNFCCC) 2017 provides climate change hazard and vulnerability assessment and sets out priority adaptation actions in all the planning sectors of Medium-Term Plans.

In 2016, Kenya under the Paris Agreement of the UNFCCC submitted its Nationally Determined Contribution that included mitigation and adaptation contributions to climate change with a commitment to reduce greenhouse gases (GHG) by 30 per cent by 2030. The Ministry of Agriculture in line with the government's commitment to combat climate change developed Kenya Climate Smart Agriculture (2017-2026) to adapt to climate change and build the resilience of agriculture systems for enhanced food, and nutrition security while improving livelihoods. To realize the sustainable development envisaged Kenya has put in place the National Climate Finance Policy (2018) intending to promote the establishment of legal, institutional and reporting frameworks for access to and management of climate finance. These systems aim to secure water towers and sustainably exploit the potential of our water resources, to address distribution, wastage, storage, and value addition in the agriculture sector.

3. Literature Review

3.1 Theoretical Literature Review

Production Theory

The production theory is the underpinning of this study in developing the theoretical framework and specification of the empirical model. The study assumed a Cobb-Douglas production function with the assumption that climate variables affect crop yield negatively. The production theory postulates input combinations and processes in producing outputs. Furthermore, it gives us a convenient way of summarizing the production possibility of a farm. It also gives a technologically feasible combination of production inputs and outputs. Allowing us to estimate the maximum potential output one can derive from a certain feasible combination of inputs. The general form of the theory can be expressed as follows;

$$Y=f(A, K, L) \qquad 3.1$$

Where Y is the output; A, represents the technological feasibility; K represents the capital and L represents the labour in a typical two factor Cobb-Douglas production function. The function is based on the work of economist Paul Douglas and Mathematician Charles Cobb who considered the importance of labour and capital in generating output.

Ricardian Theory

This study borrows from an observation made by Ricardo (1817) which observes that land values would reflect land productivity at site. This has been extensively utilized to value the contribution of environmental measures to farm incomes. Mendelsohn et al., (1994,1996,1999.) applied the approach in the United States and Brazil to estimate the effects of climate change on agricultural revenues and while in India the land value was substituted for annual revenue, by estimating maize yield performance as a substitute for land value on a selected climate variable, we can measure climate sensitivity on maize yield in the country. The studies that have taken this approach have mostly regressed the farm level performance on environmental factors, the traditional inputs like land and labour and support systems including infrastructure to measure the contribution of these factors to the farm outcomes as well as detecting the effects of long-term climate change on farm values. In Africa, such studies are limited, and researchers have used the developed countries' studies to examine the sensitivity of agriculture to changes in climate change.

Theory of Change

The theory of change sets out an impact pathway for efforts to reach a logical set of outcomes or impacts based on the experience and expertise. A key paper that set out the vision was Campbell et al. (2018), which proposed a theory of change for a transformation of food systems, which envisages transformative action being taken in eight key areas. One of the strong propositions is a strong farmer organizations and networking, farmer organization are the biggest stakeholders in as far as adaptation, mitigation and conservation is concerned.

Farmer organizations can be the champions of smart agriculture initiatives in the country. secondly, climate-informed advisories and early warning systems put in place will save the farmers for more adverse effects of climate change. In some cases, over the past years, farmers have run into losses by dint of lack of knowledge of delays in rainfall or unforeseen excessive rainfall during the harvest season for maize. Additionally, digital agriculture in this age and time where the new agricultural innovations like Internet of Things (IoT) are used to provide precision in agricultural practices that enhances productivity.

Climate-resilient and low-emissions practices and technologies is one of the critical cogs in combating the effects of climate change in the country. This requires prioritization and pathways of change to overcome this menace. Credit and insurance for farmers as a remedy to protecting farmers from the losses of climate change related events like floods, droughts in the arid and semi-arid lands (ASALs), this calls for expanded private sector activity and public-private partnerships, and capacity and enabling policy and institutions.

3.2 Empirical Literature Review

The effects of climate change studies have taken three most used approaches to examine the likely economic effects of climate change on agriculture. The agroecological models (crop simulation), Agroecological Zones Analysis (AEZ) (FAO, 1996) and Ricardian Cross-sectional analysis.

Crop Simulation Approach

This approach takes direct climate effects on individual crops. The study by (Parry et al., 2004) found that the crop yield decreased significantly in developing countries, particularly in Africa with the predicted expected loss of up to 30 per cent in the year 2018. The effects of temperature and precipitation changes crop yield beyond the inflection point of the beneficial direct effects of carbon dioxide (CO_2). Rosenzweig Cynthia, (1994) assessment of the impact of climate change on the food supply posits that increasing two-fold of atmospheric carbon dioxide decreases the food supply but on a smaller magnitude. While in developing countries, the food supply will be affected significantly, and they will bear the brunt of the effects of climate change and the adaptive measures employed by farmers will do little to minimize the disparity between the north and south.

Kumar and Sharma, (2022) conducted state wise study on the impact of climate change on agricultural productivity based on secondary data for the period of 1980 to 2009. The study analyzed both quantity and value in monetary terms and food security. They found out that climate change variations had a negative impact on both food and non-food grains productivity. The regression results showed most of the food crops produced per unit of land and value of producing a negative relationship.

D'Alessandro et al., (2015) study on Kenyan agricultural risks reveals that between the years 1980 to 2012, severe risk events had a negative impact on food security, particularly for the vulnerable rural populations. It notes that key crops in the country experienced massive losses in one out of three years of adverse risk events. This had a consequence on the GDP growth during the review period resulting in a decline in GDP of 2 to 4.2 per cent. It further indicates that maize experienced the highest losses by production value accounting for up to 20 per cent of the total loss.

A different study by (Parikh, 2020) used a crop simulation model to estimate yield changes under various climate change scenarios for two crops–rice and wheat. The results indicate that, projected significant changes in the climatic conditions would likely lead to a consequential reduction in crop yields.

Ricardian Cross- Sectional Analysis Approach

The Ricardian Approach measures the relationship between net revenues from crops and climate change using cross-sectional data. In their new method to measure the impact of climate change on agriculture, (Kurukulasuriya & Mendelsohn, 2008) predicted change in African crop revenue ranging from a loss of 14 per cent in mild climate scenario to 30 per cent in the harshest climate scenario. It further revealed that the greatest harm from climate change is that it will shift farms from high productivity to low-level productive agro-ecological zones (AEZ).

The impact of climate change on agricultural productivity in Sub-Saharan Africa studies finds the high significance of various variables. For instance, Mano & Nhemachena, (2007) regression of agricultural revenues against climate variables on a Ricardian framework found, the effects of climate change on Zimbabwean agriculture were quite significant. The sensitivity analysis under different climatic scenarios resulted in a net farm revenue decrease of up to US$0.3 billion. Mendelsohn et al., (2005) measured the climate change impacts on Sri Lankan Agriculture examining the net revenues from the farm for the four most important crops (rice, tea, rubber and coconut). The study found that temperature increase is predicted to be harmful varying from 20 per cent to 72 per cent impact on different crops a confirmation that climate change damages could be large in developing countries.

Agro-Ecological Zone (AEZ) Approach

In this method, studies utilize the Food and Agriculture Organization (FAO) methodology of Agro-Ecological Zones as the cornerstone of analysis. The FAO (1978) established the AEZ as the method of analyzing crop productivity. In this approach, other factors that are crucial to crop yields like soils, drainage, and crop type are reflected to capture their influence. For example, (Kurukulasuriya and Mendelsohn, 2008) posit that climate change is harmful to the agricultural productivity in Africa as it reduces the value of cropland. It further asserts that; the land will shift from high to low-value AEZs. It predicts a 5 per cent reduction in cropland and 14 per cent reduction in crop revenues.

3.3 Overview

Climate change has gained traction over the last few decades. There is a litany of literature that estimates the effects of environmental factors on crop yields. This notwithstanding, the rich empirical literature is mostly studies carried out in developed countries and the few studies that have been undertaken in the developing world have majorly examined the effects of climate change on overall agriculture but not on specific crops. Further, the different approaches employed by researchers have not utilized the traditional production theory in assessing the effects of climate change using time series data to analyze the issue.

4. Research Methodology

4.1 Theoretical Framework

Agricultural productivity is determined by efficient utilization of factors of production namely: land, labour, and capital. We used maize yield to measure the synergy and efficiency in utilization of these factors in production. To determine the nexus between maize yield and its determinants we utilized the neo-classical production function as the theoretical framework.

The convention two factor, labour and capital, Cobb-Douglas production function gives the sources of output. However, the function can be extended to include land as one of the factors of production in agriculture, it represents not only the physical but also the environment/weather aspects. The function can be specified as:

$$CY = AK^{\alpha} L^{\beta} Q^{\theta} \qquad 4.1$$

Where *CY*, *K*, *L* and *Q* are crop yield/output level, capital, labour, and land, respectively. *A* represents technology whereas α, β, θ represent output elasticities capital, labour and land, respectively. This is is an extended fashion of the standard cobb Douglas Production Function. It is therefore, in its nonlinear form. To linearize the equation, we present the variables in their log forms. This gives the following linear equation:

$$log\ log\ CY = \theta log\ log\ Q + \ K + \beta log\ log\ L \qquad 4.2$$

Where *CY* is crop yield; *Q* is land representing climate variability climate change variables; *K* is capital/farm machinery; and *L* labour force. Farm machinery represented capital used in production of maize yield.

4.2 Analytical Framework

Maize yield, just like most other crops, depends on capital, land and labour. It is affected by climate change especially in countries like Kenya where much of agriculture is rain-fed. Climate change is determined by the environment/land and can be measured in precipitation and temperature fluctuations. Therefore, Q in equation 2 can represent precipitation and temperature as climatic variables.

$$Q\theta = (Pr + MT) \qquad 4.3$$

The empirical model of the study can be derived from the theoretical framework to give the following:

$$MYt = f\,(Prt, MTt, At, Kt, Lt, Ft,) \qquad 4.4$$

Where *MY* is maize yield per hectare; *Pr* is precipitation, *MT* is annual average temperature, *A* is technology, *K* is farm machinery, *L* is labour, and *F* is fertilizer, it is included in the equation as part of capital used in maize production. MY was the dependent variable of the study while *Prt, MTt, At, Kt, L*t, and *Ft* were the independent variables. Equation4.4 above can be represented in its linear form as follows:

$$MY_t = \beta_o + \beta_1 Pr_t + \beta_2 MT_t + \beta_3 A_t + \beta_4 F_t + \beta_5 K_t + \beta_6 L_t + \varepsilon_t \qquad 4.5$$

Where β_o is the intercept, β_1, β_2, β_3, β_4, β_5, and β_6 represent the coefficients of the explanatory variables in the model and ε_t is the residual.

The study used annual time series data. The data were obtained from the Kenya Bureau of Statistics, Food and Agriculture Organization of the United Nations, Agriculture Organization of the United Nations, and the World Bank.

4.3 Variable Definition, Measurement and Expected Designs

The climate variables in our study are precipitation, maximum temperature, and minimum temperature. Technology and Fertilizer will be included as the control variables in our model.

Maize yield (MY)–is the amount of maize per hectare harvested in different agricultural lands. In Kenya, the total land under cultivation for maize production is about 1.5 million hectares. The annual average maize yield in Kenya is estimated to be 3 million metric tons. In this study, maize yield was measured in kilograms per hectare; that is the average produce per hectare. Maize yield is the dependent variable of the study.

Precipitation (Pre)–we define precipitation as the average annual liquid (for example, rain) or solid water (such as snow) falling from the atmosphere to the agricultural lands. It was calculated by summing the daily precipitation for each year and divided the value by the number of days in that year. It was measured in millimetres. We expected to have either a positive or a negative relationship between precipitation and maize yield in Kenya. This was because from little to optimal precipitation we expected to have a positive sign while the amount of precipitation beyond the optimal level could lead to floods and, therefore, affect maize yield negatively (Kang et al., 2022).

Annual Average Temperature (MT)–this was the mean annual temperature recorded each year. Different levels of temperature were recorded each day. It was calculated by summing up the total daily average temperature in each day and divided the value by the number of days in that year. It was measured in degrees Celsius. In the recent past Kenya has been experiencing relatively high annual average temperature of above 25°C. We expected to have a negative relationship between the annual average temperature and the maize yield (Ajetomobi & Ajiodun, 2010; Ochou and Ouattara 2022). Most places experience average temperatures of 29°C or more.

In most parts of the coast, average temperatures exceed 27°C and relative humidity is high year-round. From the humid coast, where annual precipitation is between 760 and 1,270 mm precipitation decreases westward to about 500 mm per year. Only on the southern coast is precipitation reliable enough for prosperous agriculture.

Fertilizer (F)–this was the amount of fertilizer per hectare used in production of maize. It was calculated by adding the total amount of fertilizer used and divided it by the number of hectares used in cultivation of maize. We expected fertilizer to affect maize yield positively (Yu et al., 2021).

Technology (A)–this represents the techniques applied to enhance the growth of maize. Because of a lack of data, time was used as a proxy. The assumption is that as time progresses, the techniques used are improved. For example, genetically modified seed varieties of maize have improved with time. The empirical literature suggests that the genetically enhanced maize strained have increased maize yields over time. We expected to have a positive relationship between maize yield and technology (Roy et al., 2019).

Labour (L)–we define labour as persons of working age who are engaged in any activity to produce maize, whether at work during the reference period or not at work due to temporary absence from work, or to working-time arrangement. It is calculated as a percentage of the total working population. The neo-classical production function suggests that labour has a positive relationship with maize yield.

Farm Machinery (K–this represents the value of farm tractors, implements of husbandry, equipment used for irrigation, and maintenance of farm equipment used in production of maize. It is calculated as the value of the equipment used in maize cultivation per hectare. We expected to have a positive relationship between maize yield and farm machinery as neo-classical function suggests.

4.4 Model Specification

Equation 4.1 could not be estimated directly due to the possibility of getting spurious results especially if the variables are non-stationary. The first test was for the form of association between climate change and maize yield and to decide whether to use the Autoregressive Distributed Lag (ARDL) Model or Nonlinear Autoregressive Distributed Lag (NARDL) Model. If the relationship was linear, the paper would adopt the ARDL Model because of its several advantages. It can be adopted in either I (0) and/or I (1) data series; it corrects for endogeneity problems, and it gives consistent/unbiased results in small-samples (Pesaran et al., 2001 & Jalil et al., 2014).

Table 4.1 represents descriptive statistics of the study. This included the number of observations, the mean, the standard deviation, the minimum value and the maximum value for all the variables.

Table 4.1: Descriptive statistics

	Obs	Mean	Std. Dev.	Min.	Max.
Maize yield	60	1548.16	253.77	1071.3	2071.2
Precipitation	60	725.60	144.97	498.41	1146.13
Average temparature	60	24.78	.42	23.69	25.56
Fertilizer	60	127272.10	93538.16	11100	378277.5
Technology	60	1990.5	17.46	1961	2020
Labour	60	4868.06	4010.67	37.36	12942.58
Farm Machinery	60	9956.41	3315.59	4904	15410.1

ARDL model is presented as follows.

$$\Delta ln(MY)_t = \beta_o + \sum pi{=}1B_1\Delta ln(MY)_{t-i} + \sum qi{=}1a1\Delta ln(Pr)_{t-i} + \sum qi{=}1B_2\Delta(MT)_{t-i} + \sum qi{=}1a2\Delta ln(A)_{t-i} + \sum qi{=}1B_3\Delta ln(F)_{t-i} + \sum qi{=}1B_4\Delta ln(K)_{t-i} + \sum qi{=}1B_5\Delta ln(L)_{t-i} + \epsilon1(MY)_{t-1} + \epsilon2(Pr)_{t-1} + \epsilon4(MT)_{t-1} + \epsilon5(A)_{t-1} + \epsilon6(F)_{t-1} + \epsilon7(K)_{t-1} + \epsilon8(L)_{t-1} + U_t \quad =4.6$$

Where β_o denotes an intercept, Δ represents the first differential and the signs before Δ represent short-run parameters. Superscript p signifies MY's optimal lag while superscript q denotes optimal lags for the independent variables. It is vital to note that *p* can be of lag 1 or 2 while *q* can have any lag length. The part of equation (4.6) with summation symbols represents the error correction dynamism while the last part of the equation with "Є" symbolizes long-run relationship (Jalil et al., 2014).

ARDL approach estimation procedure involved checking whether the variables in the model were cointegrated using the F-test (Pesaran, Shin and Smith, 2001). According to Pesaran, Shin and Smith (2001) critical value can be represented in two sets. These sets provide bounds of critical value to the classifications of independent variables into order of zero and one or mutually cointegrated. However, these values result in large sample sizes of 80 observations and beyond (Narayan, 2005). Therefore, the study used the bounds test to investigate whether there is a long-run relationship among the variables or not.

The optimal lag length was identified before the nature of cointegration was known. Once this was done, the Ordinary Least Squares (OLS) estimator was utilized to assess the chosen ARDL technique. Then, if there was cointegration then the lagged variables in equation (4.6) were replaced with ECTt-1, to produce equation (4.7), which signifies the Error Correction Model (ECM).

$$\Delta ln(MY)_t = \beta_o + \sum pi{=}1B_1\Delta ln(MY)_{t-i} + \sum qi{=}1a1\Delta ln(Pr)_{t-i} + \sum qi{=}1B_2\Delta(MT)_{t-i} + \sum qi{=}1a2\Delta ln(A)_{t-i} + \sum qi{=}1B_3\Delta ln(F)_{t-i} + \sum qi{=}1B_4\Delta ln(K)_{t-1} + \sum qi{=}1B_5\Delta ln(L)_{t-1} +$$

$\zeta ECT_{t-1} + U_t$ *4.7*

Where, ECT is error correction term, which depicts the long-run relationship in the model, ζ is the coefficient of the error correction term and it gives the speed at which the other variables' coefficients change (Catão and Terrones, 2005).

5. Results and Discussions

This section presents the study's empirical findings including pre-estimation diagnostics, for example, tests for stationarity and optimal lag length. The cumulative sum of squares results for model stability is also discussed in this section.

The stationarity test results show that maize yield, annual average temperature, labour, farm machinery, and fertilizer are stationary after one difference while precipitation and technology are stationary at level (Appendix 1). This meant that the variables were a mixture of I (1) and I (0) series. This justified why the study adopted the ARDL model.

Further, the Bounds Test results indicate that a long-run relationship among the variables exists. This is because the F-statistic is greater than the critical values of the lower bound at all levels of significance. F-statistic is 4.397 while the lower bounds are 2.26, 2.62, and 3.41 at 10, 5, and 1 per cent, respectively (Appendix 2). Hence, the long-run form of ARDL; that is, the Error Correction Model was estimated to achieve the objectives of the study.

Other tests such as Heteroscedasticity, autocorrelation and model stability were also tested. The results from Breush Godfrey Test, Cumulative Sum of Squares, and Breusch Pagan Test showed that there was no autocorrelation, the model was stable, and the error terms were homoscedastic, respectively.

Effects of precipitation and temperature on maize yield in Kenya

Since the bounds test results showed that there was cointegration among the variables, the Error Correction Model was estimated. It involved calculating the optimal precipitation and optimal temperature. Optimal precipitation is the most preferred level beyond which waterlogging and flooding may occur. Maize is sensitive to waterlogging and flooding could lead to damage, especially during harvesting time. The destruction is detrimental and could lead to low yields. Maize is also susceptible to changes in temperature, temperatures beyond the optimal point may lead to a decline in maize yield.

Table 5.1: Error Correction Model Results

Variable	ARDL_1	ARDL_2	ARDL_3
(Long Run)			
Maize Yield			
Error Correction Term	-0.6241***		
(-2.4400)	-0.5799***		
(-4.710)	-0.0592***		

(-4.4100)			
Precipitation	0.0192*		
(2.4700)	0.5001**		
(2.0800)	0.0250*		
(2.0000)			
Average Temperature	-0.009**		
(-4.110)	0.1486		
(0.7800)	0.5010**		
(0.2900)			
Labour	0.2913		
(1.8800)	-0.1524**		
(-2.9700)	0.2215		
(2.8800)			
Farm Machinery	0.0982		
(0.2100)	0.0780*		
(1.7100)	2.8800		
(2.4100)			
Fertilizer	0.0511**		
(2.7300)	0.0014**		
(2.3700)	0.0199**		
(2.3700)			
Precipitation Squared		-0.0003*	
(-2.0000)			
Temperature Squared			-0.0200*
(-2.000)			
(Short Run)			
Fertilizer	-0.1260***		
(-2.3100)	-0.0025**		
(-2.4600)			
Labour			0.0011**
(0.0500)			
Constant	-0.1482		
(-4.1100)	0.0292**		
(4.1070)	-2.0316		

(0.2100)			
***p=0.01 **p=0.05 *p=0.1 R-squared = 0.620 Adjusted R-squared = 0.509			

Optimal precipitation was calculated by including an additional variable, squared precipitation, to have an algebraic equation. This enabled us to use the coefficients of precipitation and precipitation squared to achieve optimal precipitation.

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Optimal precipitation was calculated by including an additional variable, squared precipitation, to have an algebraic equation. This enabled us to use the coefficients of precipitation and precipitation squared to achieve optimal precipitation.

Given the results in ARDL_2 in Table 5.1, the quadratic equation for the model becomes.

$$MY = 0.0292 + 0.5001Pr - 0.0003Pr2 + 0.1486MT - 0.1524L + 0.0780M + 0.0014F$$

Differentiating the equation with respect to precipitation (Pr) with and equating to zero to get the optimal point and solving it we have the following,

$$0.5001Pr - 0.0003Pr2 = 0$$

$$0.5001 – 0.0006Pr=0$$

$$0.5001=0.0006Pr$$

$$Pr=0.5001/0.0006$$

=883.5 Millimetres

We follow the same steps to calculate for the optimal annual average temperature. This was calculated from ARDL_3 in Table 5.1, where;

$$MY = 0.0012 + 0.5010MT - 0.0200MT2\ 0.0250Pr + 0.0199F + 0.0021M \qquad 4.2$$

Differentiating the equation with respect to Annual Average Temperature (MT) with and equating to zero to get the optimal point and solving it we have;

$$0.501MT - 0.01MT2 = 0$$

$$0.501 – 0.02MT=0$$

$$0.501=0.02MT$$

$$Pr=0.5010/0.02$$

=25.05 Degree Celsius

The model of interest was ARDL_1 in Table 4.3 and this was the model that we interpreted since it was our main equation. The adjusted R-squared is 0.509. It indicates that 50.9 per cent of the changes in maize yield in Kenya are explained by precipitation, annual average temperature, labour, farm machinery and fertilizer.

The coefficient error correction term is negative and statistically significant at 1 per cent level. It suggests that previous year's errors (or deviation from long-run equilibriums) are corrected within the current year at a convergence speed of 62.4 per cent.

The coefficient of the first lag of precipitation is 0.019 and statistically significant at 5 per cent level suggesting that, *ceteris paribus*, a one per cent increase in precipitation leads to 0.019 per cent increase in maize yield in Kenya. The results are consistent with the results of Qiua et al. (2022) who investigated the impact of precipitation on crop yield.

Annual average temperature has a negative coefficient that is statistically significant at 1 per cent level. It suggests that a one per cent increase in the first lag annual average temperature leads to a 0.009 per cent decline in maize yield in Kenya. This means that, other things held constant, when the level of temperature is above the optimal point it leads to decline in maize yield in the long run. These findings are in consensus with Musafiri et al. (2022) in their paper on *smallholders' adaptation to climate change in Western Kenya: Considering socioeconomic, institutional, and biophysical determinants*.

The coefficient of the first lag of fertilizer is 0.004 and statistically significant at 5 per cent level, suggesting that one per cent increase in inorganic fertilizer used in maize production leads to 0.051 per cent increase in maize yield, other things held constant. Aliyari et al. (2021) on their study on assessing climate change impacts on future water resources and agricultural productivity in agro-urban river basins. Further, farm machinery and labour are not statistically significant.

6. Conclusion and Recommendations

Climate change has adverse effects on economic growth and development. It also has negative effects on maize yield yet many people in rural areas are highly dependent on maize production for their livelihoods, food and nutrition security. Rain-fed maize production is the most dominant maize farming practice and maize is the main staple food in the country.

Increasing temperature has negative effects on maize yield. Maize is highly sensitive to climate variability than other cereal crops in the country. Precipitation is among the most important factors influencing maize yield. Additionally, water deficit with the combination of precipitation and temperature (which is one of the most important parameters for climate change) is even more significant and critical for maize production. It is evident from the study that, low levels of precipitation and high temperatures lead to a decline in maize yield in Kenya. As a result, maize yield is significantly associated with precipitation and temperature, and it's decreasing under the changing climate in Kenya, experienced through erratic rain seasons, droughts and floods.

Interventions towards curbing the effects of climate change on maize production are presented below:

- There is need for continued investment in irrigated agriculture both by the National and County governments; with support from the private sector and other stakeholders. This can be done through revival of the various irrigation schemes such as the Galana Kulalu to increase the area under irrigation in the country including the Arid and Semi-Arid Lands (ASALs).
- There is need for the National and County governments to consider water harvesting and stormwater management initiatives to preserve the water during the rainy seasons and the flooding in the country. These initiatives will go a long way to supplement the government aspirations for sustainable and climate-smart agriculture in the country and address the sustainable development goals of the United Nations, of zero hunger and food and nutrition security.
- Dedicated efforts towards provision of more technology and management approaches (for example appropriate tillage and agricultural water management) are needed to cope with climate change. The government and other stakeholders could also enhance the development of improved maize seeds that are climate resilient to accelerate gains and dissect stress adaptation. This could be done by first conducting prerequisite research to know the best seeds for different regions in the country because some seeds may work better in some specific areas compared to others.
- Investment in Early warning systems will enhance the resilience of farmers in adapting and mitigating the effects of climate change in the country.

- The government through research institutions like Kenya Agricultural Livestock and Research Organization (KALRO) could develop maize varieties that are high-yielding, fast maturing, and drought resistant. This will aid in making sure that we keep to the pace at which the population is growing at an exponential rate. The maize yield and by extension maize production in Kenya is synonymous to food and nutrition security.

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Appendices

Appendix 1: Stationarity of the variables

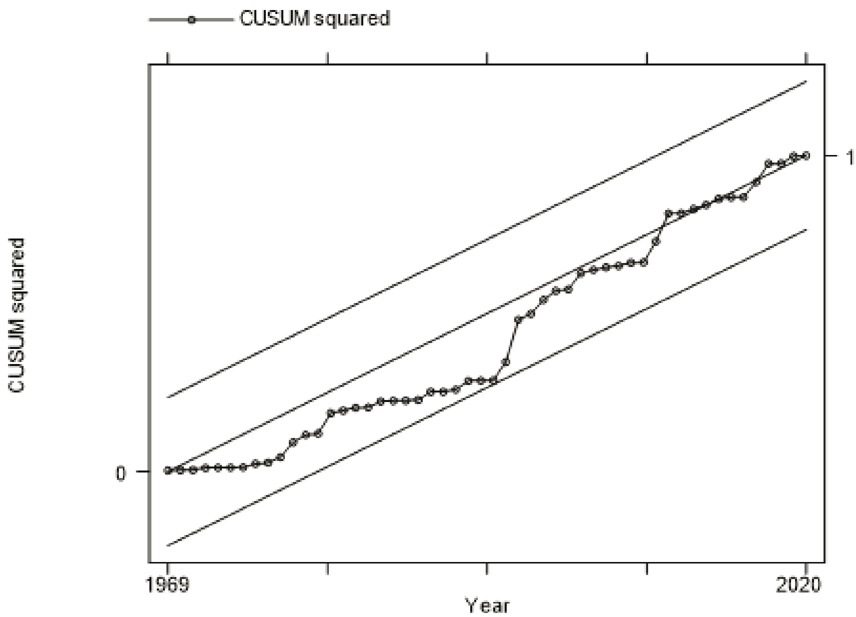
Variables at level	t-test at level	Differentiation	t-stat after 1st diff	Integ.
Maize Yield	-1.921	d.Maize Yield	-6.734	I(1)
Precipitation	-6.642			I(0)
Average Temp.	-1.152	d.Average Temp	-6.144	I(1)
Labour	-2.320	d.Labour	-7.008	I(1)
Farm Machinery	-0.305	d.Farm Machinery	-4.681	I(1)
Technology	-6.440			I(0)
Fertilizer	2.175	d.Fertilizer	-3.995	I(1)

Note: All the variables are stationary at 1% level of significance (the lowest critical value is -3.567)

Appendix 2: The nature of cointegration of the variables, Bounds Test

Test	Statistic	Critical value				
		10%		5%		1%
		I(0)		I(0)		I(0)
F-Stat	4.397	2.26		2.62		3.41
t-test	-4.530	-2.57		-2.86		-3.43

Appendix 3: Model stability



Appendix 4: Heteroscedasticity

Test	t-statistic	P-value
Heteroscedasticity	Chi2(3)=0.9	0.8257

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