Climate Change and Maize Yield in Kenya: An Econometric Analysis

George Kariuki,
Kenyatta University,
Email: kariuki.george1@ku.ac.ke.
Jennifer Njaramba,
Kenyatta University
Email: njaramba.jennifer@ku.ac.ke
Charles Ombuki
Machakos University
Email: combuki@machakosuniversity.ac.ke.

ABSTRACT

The agricultural sector plays a critical role in the Kenyan economy in terms of employment and food security. However, the sector and particularly crop farming is vulnerable to climate change, given that rain fed agriculture accounts for approximately 98 percent of agricultural activities. Crop farming in Kenya has limited diversification and maize production iscritical. Maize production forms a strong base to food security, employment, income generation, poverty alleviation, as well as economic growth and development. This notwithstanding, maize production has greatly fluctuated leaving about 40 percent of population food insecure. Maize production largely depends on climate variables and is highly sensitive to climate change. Thus, it is important to understand the effects of the changing temperature and rainfall patterns, to which this study contributes by analyzing the marginal effects of climate change on maize yield. The study adopted an econometric modeling approach using data for the period between 1970 and 2014. The study findings show that climate change has adverse effects on maize yield. In addition, the study finds a nonlinear relationship between maize yield and climatic variables. However, the direction and magnitude of the effects vary depending on the season. Hence, there is need to elevate the potential of rain fed agriculture in the midst of the risks posed by climate change.

Keywords: Maize Yield, Temperature, Rainfall, Temperature Variability, Rainfall Variability and Climate Change.

INTRODUCTION

Climate change threatens the achievement of sustainable development goals aimed at ending extreme poverty in all forms by 2030; end hunger, achieve food security and improved nutrition and promote sustainable agriculture and as well, promote sustained, inclusive and sustainable economic growth (United Nations Development Programme (UNDP), 2015). These issues are of great concern to sub-Saharan Africa where majority of the people depend on rainfed agriculture to support their livelihoods. Consequently, the effects of climate change in the agricultural sector and more specifically crop production is of great concern.

According to Intergovernmental Panel on Climate Change ((IPCC), 2014: 120), "Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". Climate change has a direct influence on quality and quantity of agricultural crop production. The climate of an area is highly correlated to the crops cultivated and thus predictability of climate is imperative for planning of farm operations (Sowunmi, 2010). Climate change is expected to increase with global warming with the average temperatures expected to increase by between 1.4° Celsius (C) and 6.4° C by 2100. This is above threshold limit of 3ºC beyond which it becomes impracticable to avoid dangerous interference with the global climatic system (World Trade Organization (WTO)&United Nations Environment Programme (UNEP), 2009). This average is anticipated to be higher throughout Africa, where average temperatureisprojected to rise 1.5 times more compared to the global level. Countries near the equator like Kenya, many of which are developing, are likely to experience unbearable heat, more frequent droughts and ruined crops, exacerbating the hunger crisis (Food and Agriculture Organization (FAO), 2012; WTO & UNEP, 2009). The increasingly irregular and erratic nature of weather conditions places more burden on food security and rural livelihoods (FAO, 2009).

In Kenya, crop production is a major source of livelihood for most rural communities practicing smallholder farming. It is mainly rain fed and changes in rainfall and temperature patterns are expected to affect its potential (Stern, 2007). Indeed, Kenya has experienced patterns of climate changes, with El Nino and La Nina episodes being most severe (Stockholm Environmental Institute (SEI), 2009). As well, temperatures are expected to increase by about 4ºC and variability in rainfall expected to rise up to 20 percent by 2030. These changes are likely to affect the optimal conditions required at each stage of crop growth and development and consequently affect the quantity and quality of harvested crops (Stern, 2007).

Crop farming in Kenya has limited diversification and maize serves as the main staple and key to food security (UNDP, 2002; Alila&Otieno, 2006). Thus, to continue supporting the livelihood of a rapidly growing population, there is need to have a sustainable increase in maize production. Although, economic incentives are provided to farmers to improve crop production, climate change is likely to undermine these efforts, threatening the livelihood of over 85 percent of Kenyan population. It is in the light of the importance of maize in Kenya's economy and to the livelihoods of majority of rural inhabitants that this study seeks to empirically determine the effects of climate change on maize yield using econometric analysis and thereof draw implications on food security as maize supply is to a large extent synonymous to food security in Kenya.

Climate Change in Kenya

From the 1960s, Kenya has generally experienced increasing temperatures at an average rate of 0.21°C per decade with trends in both minimum and maximum temperatures depicting a general warming over time. Annual highest rainfall events show a falling trend for the 24 hour intense rainfall and the amount recorded in the long rain season from 1960 to 2014 (Republic of Kenya, 2015). Figure 1 and 2 displays the year to year variability of temperature and rainfall in maize growing areas in Kenya.

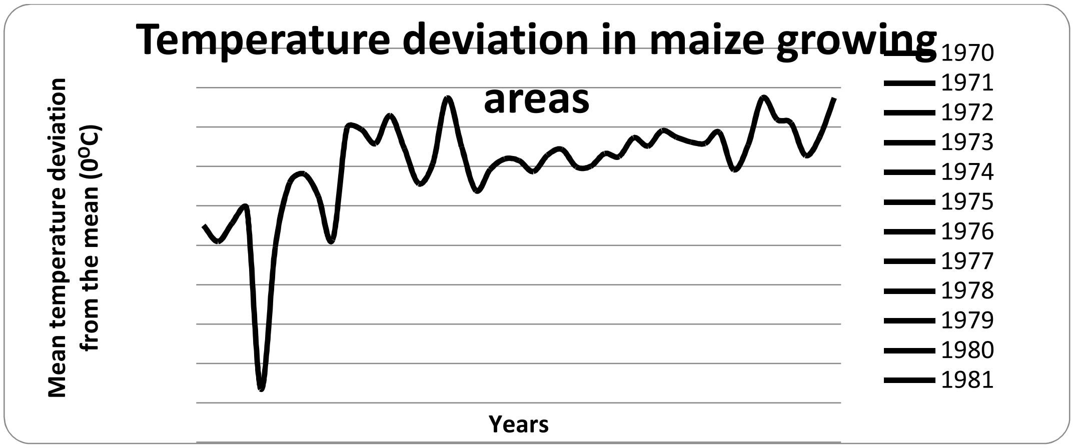

Figure 1: Annual Mean Temperature Variations in Maize Growing Areas in Kenya (1970-2014)
Source: Kenya Meteorological Department

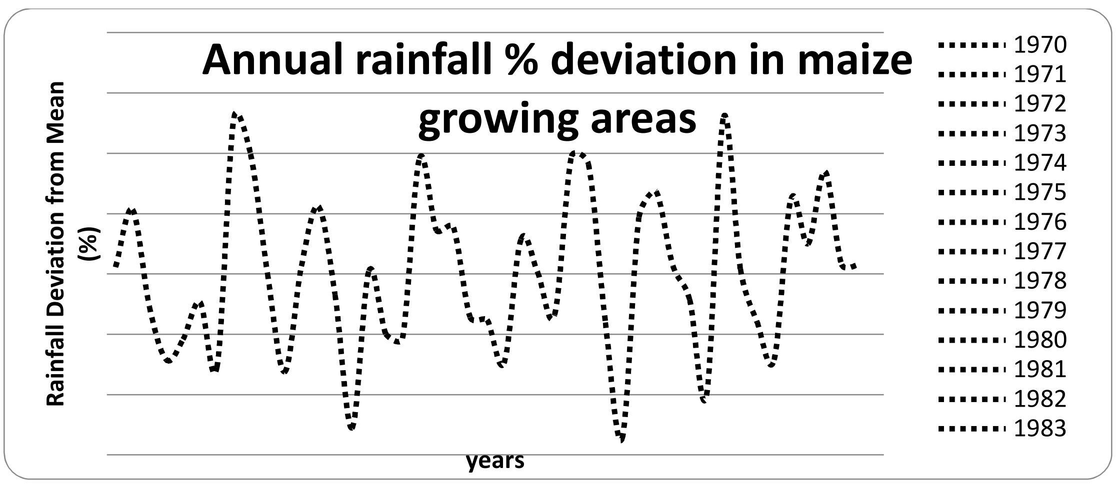

Figure 2: Annual Rainfall Deviations (%) From the Mean in Maize Growing Areas in Kenya (1970-2014). Source: Kenya Meteorological Department

The temperature and rainfall variations in maize growing areas are computed using data recorded in various weather stations, in areas where there is high potential for maize farming. These stations include: Kitale, Nyahururu, Nyeri, Thika, Narok, Nakuru, Kabete, Machakos, Kakamega, Meru, Embu, Kisii, Kericho and Eldoret.

The year to year variation of average temperature for the period 1970 to 2014 shows a slight increase in temperature with fluctuations of up to minus 2.8ºC and plus 1ºC. The deviation of rainfall amount from the mean annual rainfall for the period between 1970 and 2014 show drought and flood conditions in the crop growing regions.The fluctuations depict occurrence of extreme weather events that have been witnessed in Kenya. For instance, severe droughts occurred in 1971/73, 1983/84, 1991/92, 2004-2006, and 2008-2010. As well, flooding occurred in 1997/98 and 2002, which is closely linked to El Nino events with a severe frost occurring in 2012 (Rarieya*et* *al.,* 2009; KIPPRA, 2013).

Projections of mean rainfall indicate increases in annual rainfall in Kenya at -3 to +49mm per month for the months of October, November and December (OND) and larger proportional changes in January and February (JF) at -7 to +89% by 2030. The unpredictability of Kenya’s rainfall and the tendency for it to fall heavily during short periods is likely to cause problems by increasing the occurrences of heavy rainfall periods and flooding. As well, temperature increase is expected to exacerbate the drought conditions (Osbahr& Viner, 2006; McSweeney, 2010).

Agriculture sector in Kenya

The importance of agricultural sector and the ensuing vulnerability, more so in Kenya, makes it a key concern for this study. The agricultural sector in Kenya contributes to30 percent of Kenya's Gross Domestic Product (GDP) and employs over 40 percent of total population. Additionally, over 80 percent of rural people depend on agriculture for their livelihood. It also accounts for more than 60 percent of export earnings and about 45 percent of government revenue. Further, the sector is estimated to have an indirect contribution of nearly 27 percent of GDP through linkages with manufacturing, distribution and other service related sectors. Imperatively, the agricultural sector forms a strong base for food security, creation of employment and generation of foreign exchange and it is central to the country’s development strategy given that majority of industries in Kenya are agro-based (Republic of Kenya, 2005; 2011,2016).

Rain fed agriculture accounts for approximately 98 percent of agricultural activities in Kenya (UNEP, 2009). This makes the sector highly vulnerable to increasing temperatures, droughts, floods and changing rainfall patterns. The effects threatens livelihood of farmers and are likely to influence farming decisions. The performance of the agricultural sector mainly depends on crop production, which is largely dependent on climate conditions. Evidently, the sectors growth rate has been fluctuating over the years. This has been attributed to over reliance on rain fed agriculture, which is prone to erratic weather conditions plus high cost of agricultural production (Republic of Kenya, 2012; 2014; Alila&Otieno, 2006; KIPPRA, 2013).

Maize Production in Kenya

In Kenya, maize (*Zea Mays*) constitutes the most important staple food. Its contribution to consumption and income is important and an anchor to food security. Maize is a cereal crop grown in a range of agro- ecological environments. Globally, there are over 50 species of maize consisting of different colors, texture, sizes and shapes with yellow and white species being the most common preferred types. In Kenya, maize farming is spread all over the country from 0- 2200 meters above sea level (masl), facilitated by hybrids and composites developed for different ecological zones by the national maize breeding program (Mbithi, 2000).

Maize crop performs best in well drained and well aerated loam soils with a pH of 5.5 -7 and is intolerant to water logging. Low production is recorded in very high and low altitudes with optimum temperatures for good yield ranging between 18 to 30ºC. Cold conditions lengthen the maturity periods with high temperatures reducing production. Maize grows well with 600-900 mm of rainfall, which should be well distributed throughout the growing period. Rainfall is most critical at flowering and silking stage. Drought at the flowering stage obstructs pollination and considerably reduces yield. Towards harvesting dry conditions are necessary to support drying of the grain (Hughes, 1979; Schroeder *et al.,* 2013). As noted by Bergamaschi et al., (2004) maize plants are sensitive to water deficit during a critical stage from flowering to the start of grain filling period. At this stage, there is high water requirement in terms of high evapotranspiration and high physiological sensitivity as number of ears per plant and number of kernels per ear is determined.

In Kenya small scale maize production accounts for 75 percent while large scale production account for 25 percent (Export processing Zone Authority, 2005; Olwande, 2012). Hybrid varieties correspond to different agro ecological zones. Highland maize varieties include H627, H626 and H625 while those recommended for medium altitude agro- ecozone include H513, H515, H516, H623 and H624. In the lowland agro-ecozone, Pwani hybrids PH1 and PH4 are recommended, they are short, resistant to lodging and more tolerant to moisture stress. As well, In the dry land agro-ecozone the varieties recommended varieties include Katumani Composite, DH01, DH02, DH03, DH04, and Makueni SCDUMA43 (Schroeder *et al.,*2013; Kenya Seed Company, 2013; National Farmers Information Service (NAFIS), 2015).

Enhancement of maize production is critical as a shortage in maize supply is, largely, synonymous with food insecurity (Owour, 2010; Republic of Kenya, 2000; 2005; 2010). Majority of households in Kenya grow maize, as it is the main staple food. It forms the diet of over 85 percent of the population, accounts for 68 percent of daily per capita cereal consumption, 35 percent of total dietary energy consumption and 32 percent of protein consumption (FAO, 2008a; Mohajan, 2014). Hence, Kenya's national food security has a strong relation to production of sufficient quantities of maize to meet an increasing domestic demand arising from a growing population. In addition, maize accounts for more than 20 percent of total agricultural production and 25 percent of agricultural employment (FAO, 2008a;Schroeder*et al.,* 2013; Mohajan, 2014).

In the face of the need to increase maize production, there is evidence of stagnation in maize production and productivity. This has led to an increasing gap between production and consumption besides increasing frequency of supply shortages. Figure 3 depicts maize yield trend in Kenya for the period 1970 to 2014.

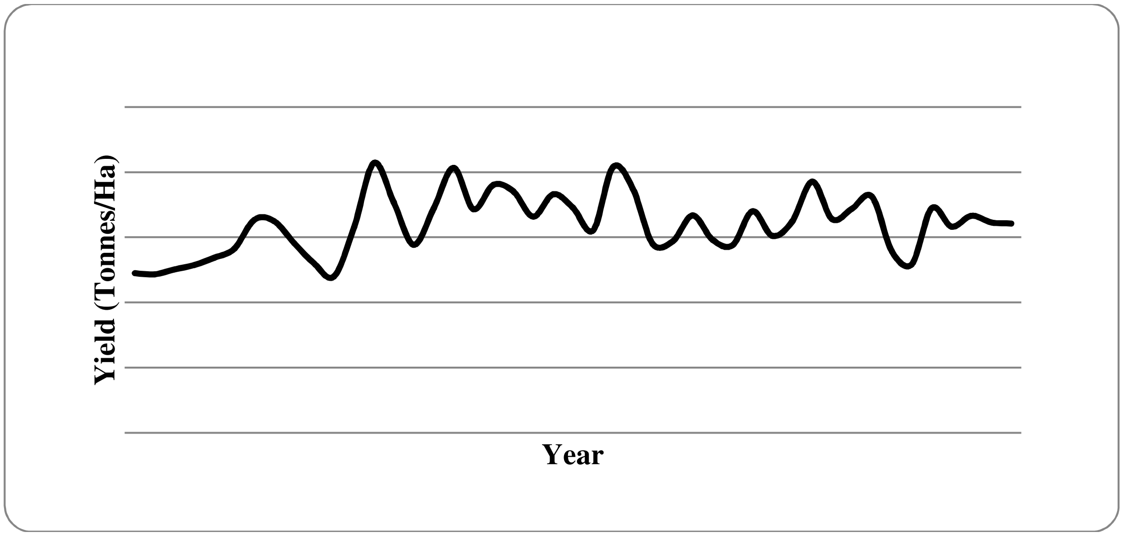

Figure 3. Maize Yield Trend in Kenya (1970-2014)
Source: Republic of Kenya. Economic Survey (Various Issues).

Figure 3 shows that there was tremendous growth in maize production between 1970 and 1982 with a peak yield of 2.07 metric tonnes per hectare. After 1982 there was a slight decline in yield after which the yield improved to a high of 1.87 metric tonnes per hectare in 1994. The growth was highly attributed to introduction of hybrid maize (Kibaara&Kavoi, 2011). However, from 1994 there has been a decline in yield with the lowest yield of 1.29 metric tonnes per hectare in 2009. Consequently leading to maize consumption deficit over the years. Figure 4 shows the gap between maize production and consumption in Kenya for the for the period 1970 to 2014

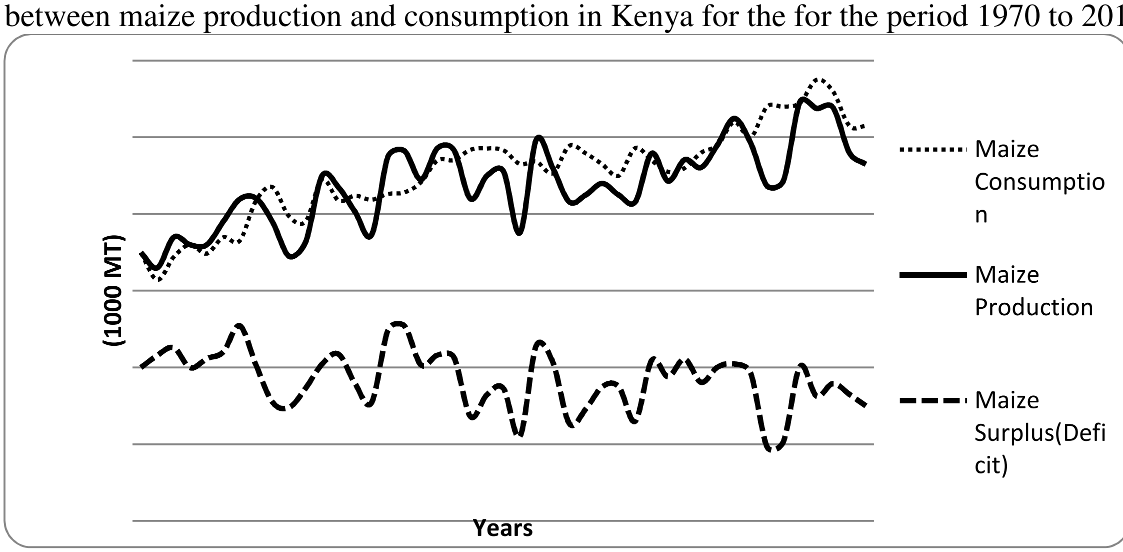

Figure 4. Maize Production and Consumption Trends in Kenya (1970-2014)
Source: Republic of Kenya. Economic survey (various issues).

Figure 4 demonstrates trends in maize production and consumption and the supply surpluses/ shortages. Notably maize production drastically dropped in some years such as 1979, 1984, 1993, 1997, 2008, 2013 and 2014. The trend shows wide fluctuation in maize production over the years resulting to a supply shortage since 1989 save for 1994, 2001 and 2003 where production was above consumption demands. Between 1970 and 2014, the average annual maize production stood at 2.3 million tonnes compared to an average annual consumption of 2.6 million tonnes in the same period (FAOSTAT, 2015). Equally, the production of rice and wheat, the main substitutes for maize, has been below the demand with the country only being able to produce 40 percent of its wheat requirements and 34 percent of the national rice consumption requirement (Republic of Kenya, 2003; 2005; 2009; 2011; 2015; Gitau*et al.,* 2011).

Moreover, growth rate in maize production has been marginal averaging about two percent which is lower than the annual population growth rate which averages 3.5 percent. Thus, for self sufficiency, maize production needs to grow by over 4 percent. Consequently, Kenya remains a net food importer with about 40 percent of its population being food insecure. As well, the overreliance on imports may trigger diversion of development resources for food procurement (Republic of Kenya, 2013; Mutimba *et al.,* 2010; FAOSTAT, 2015). The drop in maize yield coupled with increase in consumption compromises food security in the country.

Problem Statement

In Kenya, adequate supply of maize is an indication of food security, a source of employment and income generation. However, maize outputs levels have been fluctuating over the years making its production fall below consumption in most years. Further, the growth rate in maize output has been marginal, averaging about two percent which is lower than the annual population growth rate which averages 3.5 percent (Republic of Kenya, 2013; FAOSTAT, 2015). Consequently, there is need to have a sustainable increase in maize output in order to continue supporting the livelihoods of the growing population in Kenya. However, sustainable maize production is likely to be affected by climate change.

Studies measuring the impact of climate change on crop yield in Kenya have concentrated on impacts of climate means (Jones &Thorton, 2003; Kabubo-Mariara&Karanja, 2007; Bilham, 2011; Cheserek, *et al.,* 2015). Beyond changes in climatic means, variability in temperature and rainfall is expected to rise in some regions, including the intensity and frequency of extreme events (Solomon *et al.,* 2007). Such changes are likely to have more adverse effects on crop yield than changes in climate means alone (Porter & Semenov, 2005; Tubiello*et al.,* 2007; Rowhani*et al.,* 2011). To bridge the gap, this study sought to empirically, determine the effects of climate change on maize yield, by incorporating climate variable means and their variability. Anchored on empirical analysis, detailed review of literature and by considering climate factors as direct inputs, the study examined the effect of rainfall and temperature and their variability on maize yield in Kenya.

LITERATURE REVIEW

Theoretical Model

This study adopted a quantitative research design and employed production theory in developing theoretical framework and to specify empirical model. The study assumed that climate variables are likely to have nonlinear effects on crop yield. Thus, the study adopted a Cobb-Douglas production function from Blanc, (2011) and Mahmood et al., (2012). Production theory explains the economic processes of producing outputs from various combinations of inputs. Moreover, production theory provides a convenient way of summarizing the production possibilities for the firm. The theory provides a way of determining the technologically feasible combination of output and various inputs. The common way of representing the relationship of output and input in physical terms is through the use of a production function. A production function describes a frontier that represents the maximum amount of output that can be obtained from a feasible combination of various inputs (Varian, 1992; Nicholson & Snyder, 2008). In general a production function may be written as:

$$Y = f(A, K, L) \ldots \ldots \ldots \ldots (1)$$

Where: Y is output; A is technology, K is capital and L is labor. One of the most commonly used functional forms of production function is the Constant Elasticity of Substitution (CES) production function. According to Arrow et al., (1961) a CES production function takes the form:

$$Y = A(\alpha K^{\rho} + \beta L^{\rho})^{\frac{V}{\rho}} \ldots \ldots \ldots \ldots (2)$$

Where: A is an efficiency parameter, equivalent to technology in (1); ρ is substitution parameter and it measures the ease with which two inputs can be substituted; α and β are distribution parameters and they show how the two inputs are distributed over the production of one unit of output and v is the degree of the homogeneity of the production function and it's a measure of returns to scale. A CES production function assumes that the elasticity of substitution is constant. Under different assumptions about ρ, the CES production function can collapse into any of the specific forms. If $\rho = \infty$ the two factors are assumed to be complements, with C.E.S manifesting itself as a fixed proportions/ Leontief production function. However, as ρ approaches zero CES will manifest itself as a Cobb Douglas function (Varian, 1992), which takes the form:

$$Y = AK^{\alpha}L^{\beta} \ldots \ldots \ldots \ldots (3)$$

Hence, the two factors of production are imperfect substitutes. Augmenting or directly adding land and climate variables to equation (3) yields the most commonly used Cobb-Douglas production function in agricultural research. Climate variables are included to capture the effect of changing climate on agricultural output (Nastis*et al.*, 2012). The augmented Cobb-Douglas is expressed as:

$$Y = AK^{\alpha}L^{\beta}\mathrm{Ln}^{\gamma}\mathrm{W}^{\delta}\mathrm{R}^{\theta} \ldots \ldots \ldots \ldots (4)$$

Where Y is output; K is capital; L is labour; A is an efficiency parameter, Ln is land, W is a vector of climate variables, R is a vector of other variables affecting production and α, β, γ, δ and θ are input elasticities of output or factor shares (Blanc, 2011; Mundlak, 2011; Kawasaki &Herath, 2011; De-Graft &Kweku, 2012; Mohamood*et al.,* 2012; Bizuneh, 2013; Kumar, 2014).

Empirical Model

Following the production theory equation (4) expresses output as a function of capital, labour, land and climate variables. Intuitively, the production theory may also be used to measure crop yield, since yield is defined as output per unit of land. Thus from equation (4), the study estimated an extended model for maize yield (j) specified as:

$$CY_{jt} = \delta_{j0} + X'_{jt}\lambda_j + W'_{jt}\emptyset_j + \mu_{jt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where: CY is yield; t= time period from 1970 to 2014; δ_j is the unknown intercept; λ and $\emptyset$ are unknown parameters; W is a vector of agro climate variables that include: rainfall amount, temperature, rainfall variability, temperature variability, squared terms of rainfall and temperature and X is a vector of control variables that include: area under crop, fertilizer use, labor employment and use of certified seeds.

Crop Yield is the crop production per area of land under crop in tonnes per hectare; Mean temperature is measured in degree Celsius, recorded in the months of JF, MAM, JJAS and OND in a given year for selected weather stations in maize growing areas. Rainfall is amount of rainfall, measured in millimeters, recorded in the months of JF, MAM, JJAS and OND in a given year for selected weather stations in maize growing areas; Rainfall Variability is intra rainfall variability measured by the coefficient of variation of rainfall in a given year, for selected weather stations in maize growing areas; Temperature Variability is year to year variability of mean temperature measured by the squared annual temperature deviation from the long term mean; Land Use is the area under maize production measured by the number of hectares; Fertilizer use is fertilizer consumption measured in tonnes per hectare of crop area; Labour is labor force employment in agricultural sector per hectare of crop area and Seed use is the amount of certified maize seeds used in kilograms per hectare.

Area under crop is included to capture decreasing marginal productivity, as farmers are assumed to cultivate in better soils first before expanding to land of lesser quality (Blanc, 2011). This study uses national data that reflect the actual cropping decisions and thus land is included as an explanatory variable to capture decreasing marginal productivity of land (Chen *et al*, 2004; Kawasaki &Herath, 2011; Blanc, 2011; De-Graft &Kweku, 2012). The coefficient of area under crop is expected to have a negative sign to indicate diminishing marginal productivity.

For given agronomic conditions, crop yield is expected to increase with increased consumption of fertilizers. However, excessive use can be detrimental as well (Winch, 2006). Although, use of fertilizer in Sub Saharan Africa is low there has been growth in use of chemical fertilizer in Kenya since 1990, thus this study incorporates fertilizer consumption as an explanatory variable for crop yield.

Labour is a key input in agricultural production in Kenya with most farmers especially the smallholder employing traditional farming methods where most land is cultivated manually. However, most of labor is provided by family members with the level of labor input depending on family structures and the number of hours worked. As well, labor requirements differ with season and labour characteristics such as education and health. In addition, farming experiences influence crop yield through work capacity and quality of crop management practices (Blanc, 2011). Labour data specifically used in production of specific crops under study in Kenya is limited and the rural population data available may not be a good proxy for labour used in production of each crop under study. The study thus adopted employment in agricultural sector in Kenya to capture use of labor in crop production process.

The vector of climate includes the level of precipitation and temperature. These variables are expected to have both direct and indirect effects on crop yields, especially under rain fed agriculture. Thus, in this study seasonal mean temperature and seasonal rainfall are included in the specification. As well, to capture the effect of climate risks emanating from change in climate on crop yield, rainfall and temperature variability are included in the specification. Further, to account for nonlinear weather effects on crop yield, quadratic terms for rainfall and temperature are included in the specification.

METHODOLOGY

Data Type and Source

The study used annual time series data for the period between 1970 and 2014. The data was gathered from government publications, Kenya Meteorological Department,World Bank, IMF and FAOSTAT database. Weather variables used in maize model were computed using data from the following weather stations: Kitale, Nyahururu, Nyeri, Thika, Narok, Nakuru, Kabete, Machakos, Kakamega, Meru, Embu, Kisii, Kericho and Eldoret

Estimation Method and Unit root tests

Crop yield model was estimated by Ordinary Least Squares (OLS) method. Prior to model estimation, series were subjected to various tests to confirm various properties required for OLS to give results that are efficient and consistent. The model was estimated consistently by OLS after ascertaining that the error term (ε_j) is a white noise process or more generally, if the error term has a zero mean, constant variance and uncorrelated with the explanatory variables and its previous realizations. As well, given the use of time series data, it was necessary that, before estimation of the equations, the series had to be tested for unit root. The study employed the Augmented Dickey-Fuller (ADF), Philip Peron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests. (Green, 2008; Gujarati, 2004; Dickey and Fuller, 1979; Kwiatkowski, Schmidt &Shin 1992).

The unit test results showed that variables are a mixture of I (0) and I (1), the models could not be estimated at levels, since there is a likelihood of yielding spurious results (Heij*et al*., 2004; Woodridge, 2012). An alternative is to use the first difference of variables. Although, using the first difference changes the nature of model, the method is as informative as modeling in levels (Woodridge, 2012). Thus maize yield model was estimated at first difference. To ensure that estimates obtained were unbiased and consistent, diagnostic tests were undertaken. The tests included: the normality test using Jarque- Bera statistics, Breuch-Godfrey Lagrange Multiplier test for serial autocorrelation, Lagrange Multiplier test for autoregressive conditional heteroskedasticity (ARCH), Ramsey RESET test for specification error and CUSUM test for parameter constancy. The P values associated with the computed test statistics were greater than 0.05 and thus the estimates were considered to be unbiased and consistent.

RESULTS AND DISCUSSION

Effects of Rainfall and Temperature on Maize yield

The coefficient estimates for the crop's yield model are shown in Table 1.

Table 1: Maize Yield Model Coefficient Estimates

Dependent Variable	D(Maize Yield)		
Explanatory variables	Coefficient (Standard Errors)	Explanatory variables	Coefficient (Standard Errors)
D(Area Under Crop)	-6.35E-07*** (1.84E-07)	D(Squared Rainfall-MAM)	-8.46E-06*** (1.62E-06)
D(Mean Temp-JF)	-0.1222 (0.0905)	D(Squared Rainfall-OND)	-2.16E-06 * (1.07E-06)
D(Mean Temp- JJAS)	13.35869*** (3.7886)	D(Squared Mean Temp-JJAS)	-0.375089*** (0.1059)
D(Mean Temp-MAM)	10.66330*** (3.5293)	D(Squared Mean Temp-MAM)	-0.272724*** (0.1842)
D(Mean Temp-OND)	0.09483 (0.1151)	D(Fertilizer use)	0.01916** (0.0071)
D(Rainfall-JF)	-0.002596*** (0.0009)	D(Labor use)	-8.413114 (8.5114)
D(Rainfall-JJAS)	0.002399 (0.0025)	Constant	-0.002621 (0.02118)
D(Rainfall-MAM)	0.008577*** (0.0085)	R-squared	0.88
D(Rainfall-OND)	0.001972** (0.0008)	Adjusted R-squared	0.75
D(Rainfall Variability)	-0.099747 (0.3028)	F-statistic	6.63
D(Temperature Variability)	-0.05939** (0.0303)	Prob(F-statistic)	0.00
D(Squared Rainfall-JF)	7.13E-06*** (2.32E-06)	Durbin-Watson stat	1.80
D(Squared Rainfall-JJAS)	-1.84E-06 (4.04E-06)		

Standard errors in brackets; ***, **,* significant at 1%, 5% and 10% respectively
Source: Author's computation.

The regression model yield a relatively moderate value for adjusted R squared. The adjusted R^2 values of 0.75 implies that 75 percent of variations in maize yield are explained by climate variables, area under crop, fertilizer consumption and labour use.

Marginal Effects of Rainfall Amount on Maize yield

The study findings indicate a nonlinear relationship between maize yield and rainfall. Specifically, the coefficients estimates of linear terms of rainfall in March to May period and October to December period are positive and significant at 1 percent and 5 percent level respectively. Conversely, the coefficient estimate of linear term of rainfall in January to February period has a negative sign and is significant at 1 percent level. However, the coefficient of linear term of rainfall in the June to September period and the coefficient of rainfall variability are insignificant. The coefficients of squared rainfall amount in the period of March to May and October to December have a negative sign and are significant at 1 percent and 5 percent level respectively. This implies that, during the long rains and short rains period, an increase in rainfall raises maize yield with diminishing marginal benefits up to a maximum turning point after which further increase in rainfall, impacts maize yield negatively.

Since both level and square of rainfall variables are in the model, the marginal effects need to be calculated.The marginal impact of rainfall in January to February period is specified as:

$$\frac{\partial \Delta Q}{\partial \Delta R_{JF}} = -0.002596 + 2(7.13\text{E} - 06)\Delta\overline{R_{JF}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount of 117.6 mm decreases maize yield by 0.0009 tonnes per hectare.

The marginal impact of rainfall in March to May period is specified as:

$$\frac{\partial \Delta Q}{\partial \Delta R_{MAM}} = 0.008577 - 2(8.46\text{E} - 06)\Delta\overline{R_{MAM}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount 465.33 mm increases maize yield by 0.0007 tonnes per hectare.

During the October to December period the marginal effect of rainfall on maize yield is given as,

$$\frac{\partial \Delta Q}{\partial \Delta R_{OND}} = 0.001972 - 2(2.16\text{E} - 06)\Delta\overline{R_{MAM}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount 334.66 mm increases maize yield by 0.0005 tonnes per hectare.

The results indicate that an increase in rainfall, prior to the main planting period has a negative effect on maize yield. January to February period lies outside the growing season but usually corresponds to a stage where the short rains crop grown in medium potential -areas that support two growing seasons- is harvested and drying conditions are necessary. As noted by Hughes (1979) and Schroeder et al., (2013), towards harvesting, maize requires dry conditions towards to support drying of the grain. In addition, dry conditions during January to February period, facilitates adequate land preparation before planting at the onset of long rains in March. This indicates that dry conditions in January to February period, provide an enabling environment for drying of grain and adequate time for land preparation, which enhances yield. Thus, early rains can distort farmers planting plans, as they have a short time to prepare their land and as well, they may not have adequate resources in January to purchase farm inputs, thereby adversely affecting yield. This finding is consistent with Cabas (2009), who observed that an increase in precipitation in months around planting and harvesting decreases crop yield. Conversely, Kawuna (2011) indicated that in

Ethiopia Pre-season rainfall had a positive effect on maize production.

Increase in rainfall during the growing period for the main crop as well as the short rains crop is expected to increase maize yield but at a decreasing rate. As maize crop goes through the vegetative and reproductive stages, sufficient rainfall water is required. However, water level beyond the crop requirement has a negative effect on yield. These results are consistent with the findings made by Akpalu *et al.,* (2008), Blanc (2011) and Bhandari, (2013) that precipitation has a positive effect on maize yield while Sowunmi and Akimola (2010) concluded that with sufficient water maize can be grown in many parts in Nigeria. The nonlinear influence of rainfall on maize yield is consistent with the finding made by Cabas, (2009) and Blanc (2011). Further, Moula (2008) and Bhandari, (2013) observed that rainfall variability has a negative effect on maize yield. Conversely, Rowhani*et al.,* (2011) estimated that an increase in inter seasonal precipitation reduces maize yield.

Marginal Effects of Temperatureon Maize yield

On the effects of temperature on maize yield, estimates from the maize yield model show that the coefficients of linear term of mean temperature in the march to May period and June to September are positive and significant at 1 percent level. The coefficient of temperature variability is negative and weakly significant at 10 percent level. However, the coefficients of linear terms for mean temperature in January to February and October to December periods are insignificant.

The coefficients of squared term of mean temperature in the March to May period and June to September period are negative and significant at 1 percent level, indicating an inverted U relationship. This result indicate that during the main crop growing season an increase in temperature is of benefit to crops but does so with diminishing marginal benefits up to some optimal point beyond which an increase in temperature would have damaging effects.

The marginal effect of temperature in March to May period is specified as.

$$\frac{\partial \Delta Q}{\partial \Delta T_{MAM}} = 1066330 - 2(0.272724)\Delta\overline{T_{MAM}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Holding other variables constant, a rise in temperature by 1^{0}C mm relative to the period's average of 19.9 ^{0}C reduces maize yield by 0.19 tonnes per hectare.

The marginal effect of temperature in June to September period is specified as.

$$\frac{\partial \Delta Q}{\partial \Delta T_{JJAS}} = 13.35869 - 2(0.375089)\Delta\overline{T_{JJAS}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Holding other variables constant, a rise in temperature by 1^{0}C mm relative to the period's average of 18.25 ^{0}C reduces maize yield by 0.33 tonnes per hectare.

The coefficient of temperature variability is negative and weakly significant at 10 percent level. The coefficient estimate indicates that when temperature variability increases by one standard deviation, maize yield decreases by 0.06 tonnes per hectare. The nonlinear relationship between temperature and maize yield observed in the main crop growing season shows that increase in temperature leads to an increased yield but beyond the optimum level, further increase in temperature reduces maize yield. This can be as a result of the fact that higher temperatures when water /moisture is limiting usually dry out silks and damage pollen resulting in scatter grained ear or an ear with a barren tip. Consequently, this causes maize yield and output supply to decline

(FAO, 2015; Wiatrack, 2015).

These results are consistent with the findings made by Rowhani*et al.,* (2011), Blanc (2011) and Ereghaa*et al.,* (2014)that temperature has a negative effect on maize yield. Similarly, the results are consistent with those of Cabas (2009) that increase in temperature can have both positive and negative effect depending on the season. On the contrary, Akpalu *et al.,* (2008) and Bhandari, (2013) found that maize yield responds positively to temperature. The finding that temperature variability has influence on maize yield is consistent with the finding made by Moula (2008), Cabas (2009) and Bhandari, (2013). As well, the study findings are consistent with other studies that found a nonlinear relationship between temperature and precipitation on crop production (Mendelsohn *et al.,* 1994; Kabubo-Mariara and Karanja, 2008; Krukulasuriya and Mendelsohn, 2008; Cabas et al., 2009; Rowhani*et al*., 2011).

The findings indicate that during the growing season for maize, there is a higher yield, when rainfall is sufficient and when temperature is not beyond the required optimum. Adequate moisture content, during the growing period, which corresponds to March to May period and June to September period for the main crop varieties and October to December for the short rain varieties, boosts availability and uptake of nutrients. This makes the plants stronger and less susceptible to disease and insect damage ultimately increasing maize yield.

Marginal Effects of Economic Variables on Maize yield
Coefficients estimate for area under crop indicate that changes in area under crop has significant effect on maize yield. The estimated coefficient has a negative sign and is significant at 5 percent level. This result indicates that owing to decreasing marginal land productivity, maize yields is decreasing, as area under crop increases.The coefficients of fertilizer consumption is positive and significant at 5 percent level of significance. As fertilizer consumption increases by one kilogram, maize yield increases by approximately 0.0192 tonnes per hectare. Use of fertilizer improves soil fertility and is useful in replenishing soil nutrients. Thus, use of fertilizers for sustained crop yield is integral given that in Kenya, farmers cultivate sub optimal land and use the same plot season after season given that only 20 percent of land in Kenya is agriculturally productive (Johnson *et al*., 2003; Sheahan, 2011). The coefficients of labor use is insignificant while the coefficient of maize seed use is positive and significant at 5 percent level. The results show that an increase in the use of certified seeds by 1 kilogram raises maize yield by 0.046 tonnes per hectare. This indicates that one of the ways to increase maize productivity is to increase the use of certified maize seeds, as noted by Okoboi et al., (2012) farmers who apply fertilizers on improved seeds record the highest maize yield. Thus, limited use of fertilizers and improved seeds is one of the major constraints in raising maize yield.

CONCLUSION AND RECOMMENDATIONS

Maize yield analysis provides an insight on how climate change influences crop yield. The analysis showed a concave relationship between maize yield and rainfall in the long rains and short rains period. These indicate that an increase in rainfall is expected to raise yield but with diminishing marginal benefits. The findings indicate that water remains an integral factor in maize production and occurrence of adequate rainfall is imperative in boosting maize yield. Thus, low and unreliable rainfall restricts suitability of maize production and has been a contributor to declining maize yield in Kenya. Early rains have a negative effect on maize yield and indicator that changes in rainfall patterns could be making it hard for farmers to make proper and timely decisions. The unpredictability of Kenya's rainfall and its trend to fall heavily in a short period is likely to raise the climate risk faced by small scale farmers consequently raising uncertainty to food security.

The effects of increase in temperature on maize yield depend on the season and to an extent the stage of crop growth and development. Overall, the study finds that increase in temperature has a negative effect on maize yield. A concave relationship between maize yield and mean temperature is observed in March to May season. Thus, increase in temperatures beyond the optimum level even in wet seasons lowers maize yield. Additionally, analysis show that larger effects of change in temperature and rainfall on maize production are observed in the main crop growing period. These results indicate that warmer temperatures when water is not limiting tend to benefit maize crop up to a maximum threshold beyond which further increase becomes detrimental. Hence, with a projected rise in temperature maize production is likely to reduce, hence there is need to establish measures geared towards averting the situation.

Evidently, from the study findings climate variability has an adverse effect on crop production in Kenya, posing a greater concern food security. Thus, there is need for a wide-ranging policy that will elevate the potential of rain fed agriculture in the midst of the risks posed by climate change. The significant response of maize yield to climate variability points to a possible decline in crop production in the future, in absence of adaptation and mitigation mechanisms. In turn, this would make Kenya more food insecure and adversely affect foreign revenue, employment and income generation.

The adverse effects of climate change on maize yield creates a need to formulate all-inclusive policies, strategies, and instruments that specifically address effects of climate change, paramount in building adaptation and mitigation mechanisms. Specifically, amid the threat to food security, there is need to: shield highly productive agricultural land from other non-agricultural developments especially real estate development; Provide climate information to relevant stakeholders in a timely and useful format and supplement rainfed agriculture through irrigation which can be attained through rainwater harvesting. This calls for Ministry of Agriculture, Kenya Meteorological department and relevant stakeholders to commit more resources towards adaptation and mitigation mechanisms.

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