EFFECT OF CLIMATE VARIABILITY ON OUTPUT AND YIELDS OF SELECTED CROPS IN KENYA

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DECLARATION

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

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To my wife Jacinta Wangui, my daughter Annabel Wangari and in Memory of Levi Ouma

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ABBREVIATIONS

ADF-	Augmented Dickey-Fuller
ARDL-	Autoregressive Distributed Lag
CIAT-	International Center for Tropical Agriculture
CTC-	Crush, Tear, Curl
ECM-	Error Correction Model
ENSO-	El Nino Southern Oscillation
FAO -	Food and Agriculture Organization
GCM -	General Circulation Model
ICC-	International Coffeee Council
IPCC -	Intergovernmental Panel on Climate Change
ITCZ-	Inter Tropical Convergence Zone
JF -	January to February period
JJAS-	June to September
KTDA-	Kenya Tea Development Agency
KPSS-	Kwiatkowski-Phillips-Schmidt-Shin
MAM-	March to May Period

MASL- Meters Above Sea Level

NAFIS: National Farmers Information Service

NEMA- National Environment Management Authority

NCCACC- National Climate Change Activities Coordinating Committee

NEP- National Environmental Policy

NCCR- National Climate Change Response Strategy

OND- October to December

PP- Phillips and Perron

ROK- Republic of Kenya

SEI- Stockholm Environmental Institute

TBK- Tea Board of Kenya

TRFK- Tea Research Foundation of Kenya

UNDP- United Nations Development Program

UNFCCC- United Nations Framework Convention on Climate Change

WTO - World Trade Organization

WRI - World Resources Institute

OPERATIONAL DEFINITION OF TERMS

Adaptation refers to the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates, harm or exploits beneficial opportunities.

Climate Change refers to a change in the state of the climate that can be identified by changes in the mean and in the variability of precipitation and temperature that persists for an extended period—typically decades or longer.

Climate Variability refers to variation in the mean states, on all temporal scales beyond those of individual weather events.

Food Security refers to a situation where all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Vulnerabilit*y* refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.

Weather is the day-to-day state of the atmosphere and its short-term (from hours to a few weeks) variations such as temperature, humidity, precipitation, cloudiness, visibility or wind.

ABSTRACT

The agricultural sector plays a critical role in the Kenyan economy; it contributes to about 30 percent of the country's Gross Domestic Product (GDP) and employs over 40 percent of total population. It also accounts for more than 60 percent of export earnings and about 45 percent of government revenue. Indeed the sector forms a strong base for food security, creation of employment and generation of foreign exchange. Majority of industries in Kenya are agro-based, making the agriculture sector central to the country's development strategy. The agricultural sector largely depends on climate variables and is highly sensitive to climate variability such as a change in temperature and precipitation. These changes can potentially compromise agricultural production thereby have negative impact on rural economy, food security, trade balance and foreign exchange earnings. It is therefore imperative to understand the effects of the changing temperature and rainfall patterns in Kenya, to which this study has contributed by way of analyzing the responsiveness of major agricultural crops to climate variability. The crops considered namely maize, tea and coffee, play a significant role in Kenya's economic growth. Maize is critical to food security while tea and coffee are important for the improvement of trade balance, foreign earnings, employment, income generation, poverty alleviation as well as economic growth and development. However, maize production has greatly fluctuated leaving about 40 percent of population food insecure. In addition, the growth rate of tea and coffee production shows a falling trend over the study period that could adversely affect foreign exchange earnings, income generation and food security. The study utilized secondary data on respective variables in the period between 1970 and 2014. Data was collected from various government publications, Kenya Meteorological Department and FAOSTAT. The study adopted modeling approach. The study findings show that climate variability has adverse effects on crop output and yield. In addition, the study finds a non linear relationship between crop yields and seasonal rainfall and mean temperature. However, the direction and magnitude of the effects vary depending on the season. Moreover, the findings show a negative effect of temperature variability on crops output and yield. Hence, there is need to elevate the potential of rain fed agriculture in the midst of the risks posed by climate variability. The study recommends harvesting and efficient use of water to support rainfed agriculture and provides ground for government action in establishing measures towards mitigation and adaptation to climate variability. As well, climate variability affects the optimal requirements for crop growth and development at various stages and thus policies targeting non-rain fed agriculture could be most appropriate.

CHAPTER ONE

INTRODUCTION

1.1 Background

Agriculture is highly dependent on climate and a critical part of the economy in most developing countries in Africa. Climate change and its variability are emerging as major challenges to agricultural development with the increasingly irregular and erratic nature of weather conditions placing an additional burden on food security and rural livelihoods (Food and Agriculture Organization (FAO), 2009). Climate variability has a direct and in most cases adverse 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).

According to Intergovernmental Panel on Climate Change (IPCC, 2007), "Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)". While, "climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events".

Climate change and variability are closely linked in the climatic system, with long term scale climate change manifesting itself with episodes being observed in short term climate variability. Instances of climate variability consist of seasonal, annual and inter decadal variation in temperature and rainfall, extensive droughts, floods and conditions that result from periodic El Nino and La Nina events. Due to their close association, climate change and climate variability are concomitantly used together in research as well as in policy. Thus, in most cases extricating the impacts of climate change and climate variability has largely been difficult especially in the agricultural sector (Washington *et al*., 2006; Bizuneh, 2013).

Climate variability is expected to increase with global warming. Global warming refers to observed increase in temperatures over the last 50 years as a result of increased green house concentrations in the atmosphere (Solomon *et al.,* 2009). In the midst of the rise in global temperatures, changing local rainfall patterns, warming seas and melting of ice caps have been witnessed (IPCC, 2007). Furthermore, global average temperatures are expected to increase by between 1.4° Celsius (C) and 6.4° C by 2100. This increase is above threshold limit of 3^{o}C beyond which it becomes impracticable to avoid dangerous interference with the global climatic system (WTO & UNEP, 2009). This average is anticipated to be higher throughout Africa and Central Asia. In Africa average temperature is projected 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 (FAO, 2012; WTO & UNEP, 2009). However, increasing global temperature may have mixed outcomes, where crop production may increase in temperate regions but reduce yields in tropical regions (WTO & UNEP, 2009).

Beside the changes in temperature, over the years rainfall patterns have changed, with cases of heavy rainfall at crop maturity and droughts occurring at critical stages of crop growth being common (Birech *et al.,* 2008). These changes are likely to severely, compromise crop production and food security with colossal economic consequences in many African countries especially in sub Saharan Africa (Gregory *et al*., 2005).

There is likelihood that changes in temperature and rainfall patterns, will affect the potential of crop production (Stern, 2007). The effects of climate variability on crop production could be direct or indirect. Directly the effect is through changes in temperature and precipitation that affect the timing of crop development (Joshi *et al.,* 2011; Gbetibouo *et al.,* 2009; Gregory *et al*., 2005). Rising temperatures are likely to reduce crop production in the long-term especially through reduction in the number of reliable crop growing days while changes in precipitation patterns are likely to increase short term crop failures and long term production declines (Peiris *et al.,* 1996; IPCC, 2007; Joshi *et al.,* 2011). Indirectly, climate variability may increase the population and growth of pests, insects, weeds and diseases making crop management difficult and costly. These conditions are likely to impact on crop production in a negative way (Joshi *et al.*, 2011; Gbetibouo *et al.*, 2009).

Factors influencing crop production are both biophysical and economic in nature. Biophysical determinants include rainfall, temperature, solar radiation and atmospheric concentration of carbon dioxide (CO_{2}). Crop production is affected by different aspects of climate variability stemming largely from an increase in average temperature, change in rainfall amount and patterns, rising atmospheric concentration of CO_{2}, increase in extreme events and seawater rise (Chijioke *et al*., 2011).

Increase in minimum and maximum temperature make countries in tropical regions where water availability is low to be at high risk of reduced crop yield, even at 1 to 2^{o}C warming. Rising temperatures result to increased evapotranspiration, with low moisture levels adversely affecting crop growth and development (Parry *et al.*, 2007; FAO 2008b; Bals *et al.*, 2008; Chijioke *et al*., 2011). Increased temperatures make arable land become less suitable for crop production resulting in decline in yields with the severity being mild or extreme depending on the locality (Bals *et al.*, 2008; Chijioke *et al.*, 2011). Higher night temperatures may end up increasing dark respiration of plants, which diminish biomass production, while higher cold season temperature may lead to earlier ripening of annual crops, diminishing yield per crop. In addition, high temperatures may reduce killing of pests during winter, resulting in greater crop losses.

On the positive side, higher temperatures in cold season may lengthen the growing season allowing for growth of more crops per year (Bazzaz, *et al.*, 1996).

Changes in amount and pattern of precipitation could make wet areas more wetter and dry areas drier. Due to climate variability, precipitation is likely to become more erratic and unpredictable, while the intensity of rainstorms is expected to increase in sub Saharan Africa (FAO, 2008c). These rainfall changes affect moisture content and cause soil erosion thereby affecting crop production.

Decrease in precipitation coupled with increased temperatures could result in loss of arable land due to decreased soil moisture. Inadequate quality water at critical stages of crop growth in certain times of the crop-growing season will negatively influence crop production (Bals *et al.,* 2008; FAO, 2008a). Consequently, with climate variability, greater impacts are likely to be experienced in countries that largely depend on rain fed agriculture like Kenya as changing rainfall patterns may limit crop production.

Atmospheric concentration of CO_2 is also expected to rise with climate change. Under IPCC lowest emission scenario, the concentration could rise from 379 parts per million (ppm) to 550 ppm by 2100 (Schmidhuber, J. *et al.*, 2007). Increase in Atmospheric concentration of CO_2 is of benefit to plants as it enhances biomass accumulation and ultimate yield, through stimulation of photosynthesis and improvement in water use efficiency. Nevertheless, the magnitude of this effect depends on type of crop and type of management. Yield response experiments indicate that under optimal growth conditions, a rise of atmospheric concentration of CO_2 to 550 ppm will increase yield by 10 to 20 percent for C_3 crops such as wheat rice and soybean. A similar rise in CO_2 will raise yield of C_4 crops such as maize and sorghum by of 0-10 percent (Bazzaz, *et al.*, 1996; IPCC, 2007; Schmidhuber *et al.*, 2007).

According to IPCC (2007) because of climate change and variability there is increased frequency and magnitude of extreme events. These events include storm and flash floods, droughts, heat waves or cold waves and coastal storms (Mirza, 2003). These extreme events damage agricultural arable land and infrastructure. Increase of these events as experienced and projected in Sub Saharan Africa are likely to have adverse effects on crop production and food security raising the vulnerability of most developing countries (Mirza, 2003; Wassmann *et al,*. 2007; Schmidhuber *et al.*, 2007).

1.2 Kenya Climate and Agro Climatic Zones

Kenya topography rises from the coastal plains to the eastern edge of the East African Plateau, and the Great Rift Valley. The central highlands region is usually cooler with mean temperatures below 18°C in the highest altitude regions while the Kenyan coast is substantially hot at a mean of 29°C. There is a close relation between Average temperatures and ground elevations. Coldest areas are found at mountain tops where night frosts occur above 10,000 feet. Higher temperatures ranging between 22°C and

44^{o}C are experienced in arid and semi arid regions along the Somali coast and west of Lake Turkana. Annual temperature variation is usually less than 5^{o}C throughout the country (Kabubo-Mariara *et al*., 2007; McSweeney, 2010).

Kenya lies within the inter-tropical convergence zone (ITCZ), a thin belt that forms close to the equator. The ITCZ is responsible for the two rain seasons in Kenya namely, the short rains period that spans between October and December and the long rains period that occurs in March, April and May. The amount of annual rainfall received ranges between 250mm and 2500mm. The onset, duration and intensity of rainfall vary considerably from year to year (McSweeney, 2010). Surface temperatures of Indian Ocean water greatly influences rainfall pattern in Kenya. This temperature varies year to year with the most important influence being El Nino Southern Oscillation (ENSO) (McSweeney, 2010).

ENSO cycle shows the fluctuations in temperature between the ocean and the atmosphere in eastern and central equatorial Pacific Ocean off the coasts of Peru and Ecuador. These fluctuations from the normal surface temperature usually have large consequences on the ocean processes and on global weather and climate. The consequences include extremes such as droughts, floods and hot/cold spells. Though ENSO is a single climate phenomenon it has three phases namely El Nino, Neutral and La Nina. El Nino and La Nina are opposite phases with Neutral at the middle of the continuum. El Nino also referred to as the warmer phase is the periodic warming in sea surface temperature while La Nina correspond to episodes of below average sea surface temperatures in eastern and central Pacific Ocean (Pacific Marine Environmental Laboratory, 2016).

During periods of El Nino there has been disruption of weather patterns in Kenya. At onset of El Nino, enhanced rains occur during the short rains season in the months of October to December and sometimes extends to January and February of the subsequent year. Conversely, rainfall is suppressed during the June to September period in western part of Kenya. During the cold phase of La Nina there is depressed rainfall and strong winds in most parts of Kenya (Republic of Kenya, 2015).

Kenya is classified into seven agro climatic zones using a moisture index based on annual rainfall expressed as a percentage of annual evapo-transpiration (Sambroek *et al.,* 1982). The zones are described in Table 1.1

Table 1.1 Agro Climatic Zones of Kenya

Zone	Description	Areas
Zone 1	Moisture index>80; Classification: Humid Altitude: Above 1200masl; Mean temperature below $18^{o}C$; Rainfall:1100-2700 mm Suitable for livestock farming(cattle and sheep) and Crop farming-coffee, tea, pyrethrum, maize and beans	Areas surrounding Mt. Kenya, Mt Elgon
Zone II	Moisture index 65-80; Classification: Sub Humid High potential areas; Altitude :Above 1200masl ; Rainfall 1000-1600mm Suitable for livestock farming(cattle and sheep) and Crop farming-coffee, tea , pyrethrum, maize and beans	Meru, Kirinyaga, Nyeri, Kericho, Nyahururu, Mau, Aberdares, Kitale, Webuye
Zone III	Moisture index 50-65; Classification: Semi Humid and Medium potential areas Altitude 900-1800masl; Rainfall:800-1400mm Suitable for livestock farming(cattle and sheep) and Crop farming-coffee, tea, pyrethrum, maize, beans, barley, coconut ,cassava	Nandi, Nakuru, Bomet, Kitale, Vast parts of Nyanza, western and central and small strip of coast
Zone IV	Moisture index: 40-50; Classification: Semi humid to semi arid areas Altitude:900-1800masl; Rainfall:600-1100mm; Temperature ranges from $22^{o}C$ to $40^{o}C$ less suitable for agriculture	Naivasha, Laikipia, Machakos, South coast, some areas of central
Zone V	Moisture index: 25-40; Classification: Semi arid; Lower elevations; Rainfall: 300-600mm; Temperature ranges from $22^{o}C$ to $40^{o}C$ less suitable for agriculture. Supports wildlife	North Baringo, Turkana, Lower Makueni, vast parts of north eastern region
Zone VI	Moisture index: 15-25; Classification: Arid; Lower elevations; Rainfall:300-550mm; Temperature: $22^{o}C$ - $40^{o}C$.	Marsabit, Turkana, Mandela, Wajir, Chalbi desert
Zone VII	Moisture index:<15; Classification: Semi desert and desert areas; Lower elevations;Temperature:$22^{o}C$-$40^{o}C$ to;Rainfall:150-350mm	Marsabit, Turkana, Mandela, Wajir, Chalbi desert

Source: Sambroek et al., (1982) and FAO (2006).

Areas with an index higher than 50 percent are designated zones I, II and III and they account for approximately 12 percent of total land area. Areas with an index of less than 50 percent are designated zones IV, V, VI and VII. These zones are referred to as Kenyan rangelands and account for approximately 88 percent of total land mass. These zones are further sub divided according to the mean annual temperatures to identify which areas are climatologically suitable for growing major crops.

1.3 Climate Variability in Kenya

Complex patterns of climate variability have occurred in Kenya with ElNiño (1997/98) and La Niña (1999/2000) episodes being the most severe (SEI, 2009). 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 amount and the amount of rainfall recorded in the long rain season from 1960 to 2014 (Republic of Kenya, 2015). Figure 1.1 and 1.2 displays the year to year variability of temperature and rainfall in maize, tea and coffee growing areas in Kenya. 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.

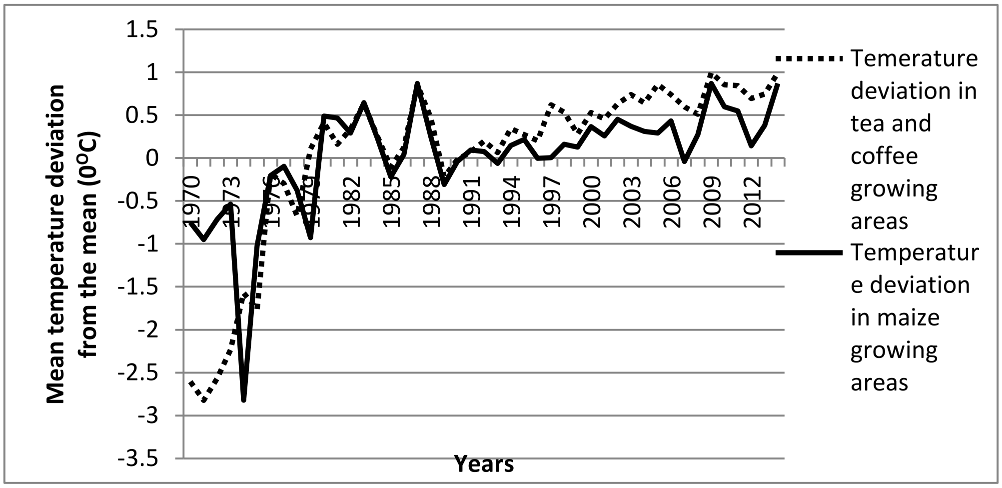

Figure 1.1 Annual Mean Temperature Variations in Maize, Tea and Coffee Growing Areas in Kenya (1970-2014)

Source: Kenya Meteorological Department

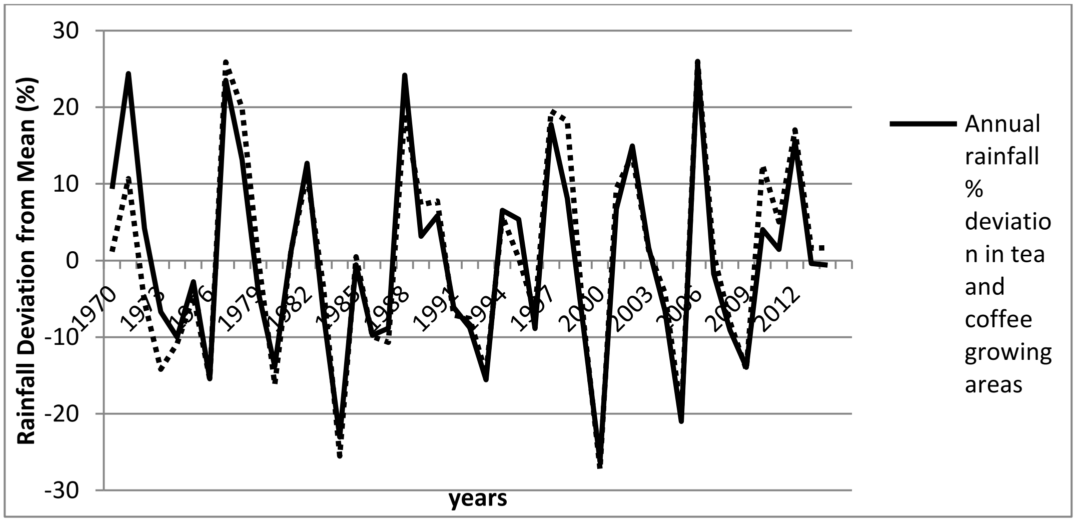

Figure 1.2 Annual Rainfall Deviations (%) From the Mean in Maize, Tea and Coffee Growing Areas in Kenya (1970-2014)

Source: Kenya Meteorological Department

The temperature and rainfall variations in tea and coffee growing area were computed using data from: Kericho, Kabete, Nyeri, Kakamega, Meru, Embu and Kisii weather stations. These weather stations are located in tea and coffee growing areas.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 observed changes are as a result of atmospheric and oceanic circulation, mostly caused by differential heating of the sun on earth. Atmospheric- Ocean circulations make climate to vary in season to season or year to year time periods. 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).

1.4 Agricultural Sector and Climate Variability in Kenya

Agricultural sector contributes about 30 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).

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). For instance, the sector performance slackened considerably from an average of 4.7 percent in the first post independence decade to below two percent in the 1990's culminating with a negative growth rate of -2.4 percent in 2000. Further, the sector's value added contracted by 4.3 percent and 2.3 percent in 2008 and 2009 respectively. Similarly, in 2011, the sector recorded a growth rate of 1.5 percent way below a high of 6.4 percent recorded in 2010, whereas the growth decelerated to 3.5 percent in 2014 from a growth of 5.2 percent recorded in 2013. In the year 2014 activities of crop growing and animal production were negatively affected by poor long rains in several parts of the country with the worst hit being the North rift region, which serves as the Kenya's grain basket. As a result, maize production dropped but production of some food commodities like Irish potatoes and pulses improved partially offsetting the negative effects of declined production of maize in the sector (Republic of Kenya, 2011; 2012; 2014; 2015).

The Kenyan agricultural sector has limited diversification with a few commodities namely maize, tea, coffee, dairy, wheat and horticulture providing livelihoods for over 85 percent of population, while both tea and coffee provide approximately 45 percent of wage employment in the sector. In addition, maize serves as the main staple commodity in the country and key to food security (UNDP, 2002; Alila & Otieno, 2006). Decline in the growth of agriculture sector amidst a growing population has far-reaching implications in terms of food security, employment, income generation and trade balance for the country. Consequently, hindering the attainment of sustainable development goals and vision 2030 (Republic of Kenya, 2013; UNDP, 2002; 2015). In the light of the importance of maize, tea and coffee in Kenya's economy and livelihoods of majority of rural inhabitants, this study focuses on these three crops.

1.4.1 Maize Production in Kenya

Climate change and variability has been cited as one of the major drivers of food insecurity in Sub Saharan Africa, since it acts both as an underlying, ongoing issue and as a short lived supply shock (Gregory *et al*., 2005). Food systems are affected by climate change in several ways. These range from effects on food crop production, market changes, food prices and supply chain infrastructure. Food crop production is directly influenced by variations in temperature and precipitation, growing season length, altered soil fertility and increase in pests and diseases. In addition, pests and diseases have a direct effect on food toxic levels as well as nutritional contents of food (Gregory *et al*., 2005; FAO, 2008a). 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 30°C. 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. These varieties are suitable for medium to high altitude areas with an altitude range of 1500-2100 masl, a temperature maximum of 28^{o}C and a temperature minimum of 8^{o}C. These varieties require precipitation ranging between 800-1500mm. The highland maize variety is grown in Transzoia, Uasin Gishu, Nakuru, Kericho, Kisii, Narok and tea zones of central and eastern region (Schroeder *et al.,* 2013; Kenya Seed Company, 2013).

In the medium altitude agro-ecozone falling between altitudes of 1000 - 1700 masl, the recommended varieties include: H513, H515, H516, H623 and H624. These varieties are grown in coffee growing regions of Kenya, Narok, Nakuru, Busia, Kakamega, Keiyo and Marakwet. These varieties mature in four to five months with a rainfall requirement range of 750 and 1000mm and temperature of 12^{o}C to 30^{o}C. In the lowland agro-ecozone Pwani hybrids PH1 and PH4 are recommended, they are short, resistant to lodging and more tolerant to moisture stress. They require minimum rainfall of 400mm and grow in an altitude range between 0-1250 masl. These varieties mature within three to four months. In the dry land agro-ecozone the varieties recommended varieties include Katumani Composite, DH01, DH02, DH03, DH04, and Makueni SCDUMA43. These varieties grow well in marginal areas at an altitude of 1000-1800 masl and low rainfall ranging between 400-800mm. These varieties mature within three to four months. Dry land agro-eco zone areas include Kitui, Machakos, Makueni, lower Meru, Siaya, Kisumu and coastal areas (Kenya Seed Company, 2013; Schroeder *et al.,* 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 lead to an increasing gap between production and consumption besides increasing frequency of supply shortages. Figure 1.3 depicts maize yield trend in Kenya for the period 1970 to 2014. While Figure 1.4 shows the gap between maize production and consumption in Kenya for the same period.

Figure 1.3 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.

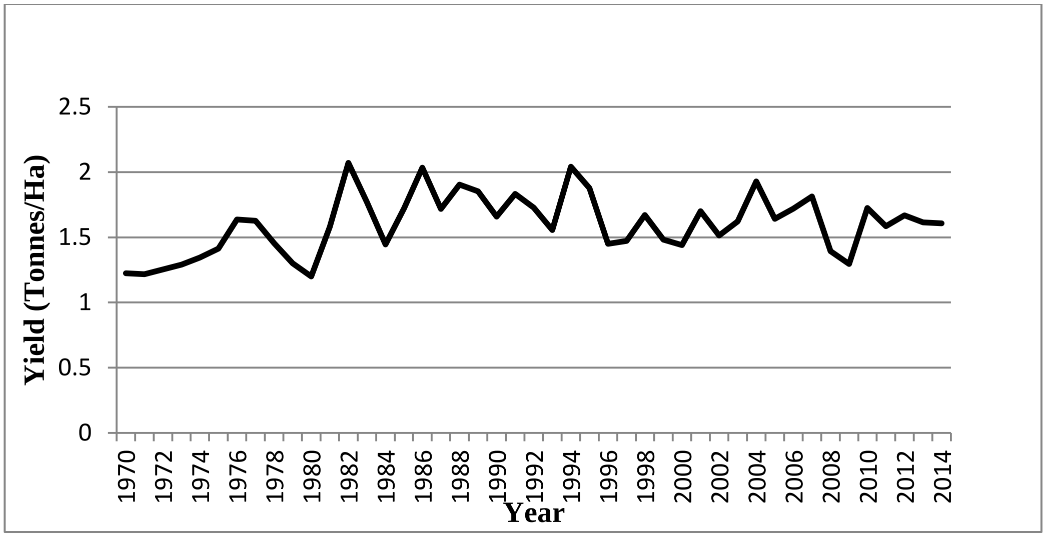

Figure 1.3 Maize Yield Trend in Kenya (1970-2014)

Source: Republic of Kenya. Economic Survey (Various Issues).

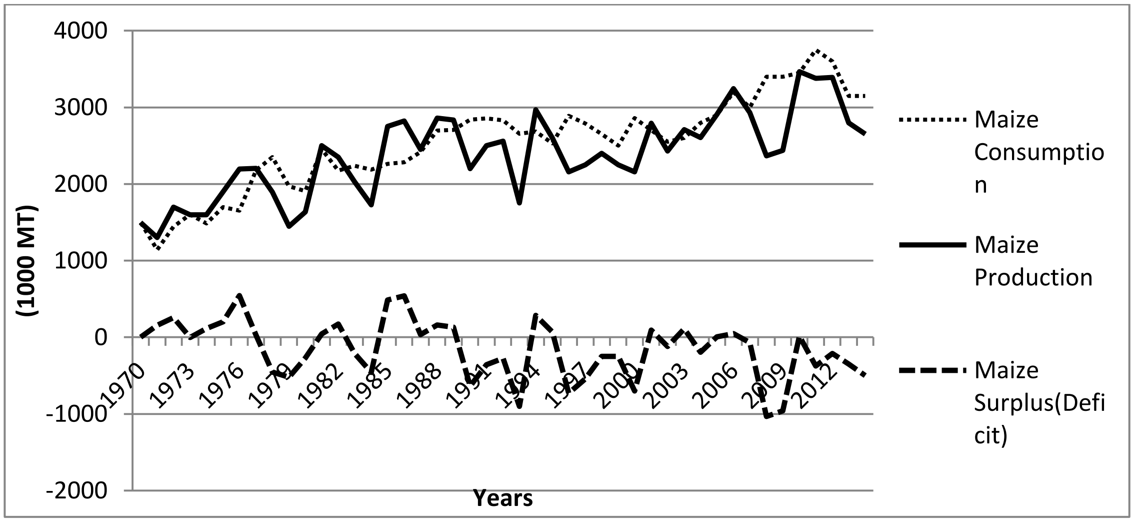

Figure 1.4 Maize Production and Consumption Trends in Kenya (1970-2014)

Source: Republic of Kenya. Economic survey (various issues).

Figure 1.4 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.

The drop in maize production per hectare over the years has been attributed to a number of factors in the literature including: low usage of fertilizers, lack of funds, withdrawal of extension services, limited high potential land, scanty and unpredictable rainfall patterns (UNDP, 2002; Alila & Otieno, 2006).

Maize production relies on sufficient and timely rainfall throughout the life cycle of the maize plant. However, in maize growing areas, there is high variability of rainfall amidst rising temperatures. In addition, the duration and amount of the long rains and short rains has also been affected. With the observed and projected changes in rainfall and temperature and over reliance on rain fed maize farming, climate variability is expected to play a major role as a supply shifter in maize production (Owuor, 2010; Nyairo, 2011; Onono *et al.,* 2013).

1.4.2 Tea Production in Kenya

Tea (*Camellia Sinensis*) is a straggling tree or a shrub of the genus *Camellia* of flowering plant that belongs to the family of *Theaceae*. The shrub/tree grows to an approximate height of 7-8 feet. There are three main varieties of tea namely, China variety (C.s *sinensis*), Assam variety (*C.s assamia*) and Cambodia variety (*C.s lasiocalyx*) (Brown & Cocheme, 1973). Assam variety though not in its pure form is the predominant variety grown in Kenya, owing to its high yield potential (Rwigi *et al.*, 2009). In Kenya, Tea Research Foundation of Kenya (TRFK) develops cloned planting materials through scientific innovations making vegetative propagation possible. As a result, high yielding and well adapted varieties have been developed. TRFK has developed about 50 varieties which are matched to specific areas where productivity is maximized (Tea Board of Kenya, 2015).

According to the Tea Board of Kenya (2012), tea is still one of the leading foreign exchange earners in Kenya accounting for 20 percent of total exports, 26 percent of global tea exports and 10 per cent of the global tea production. This is behind China and India, which account for 34 percent and 24 percent respectively of global tea production. Currently, the smallholder growers who process and market their crop, through Kenya Tea Development Agency (KTDA) Ltd., produce 62% of tea in the country. Smallholder farmers manage KTDA, making it the largest single producer of tea globally. The balance of 38% is produced by the large scale estates, which are managed by major multinational firms. The tea sector employs about 5 million people directly and indirectly. These statistics make tea one of the leading sources of livelihood. In Kenya, tea growing and manufacturing mainly occurs in rural areas and thus provides significant contribution to the rural communities.

Globally tea cultivation is restricted to the sub tropics and mountainous areas lying above an altitude of 1200 masl. Tea growing regions in Kenya are found in the Great Rift Valley, Aberdare highlands, Nyabene hills, Nandi Hills, highlands around Kericho, Mt. Elgon and the Kisii highlands. It is on the slopes of these highlands within the altitudes of 1500 to 2700 masl that tea is grown. These regions are endowed with an ideal climate for tea growing. The tropical volcanic soils rich in nutrients give the tea a unique flavour and character. The rainfall ranges between 1200mm and 1400 mm annually. These environment favor growth rate of tender shoots made up of two leaves and a bud that are harvested products in tea (Rwigi *et al.,* 2009).

Tea crop depends on air and soil temperature, rainfall, air saturation deficits, soil water, radiation, sunshine hours and evaporation (Carr, 1972; Squire & Callander, 1981, Stephens & Carr, 1991, Stephens *et al*., 1992). Tea production is greatly influenced by seasonal fluctuations in climatic variables such as rainfall, temperature, solar radiation and humidity (Etherington, 1973). Tea plant requires well distributed rainfall and a mean minimum temperature of about 13^{o}C to 14^{o} C to support shoot growth with the optimum in the range of 18^{o}C to 30^{o} C. Maximum temperatures beyond 30^{o} C and minimum temperature below 14^{o} C leads to a reduction in growth rate typified by reduced shoot extension rates and lower tea yields.

Deviation from the favorable conditions characterized by increased temperatures and reduced moisture levels lead to osmotic stress that induce biochemical and physiological responses in tea, and as a result, tea quality and quantity is adversely affected (Duan,1992; Cheserek, 2015). In addition, increased temperatures can cause sun scorch damage and reduce water content in tea, consequently, lowering the tea quality and quantity produced. Similarly, low air temperatures in high altitudes, can potentially cause a drop in growth rate and reduced yields. Changing rainfall patterns create uncertainty on the appropriate time to apply fertilizers while extreme weather events such as droughts, floods, hailstorms, frosts and landslides cause crop damage and failure. (Cheserek, 2015; Ng'etich, 1995)

According to FAO (2015) most tea growing areas in Kenya experience dry conditions regularly between December and March. In addition, occurrence of frosts poses a threat with possibility of loss of yield. The impact of changes in climate change may vary depending on the duration and intensity of the climate change effect. Due to projected increase in rainfall and temperature variability, some tea growing areas including Nandi, Kericho and Gucha may become unsuitable for growing tea and farmers may need to change to alternative crops. The suitability of these areas is expected to drop by around 40 percent by 2050. Areas like Bomet, Kisii and Nyamira may remain stable. However, areas in central region and higher altitudes around Mt. Kenya could see their potential grow by around 15 to 20 percent by 2050 (International Center of Tropical Agriculture (CIAT), 2011). Figures 1.5 and 1.6 shows tea yield trend in Kenya and production growth rate for the period 1970 to 2014, respectively.

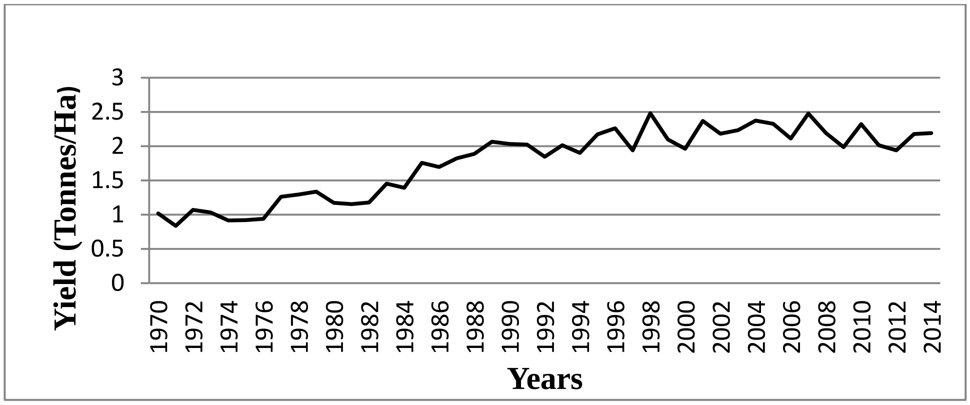

Fig 1.5 Tea Yield Trend in Kenya (1970-2014)

Source: Republic of Kenya. Economic Survey (Various Issues).

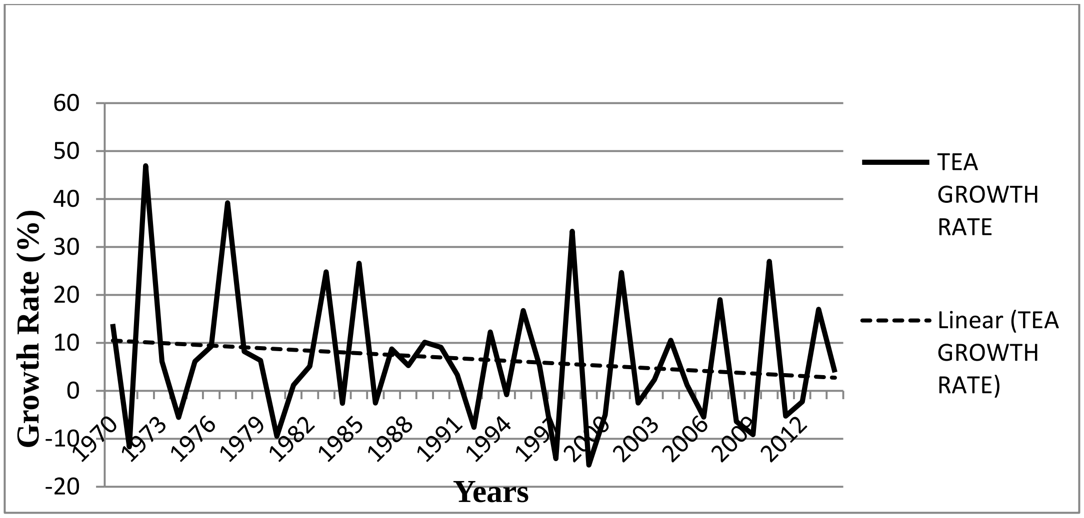

Fig 1.6 Tea Production Growth Rate Trend in Kenya (1970-2014)

Source: Republic of Kenya. Economic Survey (Various Issues).

Figure 1.5 depicts an increase in the total production of tea per hectare over the years. This positive trend has been attributed to favourable political environment as well as pragmatic economic policies favourable to tea production (Owuor, 2011). However, in terms of growth rate, there have been fluctuations in tea production with some years recording negative growth rates as shown in Figure 1.6. The figure demonstrates fluctuations in tea production over the years, with production drastically dropping for 16 years, interspersed in the period between 1971 and 2012.

Moreover, Tea production growth rate slumped from a high of 9.95 percent for the period between 1970 and 1980 to a low of 3.9 percent in the period between 2004 and 2014. Comparatively, China, which is the leading producer of tea globally, recorded an increase in growth rate of tea output from 7.7 percent to 9.4 percent in the respective periods. In some years, negative tea production growth rates have been recorded in Kenya with huge decline recorded in the year 2001 where production fell by 48 percent. Consequently, the drop in tea production negatively affects earnings made from tea. For instance, between 2010 and 2014, the value of tea shipment from Kenya dropped by 22 percent, following negative tea production growth rates in 2011 and 2012 at negative 5.3 and negative 2.3 percent respectively and a drop in growth rate by 13 percent in 2014.

The fluctuations in tea production are widely attributed to several factors that include: overproduction of tea globally and falling prices; poor road infrastructure that creates delays in collecting and transporting green leaf culminating to quality deterioration, spillage and withering; over handling and high leaf temperature; subdivision of tea farms as a result of population increase; over reliance on Crush, tear, Curl (CTC) black teas while consumption trends are moving towards orthodox, white and green teas and effects of general global warming (Owuor, 2011).

Although these fluctuations have mainly been attributed to low adoption of technology and high incidences of pests, unfavorable weather conditions could further be constraining production (Rosenzweig *et al.,* 2004; Bergamarshi *et al.,* 2004*;* Berlato *et al.,* 2005; Cosbey, 2010; Owuor, 2010; Republic of Kenya, 2014; Omoyo, 2015). According to Owuor (2011), tea production in Kenya is highly threatened by global warming which introduces new pests and diseases. As well, general global warming could reduce the area under tea production by making parts of tea growing land unsuitable to produce quality tea. More specifically, Manroy et al., (2012) attributes the drop in tea production in the year 2009 to prolonged drought experienced in the year. Due to lack of irrigation infrastructure, the drought greatly affected the small holders culminating in a drop of more than 40,000 tonnes.

Wachira (2009) and Omumbo et al., (2011) observed that warming trend in maximum, minimum and mean temperatures and reduction in amount of rainfall in Kericho in the last four decades was highly correlated to decreased yields. Correspondingly, according to Soy & Tibbs (2009) and Republic of Kenya (2012; 2011; 2010; 2009) prolonged dry weather conditions experienced in tea growing regions east of the Rift Valley coupled with unpredictable fluctuations in rainfall patterns has been evident in the last decade with long dry spells becoming common and significantly impending on tea growth. Consequently, this could have led to low production and poor profitability.

Climate variability is expected to have a significant impact on tea production since the crop requires well distributed rainfall and thus changes in rainfall patterns and rise in temperature have direct negative impacts on quantity and quality of its production. Such outcomes pose a great danger mostly to the vulnerable smallholder tea farmers (Mckee & Yuan, 2012), with extended adverse effects on trade balance, foreign revenue, employment and income generation.

1.4.3 Coffee Production in Kenya

Globally there exist over 100 species of coffee with Arabica (*coffea arabica L*) and Robusta coffees (*coffea canephora P*) dominating about 99 percent of global production. Arabica coffee is native to tropical forests of East Africa, growing at an altitude ranging from 1500 to 2800masl. In this region rainfall is well distributed ranging from 1600 mm to 2000 mm and mean temperature ranges from 18^{o} C and 22^{o}C with the dry months coinciding with the coolest season (CIAT, 2010).

Coffee production highly depends on a regular sequence of weather events. For instance, Arabica coffee requires a dry period of three months before flowering and regular rainfall through out berry development and a dry period prior to harvest.

Prolonged rains reduce flowering affecting fruit set and lowering photosynthesis while prolonged droughts weaken trees, increase mortality of young trees and make coffee trees more prone to pests and diseases (CIAT, 2010).

According to International Coffeee Council (2014), climate variability is the major factor responsible for considerable instability in global coffee production with large output in one year followed by a smaller output in the subsquent year. Climatic variables influencing coffee production include: air temperatures, solar radiation, and relative humidity. However, rainfall and temperature are considered to be the most important factors influencing coffee tree physiological processes and coffee yield. Temperatures above 23^oC accelerate the development and ripening of cherries leading to loss of quality, while temperatures exceeding 25^oC reduce photosynthetic rate. Exposure to temperatures above 30^oC suppresses coffee tree growth and cause yellowing of leaves. Relatively high temperatures especially during the dry period may cause flowering abnormalities leading to poor and low production. On the other hand, annual mean air temperature below 18^oC and occurrence of frosts hinders growth. Robusta coffee is less adaptable to lower temperatures below 6^oC and grows better in areas with annual mean between 22^oC and 26^oC. Robusta grows at an altitude ranging between sea level and 800m (Carmago & Marcelo, 2009; CIAT, 2010; Haggar & Schepp, 2012).

Coffee is vital in the Kenyan economy largely due to its contribution to foreign exchange earnings, employment creation, income generation and food security to about 700 thousand smallholder coffee farmers (Karanja & Nyoro, 2002). Kenya produces three types of Arabica coffee namely, SL 28 and 34, K7 and Ruiru 11 (Kinoti, 2005). The Arabica species is mainly grown in the upper midland agro- ecological zones. These zones are on deep, fertile and well drained volcanic soils, with higher attitudes that range from about 1400 to 2000 meters above sea level. The climate in these regions is mild with an average mean temperature of about 19^0 C and rainfall of not less than 1000 mm and not more than 1700mm.

In Kenya, coffee is produced on the slopes of Mount Kenya, Kiambu, Meru region and Western Kenya region (Karanja & Nyoro, 2002). In central Kenya, rainfall is spread in a bi modal pattern that makes the coffee tree to have two distinct flowering each year. This occurs at the onset of long rains in March and onset of short rains in October. In western Kenya, annual rainfall is uniformly distributed. The main crop ripens from October to December while the short rains crop is ready for harvesting from beginning of May (Monroy *et al*., 2013).

Over the years, unpredictable rainfall patterns have been observed and droughts experienced in Kenya, making crop management and disease control difficult (Gichimu & Omondi, 2010). This could have contributed to the declining coffee production in Kenya (Eitzinger *et al*., 2010). Climate models predict an increase in temperature and increase in rainfall in coffee growing areas in Kenya. Minimum temperatures and maximum temperatures are expected to increase to 12 and 31.2^{o}C, respectively, while the 2nd quarter, which is the coldest, is expected to get hotter by 2050. Rainfall is expected to increase by 5-20 percent from December to January and a 5-10 percent decrease in rainfall from June to August by 2050. Overall, seasonal temperature and rainfall variability are expected to increase in coffee growing areas (Haggar *et al*., 2011).

Given that optimum coffee production requires specific climatic conditions, the projected higher temperatures and erratic rains will affect the flowering of coffee trees, hinder the drying of harvested beans and reduce soil fertility. Moreover, these changes could make some regions unsuitable for growing coffee hence a shift in production posing a huge risk to farmers and ultimately could affect quantity and quality of coffee (Haggar *et al*., 2011).

Coffee is a key export crop in Kenya behind tea and horticulture. For a long period Kenyan coffee accounted for approximately 40 percent of the total value exports. However, since 1989 coffee production has continuously declined. In 2012, coffee accounted for approximately 4.4 percent of total value of exports behind tea and horticulture, which accounted for approximately 20 and 11 percent of the total value of exports, respectively (World Bank, 2013). Figures 1.7 and 1.8 show coffee yield and output growth rate in Kenya.

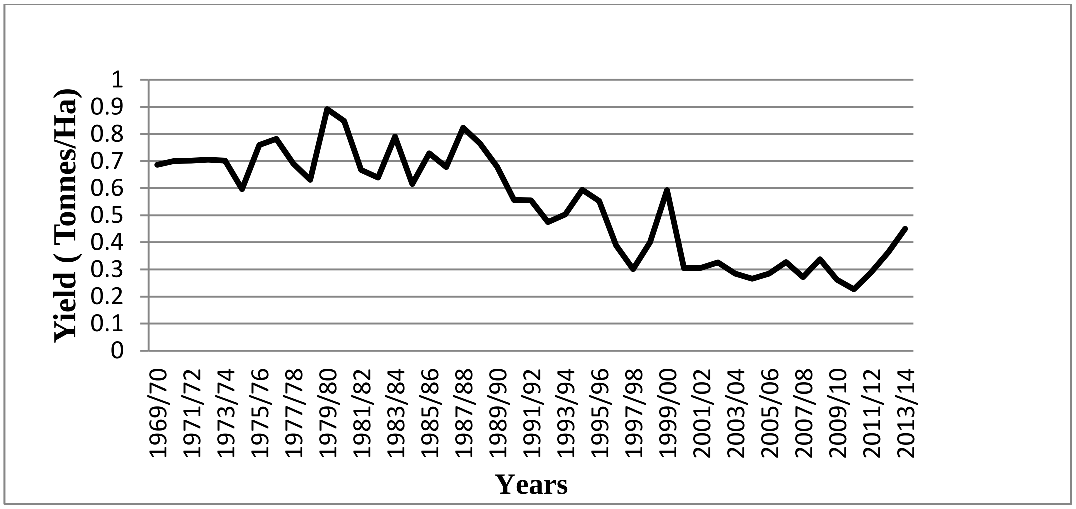

Fig 1.7 Coffee Yield Trend in Kenya (1969/70-2013/2014)

Source: Republic of Kenya. Economic Survey (Various Issues)

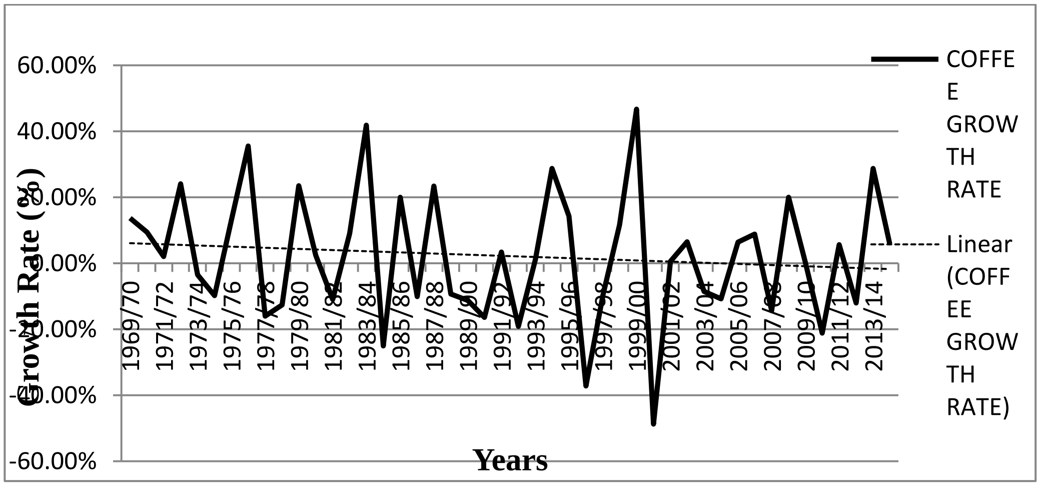

Fig 1.8 Coffee Production Growth Rate Trend in Kenya (1969/70-2013/2014)

Source: Republic of Kenya. Economic Survey (Various Issues)

As shown in Figure 1.7 Kenya's coffee production increased steadily in the first two decades after independence. Coffee production has been declining from an all time high of about 0.82 metric tonnes per hectare in 1988 to a low production of 0.22 metric tonnes per hectare in 2011, save for 1994/95 and 1999/2000 when there was a positive growth in production. The growth in production was mainly credited to increases in coffee prices following drought/frost in Brazil in 1994 and 1998 (Karanja & Nyoro, 2002).

This implied that for most of the years, the growth rate in coffee production has been negative as shown in figure 1.8, with the highest decline occurring in 2000/2001 when production dropped by 48 percent. The growth rate declined from a high of 7.5 percent for the period between 1970 and 1980 to negative 2.7 percent in the period between 2001 and 2014. This is in contrast to a dynamic growth rate obtained in the neighboring country, Ethiopia that has recorded an annual growth rate of 3.6 percent from 1990 to 2013, while the global average growth rate stands at 2.4 percent in the same period (ICC, 2014). Consequently, coffee earnings contribution to foreign earnings has dropped from 40 percent recorded between 1975 and 1986 to a low of 4 percent in 2014.

Overall, there has been a declining trend over the years. The decline in coffee production has been attributed largely to variation in weather patterns, inadequate extension services to farmers, weak institutions and insufficient research (Nyangito &

Okello, 1998; Karanja & Nyoro, 2002; Thuku, 2013). This study sought to empirically, estimate the extent to which variation in climate affects coffee production as claimed to by other researchers.

1.5 Climate Change Institutions and Policy

Since 1992, the Kenyan government has formulated policies and created various committees and institutions to address climate change. Some of the major efforts undertaken by the government of Kenya are discussed in this section. In 1992, the National Climate Change Activities Coordinating Committee (NCCACC) was established and mandated with coordinating the activities of the Government of Kenya on climate change. It has four technical working groups that deal with vulnerability, mitigation and adaptation, training, education and public awareness and Green House Gases inventory.

The National Environment Management Authority (NEMA) was established in the year 1999 under the Environmental Management and Coordination Act (EMCA) No. 8. It is a key government institution overseeing climate change issues in Kenya. NEMA hosts the Designated National Authority (DNA) responsible for approving climate change mitigation projects under the Kyoto Protocol and National Climate Change Focal Point (NCCFP), which coordinates climate change activities (Republic of Kenya, 2010b; 2013b). Part of NCCACC and NCCFP mandate includes vulnerability and adaptation, providing options for mitigation, sustainable development as well as public awareness.

In 2005, Kenya ratified the Kyoto Protocol. The protocol in part required member parties to implement and further elaborate policies and measures in accordance with its national circumstances, such as promotion of sustainable forms of agriculture in light of climate change considerations, among others (Republic of Kenya, 2010b; 2013b).

Between 2008 and 2009, the Multilateral Conventions department was established to be directly in charge of United Nations Framework Convention on Climate Change (UNFCCC) related policy activities. In 2008, National Environmental Policy (NEP) was drafted. The policy treats climate change and disaster management as an emerging environmental issue. In the year, 2010 National Climate Change Response Strategy (NCCRS) was developed to guide policy decisions and in 2013, a comprehensive National Climate Change Action Plan was established to push forward the implementation of the NCCRS (Republic of Kenya, 2010b; 2013b).

The NCCRS seeks to reinforce nationwide action towards adaptation and mitigation to climate change. Its focus is to ensure integration of climate change mitigation and adaptation in all government processes at the planning stage, budgeting and development objectives. The strategy calls upon all stakeholders for collaborative and joint action in dealing with issues emanating from climate change. The strategy identifies the most vulnerable sectors and prioritizes them for immediate action. The sectors include: agriculture, water, energy, forestry, rangelands, health, social and physical infrastructure sectors'(Republic of Kenya, 2010b; 2013b).

Under the agricultural sector, the NCCRS stipulates adaptation measures that comprise provision of downscaled weather information, provision of farm inputs; soil and water conservation; water harvesting which entail building of dams for irrigation and development of drought tolerant and pest and disease resistant crops. The NCCRS and the establishment of an action plan express an optimistic step towards climate change adaptation and mitigating. Even so, full implementation of the Action Plan is desirable, given the threats faced by farmers due to climate change. Moreover, more encompassing policies dealing with climate change are required coupled with clear guidelines for their assimilation and mainstreaming into major sectors both at the county and national levels (Republic of Kenya, 2010b; 2013b).

1.6 Statement of the Problem

Climate change and variability are anticipated to greatly affect crop production (IPCC, 2007; Schumidhuber *et al.*, 2007; Ringler *et al.*, 2010; Brown *et al.*, 2008; Lobell *et al.*, 2008b). In Kenya, crop production as 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 variability, with El Nino and La Nina episodes being most severe (Sei, 2009). As well, temperatures are expected to increase by about 4^{o}C and variability in rainfall will 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).

In Kenya, adequate supply of maize is an indication of food security. Moreover, Kenya relies on tea and coffee exports as a primary source of foreign revenue, 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). Similarly, over the years, coffee output and yield has fallen, with output growth rate declining from an average of 7.5 percent in 1970s to negative 2.7 from the year 2000 to 2014. Consequently, coffee earnings contribution to foreign earnings has dropped from 40 percent to 4 percent between 1975 and 2014.

In addition, the growth rate for tea output has also dropped from a high of 9.95 percent for the period between 1970 and 1980 to a low of 3.9 percent in the period between 2004 and 2014. Consequently, affecting earnings made from tea negatively. For instance, between 2010 and 2014, the value of tea shipment from Kenya dropped by 22 percent, following negative tea production growth rates in 2011, 2012 and 2014. Although, these fluctuations have mainly been attributed to low adoption of technology and high incidences of pests, unfavorable weather conditions could further be constraining production (Rosenzweig *et al.*, 2004; Bergamarshi *et al.*, 2004*;* Berlato *et al.*, 2005; Cosbey, 2010; Owuor, 2010; Republic of Kenya, 2014; Omoyo, 2015).

There is a need to have a sustainable increase in output of these crops in order to continue supporting the livelihoods of the growing population in Kenya. Although, economic incentives are provided to farmers to improve crop production, climate variability is likely to undermine these efforts, threatening the livelihood of over 85 percent of Kenyan population. So far studies analyzing crop output supply in Kenya have not considered the effects of climate variability (Mose *et al*., 2007; Olwande *et al.*, 2009; Onono *et al.*, 2013), yet it is expected to influence realization of supply through its influence on farmers crop choices and land allocation (Blanc, 2011). In addition, 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 seeks to empirically, determine the effects of climate variability on crop output and yield, by incorporating climate variable means and their variability. Anchored on empirical analysis and a detailed review of literature, this study sought to first ascertain the effects of climate variability on crops output while controlling for economic incentives. Secondly, by considering climate factors as direct inputs affecting crop yield, the study examined the effects of climate variables on crops yield.

1.7 Research Questions

This study sought to answer the following questions:

i. What is the response of maize, tea, and coffee output to rainfall and variability in rainfall in Kenya?
ii. What is the response of maize, tea, and coffee output to temperature and variability in temperature in Kenya?
iii. What is the effect of rainfall and temperature on maize, tea and coffee yield in Kenya?

1.8 Objectives

The general objective of the study is to analyze the production response of selected crops to climate variability in Kenya. Specifically the study sought:

i. To estimate the response of maize, tea and coffee output to rainfall and rainfall variability in Kenya
ii. To examine the response of maize, tea and coffee output to temperature and temperature variability in Kenya
iii. To determine the effects of rainfall and temperature on maize, tea and coffee yield in Kenya.

1.9 Significance of the Study

Since crop production can be increased by addressing issues that affect farmers' decision to expand crop cultivation or raise crop productivity, this study aimed at ascertaining the effect of climate variability on the conjoint issues on crop output supply and crop productivity by providing two sets of econometric analysis. The first set focuses on climate and economic factors that affect farmer's decision processes to expand output while the second set focuses on climate factors as direct inputs affecting crop yields. The study adds Knowledge to the limited but growing literature on climate and crop production in Kenya, thereby availing information for designing policies on adaption and mitigation to reduce the effects of climate risk associated with climate variability.

Findings of the study inform the Ministry of Agriculture; agriculture research institutes, Kenya Meteorological Department, interested stakeholders and policy makers in crafting policies that focus on creating awareness on changing climate and facilitation on how to adapt agricultural traditions in midst of climate variability. Knowledge of the adverse effects on agricultural sector due to climate variability is imperative for the achievement of food security, increase foreign exchange earnings and realization of developmental goals. This study provides an empirical foundation for consideration of climate variability in an endeavor to raise production of maize, tea and coffee in Kenya. The study also adds to the limited literature on the effects of climate change and climate variability on crop production in developing countries and more so in Kenya.

1.10 Scope and Limitation of the Study

The study confines itself in the examination of the production of three major crops in Kenya namely maize, tea and coffee. Maize is critical to food security while tea and coffee are important for the improvement of trade balance, foreign earnings, employment, income generation, poverty eradication as well as economic growth and development. The study used data on respective variables in the period between 1970 and 2014. This period is long enough to capture how the climate changes are translated into the changes of cash and food crop production in Kenya. The study focuses on influence of temperature and rainfall on three crops in Kenya and due to data limitations, the study did not consider several other explanatory variables such as radiation, atmospheric concentration of CO_2, crop management practices, surface runoff and pests and diseases.

1.11 Organization of the Study

This thesis is organized in five chapters. Chapter one provides the background to the study. Chapter two presents a review of theoretical and empirical literature, chapter three illustrates the theoretical and empirical models and estimation used in the study. Under chapter, four study findings and analysis are presented. Chapter five provides a summary of the study, highlights conclusion and policy implication.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of theoretical literature and empirical literature. Under theoretical literature, theories that explain farm household decision making are discussed while empirical literature reviews studies on crop output supply and crop yield.

2.2 Theoretical Literature

Under this section theories that explain the farm output decision making are explained: Profit maximizing Theory, Utility maximization Theory and Risk Aversion Theory. In addition, approaches that are employed in estimation of agricultural supply response and economic techniques applied to estimate the impact of climate change on agriculture are reviewed.

2.2.1 Profit Maximizing Theory

The theory of the firm assumes that a firm’s objective is to maximize profits. The problem facing the firm is to determine the level of output to produce, level of inputs to employ, prices of output and prices of inputs to maximize profits. This objective is achieved subject to technological and market constraints. In a profit maximizing firm, optimal choice of output is attained at the point where marginal revenue is equal to marginal cost. Optimal level of input employment is attained at the point where marginal factor productivity is equal to marginal factor cost (Mas-colell *et al.*, 1995; Varian, 1992; Nicholson *et al.*, 2008).

When firms are price takers as in the case of farmers, the decision problem becomes that of determining the level of output to produce and the level of factor inputs to employ. Optimal output level is attained at the point where marginal cost is equal to price. The firm's supply curve being its marginal cost function defined in the range where price is greater than or equal to the minimum of the average variable cost. The quantity of a product produced and supplied depends on its own price and the price of inputs (Mas-colell et al., 1995; Varian, 1992; Nicholson *et al.*, 2008).

Profit maximizing approach expresses the firm's problem in an output perspective, which is in line with the interest of the study of determining the output supply function for maize, tea and coffee. Such an approach assumes that optimization has already been achieved in the input space and that the firm uses the least cost combinations for the production of any output level. This least cost approach is conceptually plausible because producers would only want to produce a given output with the minimum cost outlay, rather than try to directly optimize in the input space by equating marginal factor productivity to marginal factor cost. Farmers may have no idea of the input marginal productivities but know the price of inputs. This makes it hard to equate the marginal revenue of employing an additional input to its marginal cost to determine optimal input levels (Muchapondwa, 2009).

The hypothesis in profit function approach to the supply is that, farmers attempt to maximize profit which is defined as the return to the variable factors. According to Lau (1972) the technology of a multiple output, multiple input can be represented by a transformation function

$$F(Y, X) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where Y and X are vectors of the quantities of outputs and inputs, respectively. Subject to the transformation function and given output and input prices, the firm maximizes

$$P = \sum_{i=1}^{m} p_i Y_i - \sum_{j=1}^{n} q_j X_j - \lambda F(Y, X) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Where the p_i's and q_j's are the output and input prices respectively and λ is a Lagrange multiplier. The maximized value of P is the profit function $\pi(p, q)$ and is given by

$$\pi(p, q) = Max\ P = \sum_{i=1}^{m} p_i {Y_i}^* - \sum_{j=1}^{n} q_j\, {X_j}^* \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where: the * signifies the optimized value and p and q are the vector of output and input prices, respectively. If the profit function $\pi(p, q)$ is characterized by the following properties: it is continuous, twice differentiable, convex, and closed in p and q in the nonnegative orthant. It is strictly increasing in p and strictly decreasing in q, it is finite for all finite p and q and is positively homogeneous of degree one in p an q. Then the first partial positive derivative of the profit function with respect to the output prices is the firms supply function and the first negative partial derivative of the profit function with respect to the input price gives the unconditional factor demand. Thus from equation (2.3) output supply is given by

$$\frac{\partial\pi}{\partial p_i} = Y_i^* \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

While the demand function for input j is given by

$$\frac{\partial\pi}{\partial q_j} = -X_j^* \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

The profit maximizing theory presumes crop-producing farmers are motivated by profit and therefore it gives a good starting base for analyzing farmers supply behavior in absence of risk and uncertainty. In addition, it assumes instantaneous response between factor inputs and output. However, this may not be the case in the agricultural sector due to some rigidities such as: production lags between input employment and harvesting; existence of technological and institutional factors that hinder farmers intended production decisions from being fully realized in any given period; price and information imperfections; change of technical rules of the production function in the course of production process and the challenge that farmers could be producing for food security and risk minimization other than for profit maximization (Mendola, 2007; Muchapondwa, 2009).

Climate variability poses an inherent constraint in smallholder agriculture in which makes profit maximization as a guide to decision making unsatisfactory in reflecting farmers' behavior. Thus, farmers could seek to maximize expected profit, which would coincide with maximizing expected utility under assumptions that farmers are risk neutral. However, most smallholder farmers are risk averse and generally face unavoidable risks when they make production and marketing decisions. Although profit maximization theory provides a good foundation for analyzing farmers supply behavior, it may not be adequate to explain the behavior of Kenyan farmers, majority of who are smallholder under the prevailing threat of climate change and variability.

2.2.2 Utility Maximization Theory

Utility maximization approaches encompass the dual character of farm households as both families and enterprises and thereby take account of the consumption side of household decision making (Mendola, 2007). Assuming that the household is a price taker in all markets, for all commodities, which it both consumes and produces, optimal household production can be determined independent of leisure and consumption choices. Given the maximum income level derived from profit-maximizing production, family labor supply and commodity consumption decisions can be made. With this sequential decision making, a recursive model that encompasses profit and utility maximization components is the appropriate analytical framework (Singh *et al.*, 1986).

The household objective is to maximize utility through the consumption of home-produced goods, market-purchased goods, and leisure, subject to full income constraints. The problem is stated as:

Maximize $U = U(X_a, X_m, X_l)$ ……………………………………………...……….…2.6

Subject to: $P_mX_m = P_a(Qa - X_a) – P_l(L - F) - P_VV + E$…………………..………..…..2.7

Where the commodities are an agricultural staple (X_a), a market-purchased good (X_m,), and leisure (X_l). Utility is maximized subject to a cash income constraint given by equation 2.7. Where P_m and P_a are the prices of the market-purchased commodity and the agricultural staple, respectively; Qa is the household's production of the staple; (Q_a - X_a) is its marketed surplus; P_L is the market wage; L is total labor input; F is family labor input; (L – F) if positive is hired labor and if negative, is off-farm labor; V is a variable input such as fertilizer; P_V, is the variable input's market price; and E is any non labor, nonfarm income. The household cannot allocate more time to leisure, on-farm production or off-farm employment than the total time available to the household and thus faces a time constraint of the form:

$X_l + F = T$…………………………………………………………...…………2.8

Where T is the total stock of household time

The household production technology is given as:

$Q_a = Q(L, V, A, K)$……………………………………………………………2.9

Where A is the household's fixed quantity of land and K is its fixed stock of capital.

The assumptions made in the model are, (i) there is only one crop, (ii) family labour and hired labour are perfect substitutes, and (iii) and perhaps most importantly, it is assumed that the four prices in the model: Pa, Pm, P_V, and P_l are not affected by actions of the household. That is, the household is assumed to be a price taker in the four markets resulting in a recursive model. The three constraints on household behavior can be collapsed into a single constraint. Substituting the production constraint into the cash income constraint for Qa and substituting the time constraint into the cash income constraint for F yields a single constraint:

$P_mX_m + P_aX_a + P_lX_l = P_lT + \pi + E$…………………………………………………2.10

Where $\pi = P_aQ_a(L,V,A,K) - P_lL - P_VV$ and is a measure of farm profits.

The left-hand side of equation 2.10 shows total household "expenditure" on three items: the market-purchased commodity, the household's "purchase" of its own output, and the household's "purchase" of its own time in the form of leisure. P_lT captures value of the stock of time owned by the household is explicitly recorded, as is any labor income (Becker, 1965). The extension for agricultural households is the inclusion of a measure of farm profits, $P_aQ_a - P_lL - P_VV$ with all labor valued at the market wage, this being a consequence of the assumption of price taking behavior in the labor market.

Equations 2.6 and 2.9 reveal that the household can choose the levels of consumption for the three commodities, and the total labor input allocation as well as the fertilizer input into agricultural production. Maximization of household utility (Equation 2.6) subject to the single constraint (Equation 2.10), with respect to X_a, X_m , X_l, L and V, yields the following first-order conditions :

$$P_a \frac{\partial Q_a}{\partial L} = P_l \dots\dots\dots\dots\dots\dots\dots\dots 2.11$$

$$P_a \frac{\partial Q_a}{\partial V} = P_V \dots\dots\dots\dots\dots\dots\dots\dots 2.12$$

$$\frac{\frac{\partial U}{\partial X_a}}{\frac{\partial U}{\partial X_M}} = \frac{P_a}{P_M} \dots\dots\dots\dots\dots\dots\dots\dots 2.13$$

$$\frac{\frac{\partial U}{\partial X_l}}{\frac{\partial U}{\partial X_M}} = \frac{P_l}{P_M} \dots\dots\dots\dots\dots\dots\dots\dots 2.14$$

Equations 2.11 and 2.12 show that the household will equate the marginal revenue products for labor and fertilizer to their respective market prices, an important attribute of these two equations is that they contain only two endogenous variables, *L* and V. The other endogenous variables, X_m, X_a, and X_L, do not appear in equations 2.11 and 2.12 and therefore, do not influence the household's choice of *L* or V provided second-order conditions are met. Accordingly, farm labor and fertilizer demand can be determined as a function of prices (P_a, P_l and P_V,), the technological parameters of the production function and the fixed area of land and quantity of capital. Since equation, 2.11 and 2.12 depict the standard conditions for profit maximization and 2.13 and 2.14 depict the standard conditions for utility maximization, it can be concluded that the household's production decisions are consistent with profit maximization and independent of the household's utility function (Nakajima 1969; Jorgenson & Lau, 1969; Singh *et al.*, 1986).

The household utility maximization model provides a strong link between household consumption and production, which characterizes smallholder agriculture in Kenya. Maize farmers are both producers and consumers of their output while cash crop farmers as well apportion part of their land to production of food crops. Family labor force and other resources are allocated between both segments indicating inseparability between consumption and production decisions. Thus, this study draws from the household model (Singh *et al.,* 1986) which captures these interactions theoretically and allows for examination of policies on well being, behavior of households and performance of agricultural production.

2.2.3 Risk Aversion Theory

According to the Standard Expected Utility theory, farmers make choices from available risky alternatives. The framework is based on the decision maker’s personal preference among outcomes, and his or her subjective probabilities of their occurrence.

Both the household behavior and its revealed attitude toward risk are reflected in its utility function. A risk-averse household prefers a smooth consumption stream to a fluctuating one, everything else being equal. This entails a low risk portfolio choice of productive activities in contexts of incomplete capital markets or underdeveloped institutional arrangements (Morduch, 1994; Mas-colell *et al*., 1995). Risk and uncertainty in decision making by farmers in Kenya may imply that production of crops will respond to changing rainfall and temperature patterns among other economic variables so as to enhance food security and increased farm income. In line with this theory climate, risk is captured in the study by considering how changes in mean and variability in rainfall and temperature influence crop production.

2.2.4 Partial Adjustment and Adaptive Expectation

According to Molua (2010) the response of farmers is constrained by several factors which include small holding, need for diversification so as to minimize risk, lack of factor inputs, low access to credit and uncertainty of weather conditions and its implication. These constraints hinder intended production decisions from being realized. To incorporate the possibility of adjustment to the desired position subject to the constraints in the production process the Nerlovian model assumes that change in yield between two periods occurs in proportion between the desired output in current period t, and actual output in period t-1. Thus, the partial adjustment model is specified as:

$$y_t - y_{t-1} = \delta({y_t}^* - y_{t-1}) + \varepsilon_t \quad 0 \leq \delta \leq 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15.$$

$$y_t = \delta {y_t}^* + (1-\delta)y_{t-1} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.16$$

Where y_t and ${y_t}^*$ are the actual and desired levels of output in period t respectively; $y_{t-1}$is the actual output in period t-1 and δ is the adjustment coefficient (Nerlove 1958; Madala, 2001; Paltasingh *et al.,* 2013).

Further, agricultural production is highly characterized by biological time lag which makes observed prices to be known after the harvest whereas the planting decision are made based on the prices expected to prevail after production has occurred. Thus, producer expectations play a major role in analysis of agricultural production behavior. In literature, three agricultural producer price expectation hypotheses have been explored, they include: the naïve expectations, rational expectations and adaptive expectations.

The naive expectation specifies that the producer prices expected in the next period are the same as those in the current year. Expectations are naive if the producer uses the output price existing at the time of input application to be the expected selling price (Nerlove 1958; Lahiri *et al*., 1985; Ahouissoussi, McIntosh, & Wetzstein, 1995; Burton & Love, 1996; Madala, 2001; Muchapondwa, 2008. The naive expectations model is specified as:

$$P^*{}_t = \alpha_0 + \alpha_1 P_{t-1} \;\; ; \quad \alpha_1 = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .\ldots\ldots 2.17$$

$P^*{}_t$ denotes expected price at period t formed in the previous period $t-1$ and P_{t-1} is the previous period price. The naive model presumes that output price at the time of input application contains all necessary information from which incisive production could profit. The model ignores probable production knowledge of likely shifts in supply or demand and their effects on price. Nerlove (1958) termed the naive model as being overly simplistic.

According to the adaptive expectations agents form expectation about what will happen in the future based on the past occurrences. Adaptive expectation implies that farmers adjust their expectation by some proportion to the extent by which expectations in the last period are different from the actual. The expected price in the subsequent period is formed by adjusting the expected price by a proportion of the error made predicting the existing period's price (Nerlove 1958; Lahiri *et al.*, 1985; Madala, 2001; Muchapondwa, 2008). The adaptive model is expressed as:

$$P^e{}_t - P^e{}_{t-1} = \lambda(P_{t-1} - P_{t-1}{}^e) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.18$$

Where $P^e{}_t$ and $P^e{}_{t-1}$ are price expectations in period t and t-1, respectively; P_{t-1} is the actual price in period t-1 and λ is the expectations coefficient. Partial adjustments and adaptive expectations in agricultural supply are taken into consideration by estimating Autoregressive distributed lag (ARDL) models. To capture these dynamics in production of maize, tea and coffee this study adopted the ARDL modeling approach.

The rational expectation hypothesis put forward that economic agents use all existing information while planning. The information includes all available observations on the variables under consideration at the time the forecast is being made (Tripathi, 2008). The hypothesis provides an ideal approach to decision making approach. For instance, reliable climate forecasts in Kenya are essential to the farmer for decision making processes. However, this may not be feasible in most developing countries like Kenya where farmer’s literacy levels are low and thus hard to obtain essential information making applicability of the hypothesis in agriculture difficult. This study assumed that farmers learn from experiences and notes that the realized output may be different from the desired due to adjustment lags of determining factors. Therefore, in this case adaptive expectations become more relevant in the study.

2.2.5 Approaches to Estimation of Agricultural Supply Response

The analysis of farmers’ output supply behavior has focused on two methodologies; the indirect structural form approach and the direct reduced form approach. The indirect structural form methodology entails derivation of factor input demand functions and output supply function and estimated using cross sectional data. The output supply is derived from the first order condition for profit maximization. The production can be a Cobb-Douglas production function, a constant elasticity of substitution function or a generalized power function.

Though the approach is theoretically thorough, it fails to consider partial adjustment and the process of expectation formation by farmers. This approach needs detailed information on all input prices. This is usually a challenge as it requires the input market to be functioning competitively, which is not the case, due to existence of market interventions in delivering farm inputs. In addition, the resulting elasticities are long run and fail to take into consideration partial adjustment and formation of expectation. This implies that there is a possibility of elasticity estimates being over estimated (Mbithi, 2000; Tripathi, 2008). For this reason, majority of output response studies have adopted the direct reduced form approach.

The reduced form models enable direct estimation of supply response. These models include the multiple linear regression models and the partial adjustment and expectation models as the Nerlovian model (1958). In a multiple linear regression model, agricultural output, acreage or yield is used as dependent variable and is usually regressed on relevant independent variables. The use of multiple regressions has been criticized on the ground that fitting time series data directly to a supply function may yield spurious results.

The Nerlovian model captures the dynamics of agriculture as it incorporates partial adjustments and price expectation in modeling agricultural supply. The model is usually extended to include other relevant variables to capture imperfect information on these variables. The model yields non-spurious results only if the variables are in levels. The presence of non stationary series would make the statistical significance of t test of the regression to have no meaning.

In the Nerlove Price Expectations Model, the desired output X_t^* is a function of price expectations P_t^e. The supply function is represented as:

$$X_t^* = a + bP_t^e \tag{2.19}$$

Where b is the long run elasticity of output with respect to price. On assumption that price expectations are adaptive that is, a farmer adjusts his price expectation by a fraction of the difference between the actual price and his previous expectation, then:

$$P_t^e - P_{t-1}^e = \delta(P_{t-1} - P_{t-1}^e) \tag{2.20}$$

$$P_t^e = P_{t-1}^e + \delta(P_{t-1} - P_{t-1}^e) \tag{2.21}$$

$$P_t^e = \delta P_{t-1} + (1-\delta)P_{t-1}^e \tag{2.22}$$

$$P_t^e = \delta P_{t-1} + (1-\delta)L\,P_t^e \tag{2.23}$$

$$P_t^e(1-(1-\delta)L) = \delta P_{t-1} \tag{2.24}$$

$$P_t^e = \frac{\delta}{1-(1-\delta)L}\,P_{t-1} \tag{2.25}$$

Where $P_{t-1}$is the price in period t-1 and$0 < \delta \leq 1$. Also assuming$X_t^* = X_t$, that is the desired output is equal to realized output in equilibrium and substituting for $X_t^*$and P_t^e from equation (2.25) into equation 2.19 yields:

$$X_t = a\delta + b\delta P_{t-1} + (1-\delta)X_{t-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots .2.26$$

Equation (2.26) implies that output supplied can be expressed as a function of its own lagged value and lagged price. Where $b\delta$ is the short run elasticity, alternatively the supply function can be derived from the partial adjustment process point of view. That is the actual change in output in one period is a fraction γ (such that 0< γ<1) of the change required to achieve the desired output X_t^* . Thus

$$X_t - X_{t-1} = \gamma(X_t^* - X_{t-1}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. \dots\dots 2.27$$

$$X_t = \gamma X_t^* + (1-\gamma)X_{t-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots . \dots\dots\dots\dots .2.28$$

$$\gamma X_t^* = X_t - (1-\gamma)X_{t-1} \dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots . \dots\dots\dots\dots\dots . \dots\dots\dots\dots\dots 2.29$$

$$X_t^* = \frac{X_t}{\gamma} - \frac{(1-\gamma)}{\gamma}X_{t-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots\dots 2.30$$

Assuming that $P_t^e = P_{t-1}$ and substituting equation (2.30) into equation (2.19) yields

$$X_t = a\gamma + b\gamma P_{t-1} + (1-\gamma)X_{t-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .2.31$$

Equation (2.31) implies that output supplied can be expressed as a function of its own lagged value and lagged price. A reduced supply function given in equation (2.32) is derived from both equations (2.26) and (2.31) which is then estimated, thus:

$X_t = \beta_0 + \beta_1 P_{t-1} + \beta_2 X_{t-1}$ ……………………………………………………..……………………..2.32

Since only the actual output rather than the optimal output is observed in reality, only the reduced form equation (2.32) or its variation can be estimated (McKay *et* al., 1999). Estimating equation (2.32) makes it difficult to distinguish between δ and γ when both adaptive expectations and partial adjustment are present. Therefore, based on this model long run price elasticity cannot be estimated unless the model is assumed either to involve a partial adjustment or price expectations only (Muchapondwa, 2009; McKay *et al*., 1999). Thus, the model is not capable of giving sufficient distinction between short run and long run elasticities. In addition, use of time series would result in spurious results if the series involved are non stationary (Wyeth, 1992; Mose *et al*,. 2007). This shortcoming is addressed using cointegration analysis and Error Correction Models (ECM) characterized by a general dynamic model where the effect of explanatory variable on dependent variable is distributed over a period of time, as adopted by Mckay *et al.* (1999); Tripathi, (2008) and Muchapondwa (2009). All the variables used in the ECM are stationary and thus the results are consistent. In addition, ECM helps in separating partial adjustments and adaptive expectations. If two variables X and P are integrated of order 1 and their linear relationship is I(0), then their long run relationship can be expressed as:

$X_t = \beta_0 + \beta_1 \mathrm{P}_t + \mu_t$ ……………………………………………………..……………………….……2.33

If the variables X_t and P_t are cointegrated and their linear combination, represented by the error term μ_t is stationary, then according to Granger representation theorem (Green, 2008) a relationship can be represented in an ECM as:

$$\Delta \mathrm{X}_t = \alpha_0 + \alpha_1 \Delta \mathrm{P}_t + \lambda\, \mu_{t-1} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots.2.34$$

Where Δ denotes the first difference operator, $\varepsilon_t$denotes the random error term, and $\mu_{t-1}$is the error term lagged one period from long run regression 2.33. From 2.33 the previous period error is:

$$\mu_{t-1} = \mathrm{X}_{t-1} - \beta_0 - \beta_1 \mathrm{P}_{t-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots.2.35$$

Plugging equation 2.35 into 2.34 yields an ECM equation specified as:

$$\Delta X_t = \alpha_0 + \alpha_1 \Delta \mathrm{P}_t + \lambda\, (X_{t-1} - \beta_0 - \beta_1 \mathrm{P}_{t-1}) + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots.\ldots..\ldots\ldots\ldots.2.36$$

The coefficient β measure's the long run elasticity; α measures the short run elasticity and λ is the coefficient of error term which denotes the extent of disequilibrium correction. Equation 2.36 implies that an ECM represent a forward looking behaviour and can be interpreted to describing farmers reaction to moving targets and optimizing their objective function under dynamic conditions(Nichell, 1985). ECM has some limitations as well in that it assumes that order of integration of all the variables is the same and known with certainty; it ignores short run dynamics when estimating the co integrating vector and when the short run dynamics are complex, this biases the estimate of long run relationships in finite samples.

The autoregressive distributed lag (ARDL) approach to cointegration rises above some of these problems. To start with, it captures both short run and long run dynamics when testing for the existence of cointegration. Secondly, it allows the estimation of cointegration relationships when variables are I(0), I(1) or a mixture of the two, so it is unnecessary to pre-test the order of integration of the variables in the model, provided that the highest order of integration is I(1). Thirdly, it offers explicit tests for the existence of a unique cointegration vector rather than assuming there is only one. Finally, it takes into account the possibility of reverse causality (i.e. the absence of weak exogeneity of the regressors), thereby ensuring that the parameter estimates are efficient and consequently valid (Pesaran *et al.*, 2001; Muchapondwa, 2009; Onono *et al.*, 2013). From the foregoing, this study employed the ARDL approach in analyzing the output supply response of each crop as explanatory factors, were found to be integrated to different orders and with a possibility of reverse causality.

2.2.6 Economic Approaches to Estimate Impact of Climate on Agriculture

Wide ranges of models have been used to assess the economic impact of climate change on agricultural production. These approaches are broadly categorized into structural and analogue approaches. However, researchers have proposed other approaches based on the neo-classical theories to bridge the gap that could not be addressed by the two approaches.

Structural approach is multidisciplinary with its foundation largely rooted in natural science. It comprises of agronomic- economics or crop response simulation models which combine farmers' economic decision with agronomic responses of plants. These models entail detailed experiments under laboratory settings that simulate different climatic conditions and other related conditions to model changes in yield by crop and region. The results from simulation are then included into economic models of farmer behavior to determine production and prices. The economics models usually seek to maximize producer and consumer welfare subject to climate and other constraints imposed on the model. This method provides an estimate of yield response of specific crop varieties to climatic and other related variables (schimmelpfennig *et al*., 1996; Adams *et al.*, 1998; McCarl *et al*., 2001; Seo *et al.*, 2005).

Under the structural approach, effects of climate change are directly incorporated on crop yields providing an all-inclusive understanding of the key physical, economic as well as biological crop responses and adjustments to climate variables. In addition, the structural modeling approach allows integration of farm level adaptation techniques and management practices such as changing planting dates, crop varieties and enhancing or adding irrigation, which are critical for policy responses to climate change.

The major challenge of using the structural approach is in identifying and integrating adaptation methods used by farmers and consumers to respond to climate change, particularly in long time horizons. Another drawback surfaces in aggregate studies where inferences on the impact of climate change has to be made from relatively few sites and few crops, to cases where inference is to be made in large areas and in diverse production systems. This can indeed make the results become unreliable. The results from this approach tend to overstate the damage caused by climate change (Adams *et al.,* 1998; Mendelsohn *et al*., 1999; McCarl *et al*., 2001). Structural models are important for scientific testing but their applicability is restricted in most developing countries where experiments are limited and economic modeling is poor (Seo *et al.*, 2005).

While structural approach is largely experimental, spatial analogue approach uses statistical or econometric estimation. The models employed assess the impacts of climate founded on observed differences in land values and agricultural production. The approach looks at how current production differs across areas with different climate, to deduce the effects of climate conditions from those differences. Using cross sectional data, this approach facilitates statistical and econometric estimation on how climate changes such as temperature and rainfall might affect production and profits.

The strength of spatial analogue approach is that climate change and farmer's responses are implicit in the analysis as they are reflected on the data used. However, one of the drawbacks of spatial analogue models is that they abstract from the issues and cost of changes in infrastructure such as irrigation systems that may be crucial to imitate warmer climate practices. As well, it ignores changes in output and input prices that are likely to occur from international changes in production, which consecutively may affect adaptation decisions at the farm level (Adams *et al.*, 1998).

One of the extensively used spatial analogue models is the Ricardian Model. The model was developed by Ricardo in 1817 and hypothesizes that, value of land is a reflection of net productivity of farmland. The model assumes that in perfect competition the value of land, which is equal to present value of expected net revenues, reflects the efficiency in use of farmland. In turn, this efficiency is affected by climate conditions. Holding price of inputs and output per area of farmland constant, changes in value of land would reflect the value of climate change to agriculture (Mendelsohn et al., 1994; Mendelsohn & Dinar, 2009; Galindo & Reyes, 2015). The net revenue equation is specified as:

$$\pi_i = \sum_j P_{ij} Q_{ij}(X_{ij} / W_{ij}, E_{si}, S_i) - \sum_j P_{ij}\, X_{ij} \dots\dots\dots\dots\dots\dots..\dots\dots\dots\dots\dots\dots\dots\, 2.37$$

Where π_i is net revenue of farm i, P_{ij} is a vector of output and input prices, Q_{ij} is production function for each crop; X_{ij} is a vector of endogenous input choices such as fertilizer, seed and irrigation; $W_{ij}$is weather conditions; is a vector of social, economic and demographic variables; S_i is a vector for soil characteristics and index j is the selection of crop. Econometric specification of the Ricardian model is a reduced form that includes net revenue or land farm values per hectare as the explained variable and weather conditions, soil type, social economic and cultural variables as explanatory variables. The model is specified in quadratic form as:

$$V_i = \beta_0 + \beta_1 C_i + \beta_2 {C_i}^2 + \beta_3 Z_i + \beta_4 X_i + \mu_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots 2.38$$

Where V_i is net land value for i farms or net revenue per hectare. Net revenue per hectare estimated as sum of quantities of crops multiplied by their respective prices, divided by the crop surface of land; C_i represent climate variables that include temperature and precipitation; Z_i is a vector for soil types and characteristics; X_i represent control variables which include household, production and geographic characteristics; β_i are estimated coefficients and μ_i is the error term (Mendelsohn et al., 1994; Mendelsohn & Dinar, 2009; Galindo & Reyes, 2015).

The model provides a link between effects of climate variables, social economic variables, environmental variables and adaptation measures on the market value of land. From the estimated coefficients of the Ricardian model, the economic value of each variable can be determined. These coefficients are further used to predict the effect of future changes in climate. If land market values are considered imperfect farm profits/net revenues are used as a proxy for land values (Sanghi *et al.,* 1998; Mendelsohn *et al*., 2001; Blanc, 2011).

The strong point of Ricardian model lies in its ability to incorporate farmers' private adaptation. Adaptation takes various forms such as varying crop mix, adjusting planting and harvesting dates as well as investing in irrigation systems. These pose additional costs to farmers and are captured by the net revenues. Hence using net revenue as a dependent variable captures farmers' adaptation (Deressa, 2007). The model is able to capture spatial adaptations an initial response to climate change as it takes into consideration different climatic zones

Though popular, Ricardian approach suffers from a number of limitations, one of the major weaknesses lie in the assumption of a perfectly rational agent whose objective is profit maximization. The assumption implies that farmers can immediately recognize climate change, evaluate generated changes in the market, and effectively adjust farming practices to allow utility maximization under existing conditions. This implies that farmers can access adaptation technologies at any given time (Mendelsohn *et al*., 2001). Nonetheless, there exist financial and political bottlenecks that could make such adaptation impossible more so in areas with great competition for more profitable use of resources. As well, farmers may not automatically adopt a technology that scientist recommends to solve their problems, even if they have detected changes in climate due to varied reasons (Maddison, 2006; Gbetibou, 2007). Due to this extreme adaptation possibility, the impacts of climate change on net revenue are systematically biased downwards where they tend to be excessively low (Polsky, 2004). The main assumption of perfect markets fails to hold in the case of developing countries where the markets do not function well as in the case of USA where it was first applied by Mendelsohn et al. (1994).

Another limitation of the Ricardian model is in the use of land values for farms near urban areas. In these areas changes in land values could be a reflection of other factors than soil productivity due to alternative uses of land. The model also fails to capture changes in price. As observed by Schimmelpfennig et al. (1996), changes in climate could cause wide spread price changes leading to incorrect estimation of land values. If prices change as a result of local circumstances, estimates from the Ricardian method would be biased (Seo *et al.,* 2005).

Studies using the Ricardian approach are frequently based on one year data which may not be adequately representative of other years as results could be biased if any exceptional climatic, agronomic or economic conditions occur in the year of analysis (Maddison *et al*., 2006). As well, given that the results are derived from analysis of cross sectional data, the model presumes that they characterize relationships that are always valid in climate change impacts. However, climate variation impacts across space could be different from those over time. The approach is therefore likely to give unreliable results, as its estimates are highly sensitive to minor changes in variables, sample and weighting (Polsky, 2004; Kurukulasuriya *et al.*, 2006). This limitation is usually addressed by ensuring normality of the year considered or carrying out the estimation for two years to ascertain likeness of results (Mendelsohn *et al*., 1994; Kurukulasuriya & Ajwad, 2007). Further, to address the weaknesses of the Ricardian approach, use of panel data sets has been proposed with the use of time series panel data sets considered more robust (Polsky, 2004; Deschênes & Greenstone, 2007).

Deschenes & Greenstone (2007; 2012) proposed an inter-temporal approach to measuring impacts of climate change on agricultural profits using panel data. Using this approach, the effects of random year to year variation in temperature and precipitation on agricultural profits were analyzed. They estimated the following equation:

$$Y_{ct} = \alpha_c + \gamma_t + X'_{ct}\pi + \sum_i \beta_i f_{i(W_{ict})} + \mu_{ct} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \dots\dots .2.39$$

Where Y_{ct} is the value of annual agricultural profits, measured by the difference between revenues and cost of production, c represent a county, t references year, α_c is county fixed effects and $\gamma_t$is the year indicator, X_{ct} is a vector of the same soil characteristics, W_{ict} is a vector of climate variables and μ_{ct} is stochastic error term(Deschênes & Greenstone, 2012).

The study used county level data for USA to gauge the effects conditional on county and state by year fixed effects. The estimates were attained through comparing counties that had a positive weather shock with those with negative weather shock within the same state. This makes variation in agricultural profits independent of its unobserved determinants.

One of the major advantages of an inter-temporal model is its ability to eliminate all time invariant unobserved farm specific factors such as: ability of management, land quality and capacity utilization that influence farms net revenue. These factors are usually taken up in the error term and if correlated with any independent variable they cause bias. Use of fixed effects eliminates the unobserved individual effects (Woodridge, 2012). Inter temporal approach can also be used in areas with minimal climate variation across space where the Ricardian approach would not be useful.

The limitation of inter temporal approach is that it ignores the cross sectional variation leading to loss of some information (Masseti & Mendelsohn, 2010). As well, there is likelihood that the climate parameters estimates will be small (Griliches & Mairesse, 1998). Deschenes & Greenstone (2007; 2012) also acknowledged that this econometric methodology does not provide for a wide range of adaptation since farmers cannot fully respond to one year weather realization. Though, lighter decisions such as the use of fertilizers, labor and other inputs are integrated, major decisions such as crop switching are not usually included as they may not be implemented with a single year weather realizations.

Given the ability of spatial analogue approach to capture climate change and farmers' responses, this study employed statistical/econometric approaches to determine the influence of rainfall and temperature on crop output supply and crop yield. Unlike the crop growth models, which are carried out under experimental conditions, use of an econometric approach allow for the quantification of changes in climate variables to crop production in an actual cropping situation.

In this study, an econometric approach was adopted. Specifically, to capture crop output supply response an ARDL model was estimated using time series data; this takes care of the effects of climate variability overtime. The ARDL model has an advantage of integrating both climatic and economic variables, which are integrated at different levels. The model takes into account both partial and adaptive expectations in agricultural supply. Estimates obtained from the ARDL approach to cointegration analysis are unbiased and efficient, free from serial correlation and endogeneity problems (Pesaran, Shin & Smith, 2001).

In addition, regression analysis is used in this study to relate crop yield to climate data. According to Parry et al. (1988) and Mahmood et al. (2012), regression analysis is of use in providing effective estimates of crop yield when crop yield is affected by temperature and rainfall. Since temperature and rainfall are likely to have a non linear relationship with crop yield, a Cobb Douglas production function, which is a non linear function, is adopted in this study. A Cobb- Douglas production function showing a technical relationship between crop yield (output) and inputs can be specified as:

$$Y_t = AX_t^{\beta} e^{\mu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.40$$

Where Y is the crop yield, X_t is a vector of inputs which include the traditional inputs namely labor(L), fertilizer(F), machinery(K) and climate variables which include temperature(T) and precipitation(P). Typically, climate variables are not included in a production function, as they are assumed constant. However, this is not the case with the presence of climate change. The model is transformed into a log linear form and can be estimated using ordinary least squares method.

$$lnY_t = \ln A + \beta \ln X_t + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.41$$

More specifically the model to be estimated can be written as:

$$lnY_t = \beta_0 + \beta_1 lnL_t + \beta_2 lnK_t + \beta_3 lnF_t + \beta_4 lnT_t + \beta_5 lnT_t{}^2 + \beta_6 \ln R_t + \beta_7 \ln R_t{}^2 + \mu_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2.42$$

For climate, variables both linear and quadratic are estimated in the model to take into consideration the non-linear relationship between crop production and climate variables (Mahmood *et al*., 2012).

2.3 Empirical Literature

Several studies have examined the impact of climate change and variability using agronomic models or statistical estimation. There exist large dispersion of results depending on the methodology, crop under consideration and the region where the study was done. This section reviews literature relating climate change and its variability to crop production under two sub sections. Under section 2.3.1, literature on the effects of climate change and climate variability on crop production is reviewed, while under section 2.3.2 literature on agricultural supply response studies is reviewed.

2.3 .1 Climate and Crop Production studies

One of the earlier studies by Mendelsohn et al. (1994) assessed the impacts of climate change on agriculture. The study estimated a crop, land model and a crop revenue model to determine the influence of agro climatic factors on USA land values. The crop, land model placed more weight on data from counties that were considered to have larger cropped areas while crop revenue model assigned higher weights to data from counties which were considered to have higher agricultural revenues. Using a climate scenario of around 2.8^{o}C temperature increase and 8 percent rise in precipitation, land values were projected to decrease under the crop, land model while the land values were projected to increase under the crop revenue model. The disparity in results was attributed to the varying weights assigned to different geographical areas and the different crop models. According to Mendelsohn the market value of output serves as a reflection of production of a particular parcel of land, implying that spatial climate variation directs variation in land productivity. The study setting permits the estimation of a reasonable link between climate and agricultural productivity in a multivariate regression model (Polsky, 2004). This study uses regression models, to estimate the effects of climate variables on crop output using time series data, which captures the effects of temporal variation in climate on crop productivity.

Reinsborough (2003) and Schlenker et al. (2005) used the same climate scenario and similar weights as Mendelsohn et al., (1994. Schlenker et al. (2005) arrived at a similar conclusion as Mendelsohn et al., (1994). However, Reinsborough (2003) predicted an increase in value of farmland in Canada under the two crop land model, concluding that Canada is expected to benefit from global warming. Conversely, Deschenes & Greenstone (2007) argued that the results obtained by Schlenker et al. (2005) were not robust and proposed the use of farmland area weights. The result of these weights predicted a decrease in farmland value albeit by a lesser magnitude.

Chang (2002) analyzed the impacts of change in climate on 59 crops, in Taiwan. The study employed an econometric model that integrated both climatic and economic variables. The explanatory climate variables in the study included: seasonal mean of monthly average temperature and monthly average precipitation, as well as variation of mean seasonal temperature and variation of seasonal mean precipitation from a 20 years long term average. For each climatic variable a linear and a quadratic term were incorporated to reflect the effect of optimum temperature and precipitation on yields. The study results revealed that increase in temperature and climate variation have a significant, non monotonic impact on yields. A positive effect of climate change was observed for vegetables and a negative impact for cereals and pulses. This study as well employs econometric methods. The models integrate economic variables and climate variables in determining their influence on maize, tea and coffee crop supply in Kenya, using data spanning 45 years. As well, in estimating the effect of climate temperature and rainfall on crop yield the study considered a non monotonic relationship between climate variables and crop yields.

Chen et al. (2004) carried a statistical investigation of climate change impacts on yield and yield variability of major U. S. major crops that included: corn, cotton, sorghum, soybean and wheat. Using panel data technique, the study established a positive impact of rainfall on crop yield and a negative impact of temperature on crop yields, with the magnitude varying depending on the functional form estimated. For instance, maize yield was found to decrease by 0.24 percent using a linear specification and a decrease of 2.98 percent when using a Cobb-Douglas specification as a result of 1 percent increase in temperature. As well, the study found that increase in rainfall reduced yield variability for corn and cotton but increased yield variability of sorghum. At the same time, higher temperatures reduced the variance of cotton and sorghum yield but raise corn yield variability. The results were attributed to the different locations where the crops were grown and crop cultural conditions. Similarly, this study seeks to derive quantitative estimates of the effect of temperature and rainfall on yield of major crops in Kenya. This study adopts a Cobb Douglas production function but uses time series data. In addition, this study estimates a linear model to capture the effects of climate variability on output supply.

In Sri Lanka, Seo et al. (2005) analyzed the impacts of climate change on agriculture using the Ricardian method and five AOGCM experimental models. The study analyzed the precipitation and temperature effects on net revenue from four crops namely tea, rice, rubber and coconut. Both models revealed that precipitation is beneficial to all the crops under examination, with benefits ranging from 11 to 122 percent of current revenue of the crops. Temperature was predicted to be harmful with a loss of 18 to 50 percent of current revenue of the crops. Informed by the findings, this study considers rainfall and temperature as key variables influencing maize and tea production in Kenya and seeks to find their influence using a different set of econometric methods.

Porter & Semenov, (2005) using computer simulation and experimental studies demonstrated the impacts of climate variability for crop production. The study results showed that increasing variability in temperature and precipitation lead to increased risks to yield. Both changes in the mean and variability in temperature were found to affect different crop processes hence having different impacts on crop growth and development. To be able to capture climate risk, this study incorporated rainfall and temperature variability to account for the effect of extreme events on crop production. However, this study follows a statistical rather than an experimental approach as in Porter and Semenov, (2005).

Maddison (2006) surveyed farmers in eleven countries in Africa and conducted a Ricardian analysis using land values as farmers perceive them as opposed to market values. The study confirmed that African agriculture is highly vulnerable to changes in climate with countries with warmer climates expected to bear huge losses. The importance of water supply was confirmed which is highly influenced by temperature and precipitation thus making it extremely sensitive to changes in climate. Similarly, Kurukulasuriya and Mendelsohn (2006) used farm level data based on an a survey in eleven countries to establish the relationship between net revenue from crop growing and climate using a Ricardian cross sectional approach. The results showed that net revenues fall with a fall in precipitation or as temperature rises. The study predicted warmer and drier temperatures, which would be unfavorable to dry land areas. The studies provide a logical link between climate and agricultural productivity.

Gay et al. (2006) estimated the impacts of climate change on coffee production in Veracruz Mexico. The study employed a multiple regression model that integrated climate and economic explanatory variables. Linear and quadratic terms for seasonal climatic means and seasonal variance of climatic variables were included in the model. Seasonal variance of climate variables captured extreme events that affect crop production. Economic variables included as explanatory variables comprised of: state coffee prices, international coffee prices, state population, producer price index and coffee stocks in USA. The model estimates revealed that coffee production responds significantly and negatively to seasonal temperature with increase in average winter temperature being more damaging. Study projections also indicated that by the year 2020 changes in precipitation and temperature could result to a 34 percent drop in coffee production. Following Gay et al., (2006) this study incorporates both economic variables and climatic variables in modeling the response of maize, tea and coffee to climate variability. In addition, to account for extreme events and the risk they pose to the farmer rainfall and temperature variability are included in the empirical model.

Tubiello (2007) through a detailed review of empirical research analyzed the response of crop and pasture plant species to climate change. The study argued that storms, floods, inter annual and decadal climate variation and large scale circulation such as El Nino south oscillation have huge impacts on crop, pasture and forest production. Thus, production losses are likely to be higher than those estimated using mean variables only as regressors. The study results showed that, although earlier studies had shown that crop biomass and yield tend to increase significantly with increase in $CO_{2,}$ climate change will modify and limit the direct effects in crop growth and development. Higher temperatures during the flowering stage of a crop may directly lower positive effects on yield by lowering the number, size and quality of grain and indirectly, increase water demands altering the positive effects of increased CO_2. In addition, changes in evapotranspiration to precipitation ratio alter ecosystem productivity and function especially in marginal areas. Under elevated $CO_{2,}$ high water efficiency may ease or offset drought effects.

Agboola & Ojeleye (2007) using a case study research design studied the impact of climate change on food crop production using bivariate Chi-square and ANOVA in Ibadan. The study interviewed 325 farmers to test the hypothesis that mate change does have a significant effect on food crop production. The study revealed that farmers have observed changes in climate condition over the last two to three decades. Further, farmers observed that food crop yield had had been affected by rise in temperatures, reduction in rainfall and a drop in relative humidity. However, using chi- square and correlation analysis the study found that climate change had no significant effect on crop yield. The regression results did not support perception by farmers. Consequently, this study assumes that farmer's perception on changes in climate variables will influence their decision processes on crop production hence affecting output supply. Nevertheless, the study seeks to find out the effect of climate change on crop production using a well-built set of econometric models given that the chi-square method may be limited as it does not give much information on the strength of the relationship or its substantive significance in the population.

Kabubo-Mariara & Karanja (2007) estimated the economic impact of climate change on crops in Kenya using a Ricardian approach. The study found that increase in summer temperature has a negative impact on crop revenue while increase in temperature in winter season has a positive effect on crop revenue. The estimated marginal impacts revealed that crop revenue is less elastic with respect to temperature than to precipitation. The study prediction showed that long term changes in temperature and precipitation will have substantial impacts on net revenue with higher impacts in medium and low potential zones. Conversely, Benhin (2008) using the Ricardian approach to estimate the impact of climate change on farm revenue in South Africa found that both increases in temperature and precipitation would lead to a fall in farm revenues. The studies provide a logical link between climate variables and crop productivity. In seeking, to find out the effect of changes in climate variables on output supply and crop yield in Kenya, this study incorporates rainfall and temperature variability in addition to seasonal rainfall and temperature means as used in Kabubo-Mariara & Karanja (2007) and Benhin (2008). Further, to be able to capture the effects from time variations the study uses time series data spanning 45 years.

Wijeratne et al. (2007) carried out an assessment on the impacts of climate change on productivity of tea in Sri Lanka. The study findings revealed that tea cultivation at low and mid elevation were more vulnerable to climate change compared to those in higher elevations. The optimum temperature for tea cultivation was found to be 22^0C while optimum rainfall varied from 223 mm to 417 mm per month across different regions. A reduction of monthly rainfall by 100 mm could reduce productivity by 30 to 80 kg of 'made' tea per ha. Increase in ambient CO_2concentration from 370 ppm to 600 ppm raised tea yield by 33 to 37 percent depending on the elevation. Crop model projections showed that rising temperatures and diminishing rainfall led to a decline in tea yields in most of tea growing regions in Sri Lanka save for wet zone up country. Further, the study projected that, as a result of climate change yield are likely to increase in high elevations but reduce in low elevations. Hence, the study proposed sustainable adaptation measures to minimize such adverse effects. Informed by the findings, this study considers rainfall and temperature as key variables influencing tea production in Kenya and seeks to find their influence using a statistical approach. However, this study did not capture the effects of changes in ambient CO_2 concentration.

Akpalu et al. (2008) examined the effects of mean temperature and precipitation on maize yield in South Africa. The study analyzed cross sectional data using a generalized maximum entropy estimation method. The study showed that increased precipitation and temperature have a positive impact on maize yield. Conversely, Moula (2008) while analyzing the impact of Cameroons agriculture using time series data spanning 40 years found that one percent standard deviation from long term mean in rainfall and temperature to have a negative effect on crop output. Informed by Akpalu et al, (2008) and Moula (2008) this study considers rainfall, temperature and their deviations from mean values as key variables influencing crop production. However, the study used time series data spanning 45 years and not cross sectional data as used in Akpalu et al. (2008).

According to Wachira (2009), there is evidence of climate change in tea growing zones. Since 1958 there is evidence of reduced rainfall, decreased soil water and increased temperatures. In 52 years covered by study, rainfall in Kericho reduced annually by 4.82mm while temperature increased annually by 0.016 ^{O}C. Maximum and minimum temperatures were observed to have increased by between 0.1 ^{O}C and 2.9^{O}C in tea growing areas. High correlation was observed between tea production and rainfall with reduction in amount of tea coinciding with periods of drought and increased soil water deficit.

Similarly, Rwigi and Oteng'i (2009) assessed the influence of climate parameters on tea yields in tea growing areas around Mount Kenya region. The study employed linear and multiple regression models. The study considered five climate variables namely; daily mean minimum temperature, daily mean max temperature, daily mean relative humidity, total weekly radiation and weekly tea yields. The results showed that weekly tea yield is highly influenced by mean minimum temperature and relative humidity. Informed by the findings, this study considers rainfall, temperature and their variability as key variables influencing tea production in Kenya. However, this study expands the scope and considers the effects of climate variability on total production of tea at the national level. In addition, the study employs a different set of econometric estimation techniques.

Bukhari (2009) carried out an econometric analysis of the impacts of climate change on cash and food crops production in the Gambia. The study ascertained the response of groundnut, paddy rice, sorghum, millet and maize to climatic changes. The study employed panel data method with random time effect. The current season output was expressed as a function of last season yield, last season price, current season level of rainfall and rainfall variability and current season land use. Other than rainfall variability, which was insignificant, all the other variables were found significant. Rainfall had the highest impact on crop output, positioning climate impact as the most important explanatory variable for the crop output in the Gambia in period of study. Following Bukhari (2009), this study incorporates both economic variables and climatic variables in modeling the response of maize, which is a food crop, tea, and coffee, which are major cash crops in Kenya to climate variability. In addition, to account for extreme events and the risk they pose to farmers, rainfall and temperature variability are included in the empirical model.

Cabas et al. (2009) assessed the effects of climate and non climate factors on the mean and variance of corn, soy bean and wheat in South Western Ontario, Canada. The study estimated three models. The first model included economic (input use change) and site characteristics (change in area planted) as independent variables. The second model incorporated summary measures of seasonal climate, in addition to economic and site characteristics. The seasonal climate variables are growing days, mean temperature for growing season, precipitation for growing season, coefficient of variation of rainfall and coefficient of variation of temperature.

Rainfall and temperature variables were included to capture the effects of extreme events on yields. The third model used monthly weather variables instead of seasonal summary measures used in the second model. These variables are mean monthly minimum temperature and total precipitation levels in a month. Squared values for precipitation and temperature were included to allow for non-monotonicity. The study findings showed that climate variables have a key impact on crop yield distribution. Mean yield were found to be largely influenced by length of growing season while variance of yield is largely explained by variance of temperature and precipitation. Increases in temperature for the spring and fall months was found to increase yields at a decreasing rate but reduces yield in summer months. Precipitation increase at the beginning of growing season and during summer increases yield but decreases mean yield for months around planting and harvesting. Informed by Cabas et al., (2009) this study included squared terms for rainfall and temperature to account for non linear relationships between crop yield and climate variables. In addition, the study included both climate and economic variables in determining their influence on output supply. Nevertheless, this study goes a step further and includes the interaction terms between temperature and rainfall to account for the effect of one climate variable given the effect of the other variable.

Using Decision Support System for Agrotechnology Transfer (DSSAT) simulation model, Basak (2009) estimated the effects of future changes in climate on rice production in Bangladesh. The results showed that with an increase in maximum temperature by 2^{o}C and 4^{o}C rice production of rice drastically falls by up to 13.5 percent and 28.7 percent respectively. The model results also show that fall in minimum temperatures reduces yield, but the increase in maximum temperatures has harm that is more drastic.

Wangui (2010) studied the effects of temperature and rainfall variability on large scale coffee estate in Kiambu county, Kenya. Using Pearson correlation coefficient the study revealed that rainfall fluctuation and temperature increase had occurred in area of study, consequently lowering the coffee yields. Informed by the findings, this study considers rainfall and temperature variability as key variables influencing coffee production in Kenya. However, this study expands the scope and considers the effects of rainfall and mean temperature and their deviation from the mean on total production of coffee at the national level. In addition, the study employs a different set of econometric estimation techniques.

Welch et al. (2010) employed a multiple regression model to analyze data from 227 irrigated rice farms in six countries, observed over multiple growing seasons. The model included, farm specific weather variables as well as farm and site specific economic variables. Economic variables were included to make the study estimates more precise as opposed to modeling using weather variables only. From the estimated coefficients, temperature and radiation had statistically significant impacts both at the vegetative and ripening phases of rice plant. Higher minimum temperatures were found to reduce yield while higher maximum temperatures increased yield. Study projection indicated a reduction in rice yield from moderate warming in the next decades. Rainfall had no substantial impact with the possibility that during the period of study, rainfall did not limit irrigation levels. The study findings showed that rainfall and temperature effects on crop are dependent on the growth and development stage of the crop plant.

Huang et al. (2010) estimated the yield responses of corn, soybeans and wheat to output prices and to changes in climate and technology over time in the US using county-specific, historical data for 1977-2007. A general form of a crop yield model was employed using a county level panel data. Climate variables included were: monthly mean precipitation and their squared terms, growing season degree days, and monthly deviation in temperature (maximum – minimum temperature) to control for variability in temperature. The study found that climate variables have significant impact on the yields for all three crops and high temperature can lead to reduced crop yields while more precipitation will just enhance corn and soybean yields. The results regarding the impacts of precipitation on wheat yields are inconclusive. Thus from the study changes in precipitation could possibly increase or decrease crop yields.

Sowunmi & Akinola (2010) examined the effect of climate variability on maize production in Nigeria. The study employed a two way ANOVA and CV to analyze the dynamic link between changes in climate variables and agronomic parameters for maize production. The study identified seven ecological zones and data for the period 1980-2002. The results showed that with availability of sufficient water maize can be grown in most parts in Nigeria, throughout the year with insignificant temperature variation. The study showed that water is a critical input in maize production. Thus, using national data and a set of econometric techniques, this study sought to establish the effects of rainfall amount and its variability on maize output supply and maize yield, given that Kenya is highly dependent on rain fed crop production.

Blanc (2011) conducted a comprehensive assessment of the impacts of climate change on crop production in Sub Saharan Africa. The crops under study included: Maize, cassava, millet and Sorghum. The study estimated crop productivity and supply response to changes in climate. The first set of econometric analysis estimated the effect of changing weather on crop yield. The estimates revealed a significant impact of temperature, precipitation, evapo-transpiration, floods and droughts on crop yields. Temperature and precipitation had larger effects in countries with less favorable agricultural conditions. CO_2 concentration had a significant effect on millet only. The second set of economic analysis estimated the effects of climate change on farmers cropping decision. Regression estimates indicated that farmers supply decision appear to be more responsive to export crop prices, precipitation variability and temperature variability. Both temperature and precipitation variability had a negative effect on area of land allocated to crops. The result indicates that as climate risk grows, farmers participate in other activities or diversify to other crops. Hence the study provides a link between changes in climate and the farmers' decision process. Thus, Blanc (2011) informs the estimation of output supply response to changes in climate variables as pursued in this study. In addition, to establishing the effect of changes in climate variables to a food crop, this study considers cash crops as well.

Okoth (2011) assessed the potential impact of future climate change on tea production in Kericho County, Kenya. Kericho serves is a major tea growing zone in Kenya. The study was based on PRECIS regional climate model outputs. The study was conducted on seasonal time production periods with two peak periods and two low periods using tea production data obtained for Kapkatet tea factory. The analysis showed increasing trend in maximum and minimum temperatures in most seasons. Study projections indicate that by 2070 increase in rainfall will raise production while an increase in maximum temperature was found to generate a potential fall in production. The study confirmed that changes in climate have occurred in Kericho County and will probably change in the future. Using a different approach from the simulation method employed by Okoth (2011), this study employed econometric techniques to assess the effects of climate variability on tea production. The study uses national data, which takes into consideration production in all tea growing zones.

Rowhani et al., (2011) examined the impacts of both the seasonal climate means and climate variability on cereal yield using statistical method in Tanzania. The study results indicated that both intra seasonal and inter seasonal changes in temperature and precipitation influence cereal yields in Tanzania. Seasonal temperature had the most impact on yield with an increase of temperature with a 2^{O} C reducing maize, sorghum and rice yield by 13, 8.8 and 7.6 percentage respectively by 2050. A 20 percent increase in inter seasonal precipitation was projected to reduce maize, sorghum and rice by 4.2, 7.2 and 7.6 percent respectively by 2050. The study also shows that climate impacts are under estimated by 3.6, 8.9 and 28.6 percent for maize, sorghum and rice respectively if climate variability is ignored and focus is only on climate means. To obtain robust estimates the study forms basis for inclusion of seasonal means of rainfall and temperature as well as rainfall variability and temperature variability. This study uses different estimation techniques using a longer data set than in Rowhani et al., (2011). In addition, this study estimates the response of a food and cash crops in a different physical location. Effects of changes in climate variables on crop yield are expected to vary depending on the location study and the choice of explanatory variables used in the study.

Kawasaki & Herath (2011) assessed the impacts of climate change on rice production by estimating a Cobb Douglas production function. The study found that area under crop, solar radiation and temperature as the most significant factors influencing rice yield. Rainfall was found to have an insignificant effect on rice production, which was attributed to responsible water management practices by farmers who cultivated drought tolerant rice varieties. The study shows that changes in climatic conditions elicit changes in the decision making processes, towards adaptation and in turn influences the level of production.

Tesso et al., (2012) employed co integrated VAR and ECM in carrying out a time series analysis of climate variability and its impact on food production in Ethiopia. The study used data spanning three decades. The study results indicated that food production is significantly affected by improved technology, area under irrigation, usage of manure, *Meher* rain and average temperature. *Belg* rainfall and fertilizer application were found to be less significant. About 90 percent of productivity variation was explained by *Meher* rain, average temperature, *Belg* rainfall as well as area under irrigation, usage of manure per hectare and the change in usage of improved hectare. Hence, rainfall and temperature in different seasons are expected to have different impacts on crop production. Similarly, this study considers the effects of seasonal changes in climate variables on crop output supply and yield.

Bhandari (2013) assessed the effect of precipitation and temperature variation on the yield of major cereals in Dadeldhura district of far western development region, Nepal. The study used an exponential growth curve model and employed time series data. The study found out that temperature and rainfall had substantial effects on yield of different cereals. Rainfall was found significant in influencing yield for maize and barley while insignificant in influencing yield for rice, wheat and millet. Temperature was found significant in influencing yield of the five cereals. Maximum temperature and rainfall have positive effects on maize and rice yields. Generally, increase in rainfall and temperature variances was found to have adverse effects on crop production. The study highlights that changes in rainfall and temperature bring in heterogeneous impacts, which can be harmful or beneficial depending on the crop type, season or altitude.

Eregha et al., (2014) examined the impact of climate change on crop production in Nigeria using an Error Correction Model. The study assessed the effect of temperature, rainfall and carbon emission on production of maize, rice, beans, cassava, cocoa, groundnuts, millet, potatoes, sorghum and yams. The study found that temperature had a negative impact on production of maize, rice, beans, cocoa and sorghum. However, temperature had a positive impact on production of groundnuts. Rainfall was found to have a positive effect on production of beans, cocoa, potatoes, cassava and rice but a negative effect on groundnut production. Carbon emissions were found to have a negative impact on maize, millet, rice and sorghum production. Similar to Bhandari (2013), Eregha et al., (2014) highlights that changes in rainfall and temperature bring in varied effects which can be damaging or favorable depending on the crop type. Eregha et al., (2014) used annual time series data on rainfall and temperature. However, as noted by Gay et al., (2006) in relating climate variables and plant phenology in a more direct way seasonal means are more important than the annual values. Thus, this study relates seasonal climate data to crop output and yield.

Mwaura & Okobole (2014) observed the relationship between climate variation and crop output in Uganda. The study employed time varying ARCH model using data straddling from 1981 to 2008. The model estimates showed that rainfall variation and temperature variation from their long term means had significant effects on crop output. Increase in temperature deviation led to an increase in crop output deviation while exponential increase in rainfall had a damaging effect on crop output. The findings demonstrated that climate variability had an effect on crop output. However, the study did not incorporate climate means in their analysis.

Hamjah (2014) developed a multiple regression model to measure the climate effects on tea and cotton in Bangladesh. The study also measured production efficiency due to climate using a stochastic frontier model. From the estimates, only sunshine hours and wind speed during summer were found to be negative and significant on tea production. These climate variables explain 92 percent of variations in tea production Bangladesh. Informed by the findings, this study sought to determine how changes in climate variables influence tea production in Kenya using a statistical approach. However, this study did not capture the effects of changes in sunshine hours and wind speed.

Kumar (2014) estimated the impacts of climate change on sugar cane productivity by estimating a simple regression model, a Cobb Douglas model and a Ricardian productivity regression. The study found that rainfall and temperature had a significant impact on sugarcane with the magnitude varying across different seasons. Similary, Mahmood et al., (2012), Nastis et al., (2012) and Lee et al., (2012) analyzed the impacts of climate change on agricultural productivity by estimating a Cobb Douglas production function. The studies found that precipitation and rainfall had significant effects on agricultural production. This study adopts the Cobb Douglas model in relating crop yield to climate variables.

Cheserek et al., (2015) analyzed the links between weather and tea productivity in Kenya. The study was carried out in Timbilil tea estate, Magura tea estate and Kangaita farm. Data analysis showed that the estates have experienced increasing temperatures and rainfall distribution has become unpredictable. The study indicated that tea does well in warm temperatures when soil moisture is not inhibitive. In all the study sites when soil moisture is not limiting, a significant positive relationship between mean air temperature and yield of tea was observed. Using a different approach from the correlation method employed by Cheserek et al., (2015) this study used a set of econometric techniques to assess the effects of climate variability on tea production. While Cheserek et al., (2015) considered data from three estates; this study uses national data, which takes into consideration production in all tea growing zones in Kenya

Craparo et al., (2015) assessed the decline in Coffee Arabica yield in Tanzania due to climate change. The study found that increasing night temperatures were responsible for diminishing coffee yields for the period between 1961 and 2012.Minimum temperature were found to have increased by 0.31^{o}C per decade and for every 1^{o}C rise in minimum temperatures yields reduced by 137 ±16.87 kg per hectare. The study provides a link between coffee production and changes in climate variables over time.

2.3 .2 Crop Production Supply Response Studies

Maitha (1970) estimated the price responsiveness of coffee growers in Kenya. The study examined the influence of price changes on productivity pointing out the particular suitability of the approach to Kenya where the government attempts at controlling coffee output were implemented largely through a planting license scheme. The study model embodied a constant elasticity of substitution production function. The study found that price of coffee had a strong effect on coffee yield but no significant effect on acreage. Although, the study did not include climate variables, its points that in addition to relative prices, cropping decisions can be affected by farmer's perception of risk, especially that emanating from the market and weather variables. This study incorporates climate variables to account for the effect of climate risk on farmers cropping decision and as well, includes price as a control variable. In addition, this study uses output rather than acreage as a dependent variable in estimating farmer's response given that tea and coffee are perennial crops.

Odhiambo (1993) analyzed the response of coffee farmers to coffee prices and non price factors in five districts in Kenya using Fisher lag scheme and inverted V lag distribution models. The study found farmers price expectation to be the major factor influencing coffee supply. In a similar study, Owango (2009) estimated the response of small scale coffee producers to real producer prices using Nerlove Partial Adjustment model and Error Correction Model. The study incorporated amount of rainfall and number of wet days as regressors. Annual average rainfall has a negative influence on coffee production. Soderlund and Oberg (2001) observed that both domestic and international factors contribute to the decline in coffee production. The factors includes higher prices on farm inputs, wages, fuels and interest rates, lack of access to credit to short-term working capital needs and long-term investments, low coffee payments, liberalization and privatization policy guidelines. This study considers both price and non price factors in explaining output supply. In addition, other than rainfall and price, this study considers the influence of temperature, variation of rainfall and temperature and other non price factors on farmers cropping decisions.

Mbithi (2000) using time series data for the period 1970 to 1998 analysed how maize production is influenced by output price, average annual rainfall, price of fertilizer before and after liberalization. Statistical analysis showed that with liberalization of input and output markets, maize production and yield increased. Maize production was found to be price inelastic while average annual rainfall was found to influence maize performance. Following Mbithi (2000), this study relates both maize output and maize yield to price and non price factors in explaining output supply. However, this study considered an extended period spanning from 1970 to 2014. In addition, while Mbithi (2000) considered annual rainfall as an explanatory variable , this study considered seasonal means of rainfall and temperature as explanatory variables, in an effort to relate climate variables and plant phenology in a more direct way (Castillo *et al*., 2003; Gay *et al.* 2006).

Mose et al., (2007) estimated aggregate supply response for maize in Kenya using data from Trans Nzoia district covering the period 1980 to 2003. Cointegration Analysis and ECM techniques were employed. The study adopted a generalized single cointegration relationship involving several variables where regressors were assumed to be weakly exogenous. The study dropped yield and rainfall after they were found to be stationary at levels while other variables were I (1). The results indicated that both in the short run and long run maize output had an elastic response with respect to its price. The short run elasticity of maize supply with respect to fertilizer prices was found to be elastic in short run but inelastic in the long run. Informed by Mose et al., (2007) output price, input price are included in this study as control variables when modeling for the output supply response for each crop. To avoid dropping variables in estimation of output supply, the study uses an ARDL approach to cointegration as it allows estimation of cointegration when variables are a mixture of I(0) and I(1).

Muchapondwa (2008) estimated agricultural supply response in Zimbabwe using ARDL approach to cointegration. The study sought to provide empirical evidence on supply response of Zimbabwean agriculture through estimation of supply elasticities with respect to price and non price factors. Agricultural supply (X) was expressed as a function of its own lagged value and prices (P). Variables in the study also included area under cultivation, which was aggregated using equal weights, mean annual rainfall and annual fertilizer consumption. The results from the estimated ARDL (1, 1) model showed insignificant long run supply response to price changes. Magnitude of rainfall elasticity was small although rainfall was found to be a key determinant of agricultural supply in the long run. Following Muchapondwa (2008), this study adopted the ARDL approach to cointegration in estimation of crop output supply.

Olwade et al., (2009) assessed the responsiveness of maize output to price and non price factors using farm level data in the high potential maize zones in Kenya during main cropping season in the year 2003/2004. In estimating the maize supply and variable input demand elasticities, the study employed a normalized translog profit function. The study found that maize output had a positive and inelastic response with respect to price, while input prices had a negative effect. The study recommended public investment in rural infrastructure and efficient importation systems so as to reduce price of fertilizer and hence boost production. Although changes in climate variables are likely to further constraint crop production Olwade et al., (2009) did not include climate variables as regressors. As noted by Winch, (2006) application of fertilizer on rainfed crops is not necessarily efficient as fertilizers are most effective if applied on moist soils. Thus, changing climate is likely to influence the farmers cropping decisions even with increase in application of fertilizer.

Mohamad (2013) estimated the effect of climate change on supply response of Florida citrus crops using state level data from 1980 to 2010. The study analyzed the acreage and the yield responses of fresh oranges and grapefruits using Prais-Winsten and ECM. The independent variables included the lagged own- price, wage rate, fertilizer price index, technical progress, climate conditions and a constant respectively. The climate variable includes the yearly mean temperatures and the yearly precipitation for the state of Florida. The study found temperature to have a positive impact on the acreage response of fresh oranges, whereas it had a negative impact on the grapefruits yield. Findings suggest that an increase of global temperature will lead to an increase in fresh orange acreage. However, there was no significant impact of precipitation on the supply response.

Onono et al., (2013) investigated the response of maize production to both price and various non-price incentives in Kenya with a view to determine the relative influence of each on the crop’s production. The study found that maize production respond positively to its output price, development expenditures in agriculture, maize sales to marketing boards, inflation, growth in per capita GDP, liberalization, governance reforms of 2003-2008, favourable weather and availability of cheap fertilizers. Maize output was found to respond negatively to increase in price of fertilizer, unfavourable weather, shocks of the failed coup *d'état* attempt of 1982. The study employed an ARDL time series approach, adopted by this study. Additionally, this study in analyzing the output supply response for maize, included price, development expenditure on transport and communication, maize sales to marketing boards, variables as control variables in addition to climate variables. In a similar study, Ogazi (2009) analyzed rice output response to the changes in real prices in Nigeria using ARDL approach for the period 1974 to 2006. The study analyzed the response of rice output to area, real prices of maize, real prices of rice, weather and time trend. Results indicated weather as statistically significant at one percent. The study employed error correction version of ARDL approach to cointegration.

Whereas Onono et al., (2013) focused on food crops this study considers tea and coffee which are key cash crops in Kenya. Further, the inclusion of seasonal rainfall, seasonal mean temperature, rainfall variability and temperature variability in this study helps to account for climate risk. As noted by Collier and Gunning (1999) and Blanc (2011) farmers in Africa endure greater risks compared to other farmers, making risk an key variable in making production decisions, especially for small holder farmers who are risk averse. Thus, the consideration of climate risk in addition to market risk and institutional risk is likely to guide farmers' crop output supply decisions depending on perception and the scale of risk aversion.

2.4 Overview of Literature

The study has reviewed studies in two main areas, those relating to crop output response and those relating to crop yield and climate change. First, an overview of literature concerning output supply is made, followed by that relating to, crop yield and climate change.

Literature on crop output response shows that output response studies have been carried at the individual crop level and at the aggregate output level. Studies that incorporate weather variables reveal the importance of climate in influencing agricultural production decisions. However, some studies incorporate amount of rainfall as the only climate variable with some dropping the variable after failing at the unit root test (Mose *et al.*, 2007). Crop production response studies in Kenya have largely focused on the response of maize and other food crops to price and non price factors (Mbithi, 2000, Mose *et al*., 2007, Olwade *et al.*, 2009, Onono *et al.*, 2013).

Based on the idea that farmers have to simultaneously make crop production and input decisions, the realization of output will also depend on uncontrolled natural events. Although, some studies acknowledge the influence of weather on crop production, they have not shown exhaustively the effect of climate variability. This would be critical in guiding farmers and other policy makers on climate change adaptation and mitigation. In addition, it is worth diversifying the scope by evaluating the output response to economic and climatic variables to tea and coffee, which play a key role in the Kenyan economy.

Literature relating to crop yield shows that studies have been carried to estimate the impacts of climate change in the agricultural sector and more specifically the impacts on crop yield. Simulation methods (Porter and Semenov, 2005; Basak, 2009; Cheserek, 2015) and regression methods have largely been utilized. Using the regression approach, climate variables have been modeled as explanatory variables to crop yield (Wijeratne, 2007; Akapalu *et al.*, 2008; Cabas *et al.*, 2009; Wangui, 2010; Sowunmi & Akinola, 2010; Huang, 2010; Rowhani *et al.*, 2010; Blanc, 2011; Tesso *et al.*, 2012; Mohamad, 2013; Bhandari 2013; Eregha, 2014; Hamjah, 2014; Mwaura & Akibole, 2014;Craparo *et al.*, 2015); farmers revenue (Seo *et al.*, 2005; Kabubo- Mariara & karanja, 2007; Benhin , 2008) and land values (Mendelsohn, 1994; Reinsborough, 2003; Schlenker et al., 2005; Deschenes & greenstone, 2007).

Studies using crop land or crop revenue models to determine the impact of climate change on agriculture show mixed results with regard to the sign and magnitude of the impact. Majority of the studies indicate a negative impact of climate change on crop revenue and land values (Mendelsohn et al., 1994; Schlenker *et al.*, 2005; Deschenes & Greenstone, 2007; Maddison, 2006; Kurukulasuriya and Mendelsohn, 2006; Benhin, 2008), but some indicate a positive impact (Reinsborough, 2003) and others report both and negative impacts depending on the season(Kabubo-Mariara & Karanja, 2007).

Majority of the studies have focused on estimating the impact of climate change on crop yield while using climatic means as regressors. The results largely show that climate change has a significant influence on crop yield(Wijeratne, 2007; Akapalu *et al.,* 2008; Cabas *et al.,* 2009; Wangui, 2010; Sowunmi & Akinola, 2010; Huang, 2010; Rowhani *et al.,* 2010; Blanc, 2011; Tesso *et al.,* 2012; Mohamad, 2013; Bhandari 2013; Eregha, 2014; Hamjah, 2014; Mwaura & Akibole, 2014;Craparo *et al.,* 2015). However, Agboola & Ojeleye (2007) showed no significant effect of climate change on yield. The effects vary depending on the crop, site location of the study and choice of explanatory variables used as explanatory variables. Thus, changes in climate variables are expected to have negative impacts in some areas and positive impacts in other regions. Nevertheless, beside changes in climate variable means, climate variability has been on the increase as exhibited by increased frequency and intensity of extreme events. Climate variability is expected to have a greater undesirable impact on crop production than changes in mean climate variables only (Porter & Semenov, 2005; Tubiello *et al.,* 2007 IPCC, 2007).

Whereas literature on climate change is on the increase globally, there are only a handful of studies in Kenya and East Africa at large, on the impact of climate change on crop production(Kabubo-Mariara & Karanja, 2007; Rwigi & Oteng'i, 2009; Rowhani *et al.,* 2010; Wangui, 2010; Okoth, 2011, Cheserek, 2015; Mwaura & Akibole, 2014). Some of the studies carried out in Kenya to measure the impact of climate change on crop production have used simulation method or are experimental based (Okoth, 2011;

Cheserek, 2015). Those using the statistical approach largely make use of cross sectional data at the farm level to examine the effect of climate means on farm revenues and on yields (Kabubo-Mariara & karanja, 2007; Wangui, 2010).

However, these studies in Kenya have not included both the mean climatic variables and climate variability variables as explanatory variables in one model. Failure to do this creates a possibility of under estimating the impact of climate change on crop production. Thus to generate more precise estimates, variables capturing seasonal variability in temperature and rainfall were included in addition to their climatic means in this study. Moreover, this study employs aggregate production at the national level using long term data, sufficient enough to capture climate change and its variability.

This study therefore addresses the shortcomings in literature about climate change in Kenya by incorporating both climate variables more specifically rainfall, rainfall variability, temperature and temperature variability and economic variables to assess their effects on maize, tea and coffee production using historical data. The results have potential to guide reforms that are likely to induce changes in climate mitigation and adaptation.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter develops the theoretical framework, models and empirical models that will help to achieve the objectives of the study. Included in this chapter is the estimation method, description and measurement of variables, type and sources of data used and data analysis techniques employed.

3.2 Research Design

This study adopted a quantitative research design. The study used the utility maximization theory and production theory, to develop the theoretical framework and to specify empirical models. Time series data was used in models estimation and for each model, diagnostic tests were undertaken to ensure that estimates are robust and the model is not misspecified. In addition, the study assumes that farmers are forward looking, learning from their past experiences and that the realized output may be different from the desired due to adjustment lags of determining factors. Thus, to be able to take into account this adaptive behaviour, the study adopted the ARDL modeling approach from Ogazi,(2009); Muchapondwa, (2009) and Onono *et al.* (2013). Moreover, climate variables are likely to have non linear effects on crop yield. Thus, to consider this, the study adopted a Cobb-Douglas production function from Blanc, (2011) and Mahmood et al., (2012)

3.3 Theoretical Framework

As mentioned earlier, this study followed the utility maximization theory in estimation of crop output supply and production theory in modeling crop yield. These theories are explained in section 3.3.1 and section 3.3.2, respectively.

3.3.1: Maximization of Agricultural Crop Output

This study assumes that a farmer is a rational economic agent. A suitable approach to explaining this behaviour is based on utility maximization theory as proposed, for example in Singh et al., (1986). The study also assumes that the farmer is the household head and largely influences the household's decision making as a family unit. Therefore, what follows describes the household utility maximization model.

For a household that consumes three goods, a farm produced good (X_a), a market purchased good (X_m) and leisure (X_l). The objective of the household is to maximize utility derived from consumption of the three goods subject to an income constraint where the expenditure on the market purchased good is equal to the sum of net income from the marketed surplus of the farm produced good and income derived from other sources other than from the farm or labor supply. The income constraint in turn depends on production of the staple. Thus, the household chooses the levels of consumption for each of the three goods that will maximize utility and as well make production decisions on the farm produced good, given that $\mathrm{X_a}$ is a share of the farm produced good $\mathrm{Q_a}$, with the surplus being marketed as a source of income (Singh *et al.*, 1986).

Notably, the production of the farm produced good is influenced by various factors that include: production inputs such as labor and fertilizer and agro-climatic factors. Thus, the household production technology for the staple can be specified as:

$$Q_a = \mathrm{Q}\ (\mathrm{L, V, A, K, W}) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.1)$$

Where L is the labor input, V is variable input such as fertilizer, A is the household's fixed quantity of land; K is its fixed stock of capital and W represent agro-climatic conditions such as temperature and precipitation.

Accordingly, the objective of the household can be stated as:

$$\text{Maximizing } \mathrm{U} = \mathrm{U}\ (\mathrm{X_a, X_m, X_l}) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.2)$$

Subject to an income constraint specified as

$$\mathrm{P_m\, X_m + P_a X_a + P_l X_l = P_l\, T + (\, P_a Q_a(L, V, A, K, W) - P_l L - P_v V\,) + E} \dots (3.3)$$

Where $\mathrm{P_m}$ is the price of the market-purchased commodity; $\mathrm{P_a}$ is the price of the agricultural staple; $\mathrm{P_L}$ is the market wage; $\mathrm{P_V}$ is the variable input's market price; T is the total stock of household time, E is any non labor, nonfarm income and other variables are as previously defined.

Let Y denote total income as:

$$\mathrm{Y} = \mathrm{P_l}\ \mathrm{T} + (\ \mathrm{P_a Q_a}(\mathrm{L, V, A, K, W}) - \mathrm{P_l L} - \mathrm{P_v V}\ ) + \mathrm{E} \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots (3.4)$$

Therefore, the household maximization problem may be expressed in a Lagrangian function as:

$$Z = \mathrm{U}\ (\mathrm{X_a, X_m, X_l}) + \lambda(\mathrm{Y} - \mathrm{P_m}\ \mathrm{X_m} - \mathrm{P_a X_a} - \mathrm{P_l X_l}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots (3.5)$$

Setting up the partial derivatives of equation (3.5) with respect to L,V, X_a, X_m ,X_l and λ to zero, yields the following first-order conditions necessary for maximization problem:

$$\frac{\partial Z}{\partial L} = P_a \frac{\partial \mathrm{Q_a}(\mathrm{L, V, A, K, W})}{\partial L} - P_l = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots..\ldots\ldots\ldots..\ldots\ldots\ldots. (3.6)$$

$$\frac{\partial Z}{\partial V} = P_a \frac{\partial Q_a(\mathrm{L, V, A, K, W})}{\partial V} - P_V = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots (3.7)$$

$$\frac{\partial Z}{\partial \mathrm{X_a}} = U_{\mathrm{X_a}}(\mathrm{X_a, X_m, X_l}) - \lambda\ \mathrm{P_a} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots,,\ldots\ldots\ldots\ldots. (3.8)$$

$$\frac{\partial Z}{\partial \mathrm{X_m}} = U_{\mathrm{X_m}}(\mathrm{X_a, X_m, X_l}) - \lambda\ \mathrm{P_m} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.9)$$

$$\frac{\partial Z}{\partial \mathrm{X_l}} = U_{\mathrm{X_l}}(\mathrm{X_a, X_m, X_l}) - \lambda\ \mathrm{P_l} = 0 \ldots\ldots\ldots\ldots\ldots..\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots.\ldots\ldots (3.10)$$

$$\frac{\partial Z}{\partial \lambda} = \mathrm{Y} - \mathrm{P_m}\ \mathrm{X_m} - \mathrm{P_a X_a} - \mathrm{P_l X_l} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots. (3.11)$$

Since the functional forms are not specified, the standard profit maximizing conditions given in equation (3.6) and (3.7), can be written in general as:

$$F(\mathrm{P_a}, \mathrm{P_m}, \mathrm{P_v}, \ \mathrm{P_l}, L, V, A, K, W) = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (3.12)$$

Using the implicit function theorem (Chiang, 1984), from equation (3.11) the input demand for labor and capital can be written generally as:

$$V = f(\mathrm{P_a}, \mathrm{P_m}, \mathrm{P_l}, \mathrm{P_v}, L, V, A, K, W) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots (3.13)$$

$$L = f(\mathrm{P_a}, \mathrm{P_m}, \mathrm{P_l}, \mathrm{P_v}, L, V, A, K, W) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots\dots\dots (3.14)$$

Once the profits are maximized, its value can be substituted into the constraint equation to yield:

$$\mathrm{Y}^* = \mathrm{P_m}\ \mathrm{X_m} + \ \mathrm{P_a X_a} + \ \mathrm{P_l X_l} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . . \dots (3.15)$$

Where Y^* denotes total income for a profit maximizing household. Having optimized on profit, the household maximizes utility subject to the total income. The solution to equations (3.4), (3.5) and (3.15) can implicitly be written as:

$$F(\mathrm{X_a}, \mathrm{X_m}, \mathrm{X_l}, \mathrm{P_a}, \mathrm{P_m}, \mathrm{P_v}, \ \mathrm{P_l}, Y^*) = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.16)$$

Again, using the implicit function theorem (Chiang, 1984), from equation (3.16) the input demand for farm produced good can generally be written as:

$$X_a = f(\mathrm{P_a}, \mathrm{P_m}, \mathrm{P_l}, \mathrm{P_v}, Y^*) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.17)$$

Equation (3.17) shows that the demand for farm produced good is affected by price of outputs, prices of variable inputs and total income. The presence of profits in Y^* further shows that farm technology, quantities of fixed inputs and agro-climatic conditions affect the demand for the farm produced good (Singh *et al.*, 1986).

If the farmer is a price taker in all markets, for all commodities which he both consumes and produces; the farmers solution gives an output supply dependent on output prices $(P_i, i = 1, \dots, n)$, variable input prices $(P_v, v = 1, \dots, V)$, production technology, quasi fixed inputs of land and capital $(A_j, j = 1, \dots, J)$ and agro-climatic conditions (W). The output supply function for crop i can therefore be expressed as:

$$Q_i = f(\mathrm{P_i}, \mathrm{P_v}, \mathrm{A_j}, \mathrm{W}) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.18)$$

An increase in output prices with fixed input raises the profits serving as an incentive to farmers to produce more. Conversely, an increase in prices of inputs raises the cost of production serving as a disincentive to increase production (Singh *et al.*, 1986).

According to Key et al. (2000) the existence of fixed and variable transaction costs, raise the total cost of production. The fixed transaction costs include: the search for market, negotiations, bargaining and screening of buyers of the produce and sellers of inputs. On the other hand, variable transaction costs include transportation costs and time taken to transport products to the market and inputs from the market. While fixed transaction costs are lump sum, the variable transaction costs increase the per unit cost of accessing the market which raise the price effectively paid for inputs and lowers the price effectively received for output. Consequently, this creates a price band within which households find it unprofitable to supply output or buy inputs. Thus, net prices can be expressed as:

$$P^{*}{}_{i} = P_{i} - t^{s}(Z_{it}^{s}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.19)$$

$$P^{*}{}_{vi} = \mathrm{P}_{vi} - t^{b}\left(Z_{it}^{b}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.20)$$

Where $P^{*}{}_{i}$ is net output price received; $P^{*}{}_{vi}$ is the net input prices paid; P_{i} is the output market price, P_{vi} is the input market price; t^{s} is the transaction cost associated with marketing output and t^{b} are transaction cost associated with purchase and use of inputs. Z is a vector of all factors that influence transaction costs. Transaction costs are influenced by factors such as rural infrastructure and macroeconomic conditions. Incorporating (3.19) and (3.20) into (3.18) yields:

$$Q_{i} = f\left(\mathrm{P_i}^{*}, \mathrm{P_v}^{*}, \mathrm{A_j}, \mathrm{W}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.21)$$

Equation (3.21) implies that factors influencing transaction costs influences agricultural output supply.

Following the utility maximization theory, equation (3.21) is augmented to account for factors considered important in explaining output supply. Manmingi (1997) argued that, in addition to price of input and price of output, supply function can be extended to include other factors that do influence the farmers' production decisions. These factors can be classified under four categories namely: rural infrastructure, human capital, technology and agro-climatic conditions. Rural infrastructure services, such as market facilities; roads, transport and communication services; access to credit facilities; availability of fertilizers; provision of high variety seeds and pesticides and irrigation facilities are expected to positively impact agricultural output through enhanced productivity and reducing the cost of production. Research and technological progress is also expected to have a positive influence on output through improved efficiency and cost reduction. Among the climatic factors, temperature and rainfall amount and distribution are expected to be the most influential in explaining supply response. These two climatic measures are observable by farmers and likely to influence decisions to grow a certain crop and the area to allocate it as demonstrated in equation (3.1) and (3.17).

In addition, climate forecast and timing are critical in informing farming decisions such as planting and harvesting. As well, seasonal climate forecasts provide a chance to reduce vulnerability of crop production to climate variations by helping farmers make informed cropping decisions(Smit and Skinner, 2002; Hansen, 2002). However in most developing countries usefulness of climate forecasts by farmers is still low due to low credibility, poor understanding ability, geographical scale and broadcasting barriers. In Kenya as revealed by Recha et al., (2008) farmers have little trust on meteorological forecasts and majority of farmers do not base their decisions based on climate forecasts. Given the low dependence on weather and climate forecasts when making farming decisions, their decisions are mainly based on perceived change in climate over the previous years and what they perceive as expected future weather conditions (Blanc, 2011).

In an endeavor to increase crop output supply and reduce cost of agricultural production in Kenya, the government usually provides funds for infrastructure development, offers subsidized fertilizers and funds research and development. In case of maize the government usually provides a market for output through purchases by National Cereals and Produce Board. These facilities reduce the transaction costs and create an environment that enhances production. Nevertheless, changes in temperature and rainfall have been experienced, further constraining output supply.

In the case of export crops, the relative price of exports and imports between Kenya and other trading partners, measured by REER, is expected to have a significant impact on the level of agricultural output. If REER rises ceteris paribus, the purchasing power of domestic currency rises undermining the competitiveness of exports (Oriavwote *et al.,* 2013). Low levels of international competitiveness would lower the capacity of Kenyan farmers to compete with those from other parts of the world. Adjustments in REER fling all commodity market, which includes the agricultural sector in disequilibrium leading to changes in agricultural production.

Thus in Kenya, output price, input prices, expenditure on rural infrastructure services, government purchase of output, REER and agro-climatic conditions more specifically temperature and precipitation are considered to be important factors in determining crop output supply realized. Incorporating these factors in equation (3.21) yields:

$$Q_i = f(\mathrm{P_i}^*, \mathrm{P_v}^*, \mathrm{W}, \mathrm{G}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .\ldots \ldots (3.22)$$

Where variables are as defined earlier and G is a vector including all the other factors influencing output supply including: area of land under crop, expenditure on rural infrastructure services, government purchase of output in the case of maize, REER in the case of cash crops, tea and coffee and $\mathrm{A_j}$, the fixed inputs.

3.3.2: The Augmented Production Function

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:

$$Y = f(A, K, L) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots ,,, \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.23)$$

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:

$$Y = A(\alpha K^{\rho} + \beta \, L^{\rho})^{\frac{V}{\rho}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (3.24)$$

Where: A is an efficiency parameter, equivalent to technology in (3.23); 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), as shown in Appendix 3.1, which takes the form:

$$Y = AK^{\alpha}L^{\beta} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . \dots \dots \dots \dots \dots \dots \dots (3.25)$$

Hence, the two factors of production are imperfect substitutes. Augmenting or directly adding land and climate variables to equation (3.25) 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:

$$Y = AK^{\alpha}L^{\beta}\mathrm{Ln}^{\gamma}\,\mathrm{W}^{\delta}\,\mathrm{R}^{\theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots 3.26$$

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).

3.4 Empirical Models

The theoretical model derived from the previous section can be used to specify an output supply for selected crops in Kenya. Moreover, a production function for each of the selected crop can be specified. The specifications are described in section (3.4.1) and (3.4.2)

3.4.1: Output Supply Model

Maize farmers in Kenya cultivate maize for subsistence and income generation by selling the surpluses. On the other hand, tea and coffee farmers produce for income generation but part of their land is used for production of food crops. If there is a need to increase production of food crops, more land is allocated for their production. Income from the cash crops is used to purchase goods from the market which together with the farm produced goods and leisure constitute the consumption basket of the household. Majority of Farmers in Kenya are small holders and assume the dual character of being producers and consumers at the same time.

Following the utility maximization problem in (3.3.1), equation (3.22) may be generalized to specify the output supply model for a particular crop (j) given as:

$$Q_j = \alpha j e_T + P_j\beta_j + W_j\theta_j + G_j\pi_j + \varepsilon_j \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots (3.27)$$

Where: Q_j is a (Tx1) vector of observations on crop j; P_j is a (TxK) matrix of

observations on all prices of crop output and input prices; W_j is a (TxH) matrix of agro-climatic variables specific to crop growing areas and season; $G_j$is a (TxM) matrix of other factors influencing output supply of crop j; α is the unkown intercept; e_T is a column vector of I's with dimension T ; β_j, θ_j and π_j are vectors of unknown coefficients corresponding to P_j , $W_j$and G_j respectively; ε_j is the stochastic error with zero mean and constant variance, uncorrelated with the explanatory variables and its previous realizations.

This study assumes that farmers are forward looking, they seek to maximize crop production in a dynamic situation, and they take into consideration their past experiences in making production decisions in the future. The farmer's behaviour has been taken in to consideration in earlier literature, such as the work of Nerlove (1958) which included partial adjustment and price expectations in modeling agricultural supply. However, the Nerlove model is not capable of giving a distinction between short run and long run elasticities, when both partial adjustment and price expectations are included and thus restrictions have to be made. Consequently, the Nerlove model assumes a fixed target supply based on stationary expectations and thus it is not able to capture the full dynamics of supply (Thiele, 2000). The shortcomings of the Nerlove model can be addressed through the use of ARDL in modeling output supply, where lags of dependent and explanatory variables are included in the model. The lagged values enables the model to capture the full dynamics of output supply as it takes into consideration, the role of observed variables in influencing farmers decision (Muchapondwa, 2008; Ogazi, 2009).

Therefore, the model in (3.27) can be modified to include the lags of the dependent and explanatory variables in the form of an ARDL model, specified as:

$$Q_{jt} = \alpha_{j0} + \sum_{i=1}^{P} \delta_{ji} Q_{jt-i} + \sum_{k=1}^{K}\sum_{i=0}^{P} \beta_{jki}\, P_{jkt-i} + \sum_{h=1}^{H}\sum_{i=0}^{P} \theta_{jhi}\, W_{jht-i} + \sum_{m=1}^{M}\sum_{i=0}^{P} \pi_{jmi}\, G_{jmt-i} + \varepsilon_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.28)$$

This can be rewritten as,

$$Q_{jt} - \sum_{i=1}^{P} \delta_{ji} Q_{jt-i} = \alpha_{j0} + \sum_{k=1}^{K} \sum_{i=0}^{P} \beta_{jki}\, P_{jkt-i} + \sum_{h=1}^{H} \sum_{i=0}^{P} \theta_{jhi}\, W_{jht-i}$$

$$+ \sum_{m=1}^{M} \sum_{i=0}^{P} \pi_{jmi}\, G_{jmt-i} + \varepsilon_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.29)$$

By employing a lag operator and dropping the subscript j for ease of illustration, the corresponding equation in lag polynomial is

$$A(L)Q_t = \alpha_0 + \sum_{\mathrm{k}=1}^{\mathrm{K}} \beta_k\,(L) P_{kt} + \sum_{h=1}^{H} \theta_h\,(L) W_{ht} + \sum_{m=1}^{M} \pi_m\,(L) G_{mt}$$

$$+ \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.30)$$

Where:

$$A(L) = 1 - \sum_{i=1}^{P} \delta_i\, \mathrm{L}^{\mathrm{i}}\ ,\ \ \beta_k(L) = \sum_{\mathrm{i}=0}^{\mathrm{P}} \beta_{ki} \mathrm{L}^{\mathrm{i}},\ \ \theta_h(L) = \sum_{h=0}^{H} \theta_{hi}\, \mathrm{L}^{\mathrm{i}}$$

and $\pi_m(L) = \sum_{m=0}^{M} \pi_{mi}\, \mathrm{L}^{\mathrm{i}}$

The distributed lag form of the model that defines long run relationship is given as:

$$Q_{jt} = \frac{\alpha_0}{A(L)} + \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \beta_k\,(L)}{A(L)} P_{kt} + \frac{\sum_{h=1}^{H} \theta_h\,(L)}{A(L)}\, W_{ht} + \frac{\sum_{m=1}^{M} \pi_m\,(L)}{A(L)}\, G_{mt}$$

$$+ \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.31)$$

Where: $A(L) \neq 0$

The number of lags is determined using Akaike Information criterion (AIC), Schwarz Information Criterion (SIC) and Hannan-Quinn Information Criterion (HQ).

3.4.2: Agriculture Crop Yield Model

Following the production theory in (3.3.2), equation (3.26) 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 (3.26), the study estimated an extended model for each crop yield (j) specified as:

$$CY_{jt} = \delta_{j0} + X'_{jt}\lambda_j + W'_{jt}\emptyset_j + \mu_{jt} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots\dots\dots (3.29)$$

Where: CY is yield for a given crop; j= 1,2,3 corresponding to maize, tea and coffee in this study, 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 in case of maize yield.

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 (Upton, 1987; Blanc, 2011). Empirical studies using experimental methods do not include area under crop as an explanatory variable because area of land expansion is not applicable and thus do not cause omitted variable bias. However, studies using national data that reflect the actual cropping decisions include land as an explanatory variable to capture decreasing marginal productivity of land (Chen *et al*, 2004; Kawasaki & Herath, 2011; Blanc, 2011; De-Graft & Kweku, 2012). This study employs national data and considers differences in land productivity across farms by incorporating area under crop as an explanatory variable. The coefficient of area under crop is expected to have a negative sign to indicate diminishing marginal productivity.

Application of fertilizer is a common practice carried out by farmers aimed at increasing crop yield by avoiding depletion of soil nutrients and preserving soil quality which is essential for future yields. According to IPCC (2007) efficient use of fertilizers has been shown to be environmentally effective. 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 (Mathenge, 2009; Blanc, 2011). 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 (Upton, 1987; 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.

In addition, the intensity of mechanization greatly influences efficiency and hence as agriculture get more mechanized the level of productivity is expected to increase. Nevertheless, the capital requirement for traditional farming methods largely practiced in most African countries including Kenya is minimal. In addition, the costs of implementation and the capacity of use especially for imported technologies hinder mechanization (Inter Academy Council, 2004; Blanc, 2011). Thus, due to these restrictions mechanization is not included in the specification.

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 non linear weather effects on crop yield, quadratic terms for rainfall and temperature are included in the specification.

3.5 Estimation Method

Each ARDL crop output model and crop yield model were estimated by least squares method. The models are estimated consistently by Ordinary Least Squares (OLS) if 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. The ARDL models were estimated in a semi log linear form to derive elasticities with respect to control variables and semi elasticities with respect to the climatic variables.

The models were estimated using annual time series data for the period between 1970 and 2014. 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, as described in section (3.6)

3.6 Time Series Properties

Since this study uses time series data, it is necessary that, before estimation of the equations, the series have to be tested for unit root and existence of cointegration as described in section (3.6.1) and (3.6.2), respectively.

3.6.1 Testing for Stationarity of Data

To detect presence of unit root in the series, the study employed the Augmented Dickey-Fuller (ADF), Philip Peron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin

(KPSS) tests. The ADF test for stationarity in a series y involved estimating the equation

$$\Delta \mathrm{y_t} = \mu + \beta \mathrm{t} + \gamma \mathrm{y_{t-1}} + \sum_{\mathrm{i=1}}^{\mathrm{P}} \emptyset_{\mathrm{i}} \Delta \mathrm{y_{t-i}} + \varepsilon_{\mathrm{t}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.30)$$

Where μ is the drift (intercept), t is the trend, i equal the number of lags in $\Delta \mathrm{y_{t-i}}$, P is the maximum number of lags determined using Akaike Information Criterion (AIC) and Schwartz Criterion (SC) and ε_{t} is the random error term. The null hypothesis H_O: $\gamma = 0$ (unit root) was tested against the alternative hypothesis H_A: $\gamma < 0$ (no unit root). If the computed test statistic was found greater than the critical value then the null hypothesis was not rejected. If H_O could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary. If its first difference is then tested and found stationary, the series was concluded to be an I(1) (Green, 2008; Gujarati, 2004; Dickey and Fuller, 1979). Time series were also subjected to a Phillips –Perron test which has a higher power.

The PP test took the form

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{m} \delta_i Y_{t-i} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.31)$$

Where ΔY_t was the first difference of the dependent variable; i is the number of truncation lags, where i=1, 2,…, m; θ and δ are coefficients and ε_t is the error term. The null hypothesis of, $H_0: \delta_i = 0$ (unit root) was tested against the alternative,

$H_A: \delta_i < 0$ (no unit root). If the computed test statistic was found greater than the critical value at 5 percent level of significance then the null hypothesis was not rejected. If H_O could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary.

To confirm the test results obtained from the ADF and PP tests, Kwiatkowski Phillips, Schmidt and Shin's test (1992) (KPSS) was employed to eliminate a possible low power against stationary near unit root processes which occurs in the ADF and PP tests. KPSS has a null hypothesis of stationarity of a series around either mean or a linear trend; and the alternative hypothesis that assumes that a series is non-stationary due to presence of a unit root. If the computed test statistic was found less than the critical value then the null hypothesis was not rejected.

The test is based on representation of a series y_t , which is decomposed as:

$$y_t \ = ʒ\mathrm{t} + r_t + \varepsilon_t \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . . \dots\dots\dots (3.32)$$

$$r_t \ = r_{t-1} + \mu_t \ \dots\dots\dots\dots\dots\dots\dots\dots . . \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . . \dots\dots\dots (3.33)$$

Where y_t , $\mathrm{t} = 1,2, \dots \mathrm{T}$ is the observed series; ʒt is a deterministic trend; ε_t is a stationary error and r_t is a random walk where μ_t are iid$(0, \sigma_\mu^2)$. The first value r_0 is assumed to be fixed and thus acts as an intercept. The series behavior depends on one parameter, which is variance of $\mu_{t\,,}\sigma_\mu^2$. if it equals 0, then r_t =constant and y_t is trend stationary, and if $\sigma_\mu^2 > 0$ r_t is a random walk and y_t is non stationary. If $ʒ = 0$

under the null hypothesis y_t is stationary around a level r_0 (Kwiatkowski, Schmidt &Shin 1992; Green, 2008).

3.6.2 Cointegration Analysis

After testing for stationarity, there is need to test data for possible cointegration before estimating a time series regression. Two or more series of trending variables are said to be co-integrated if they are integrated of the same order and a stationary linear combination exist between them. The cointegrated variables will by no means move far apart and they will be attracted to their long run relationship. The order of integration of the variables is used to determine whether there is a non spurious long run equilibrium relationship between them. Thus, cointegration serves as a qualification for the existence of a long run equilibrium relationship between two or more variables having unit roots (Engel & Granger, 1987). It was therefore necessary to confirm existence of cointegration since the dependent variables and some of the regressors were integrated of order one. According to Hatanaka (1996) cointegration relation must involve at least two I(1) variables and therefore I (0) variables may also be included in the cointegrating equation. The test for cointegration involved running a regression of each crop output on climate and other control variables. From the estimated equations, residual series were obtained and tested for the presence of unit root. Once cointegration is established using the model with at least two I (1) series, then I (0) variables could also be added in the ARDL model. Adding I (0) variables does not alter I (0) characteristics of the error term (Hill *et al.,* 2012).

3.7 Definition and Measurement of Variables

Output of Crop is the output of the crop under consideration: maize, tea and coffee measured in tonnes for a given year.

Crop Yield is the crop production per area of land under crop in tonnes per hectare.

Prices are measured using:

Price of Output is the average market price for the crop in a given year in Kenya shillings per Kg.

Price of Fertilizer is the price of fertilizer measured in growth terms by the difference between input price index for the given period and that in the previous year

Wage rate is the average wage in agricultural sector measured by the minimum wage for rural farm worker in Kenya shillings.

Price of seed is the price of certified maize seed measured in growth terms by the difference between input price index for the given period and that in the previous year

Agro-climatic variables are measured using:

Mean temperature- mean temperature in degree Celsius, recorded in the months of JF, MAM, JJAS and OND in a given year for selected weather stations in maize, tea and coffee growing areas.

Rainfall- 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, tea and coffee 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, tea and coffee growing areas.

Temperature Variability is year to year variability of mean temperature measured by the squared annual temperature deviation from the long term mean.

Control variables are measured using:

Land Use is the area under crop (maize, tea, coffee) production measured by the number of hectares.

Real Effective Exchange Rate is the weighted average of Kenya's currency relative to an index or basket of other major currencies adjusted for the effects of inflation.

Government Spending on Infrastructure is the amount of money allocated by the central government for development in transport system for a given fiscal year measured in Kenya shillings

Maize Sales to Marketing Boards- this is the quantity of maize in metric tonnes delivered to marketing boards in a year

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

Seed use is the amount of certified maize seeds used in kilograms per hectare.

3.8 Data Sources

The study used secondary data on all the variables. The data was gathered from government publications, Kenya Meteorological Department, Coffee Board of Kenya, Tea board of Kenya, 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. Climate variables used in tea and Coffee models were computed using data from the following weather stations: Kericho, Kabete, Nyeri, Kakamega, Meru, Embu and Kisii.

3.9 Data Collection and Cleaning

The data used was compiled from various sources as indicated in section 3.6 in the months of February March and April of 2014 and September 2015. Nominal values of government spending on roads, transport and communication were converted to real values using the CPI for 2010. The data used is presented in Tables A1, A2, A3, A4, and A5 in Appendix 1.

3.10 Diagnostic Tests

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.

3.11 Data Analysis and Interpretation

Analysis of data was carried out in line with the objectives of the study. In order to determine the response of crop output to climate variability, variables were transformed and included in the estimated functions in their log form, save for the climate variables. This transformation improves variable distribution as it reduces presence of data outliers and removes the influence of the unit of account on the estimated coefficients. This aids the comparison of the impact of different variables and makes it easier to estimate parameters as it produces constant elasticities of the dependent variable with respect to explanatory variables. However, the climate variables were not transformed to logs so as to generate semi elasticities. This is to allow direct determination of the impact of temperature and precipitation on output supply, such as the effect of 1^0c increase in temperature or a 100 mm increase in rainfall on crop output supply/ yield.

In order to determine the effect of climate variables on crop yield, explanatory variables specified in equation (3.29) were subjected to unit root tests specified in section (3.6.1).

With the unit test results showing that variables are a mixture of I(0) and I(1), the models were estimated at first difference. The differenced I(1) variables are usually stationary, even if the variables were non stationary at level. When time series have unit roots they cannot be used at levels since there is a likelihood of yielding spurious results (Heij *et al*., 2004; Woodridge, 2012). An alternative to using the variables at levels 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). However, as noted by Heij et al., (2004) the interpretation of the model changes, as it is concerned with short run relationship between variables as their long run dependence is eliminated by differencing. The estimated equations were then subjected to diagnostic tests highlighted in section (3.10).

Appendix 3.1: Convergence of a CES production function to a Cobb Douglas production function

Starting with a CES production function (Varian 1992), it can be shown that CES converges to Cobb-Douglas function when ρ converges to zero.

$$Y = A(\alpha K^{\rho} + \beta\, L^{\rho})^{\frac{1}{\rho}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.34)$$

Dividing both sides of equation (3.38) with A

$$\frac{Y}{A} = (\alpha K^{\rho} + \beta\, L^{\rho})^{\frac{1}{\rho}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.35)$$

Raising both sides of equation (3.39) with ρ gives:

$$\left(\frac{Y}{A}\right)^{\rho} = \alpha K^{\rho} + \beta\, L^{\rho} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.36)$$

Taking the total derivative of equation (3.40) gives:

$$\frac{1}{\mathrm{A}}\rho Y^{\rho-1}\mathrm{dY} = \rho\alpha K^{\rho-1}\mathrm{dK} + \rho\beta\, \mathrm{L}^{\rho-1}\mathrm{dL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.37)$$

Dividing both sides of equation (3.41) by ρ yields:

$$\frac{1}{\mathrm{A}} Y^{\rho-1}\mathrm{dY} = \alpha K^{\rho-1}\mathrm{dK} + \beta\, \mathrm{L}^{\rho-1}\mathrm{dL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.38)$$

Taking limits: as ρ tends to zero equation (3.42) approaches:

$$\frac{1}{\mathrm{A}} Y^{-1}\mathrm{dY} = \alpha K^{-1}\mathrm{dK} + \beta\, \mathrm{L}^{-1}\mathrm{dL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.39)$$

Integrating equation (3.43) and simplifying gives a Cobb-Douglas production function (3.48)

$$\frac{1}{\mathrm{A}}\int \frac{1}{\mathrm{Y}}\mathrm{dY} = \alpha \int \frac{1}{\mathrm{K}}\mathrm{dK} + \beta \int \frac{1}{\mathrm{L}}\,\mathrm{dL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.40)$$

$$\frac{1}{\mathrm{A}}\ln\mathrm{Y} = \alpha\ln\mathrm{K} + \beta\ln\mathrm{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.41)$$

$$\frac{1}{\mathrm{A}}\ln\mathrm{Y} = \ln\left(\mathrm{K}^{\alpha}\mathrm{L}^{\beta}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.42)$$

$$\frac{1}{\mathrm{A}}\mathrm{Y} = \mathrm{K}^{\alpha}\mathrm{L}^{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.43)$$

$$\mathrm{Y} = \mathrm{A}\mathrm{K}^{\alpha}\mathrm{L}^{\beta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.44)$$

CHAPTER FOUR

EMPIRICAL FINDINGS

4.1 Introduction

This chapter presents findings of the study. Descriptive statistics, tests results of time series properties and diagnostic tests on estimated models are presented. Further, using the estimated econometric model, the findings of maize, tea and coffee output response to climate variability and other economic variables are discussed. Lastly, the chapter presents findings and discussion on the marginal effects of climate conditions on crop yield.

4.2 Descriptive Statistics

The summary statistics on the variables are presented in Table 4.1

Table 4.1: Summary Statistics on Climate and Crop Variables

Variables	Mean	Maximum	Minimum
Maize output(tonnes)	2,402,976	3,600,000	1,400,000
Area under maize(ha)	1,497,805	2,159,322	985,000
Maize yield(tonnes/ha)	1.60	2.07	1.2
Tea output(tonnes)	196,930.7	399,006.4	36,289.85
Area under tea(ha)	103,786.1	190,717	40,274
Tea yield(tonnes/ha)	1.75	2.48	0.84
Coffee output(tonnes)	74,341.12	128,941	36,629
Coffee yield(tonnes/ha)	0.55	0.89	0.23
Area under coffee(ha)	134,762.6	170,000	83,700

Table 4.1: Continued

Variables	Mean	Maximum	Minimum
Climate variables in maize growing areas			
Mean temperature(^{0}C)-JF	19.22	19.96	17.98
Mean temperature(^{0}C)-JJAS	17.75	18.70	16.50
Mean temperature(^{0}C)-MAM	19.39	20.38	18.17
Mean temperature(^{0}C)-OND	18.67	19.61	17.57
Rainfall(mm)-JF	117.11	381.25	29.86
Rainfall(mm)-JJAS	325.54	467.18	216.86
Rainfall(mm)-MAM	465.13	656.26	223.07
Rainfall(mm)-OND	334.16	714.05	167.43
Climate variables in tea and coffee growing areas			
Mean temperature(^{0}C)-JF	19.09	20.4	15.92
Mean temperature(^{0}C)-JJAS	17.62	18.85	14.92
Mean temperature(^{0}C)-MAM	19.27	20.40	16.13
Mean temperature(^{0}C)-OND	18.63	19.78	15.95
Rainfall(mm)-JF	138.77	415.01	34.85
Rainfall(mm)-JJAS	364.16	539.16	245.14
Rainfall(mm)-MAM	579.37	895.0	313.47
Rainfall(mm)-OND	441.66	927.94	231.37

Source: Author's calculations

Based on 45 annual observations, the data shows that between 1970 and 2014 maize output averaged 2.4 million tonnes with a maximum output of 3.6 million tonnes and a minimum of 1.4 million tonnes. Area under maize production averaged approximately 1.5 million hectares. Maize yield ranged from 1.2 to 2.07 tonnes per hectare with an average of 1.6 tonnes per hectare. Tea production averaged approximately 197 thousand tonnes ranging between a minimum of 36 thousand tonnes and a maximum of 399 thousand tonnes during the study period. Area under tea production averaged approximately 103 thousand hectares. Tea yield ranged between a minimum of 0.84 and a maximum of 2.48 tonnes per hectare with an average of 1.75 tonnes per hectare. Coffee production averaged approximately 74 thousand tonnes ranging between a maximum of 128 thousand tonnes and a minimum of 36 thousand tonnes during the study period. Area under coffee production averaged approximately 134 thousand hectares while coffee yield recorded a minimum of 0.23 and a maximum of 0.89 tonnes per hectare with an average of 0.55 tonnes per hectare.

On climate variables, the study defines four periods namely, January to February (JF), March to May (MAM), June to September (JJAS) and October to November (OND). JF is a dry period, which comes before the onset of the main rainy season MAM. JJAS is a relatively cold period and is an extension of the main cropping season, which starts with onset of long rains in March while OND corresponds to the short rain season.

Mean temperature and rainfall statistics are calculated using data from main crops growing areas. Tea and coffee are usually grown in high potential/ humid areas (Zone I) while maize is grown in high potential areas as well as medium potential/ semi humid areas (Zone I to Zone III) which form basis of the selection of weather stations used. The data shows that mean temperature is relatively high in maize growing areas for all periods compared to tea and coffee growing areas. Higher mean temperatures are observed in March to May period with an average mean of 19.39^0C and 19.27^0C in maize and tea and coffee growing regions respectively. Lower mean temperature is observed in June to September period with an average of 17.75^0C and 17.62^0C in maize and tea and coffee growing regions respectively.

Rainfall amount is higher in tea and coffee growing areas compared to that received in maize growing areas for all periods. Higher amount is received in March to May period corresponding to long rains season. During this period, rainfall ranges between a minimum of 313 mm and a maximum of 895 mm with an average of 579 mm in tea and coffee growing areas. In maize growing areas, rainfall ranges from 223 mm to 656 mm with an average of 465 mm. Lower rainfall is received in January to February period corresponding to relatively dry season. During this period rainfall falls between a minimum of 34 mm and a maximum of 415 mm with an average of 138 mm in tea and coffee growing areas whereas in maize growing areas, rainfall ranges from 29 mm to 381 mm with an average of 117 mm.

4.3 Time Series Properties

Use of least squares method in model estimation requires that all assumptions of the model hold, as well as various properties of data used, for it to yield estimates that are efficient and consistent. Thus, unit root and cointegration tests were performed before estimation of the equations. The results of the tests are discussed in section 4.3.1 and 4.3.2 respectively.

4.3.1 Unit Root Tests

The major reason for conducting unit root tests was to establish the order of integration, crucial for setting up the econometric models from which implications are made. Since most of the economic data are non stationary, OLS regression based on such data is likely to give spurious results. Thus, each of the series used in the study was tested for presence of a unit root based on ADF, PP and KPSS. The KPSS was added to confirm test results because ADF and PP statistics have limitations of lower tests power and successive or persistent unit roots respectively. They tend to accept the null hypothesis of presence of unit roots. Table A6 in Appendix 2 presents the results of the stationarity tests.

The unit root test results, indicate the following variables are stationary: rainfall variability, temperature variability, log maize sale to marketing boards, log development expenditure on roads, transport and communication, log agricultural wage rate, mean temperature in maize growing areas; rainfall amount in both maize and tea and coffee growing areas and squared terms for rainfall and temperature in maize, tea and coffee growing areas.

Conversely, the following variables were found to be integrated of order 1: log maize output; log coffee output; log tea output ; log maize yield; log coffee yield; log tea yield; Log area of coffee production; log area of tea production; log area of maize production; log price of coffee; log price of tea; log price of maize; log price of maize seed, mean temperature in coffee and tea growing areas; log price of fertilizer; log real effective exchange rate; fertilizer consumption and labor employment in agriculture. Thus, the variables used in the study are a mixture of I(0) and I (1). The regression of non stationary series on other series may possibly produce spurious regression. However, there is a possibility that the regression can be meaningful if the variables are cointegrated (Yule, 1989; Ssekuma, 2011). Hence, there is need to carry out cointegration tests on the integrated variables.

4.3.2 Cointegration Analysis

According to Hatanaka (1996) cointegration relation must involve at least two I(1) variables. Therefore, I (0) variables may also be included in the cointegrating equation. The test for cointegration involved running a regression of log maize output, log coffee output and log tea output on climate and other control variables. Residual series were obtained from the estimated equations and tested for the presence of unit root. The null hypothesis of existence of a unit root, which implies there is no cointegration, was rejected at 5 percent level of significance for each of the estimated residuals. The cointegration test results are shown in Table A7 of appendix 2. The results show that linear combination of the variables in each regression was stationary. The results vindicate existence of a long run relationship among variables in each of the models.

4.4 Diagnostic and Stability Tests

To test out the estimated models various diagnostic and stability tests were carried out. The results are presented and discussed in sections 4.4.1, 4.4.2 and 4.4.3

4.4.1 Normality, Serial Correlation and Heteroscedasticity tests

Residual based tests were carried out on all residual series from each of the output response equation. Normality, serial correlation and heteroscedasticity tests were performed. The results are presented in Tables A9, A10 and A11 in Appendix 3 and Tables A13, A14 and A15 in Appendix 4. From the histogram-, normality tests the probability values (P values) of the Jarque Bera statistic are greater than 0.05 and thus the null hypothesis that standardized residuals are normally distributed could not be rejected at 5 percent level of significance. This implied that the series is normally distributed and t and F tests are used for hypothesis testing as they assumed normal distribution.

The Breush-Godfrey Lagrange multiplier (LM) test for serial correlation was also carried out and the results show no evidence of autocorrelation. The probability (P) associated with the computed test statistic is greater than 0.05 and thus the null hypothesis of no serial correlation in the residuals could not be rejected at 5 percent level of significance. To ascertain whether the standard errors of the estimates are biased the LM test for no autoregressive conditional heteroscedasticity (ARCH) was carried out in each of the equations. The P value associated with the computed test statistic is greater than 0.05 and thus the null hypothesis of homoscedasticty, could not be rejected at 5 percent level of significance.

4.4.2 RESET Test and Parameter Constancy Tests

Ramsey Reset tests whether non linear combinations of fitted values help explain the dependent variable. The intuition is, if non linear combinations of the explanatory variable have any power in explaining the dependent variable, the model is misspecified and violates the assumptions of the classical normal linear regression. Therefore, the Ramsey RESET test is conducted on each of the response equations. Table A12 in Appendix 3 and Table A16 in Appendix 4 present the results of the tests. The findings show that the P values are greater than 0.05 and thus unable to reject the null hypothesis that the powers of the dependent variable have zero coefficients. This implies that the functional form of the models is correctly specified ruling out the possibility of specification errors in the models.

To determine parameter constancy, recursive estimations were performed on each of the crop response equations. Recursive coefficient tests, CUSUM tests, CUSUM residual squares test, one step forecast test and N steep forecast tests were performed. The results are presented in Figures A1 to Figure A18 in Appendix 4. In all the cases, the plots do not diverge significantly from the zero line and the residuals lie within the standard error band suggesting stability in the parameters of the equation.

4.5 Maize, Tea and Coffee Output Response to Climate Variables

To determine the response of crop output supply to climate variables, three ARDL output response equations were estimated. Before the estimation of maize, tea and coffee output supply models the optimal lag length for each model was determined. Based on the lag order selection criteria results shown in Table A7 in Appendix 2, an optimal lag order of 2 was selected for maize, tea and coffee output supply models based on the AIC criterion.

The coefficient estimates and their corresponding standard errors and long run coefficient estimates from each of the crop's output ARDL model are shown in Table 4.2 and Table 4.3 respectively. The long run coefficient for an independent variable X_i was derived according to the ratio of sum of coefficients of explanatory variable X_i

from lag zero to lag 2 to the value of the polynomial associated to the dependent variable.

The regression models yield relatively high values for adjusted R squared. The adjusted R^2 values of 0.81, 0.95 and 0.83 in maize, tea and coffee output functions respectively imply that 81 percent, 95 percent and 83 percent of variations in maize, tea and coffee output respectively, are explained by climate variables and specified control variables.

Table 4.2: Crops Output Response Equations Coefficient Estimates

Explanatory variables	Dependent Variables		
	Log maize output	Log tea output	Log coffee output
First lag of log crop output	0.0769	0.6214***	0.1391
	(0.1269)	(0.1324)	(0.2254)
Second lag of log crop output	-0.4131***	0.2774**	-0.4961**
	(0.1211)	(0.1193)	(0.1901)
Log price of output	-0.1528	0.2512**	0.0324
	(0.0846)	(0.1032)	(0.2273)
First lag log price of output	0.2627***	-0.0027	-0.0135
	(0.0952)	(0.0970)	(0.0713)
Rainfall variability	-0.0999	-3.8640	0.2765
	(0.3176)	(3.0052)	(0.2995)
Temperature variability	-0.0348**	2.7939	-0.0377***
	(0.0158)	(3.4095)	(0.0117)
First lag of temperature variability	-	-	0.0360**
	-	-	(0.0127)
Mean temperature (Jan- Feb)	0.1271	-0.0684	0.03397
	(0.0777)	(0.0626)	(0.0258)
Mean temperature(June-Sept)	-0.3034***	0.0548	0.0559
	(0.0940)	(0.1018)	(0.0338)
Mean temperature (March-May)	-0.0890	0.0075	-0.0380**
	(0.0860)	(0.0923)	(0.0152)
Mean temperature (Oct-Dec)	0.2706***	-0.0267	0.04834
	(0.0838)	(0.0631)	(2.6.36)
First lag mean temp (Oct-Dec)	-	-	0.0222
			(0.016)
Rainfall (Jan-Feb)	0.0002	0.0008***	-0.0010
	(0.0003)	(0.0002)	(0.0008)
Rainfall (June -Sept)	0.0014***	0.0002	0.0029
	(0.0004)	(0.0036)	(0.0023)
Rainfall (March-May)	3.75E-05	0.0005**	-0.0037
	(0.0002)	(0.0002)	(0.0023)

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

Table 4.2 Continued:

Explanatory variables	Dependent Variables		
	Log maize output	Log tea output	Log coffee output
Rainfall(Oct-Dec)	0.00042**	5.60E-05	0.0012
	(0.00015)	(0.0055)	(0.0015)
First lag Rainfall(Oct-Dec)			0.0036**
			(0.0014)
Log Spending on roads transport and communication	0.0301	0.0664**	0.1134**
	(0.0276)	(0.0267)	(0.0514)
First lag of log spending on roads transport and communication	-	-0.0600**	-
		(0.0230)	
Log Price of fertilizer	-0.0628	-0.0790***	-0.1755**
	(0.0883)	(0.02971)	(0.0695)
Log Agricultural Wage	-0.2399**	0.0535	-0.6776***
	(0.0885)	(0.0809)	(0.1768)
Log Area under crop	0.1195**	0.2171	0.0903
	(0.0479)	(0.2426)	(0.2926)
Log Price of maize seed	0.0119	-	-
	(0.0612)		
Log Sales to marketing board	-0.0274	-	-
	(0.0706)	-	-
First Lag of Sales to marketing board	0.1595*	-	-
	(0.0789)	-	
Real effective exchange rate		-0.1853	-0.6650
		(0.1451)	(0.4016)
First lag Real effective exchange rate			-0.9819**
			(0.4311)
Constant	18.5486***	-0.2512	-0.5204
	(2.7747)	(2.8923)	(4.9419)
R-squared	0.90	0.97	0.93
Adjusted R-squared	0.81	0.95	0.83
F-statistic	9.38	18.4	9.34
Prob(F-statistic)	0.00	0.00	0.00

Standard errors in brackets; ***, **,* significant at 1%, 5% and 10% respectively

Source: Author's computation

Table 4.3: Elasticity and Semi Elasticity Estimates of Crops Output with Respect to Climate Variables and other Control Variables

Explanatory variables	Dependent variables		
	Log maize output	Log tea output	Log coffee output
Log Price of output	0.082	2.46	-
Temperature variability	-0.03	-	-0.05
Mean temperature(June-Sept)	-0.23	-	-
Mean temperature (March-May)	-	-	-0.03
Mean temperature (Oct-Dec)	0.20	-	-
Rainfall (Jan-Feb)	-	0.0078	-
Rainfall (March-May)	-	0.0049	-
Rainfall (June-September)	0.002	-	
Rainfall(Oct-Dec)	0.003	-	0.004
Log spending on roads transport and communication	-	0.06	0.08
Log price of fertilizer	-	-0.78	-0.13
Log Agricultural wage	-0.18		-0.50
Log Area under crop	0.09	-	-
log sales to marketing board	0.10	-	-
log real effective exchange rate			-1.21

Source: Author's computation

4.5.1 Maize, Tea and Coffee Output Supply Response to Rainfall and Rainfall Variability

To determine the response of maize, tea and coffee output supply to rainfall and rainfall variability, each of the estimated ARDL model included seasonal rainfall and rainfall variability as regressors among other control variables.

From the estimated results in the maize output supply model, the coefficient estimates of rainfall amount in the month of June to September and October to December are positive sign and significant at one percent and 5 percent level respectively. The coefficient of rainfall variability and the coefficient of rainfall in the months of January and February and March to May periods are insignificant. The positive sign of the coefficient estimate shows that an increase in rainfall leads to an increase in maize production in both the main crop season and the short rains season. Further, the study findings show that the amount of rainfall in January and February, which is the pre season before the main growing season, marked by onset of long rains in March, does not influence the level of maize output. However, the findings are in contrast those of Kawuma (2011) which showed that the preseason rainfall coefficient had a positive and significant influence on crop production in Ethiopia.

Semi elasticity estimates show that an increase in rainfall amount by 100 mm increases maize output by 0.2 percent during the months of June to September while an increase in rainfall by 100 mm increases maize output by 0.3 percent during the short rains season. Overall rainfall has a positive effect on maize supply. These results indicate that when rainfall amount is not limiting in the months of June to September, production of the main crop planted at the onset of long rains increases. This is in line with the observation that maize requires rainfall to be well distributed throughout the growing period and especially during flowering and silking stages which corresponds to these period. As well, the results imply that additional rains during the main growing season and during the short rain season maize growing season raise maize production and thus may in turn serve as an incentive to farmers expand maize production through allocation of more land to crop and better farm management.

In addition, occurrence of short rains between October and December presents an opportunity to boost maize production in medium and low altitude areas that support two growing seasons. During this period of three months, the short rain varieties go through vegetative and reproductive stages that require adequate rainfall. This concurs with Seifu, (2004) observation that greatest decline in maize output is caused by water deficient during the flowering period and yield formation periods. However, water deficient during ripening period has little effect on grain yield. The findings are consistent with those of Oseni (2011) that a reduction in mean annual rainfall in the planting season has a negative impact on maize production and those of Eregha et al., (2014) that rainfall has a positive impact on the production of maize. In contrast, Issahaku and Maharjan (2014) observed that rainfall did not influence planting decision by maize farmers in Ghana.

The study findings from the tea output supply model in Table 4.2 show that the coefficients of rainfall amount in January to February and March to May periods have a positive sign and are significant at one percent and 5 percent level of significance respectively. However, the coefficients of rainfall amount in the short rain season and rainfall variability are insignificant. The findings are consistent with those of Seo et al., (2005) and Okoth (2011) that increase in precipitation is beneficial to tea production. However, Cheserek (2015) found a weak negative relationship and a weak positive relationship between rainfall and tea production in Timbilil tea estate and Magura tea estate respectively.

Semi elasticity estimates in Table 4.3 show that, in the months of January and February, which is a relatively dry period an increase in rainfall by 100 mm increases production of tea by 0.78 percent. For the period of March to May which corresponds to the long rain season, an increase in rainfall by 100 mm increases tea production by 0.49 percent. Overall rainfall amount has a positive impact on tea output supply. The results indicate that rainfall increase in the relatively dry months raise the quality and quantity of tea production as tea requires well rainfall distribution. As well, increase in tea production raises tea production and could serves as an incentive to farmers to expand tea production by allocating more land to tea production and properly managing the tea bushes.

The coefficient estimates from the coffee output model in Table 4.2 shows that, the coefficient for rainfall amount in the short rain period in the previous year is positive and significant at 5 percent level. This period coincides with the start of the crop year in Kenya, which extends from October to September. The coefficients for rainfall variability and rainfall in other periods are insignificant. Gay et al., (2006), who observed that coffee production in Veracruz Mexico responds positively to spring precipitation, though with a low response, obtained a similar result. However, Wangui (2010) observed that there is no significant relationship between rainfall and large scale coffee production in Kigutha coffee estate in Kiambu County, Kenya. The observation may have resulted due to use of irrigation in times of water shortage and thus at no times was soil moisture limiting. Given that the national output data, considered in this study takes in the small holder and estates, the smallholder coffee farmers may not have the capacity to employ irrigation methods due to the high costs involved and thus, they are highly dependent on rainfall.

From the semi elasticity estimates in Table 4.3, for October to December period, a semi elasticity value of 0.004 is estimated. This signifies that an increase of rainfall amount in the short rain period by 100 mm increases coffee output by 0.4 percent. This is in line with the observation that occurrence of short rains usually coincides with the flowering stage of coffee when the crops require regular rainfall throughout to berry development. Overall coffee output supply responds positively to rainfall with an increase in rainfall in the short rain period, raising coffee output supply. This could serve as an incentive to expand coffee production

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4.5.2 Maize, Tea and Coffee Output Supply Response to Temperature and Temperature Variability

The study as well, sought to determine the response of maize, tea and coffee production to temperature and temperature variability. To do so, each of the three ARDL models estimated included mean temperature and temperature variability as regressors among other variables.

The study findings from the maize output model in Table 4.2 show that the coefficient of mean temperature in June to September period has a negative sign and is significant at 1 percent level, while the coefficient of mean temperature in October to December season has a positive sign and is significant at 1 percent level. The coefficients of mean temperature in other periods were insignificant.

From Table 4.3, computed semi elasticity estimates for maize production with respect to mean temperature in June to September period shows that when mean temperature increases by 1^0 C maize output reduces by 0.23 percent. On the other hand when mean temperature increases by 1^0 C in the short rains period, between October and December, output increases by 0.20 percent. Notably, June to September period coincides with critical flowering and silking stages for the late maturity hybrid variety planted in the major planting season at the onset of long rains. These stages are highly sensitive to water deficit and an increase in temperature when moisture content is limiting obstructs pollination adversely affecting the output level (Bergamaschi *et al.*, 2004). Crop failure in this period could possibly make farmers consider alternative crops that are more resilient to high temperatures and water deficit. The positive effect of temperature on maize output in the short rain season indicates that when moisture content is not limiting an increase in temperature boost maize production. Overall, temperature has a negative net effect on maize output supply.

The coefficient estimate of temperature variability has a negative sign and is significant at 5 percent level. This shows that as temperature variability increases by one standard deviation from the mean, maize production reduces by 0.03percent. The result signifies that, as climate risk increases, maize farmers may diversify or switch toward other crops or participate in other activities. The expected rise in temperature in the next decades could end up straining maize production that will further exacerbate food insecurity. The findings are consistent with those made by Nyairo (2011). On the other hand, Akpalu *et al.,* (2008) and Bhandari, (2013) found that changes in temperature had a positive effect on maize crop. Issahaku and Maharjan (2014) observed no relationship between maize production and minimum and maximum temperature but also noted that farmers increased land allocation for maize production as maximum temperatures increased.

Findings from the tea output model shown in Table 4.2, indicates that the coefficient estimates of mean temperature in all periods and coefficient estimate of temperature variability are insignificant. The results obtained from the coffee output model shows that the coefficient estimate of mean temperature in March to May season has a negative sign and is significant at 5 percent level. The coefficients estimates of mean temperature in other periods are insignificant. The semi elasticity estimate shows that an increase of mean temperature by 1^0 C in the months of March to May corresponding to the long rains season, reduces coffee output by 0.03 percent. Overall temperature increase has a negative effect on coffee output supply.

Typically, the start of long rains coincides with the flowering stage of the main coffee crop and excessively high temperatures at this stage increases the chances of abortion of flowers subject to other environmental conditions, which has a negative impact on coffee output (ICC, 2009; CIAT, 2010). This makes management of coffee crop a challenge and increases cost of production, which serves as a disincentive to coffee farmers. Eventually farmers may end up cutting down coffee tree for alternative crops or alternative land uses. The findings are consistent with those made by Wangui (2010) that there is a negative relationship between temperature and coffee production and that there is a positive correlation between increase in temperature and water supplied to the estate for irrigation. Increase of irrigation costs raises the overall cost of production and consequently reduces output.

In addition, the coefficient estimate of temperature variability and its second lag have a negative sign and significant at 1 percent level. The coefficient of the first lag of temperature variability has a positive sign and is significant at 5 percent level. The net effect is however negative with a one standard deviation increase in temperature variability reducing coffee output by 0.05 percent. The findings indicate that increase in deviations from the mean temperature is detrimental to coffee production and may be altering the distribution of coffee growing areas. As well, the results possibly indicate a case of crop substitution with other crops or converting area under crop to other land use activities as temperature becomes more erratic making the land under coffee less productive. The long term effect could be huge if mitigation and adaptive measures are not put in place and enhanced. This result concur with the findings of Gay *et al.* (2006) and Carmago (2010) that temperature is one of significant climate factors for coffee production, as high temperature and dry conditions during the reproductive phase are critical for the optimum coffee production and quality.

4.5.3 Maize, Tea and Coffee Output Response to Economic Variables

The results obtained from ARDL model for maize in Table 4.2 show that the coefficient of second lag of maize output is significant showing a partial adjustment of output in each period towards equilibrium values. The coefficient of the first lag of price of maize is positive and significant at 1 percent level. This is in line with the theory, that maize output supply positively responds to price changes. As price increases, farmers are encouraged to increase maize crop production. Elasticity estimate shows that when price increases by 10 percent maize output increases by 0.8 percent. This inelastic finding is consistent with literature on crop supply responses in Africa. Notably the response is lower than in Mbithi (2000), Olwande et al., (2009) Mose et al., (2007) and Onono *et al.,* (2013).

The coefficient of area under maize production is positive and significant at 5 percent. Moreover, the elasticity value of 0.09 shows that a 10 percent increase in acreage is expected to increase maize production by 0.9 percent. The coefficient estimate of price of fertilizer is statistically insignificant in influencing maize output supply. This result is consistent with other studies that blame low application of fertilizers due to escalation of farm gate prices of fertilizer as a cause of low production (Nyoro, 2002; Kibaara, 2005; Olwande, 2012; Onono, 2013).

The coefficient of agricultural wage is negative and statistically significant at 5 percent level. The negative sign implies that high wages leads to a decline in maize output. Increase in wages translate to higher cost of production which hinder proper management of maize crop translating to decline in production. Increased labour costs therefore inhibit expansion of maize production. The estimated elasticity of -0.18 shows that a 10 percent increase in agricultural wage reduces maize output by 1.8 percent ceteris paribus. The inelastic response can be attributed to the fact that over 70 percent of agricultural output is under small scale, which largely makes use of family labor

(Olwande, 2012). Together with capital, hired labour is a critical input in maize production.

Estimated coefficients of spending on roads, transport and communication and its first lag are insignificant. The coefficient estimate of first lag of maize sales to marketing board has a positive sign and is weakly significant at 10 percent level. This indicates that maize output increases with the capacity of National Cereals and Produce Board to absorb farmer's production. This happens with an inelastic response, with a 10 percent increase in sales to marketing boards raising maize output by approximately one percent. The finding imply that there could be institutional rigidities and transport bottlenecks that could hinder farmers more so the small holder from delivering their harvest to National Cereals and Produce Board.

The results obtained from the tea output analysis in Table 4.2 shows that the coefficient estimates of first and second lags of tea output are significant showing a partial adjustment of output in each period towards equilibrium values. The coefficient estimate of Price of tea is positive and significant at 5 percent level. A 10 percent increase in price of tea increases tea output by 24.6 percent. In addition, the coefficient estimate of fertilizer price has a negative sign and is statistically significant at 1 percent level. The elasticity of tea output with respect to price of fertilizer was estimated at -0.78 implying that a 10 percent increase in fertilizer price lowers tea output by 7.8 percent. Though inelastic, it shows that an increase in the price of fertilizer has adverse effects on tea output supply.

The coefficient of spending on roads, transport and communication is positive and significant at 5 percent level. However, the coefficient of its first lag is negative and is statistically significant at 5 percent level. The computed net elasticity value of 0.06 imply that a 10 percent increase in spending on roads transport increases tea output by 0.6 percent. Though inelastic this could serve as an indicator that infrastructure development is important in the tea industry, with maintenance of rural access roads, which generally create an enabling environment for expansion of domestic and international markets through reduction in transport costs.

From the results obtained in the coffee output analysis shown in Table 4.2, the coefficient of second lag of coffee output is significant showing a partial adjustment of coffee output in each period towards equilibrium values. The coefficients of first lag of coffee output and price of coffee are insignificant. These results contradict the observation made by Maitha (1970) that coffee production responds strongly to an increase in the producer prices. Further, the coefficient of fertilizer price has a negative sign and is significant at 5 percent level. The elasticity of coffee output with respect to price of fertilizer was estimated at -0.13, implying that a 10 percent increase in fertilizer price lowers coffee output by 1.3 percent. Though inelastic, it shows that an increase in the price of fertilizer has a net effects on coffee output level.

The coefficient of the first lag of REER has a negative sign and is significant at 5 percent level. The results show an estimated elasticity of -1.21, an indication that the competitiveness of Kenyan economy has significant influence on the level of coffee production. The results signify that a 10 percent increase in REER lowers output by 21.1 percent. This result indicates that low level of competitiveness of Kenyan exports reduces the capacity of Kenyan coffee farmers to compete with those from other coffee producing countries. Estimated coefficient of spending on roads, transport and communication has a positive sign and is significant at 5 percent level. The computed net elasticity value of 0.08 imply that a 10 percent increase in spending on roads transport increases coffee output by 0.08 percent. This shows that infrastructure development is important to coffee farmers. Properly maintained roads reduce the transaction costs incurred by farmers, as well as ease access to the millers hence reducing damage during transportation.

The coefficient of agricultural wage is negative and statistically significant at one percent level. The negative sign implies that high wages leads to a decline in coffee production. Increase in wages translate to higher cost of production which hinder proper management of coffee crop translating to decline in production. Increased labour costs therefore inhibit expansion of coffee production. The computed elasticity estimate of -0.50 indicates that, an increase in agricultural wage by 10 percent will reduce coffee output by 5 percent.

The low output response to price and non price factors have previously been attributed to infrastructure bottlenecks and credit constraints (Olayiwola, 2008). Across different crops, there are varying outcomes of a variety of degrees of response. Given the inelastic response of crops production to price and economic incentives, in order to raise crop production in Kenya there is a need to focus beyond these incentives. While increased provision of economic incentives may increase crop production, unexpected changes in climatic conditions may relatively undermine their effectiveness.

4.6 Effects of Rainfall and Temperature on Maize, Tea and Coffee Yield

To achieve the third objective, a first difference model was estimated for each crop yield specification as unit root tests showed that the regressors were a mixture of I(1) and I(0). The model specification included quadratic terms for climate variables to account for non linear climate condition effects on crop yields. The coefficient estimates of climatic variables and their corresponding standard errors from each of the crop's yield model are shown in Table 4.4.

The regression models yield a relatively moderate value for adjusted R squared. The adjusted R^2 values of 0.75, 0.82 and 0.68 in maize, tea and coffee yield functions respectively implies that 75 percent, 82 percent and 62 percent of variations in maize, tea and coffee yield respectively are explained by climate variables, area under crop, fertilizer consumption and labor use .

Table 4.4: Coefficient Estimates from Crop Yield Models

Explanatory variables	Dependent Variables		
	D(Maize Yield)	D(Tea Yield)	D(Coffee Yield)
D(Area Under Crop)	-6.35E-07***	-1.35E-05**	-9.48E-07
	(1.84E-07)	(5.45E-06)	(8.83E-07)
D(Mean Temp-JF)	-0.1222	-0.119172**	1.2536
	(0.0905)	(0.0535)	(0.8697)
D(Mean Temp- JJAS)	13.35869***	5.849305**	9.0083***
	(3.7886)	(2.4638)	(1.7307)
D(Mean Temp-MAM)	10.66330***	-3.514287**	3.3154**
	(3.5293)	(1.3254)	(1.2338)
D(Mean Temp-OND)	0.09483	-0.437594	-0.0037
	(0.1151)	(1.3133)	(0.0494)
D(Rainfall-JF)	-0.002596***	0.001416*	-0.00037***
	(0.0009)	(0.0006)	(0.00013)
D(Rainfall-JJAS)	0.002399	-0.002031	0.0002
	(0.0025)	(0.0002)	(0.0002)
D(Rainfall-MAM)	0.008577***	0.002400***	-0.003156***
	(0.0085)	(0.0007)	(0.000514)
D(Rainfall-OND)	0.001972**	-0.00029	0.00078**
	(0.0008)	(0.0005)	(0.0003)
D(Rainfall Variability)	-0.099747	3.59315	-1.2623
	(0.3028)	(2.8565)	(1.5745)
D(Temperature Variability)	-0.05939**	-0.07259**	-0.33932***
	(0.0303)	(-0.07259)	(0.0716)
D(Squared Rainfall-JF)	7.13E-06***	-1.44E-06	-
	(2.32E-06)	(1.59E-06)	
D(Squared Rainfall-JJAS)	-1.84E-06	3.31E-06	
	(4.04E-06)	(3.22E-06)	
D(Squared Rainfall-MAM)	-8.46E-06***	-1.95E-06***	2.73E-06***
	(1.62E-06)	(6.03E-07)	(4.56E-07)
D(Squared Rainfall-OND)	-2.16E-06 *	8.04E-08	-6.37E-07**
	(1.07E-06)	(4.80E-07)	(3.10E-07)
D(Squared Mean Temp-JF)	-	-	0.03247
	-		(0.0228)

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

Table 4.4 Continued:

Explanatory variables	Dependent Variables		
	D(Maize Yield)	D(Tea Yield)	D(Coffee Yield)
D(Squared Mean Temp-JJAS)	-0.375089***	-0.165364**	-0.256963***
	(0.1059)	(0.0690)	(0.049010)
D(Squared Mean Temp-MAM)	-0.272724***	0.092722**	-0.083688**
	(0.1842)	(0.0343)	(0.031635)
D(Squared Mean Temp-OND)	-	0.00943	-
		(0.0351)	
D(Seed use)	0.04551**	-	
	(0.0159)		
D(Fertilizer use)	0.01916**	0.04007**	0.10510***
	(0.0071)	(0.01558)	(0.0304)
D(Labor use)	-8.413114	-1.341066	-6.7045
	(8.5114)	(0.0400)	(3.4396)
Constant	-0.002621	0.0526***	-0.09220***
	(0.02118)	(0.01629)	(0.0164)
R-squared	0.88	0.90	0.83
Adjusted R-squared	0.75	0.82	0.68
F-statistic	6.63	10.4	5.68
Prob(F-statistic)	0.00	0.00	0.00
Durbin-Watson stat	1.80	1.81	1.70

Standard errors in brackets; ***, **,* significant at 1%, 5% and 10% respectively

Source: Author’s computation.

4.6.1 Marginal Effects of Rainfall Amount and Temperature on Maize yield

The estimates obtained from maize yield regression; show that the coefficients 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. The coefficient of linear term of rainfall amount in January to February period has a negative sign and is significant at 1 percent level. However, the coefficient of linear term of rainfall amount 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, indicating a non linear relationship between maize yield and rainfall.

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 variable are in the model, the marginal effects need to be calculated.

The marginal impact of rainfall in January to February period is specified as:

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{JF}} = -0.002596 + 2(7.13\mathrm{E}-06)\Delta\overline{R_{JF}} \;\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\; 4.1$$

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{JF}} = -0.002596 + 2(7.13\mathrm{E}-06)117.6 = -0.0009 \;\dots.\dots\dots\dots\dots\dots\dots\; 4.2$$

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:

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{MAM}} = 0.008577 - 2(8.46\text{E} - 06)\Delta\overline{R_{MAM}} \; \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 4.3$$

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{MAM}} = 0.008577 - 2(8.46\text{E} - 06)465.63 = 0.0007 \dots \dots \dots \dots \dots \dots \dots \dots . . 4.4$$

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,

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{OND}} = 0.001972 - 2(2.16\text{E} - 06)\Delta\overline{R_{MAM}} \dots \dots \dots \dots \dots \dots \dots \dots \dots . \dots \dots \dots \dots 4.5$$

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{OND}} = 0.001972 - 2(2.16\text{E} - 06)334.66 = 0.0005 \dots \dots \dots \dots \dots \dots \dots \dots \dots 4.6$$

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 in January to February period, 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 distorts 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 in the period of March to May and October to December is expected to increase maize yield but at a decreasing rate. These periods coincide with the growing period for the main crop as well as the short rains crop. 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 non linear 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.

On the effects of temperature on maize yield, estimates from the maize yield model as shown in Table 4.4, 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.

$$\frac{\partial \Delta Q}{\partial \Delta\ T_{MAM}} = 1066330 - 2(0.272724)\Delta\overline{T_{MAM}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 4.7$$

$$\frac{\partial \Delta Q}{\partial \Delta\ T_{MAM}} = 1066330 - 2(0.272724)19.9 = -0.19 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 4.8$$

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.

$$\frac{\partial \Delta Q}{\partial \Delta\ T_{JJAS}} = 13.35869 - 2(0.375089)\Delta\overline{T_{JJAS}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 4.9$$

$$\frac{\partial \Delta Q}{\partial \Delta\ T_{JJAS}} = 13.35869 - 2(0.375089)18.25 = -0.33 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. 4.10$$

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 non linear 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 Eregha *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 non linear 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.

4.6.2 Marginal Effects of Rainfall and Temperature on Tea yield

The estimates obtained from tea yield regression in Table 4.4 show that the coefficient of linear term of rainfall in January to February period has a positive sign and is weakly significant at 10 percent level. As well, the coefficient of linear term of rainfall in March to May period is positive and significant at 5 percent level. Conversely, the coefficients linear term of rainfall in June to September and October to December period and the coefficient of rainfall variability are insignificant.

The coefficient of squared rainfall amount in the period of March to May has a negative sign and is significant at 5 percent level while the coefficients of squared rainfall amount in other periods are insignificant. The results indicate a non linear relationship between tea yield and rainfall. This implies that, during the March to May period an increase in rainfall raises crop yield with diminishing marginal benefits up to a maximum turning point after which, further increase in rainfall has a negative impact on tea yield.

The coefficient estimate of rainfall amount in January to February period indicates that when rainfall increases by 1 mm tea yield increases by 0.0014 tonnes per hectare. Since both linear and squared terms for rainfall in March to May period, the marginal effect is specified as:

$$\frac{\partial\Delta Q}{\partial\Delta\, R_{MAM}} = 0.0024 - 2(1.95\mathrm{E} - 06)\Delta\overline{R_{\mathrm{MAM}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.11$$

$$\frac{\partial\Delta Q}{\partial\Delta\, R_{MAM}} = 0.0024 - 2(1.95\mathrm{E} - 06)579.87 = 0.00014 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.12$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount 579.87 mm increases tea yield by 0.00014 tonnes per hectare.

From the study findings, increase in rainfall raises tea yield, with a higher impact on yield observed during the dry period covering January and February. As noted by Bhagat et al., (2010), scanty rainfall more so during dry seasons makes tea crop to suffer moisture stress. Thus, an increase in rainfall in this period is of great benefit to tea crop. In addition, the concave relationship between rainfall and tea yield in March to May period shows that tea requires optimum rainfall and does not support excess water especially in the long rains period. This results show that rainfall has a positive impact to tea yield up to some optimum level beyond which it has negative effects. Wijeratne et al., (2007), Wachira (2009) and Okoth (2011) obtained comparable results. The studies observed that rainfall has a positive effect on tea production.

In addition, the estimates of tea yield models show that the coefficients of linear term of mean temperature in January to February and March to May period and the coefficient of temperature variability are negative and significant at 5 percent level. The coefficient of linear term of mean temperature in June to September is positive and significant at 5 percent level. However, the coefficient of linear term in October to December period is insignificant. The coefficients of squared terms of mean temperature in January to February and October to December periods are insignificant. The coefficient of squared term of mean temperature in March to May period has a positive sign and significant at 5 percent level while the coefficient of squared term of mean temperature in the June to September period is negative and significant at 5 percent level.

The positive coefficient of linear term of mean temperature and the negative coefficient of the squared term mean temperature in June to September period shows a concave relationship between tea yield and temperature. This indicate that when the moisture content is not limiting in the wet and cold period, an increase in temperature raises tea yield but up to a maximum point beyond which an increase in mean temperature has negative effects on tea yield.

The coefficient of mean temperature in January to February period shows that when temperatures rise by 1^0C above the periods mean tea yield decreases by approximately 0.119 tonnes per hectare. The marginal effect of temperature in the March to May period is specified as:

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{MAM}} = -\,3.514287 + 2(0.092722)\Delta\overline{T_{\mathrm{MAM}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.13$$

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{MAM}} = -\,3.514287 + 2(0.092722)19.77 = 0.0919 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.14$$

Holding other variables constant, an increase in temperature by 1^0C relative to the periods mean of 19.77^0C, increases tea yield by approximately 0.092 tonnes per hectare. During the June to September period, the marginal effect of temperature is calculated as follows:

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{JJAS}} = 5.849305 - 2(0165364)\Delta\overline{T_{\mathrm{JJAS}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .\ldots\ldots 4.15$$

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{JJAS}} = 5.849305 - 2(0165364)18.12 = -0.1435 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.16$$

Holding other variables constant, an increase in temperature by 1^0C relative to the periods mean of 18.12^0C, reduces tea yield by approximately 0.144 tonnes per hectare. The coefficient of temperature variability indicates that when temperature variability increases by one Standard Deviation from its long-term mean, tea yield decreases by approximately 0.723 tonnes per hectare.

The findings indicate that an increase in temperature when moisture content is not restraining, boosts tea yield. However, increase in temperatures in relatively dry period reduces tea yield. High temperatures reduce water content in tea and cause sun scorch damage, which lowers the quality of harvested tea. The negative effect of temperature variability indicates that extreme temperatures create uncertainty in tea farming, making crop management difficult and ultimately reducing yield. As noted by De Costa (2007), when water deficit exceeds a genotypically and environmentally determined threshold, shoot initiation and extension rates diminish, ultimately reducing yield.

The study results reveal both positive and negative effects of change in temperature on tea yield. Increase in mean temperature result to an increase in yield during the long rain period but to a decrease in yield in other periods. Comparatively, Okoth (2011) found that an increase in maximum temperatures had a negative impact on tea production, while Cheserek et al., (2015) found a positive correlation between tea yield and mean air temperature when soil moisture is not limiting. Additionally, Rwigi and Oteng'i (2009) established that weekly tea yield is highly influenced by mean minimum temperature while Wachira (2009) observed high correlation between tea production and rainfall with reduction in amount of tea coinciding with periods of drought and increased soil water deficit. However, Hamjah (2014) found that temperature does not influence tea yield.

4.6.3 Marginal Effects of Rainfall and Temperature on Coffee yield

The estimates obtained from coffee yield regression shown in Table 4.4, indicate that the coefficients of linear term of rainfall in the period of January to February and March to May period have a negative sign and are significant at 1 percent level. The coefficient for squared term for rainfall in the January to February period is insignificant while that corresponding to March to May period is positive and significant at 1 percent level. The coefficient of linear terms of rainfall in the period of October to December is positive and significant at 5 percent level while the coefficients of its corresponding squared terms has a negative sign and is significant at 5 percent level. The coefficients of rainfall variability and linear and squared terms for rainfall in the June to September period are insignificant.

The negative and significant coefficients of squared terms of rainfall indicate a non linear relationship between coffee yield and rainfall in the short rains period. This implies that, during this period an increase in rainfall raises crop yield with diminishing marginal benefits up to a maximum turning point after which further increase in rainfall impact coffee yield negatively. Conversely, in March to May period, which coincides with the long rains, there is a U shaped relationship between rainfall and coffee yield. The net effect of rainfall on coffee yield for each period is determined by taking into account the coefficients of linear and quadratic terms.

The coefficient of rainfall amount in January to February period indicates that when rainfall increases by 1 mm coffee yield decreases by 0.0004 tonnes per hectare. During the March to May period, the marginal effect of rainfall on coffee yield is specified as:

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{MAM}} = -0.003156 + 2(2.73\mathrm{E} - 06)\overline{\Delta R_{\mathrm{MAM}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots 4.17$$

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{MAM}} = -0.003156 + 2(2.73\mathrm{E} - 06)579.87 = 0.0001 \ldots\ldots\ldots.\ldots\ldots\ldots\ldots 4.18$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount 579.87 mm increases coffee yield by 0.0001 tonnes per hectare.

For the period of October to December, the marginal effect of rainfall on coffee yield is given as:

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{OND}} = 0.00078 - 2(6.37\mathrm{E} - 07)\overline{\Delta R_{\mathrm{OND}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots 4.19$$

$$\frac{\partial \Delta Q}{\partial \Delta\, R_{OND}} = 0.00078 - 2(6.37\mathrm{E} - 07)442.16 = 0.00022 \ldots.\ldots\ldots\ldots\ldots\ldots\ldots.\ldots 4.20$$

Holding other variables constant, an increase in rainfall amount by 1 mm relative to the periods mean rainfall amount 442.16 mm increases coffee yield by 0.00022 tonnes per hectare.

From the findings, increase in rainfall reduces coffee yield during the dry period covering January and February while a positive effect is observed in March to May and October to December periods. Thus, an increase in rainfall during these relatively wet periods is of benefit to coffee production. In addition, the observed concave relationship between rainfall and coffee yield shows that coffee requires optimum rainfall amount and does not do well with excess water. Heavy rains are likely to damage the crop and are associated with proliferation of coffee berry disease, which contributes to drop of coffee yield (Porter *et al.,* 1991; Wangui, 2010; Jaramillo *et al.,* 2011). Additionally, heavy and erratic rains cause soil erosions leading to loss of soil nutrients, which consequently lower coffee yield (Turral *et al.,* 2009; CIAT, 2010; Haggar *et al*., 2011).

The negative effect of rainfall in January to February period shows that early rains are detrimental to coffee yield. Normally, coffee trees require a dry weather period also known as a period of stress before the onset of rains for them to flower. Therefore, rainfall in the dry months of January and February inhibits flowering and growth of berries consequently lowering yield. As well, unpredictable rainfall patterns make crop management and control of diseases rather difficult for farmers (Gichimu and Omondi, 2010). Due to early rainfall, coffee flowers earlier than normal and May later dry up from water deficiency before the long rains arrive in March. Moreover, this period usually corresponds to a stage where unhulled beans dry in the sun and rainfall in this period would adversely affect the quality of harvested beans as well.

In addition, estimates obtained from coffee yield model; show that the coefficients of linear term of mean temperature in March to May period and June to September period are positive and significant at 5 percent and one percent level respectively. The coefficient of temperature variability is negative and significant at one percent level.

The coefficients of mean temperature in the period January to February and October to December are insignificant. The coefficients of squared terms for mean temperature in the March to May period and June to September are negative and significant at 5 percent and 1 percent level respectively. The squared term of mean temperature for the period of January to February is insignificant.

The positive coefficient of linear term of mean temperature and the negative coefficient of the squared term mean temperature in March to May and June to September periods show that the relationship between coffee yield and temperature is concave. This indicate that when the moisture content is not limiting in the relatively wet and cold periods, an increase in temperature raises coffee yield but up to a maximum point beyond which an increase in mean temperature has negative effects on coffee yield.

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

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{MAM}} = 3.315485 - 2(0.083688)\Delta\overline{T_{\mathrm{MAM}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.21$$

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{MAM}} = 3.315485 - 2(0.083688)19.77 = 0.0065 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.22$$

Holding other variables constant, an increase in temperature by 1^0C relative to the periods mean of 19.77^0C, increases coffee yield by approximately 0.0065 tonnes per hectare.

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

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{JJAS}} = 9.008373 - 2(0.256963)\Delta\overline{T_{\mathrm{JJAS}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots 4.23$$

$$\frac{\partial \Delta Q}{\partial \Delta\, T_{JJAS}} = 9.008373 - 2(0.256963)18.12 = -0.3040 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.24$$

Holding other variables constant, an increase in temperature by 1^0C relative to the periods mean of 18.12^0C, reduces coffee yield by approximately 0.3040 tonnes per hectare.

The coefficient of temperature variability indicates that when temperature variability increases by one Standard Deviation from its long term mean, coffee yield decreases by approximately 0.339 tonnes per hectare.

Although increase in temperature has positive effects on coffee output during the March to May period, it has negative effect in June to September period. This period corresponds to berry development stage, which requires regular rainfall. Thus, an increase in temperature leading to drought conditions in this period may not be suitable for creating large and quality berries as drought conditions usually hamper the expansion of the endosperm. In addition, prolonged dry conditions make coffee trees weak and more prone to pests and trees. The positive effect of increase in temperature on coffee during the short rain season is dependent on the condition that, rainfall is not limiting. Thus, an optimal combination of rainfall and temperature conditions provides ideal condition for high yields.

4.6.4 Marginal Effects of Economic Variables on Maize, Tea and Coffee yield

Coefficients estimates for area under crop indicate that changes in area under crop have significant effects on maize and tea yield and insignificant effects on coffee yield. For area under maize and tea crop, the estimated coefficients have a negative sign and are significant at 5 percent level. This result indicates that owing to decreasing marginal land productivity, maize and tea yields are decreasing, as area under crop increases.

The coefficients of fertilizer consumption in maize, tea and coffee yield functions are positive and significant at 5 percent level of significance. The regression results shown in Table 4.4 show that as fertilizer consumption increases by one kilogram, maize yield, tea yield and coffee yield increases by approximately 0.0192, 0.040 and 0.105 tonnes per hectare respectively. 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 medium and high potential agricultural land amid a growing population (Johnson *et al*., 2003; Sheahan, 2011)

The coefficients of labor use are 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.

CHAPTER FIVE

SUMMARY, CONCLUSION AND POLICY IMPLICATIONS

5.1 Introduction

This chapter provides the summary, conclusion and policy implications of the study.

5.2 Summary

Crop production forms a strong base of food security and a source of livelihood to a large percentage of the rural people. Crop production is largely dependent on climate conditions, making it vulnerable to changing climate. According to the literature, impacts of climate change on crop production are addressed through estimation of crop yield models using crop response simulation models and statistical or econometric estimations. As well, impacts of climate change on farm revenues have been estimated using the Ricardian technique. Use of different methods and different sets of climate data has produced mixed results.

To provide an assessment on the effects of climate variability on crop production in Kenya, this study focused on three important crops specifically maize, tea and coffee. This study aimed at ascertaining the effect of climate variability on crop output supply and crop yield by providing two sets of econometric analysis. Given that crop production can be enhanced by addressing issues that affect farmers' decision to expand crop cultivation or raise crop productivity, the first econometric model estimated a linear model relating climate and economic factors that affect crop output supply while the second set focuses on non-linear effects of climate variables on crop yields.

This study is different from other studies carried out in Kenya in several ways. First, this study employs crop production data at the national level, thereby taking into consideration the influences of climate variability on both the smallholder farmer and large-scale farmers. Secondly, the use of time series in a climate study helps in identifying the effects of temporal variations of climate variables on crop production, as climate variations effects across space could be different from those over time. Third, in addition to economic variables and means of climate variables, this study incorporated rainfall variability and temperature variability in addition to climate means, to capture the effects of extreme events on crop output and yield. Fourth, most studies estimating tea and coffee yield in Kenya are rooted in natural science and make use of detailed experiments, this study employed econometric modeling approach. In modeling crop output supply, the study employed an ARDL model approach. This model is able to take into consideration partial and adaptive expectation inherent in agricultural supply.

The motivation of the study is the fact that climate change and its variability may have led to adverse effects in the prioritized Kenyan agricultural sector. The continued increase in the frequency of dry spell and uneven distribution of rainfall may have contributed to the low food production in Kenya, consequently making the country a net food importer and hence food insecure. In Kenya, maize production signals the level of food security given that it is a key staple food. In addition, Kenya relies on tea and coffee exports as a primary source of foreign revenue, employment and income generation. However, climate change and its variability adversely affect the production of these crops as implied in this study. Thus, there is a need to boost crop production especially amid a growing Kenyan population in the midst of climate change and its variability.

This study follows agricultural household maximization behaviour theory, which encompasses profit and utility maximization components and thus lays the foundation for the modeling of aggregate supply response. Each crop output model includes rainfall amount, rainfall variability, temperature, temperature variability among other economic variables as regressors. The economic variables considered included: output prices, price of fertilizer, agricultural wage, area under crop, government spending on roads infrastructure, price of maize seed, maize sales to marketing boards and real effective exchange rate.

To analyse the effects of climate variability on crop yield, a production function for each crop was specified. Each production specification included linear and quadratic terms of rainfall and mean temperature. This is to test whether at some point excess rain and extreme temperatures affect crop yield. Data on the climate variables was obtained from the Kenya Meteorological Department; tea related data was obtained from Tea

Board of Kenya while data on coffee variables was obtained from Coffee Board of Kenya. Data on other variables was obtained from published sources, which include FAOSTAT website, World Bank, Economic Surveys and Statistical Abstracts. All data covered the period from 1970 to 2014.

To determine the effects of climate variability on crop output, an ARDL crop output model for each crop was estimated using least squares, method and the associated elasticities and semi elasticities were calculated. In addressing the effects of climate variability on crop yield, first difference yield model was estimated for each crop and from the obtained coefficient estimates, marginal effects were computed. Diagnostic tests, assessment of residual properties and stability tests were performed for each of the equations. The tests results signify that the models as statistically robust.

Estimates show that maize output has a positive response to rainfall amount in the June to September period and October to December period, mean temperature in October to December period, output price in the previous period and previous period sales to marketing board. Conversely, maize output has a negative response to increase in mean temperature in July to September period, temperature variability and increase in agricultural wage. Maize output has an inelastic response to rainfall, mean temperature, temperature variability and agricultural wage.

Estimates from the tea output function shows that tea output responds positively to output price, rainfall amount in January to February and March to May periods and government spending on roads and transport. Tea output has a negative response to: price of fertilizer. Tea output has an elastic response to Price of tea and an inelastic response to response to rainfall amount in January to February and March to May periods, fertilizer price and spending on roads transport and communication.

Coffee output has a positive response to rainfall amount in October to December period and spending on roads transport and communication. However, coffee output has a negative response to: mean temperature in March to May period, temperature variability, price of fertilizer and effective exchange rate. Coffee output has an elastic response real effective exchange rate and an inelastic response to rainfall amount, fertilizer price and spending on roads transport and communication.

Estimates obtained from the yield regressions show that a non-linear relationship exists between climate variables and yields of maize, tea and coffee. From the maize yield analysis, coefficients of linear terms of rainfall in all periods show that increase in rainfall has a positive effect on maize yield, save for January to February period which shows a negative effect. The coefficient of squared rainfall amount in the period of March to May is negative and significant indicating a concave relationship between maize yield and rainfall in the long rains period. This shows that too much rainfall affects yield negatively. In addition, the coefficients of linear term of mean temperature

in March to May and June to September period are positive while the coefficients of the corresponding squared term coefficients are negative. As well, this indicates a concave relationship between mean temperature and maize yield in main crop growing period.
Tea yield analysis reveals that tea yield responds positively to rainfall in the periods of January to February and March to May. Conversely, tea yield does not respond to linear term of rainfall in June to September and rainfall variability. The coefficient of squared rainfall amount in the period of March to May is negative and significant while the coefficients of squared terms of rainfall in other periods are insignificant. Thus, tea yield and rainfall in the long rains period have a concave relationship. This shows that excess rainfall reduces yield.

In addition, the estimates of tea yield model show that, linear term of mean temperature has a positive effect on tea yield in June to September period and a negative effect in January to February and March to May periods. The coefficients of squared terms of mean temperature in March to May and June to September periods are significant and have a positive and a negative signs respectively. This indicates a concave relationship between tea yield and mean temperature in March to May period and a convex relationship in June to September period. Moreover, the coefficient of temperature variability is significant and negative.

The estimates obtained from coffee yield model; show that the coefficients of rainfall in the periods of January to February and March to May are negative and significant, while the coefficient of rainfall in October to December period is positive and significant. The coefficient of squared term of rainfall is positive and significant in March to May period; while the coefficient of squared term of rainfall in October to December period is negative and significant. The results indicate a concave relationship between rainfall in the period of March to May and a convex relationship in the period of October to December. Moreover, the estimates of coffee yield models show that the coefficient of temperature variability is negative and significant. The coefficients of linear terms of mean temperature in March to May and June to September periods are positive, while the coefficients of their corresponding terms are negative, depicting a concave relationship between temperature and coffee yield in these periods.

The estimated models included control variables. From the maize output supply, results on these variables show that, the coefficient of the first lag of price of maize is positive and significant, indicating that an increase in price of maize serves as an incentive in maize crop production. The coefficient of area under maize production is positive and significant while the coefficient of agricultural wage is negative and statistically significant. The negative sign implies that high wages leads to a decline in maize output. The coefficient estimate of first lag of maize sales to marketing board has a positive sign and is weakly significant. This indicates that maize output increases with the capacity of National Cereals and Produce Board to absorb farmer's production. The coefficients estimate of price of fertilizer and spending on roads, transport and communication and its first lag are insignificant in influencing maize output.

The results obtained from the tea output analysis show that the coefficient estimate of price of tea is positive and significant. In addition, the coefficient estimate of fertilizer price has a negative sign and is statistically significant. The findings indicate that an increase in the price of fertilizer has negative effects on tea output. The coefficient of spending on roads, transport and communication is positive and significant. This could serve as an indicator that expansion of infrastructure boosts tea production. From the results obtained in the coffee output analysis, the coefficients of first lag of coffee output and price of coffee are insignificant. Further, the coefficient of fertilizer price has a negative sign and is significant. The findings show that an increase in the price of fertilizer has a net effects on coffee output level. The coefficient of the first lag of REER has a negative sign and is significant, an indication that the competitiveness of Kenyan economy has significant influence on the level of coffee production. Estimated coefficient of spending on roads, transport and communication has a positive sign and is significant. This shows that increase in infrastructure development is has a positive effect on coffeee output. The coefficient of agricultural wage is negative and statistically significant. This implies that increase in agricultural wages leads to a decline in coffee production.

Further, the coefficient estimates of control variables in the yield models show that the coefficients for area under crop are significant in maize and tea yield models and insignificant in coffee yield model. The coefficients have a negative sign, which implies that expansion of maize and tea crop cultivation is first carried out in high potential areas and thereafter extended to low potential areas. Thus, there is decreasing marginal land productivity in case of tea and maize. The coefficients of fertilizer consumption in maize, tea and coffee yield functions are positive and significant. Thus, increase in use of fertilizer, raises crop yield. The coefficients of labor use are insignificant while the coefficient of maize seed use is positive and significant. The results show that an increase in the use of certified seeds raises maize yield.

5.3 Conclusion

Output supply analysis provides an insight on how climate variability affects crop output. The study findings indicate that maize, tea and coffee output are affected by climate variability as well as other economic factors. On the response of crop output supply to rainfall and rainfall variability, the study findings indicate that: an increase in rainfall in the main cropping season and in the short rains period increases maize output. As well, rainfall has a positive effect on tea output. This signifies that an increase in rainfall especially in the January to February period, which is a relatively dry period, increases tea output. Similarly, rainfall has a positive effect on coffee supply, more so during the short rains season. This indicates that increased rainfall boosts coffee production. Thus, as noted by Bals et al. (2008) and FAO (2008), inadequate quality water at critical stages of crop growth in certain times of the crop growing season will negatively impact on crop production. Thus, with climate variability greater adverse impacts are likely to occur in Kenya, due to her over reliance on rain fed agriculture. Changing rainfall patterns may reduce the desirability of cultivating maize, tea and coffee.

On the response of maize output supply to changes in temperature and temperature variability, the study finds that, an increase in temperature has a positive effect on maize output supply during the short rains period but has a negative effect in June to September period. This indicates that higher temperatures will raises maize output during the rainy period and a reduce output in other periods. Temperature variability has a negative effect on maize output, this shows that increased deviations of mean temperature from its long term mean hinders increase in maize output. Temperature variability exposes farmers to climate risk making them to prefer growing other crops or even participate in other income generating activities.

On the response of tea output supply to changes in temperature and temperature variability, the study found that changes in temperature and temperature variability have no significant effects on tea output supply. This shows that observed changes in temperature have not influenced expansion of tea output. On the response of coffee output supply to changes in temperature and temperature variability, the study found that: An increase in temperature and temperature variability has had adverse effects on coffee output. These conditions increase climate risk and greatly compromise the economic viability of the coffee crop, making coffee farming less desirable. In some instances, this may have resulted to farmers uprooting coffee and adopting new crops that are better suited to new climate conditions or converting are under crop to other land uses other than farming. As noted by Gichimu and Omondi (2010) and Eitzinger et al., (2010) unpredictable rainfall patterns make crop management and disease control difficult and largely contribute to the declining coffee production in Kenya (Gichimu & Omondi, 2010; Eitzinger *et al*., 2010). Thus, increase in mean temperature and its variability has been a contributor to the decline of coffee output.

On the other hand, crop yield analysis provides an insight on how climate variability influences crop yield. Maize yield 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 over the years. Early rains have a negative effect on maize yield and indicator that changes in rainfall patterns make 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.

Similar to the crop supply, crop yield 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.

Tea yield analysis reveals a non-linear relationship between tea yield and rainfall during the periods coinciding with the long rains. Thus, for improved tea production considerable amount of rainfall is required at various stages of crop development, thus periods of heavy rains in a short period may have unfavorable effects on tea production. Moreover, a concave relationship is observed between temperature and tea yield. Effects of temperature increase on tea yield vary with season; there is a positive effect during long rain periods and a negative effect in the relatively dry periods. Overall increase in temperature and temperature variability has a negative effect on tea yield. Noticeably, climate variability has a significant effect on tea production in Kenya, with deviation from the favourable conditions impeding tea growth and hence lower tea yields. With climate projection indicating an increase in mean temperature and temperature variability in Kenya by 2030 (McSweeny, 2010), if mitigating and adaptation measures are not carried out there could be undesirable effects on tea production. The observed outcomes pose a great danger mostly to the vulnerable smallholder tea farmers.

Coffee yield analysis indicates a non-linear relationship between coffee yield and rainfall. Increase in rainfall has a negative effect on coffee yields in January to February period and a positive effect in other periods. The non linear relationship show that, increase in rainfall in long rains period has a positive effect on coffee yield but increase beyond the optimum point required by the crop, reduces yield. Thus, for improved coffee yield, timely and adequate amount of rainfall is required at various stages of crop development. Hence, observed climate variability has contributed to the decline in coffee yield in Kenya.

Further, coffee yield has a concave relationship with mean temperature in March to May and June to September periods. This shows that higher temperatures are beneficial to coffee up to optimum level required by the crop, beyond which coffee yield starts to fall. The combined effect of higher temperatures and erratic rains affects the flowering of coffee trees, hinder the drying of harvested beans and reduce soil fertility. Furthermore, these changes could make land, currently under coffee trees unsuitable for growing coffee (Camargo & Marcelo, 2009; CIAT, 2010; Haggar *et al*., 2011). These conditions expose farmers to more climate risk as it triggers a shift in production and ultimately reduce quantity and quality of coffee. Thus from this study climate variability is expected to have both positive and negative effects on coffee yield depending on the stage of crop growth and development. Deviations from the optimal climatic conditions required at any particular stage of growth and development is a contributor to the declining trend of coffee yield in Kenya.

The elasticities, semi elasticities and marginal effects obtained in this study are thus important to policy makers and all relevant stakeholders in allocating and achieving production targets and in long term planning. In addition, the coefficients can be used to forecast the effect of future changes in temperature and rainfall on maize, tea and coffee production.

5.4 Policy Implications

Evidently, from the study findings climate variability has an adverse effect on crop production in Kenya. 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, tea and Coffee output 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.

Following the negative effects of climate variability on crop output and yield, there is a need to formulate all-inclusive policies, strategies, and instruments that specifically address effects of climate change, paramount in building adaptation and mitigation mechanisms. For instance, the National Climate Change Steering Committee should fast track the implementation of National Climate Change Action Plan 2013-2017. Moreover, there is need to include climate change concerns in national and county governments planning, budgeting and development processes given that climate change is a function of both the national and the county governments as stipulated under the County Governments Act 2012.

Amid the threat to food security and export earnings due to potential adverse effects of climate variability on crop production, as found in the study, there is need to shields high agricultural potential areas from other non agricultural developments especially real estate development. This requires collaboration of Ministry of Land, Housing and Urban Development, Ministry of Agriculture, Ministry of Environment, Water and Natural resources and the county governments to integrate the climate change policy with land use policy in order to assign particular areas for definite purposes to facilitate proper planning of land use.

As manifested in the study, water is a key input in the crop production. In an endeavor to mitigate production risk especially for the food crop, there is need for supplement rainfed agriculture through irrigation. To achieve this rainwater harvesting is recommendable to supplement water supply for small scale and large-scale irrigation. This is achievable at the household level, through water conservation coupled with investments in more efficient storage infrastructure. In addition, local communities, nongovernmental organizations and the county governments should facilitate construction of water collection dams for irrigation purposes managed at the community level. There is also the need to equip farmers with requisite technical support to ensure better management of irrigation schemes to avoid water loss or excess watering of crops especially in rainy periods.

The study finds that, variability in temperature and timing of rainfall affects crop output and yield. Thus, provision of timely information on expected changes on these variables is critical in improving awareness and for rapid consideration for adaptation. This calls for Kenya Meteorological department and Ministry of Agriculture to commit more resources in equipment and provision of extension services, to increase awareness and enhance capacity in use of climate information.

To enhance continued production of maize, tea and coffee, under the constraint of climate variability, there is need for Ministry of Agriculture, county governments and other relevant stakeholders to come up with timely measures in adaptation and mitigation. This will ensure that farmers can respond to climate threats when they need to, avail support to farmers as they consider their options.

5.5 Contribution to Knowledge

This study contributes to knowledge from the findings. First, the study finds that temperature variability has a negative effect on crop output and yield beyond those of climate means. Second, the study finds that excess rainfall and extreme temperature beyond the crop-required optimum have negative effects on crop yield. Third, the study finds that early rains in January and February have negative effects on maize and coffee yield, which negates the expectation that increase in rainfall, will increase crop yields. These contributions are useful to stakeholders in agricultural sector, involved in designing and implementing appropriate measures for adaptation and mitigation given that climate projections indicate an increase in climate variability in the future. Further, the estimates obtained from output and yield analysis in this study contributes to knowledge as they can be combined with climate change forecasts to construct predictions of crop production for the future.

5.6 Areas of Further Research

This study confined itself in the examination of the production response of three major crops in Kenya namely maize, tea and coffee. Further research on how individual farmers are adapting to climate change and an assessment on the cost of adaptation and mitigation would be integral to finding out the economically feasible ways that would minimize the farmers' exposure to climate risk. Further research on other important crops like wheat, sugarcane and vegetables should be carried out.

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APPENDICES

Appendix 1: Data Used in the Study

Table A1: Crop Output, Area of Production and Prices

Year	Maize Output - Tonnes'000 '	Tea Output (tonnes)	Coffee Output (Mt)	Price Of Maize (Kshs/100 kg)	Price Tea-Kshs/Kg	Price of coffee Kshs/Kg
1970	1,470,000	41,077.59	52,796	35	7.50	7.42
1971	1,400,000	36,289.85	54,902	35	7.21	5.68
1972	1,630,000	53,322.47	58,346	35	6.645	7.02
1973	1,870,000	56,578.1	74,690	35	6.71	9.02
1974	1,950,000	53,439.67	72,016	41.8	7.81	9.82
1975	2,050,000	56,729.78	65,449	62.8	8.72	9.4
1976	2,600,000	61,984.46	73,810	68.9	10.74	22.31
1977	2,553,000	86,291.42	97,345	80	19.07	39.52
1978	2,169,000	93,373.42	81,429	69.7	17.12	26.07
1979	1,755,000	99,275.29	72,888	80	14.12	26.6
1980	1,620,000	89,893.36	91,009	85.8	15.50	24.83
1981	1,768,000	90,941.41	98,751	90	16.14	22.58
1982	2,502,000	96,033.08	86,923	96.3	19.38	27.8
1983	2,300,000	119,738.4	85,450	138.6	24.52	34.88
1984	1,422,000	116,171.9	128,941	157.5	41.55	38.44
1985	2,430,000	147,103.6	96,639	168.3	30.36	39.72

Table A1 Continued:

Year	Maize Output - Tonnes'000'	Tea Output (tonnes)	Coffee Output (Mt)	Price Of Maize (Kshs /100kg)	Price Tea-Kshs/Kg	Price of coffee Kshs/Kg
1986	2,898,000	143,316.8	113,927	178.2	29.67	50.2
1987	2,415,600	155,807.8	104,288	188.1	24.24	36.62
1988	2,761,200	164,030.4	128,862	192.8	26.81	44.65
1989	2,630,700	180,600.5	116,989	201	33.31	43.12
1990	2,289,600	197,008.3	103,839	235.5	37.14	36.36
1991	2,400,000	203,588.7	79,497	258.3	43.47	46.54
1992	2,430,000	188,072.3	75,207	216	57.04	41.46
1993	2,089,000	211,168.4	71,787	729	99.10	98.86
1994	3,060,000	209,422.9	90,999	855	99.30	144.28
1995	2,698,863	244,525.2	96,994	720	79.19	159.66
1996	2,160,000	257,161.9	67,997	954	88.51	139.14
1997	2,214,000	220,722.1	55,634	1236	121.24	251.5
1998	2,464,101	294,165.1	68,677	1152	126.26	257.18
1999	2,322,140	248,708.1	100,850	1251	135.40	156.32
2000	2,160,000	236,286.1	50,543	1305	161.73	115.09
2001	2,790,000	294,631.3	51,900	1052	127.35	117.76
2002	2,408,596	287,102.2	51,895	1358	125.91	116.39

Table A1 Continued:

Year	Maize Output – Tonnes '000'	Tea Output (tonnes)	Coffee Output (tonnes)	Price Of Maize (Kshs /100kg)	Price Tea-Kshs/Kg	Price of coffee Kshs/Kg
2003	2,710,848	293,670.2	55,443	1482	123.7	117.93
2004	2,607,139	324,608.6	48,431	1363	130.15	126.96
2005	2,905,559	328,497.6	45,245	1300	122.55	118.24
2006	3,247,200	310,578	48,303	1200	150.76	109.52
2007	2,928,793	369,606.2	53,368	1566.4	124.74	195.61
2008	2,367,237	345,816.8	42,000	2445.4	162.21	177.21
2009	2,439,000	314,198.4	54,020	2391.33	203.23	195.44
2010	3,464,541	399,006.4	42,000	1721.35	221.62	396.78
2011	3,376,862	377,912.2	36,629	2499.92	259.71	594.53
2012	3,600,000	369,561.9	49,960	3396	260.93	333.87
2013	2,800,000	432,400	38,400	4200	219.03	284.09
2014	2,650,000	445,100	42,500	4200	190.64	391.85

Table A2: Crops' Area of Production and Input Prices, Expenditure on Roads Transport and Maize Sales to Marketing board

Year	Area under maize production (Ha)	Area under Tea pdn (Ha)	AREA under Coffee Pdn (Ha)	Fertilizer price index	Real Development Expenditure On Roads Transport And Communication	Maize Sales To Marketing Boards (Mt)
1970	1,200,000	40274	83,960	7677.106	23118.58	373
1971	1,150,000	43,366	83,700	6165.355	21501.57	373
1972	1,300,000	49,761	85,090	5662.544	20880.73	373
1973	1,450,000	54,796	84,222	7435.634	21276.83	440.8
1974	1,450,000	58,735	84,729	13520.35	15322.43	365.4
1975	1,450,000	61,542	86,389	9821.559	17005.48	487.8
1976	1,590,000	65,951	85,198	3313.008	18301.62	564.7
1977	1,570,000	68,500	84,421	2862.286	11355.11	424
1978	1,490,000	72,069	87,488	2425.617	5567.997	236.3
1979	1,350,000	74,300	91,769	2945.649	5219.295	241.7
1980	1,350,000	76,541	102,404	2587.121	4160.337	217.9
1981	1,120,000	78,896	117,571	1676.114	7567.217	472.9
1982	1,208,000	81,082	131,108	1490.391	8038.149	571.3
1983	1,300,000	81,536	134,572	1396.768	8178.899	637.1
1984	985,000	83,372	149,946	1273.797	6488.499	560.6
1985	1,411,000	83,827	152,039	1377.317	6120.406	582.9
1986	1,424,600	84,400	156,304	1585.126	6742.797	669.5
1987	1,406,956	85,420	154,534	1459.095	5992.852	651.9

Table A2 Continued:

Year	Area under maize production (Ha)	Area under Tea pdn (Ha)	AREA under Coffee Pdn (Ha)	Fertilizer price index	Real Development Expenditure On Roads Transport And Communication	Maize Sales To Marketing Boards (Mt)
1988	1,450,939	86,802	153,030	1336.602	3927.99	485.3
1989	1,420,000	87,473	155,666	1261.386	4461.632	625.9
1990	1,380,000	97,020	115,543	1295.775	2948.396	509.3
1991	1,310,000	100,626	158,262	1132.925	1534.851	303.5
1992	1,407,000	103,502	158,723	978.5448	1949.195	515.2
1993	1,343,500	104,863	161,032	889.8557	591.3519	241.8
1994	1,500,000	110,221	161,032	506.1296	724.8882	316
1995	1,438,740	112,556	162,410	479.5183	860.5784	401
1996	1,489,000	113,682	162,470	469.087	573.0569	295.5
1997	1,504,820	117,351	167,398	705.1222	355.9902	204.6
1998	1,475,740	118,418	167,398	757.6848	376.7645	218
1999	1,567,240	118,542	167,398	847.2148	349.7852	223.5
2000	1,500,000	120,396	167,398	802.8455	281.6878	201.2
2001	1,640,000	124,292	170,000	955.0553	3614.993	461.5
2002	1,592,315	130,340	170,000	860.2835	1971.882	398
2003	1,670,914	131,453	170,000	115.378	1819.953	280.5
2004	1,351,327	136,708	170,000	121.4544	2374.847	448.5
2005	1,771,123	141,315	170,000	127.6	10612.13	416.2

Table A2 Continued:

Year	Area under maize production (Ha)	Area under Tea Pdn (Ha)	AREA under Coffee Pdn (Ha)	Fertilizer price index	Real development expenditure on roads transport and communication (kshs)	Maize Sales to marketing boards (Mt)
2006	1,888,185	147,076	170,000	107.3796	3587.708	470.7
2007	1,615,304	149,196	162,720	95.76261	7762.301	508.8
2008	1,700,000	157,720	162,720	148.6256	15300.61	340.5
2009	1,884,368	158,394	108,784	118.224	294.6	340.5
2010	2,008,346	171,916	108,784	109.9988	19274.03	340.5
2011	2,131,887	187,855	108,784	124.425	27936.55	405.8
2012	2,159,322	190,717	109,795	115.6709	29501.19	387.3
2013	1,800,000	198,600	109,800	250.5	64400	316.4
2014	1,365,000	203,000	110,000	230.7	94700	338.4

Table A3: Input Prices, Input Use, CPI and REER

Year	Real annual wage rate	Real Maize Price index	Seed use in kgs per ha	Fertilizer consumption kgs per ha	Labor use per ha	CPI 2010	REER
1970	167,111.7	9408.43	28.7500	2.8462	0.0481	0.01	99.5
1971	172,464.7	25362.46	33.9130	3.0986	0.0480	0.01	98.4
1972	191,719.3	10197.83	33.4615	4.0977	0.0624	0.01	94.8
1973	174,316.9	9481.05	30.0000	4.9208	0.0670	0.01	90.3
1974	151,925	8633.90	30.0000	6.1286	0.0659	0.01	91.7
1975	144,030.2	9070.05	32.8966	7.8145	0.0563	0.02	95.2
1976	160,140.6	5966.49	29.6226	8.4733	0.0568	0.02	92.0
1977	139,989.5	6391.50	28.4713	8.3355	0.0608	0.02	96.7
1978	142,027.3	8096.80	27.1812	10.7360	0.0568	0.02	105.4
1979	144,372.3	7004.61	30.0000	12.5475	0.0595	0.02	104.1
1980	155,066.3	6152.05	24.8889	11.9494	0.0541	0.03	104.9
1981	154,102.1	3167.55	32.3571	13.4486	0.0550	0.03	94.2
1982	133,238.1	2684.09	32.2848	12.8692	0.0523	0.04	91.7
1983	129,050.8	2787.75	22.7308	13.3165	0.0540	0.04	84.7
1984	130,824.5	2923.23	42.9746	10.4153	0.0560	0.05	97.9
1985	127,947	2782.05	30.2892	12.5984	0.0477	0.05	96.8
1986	140,698.6	3041.37	29.6287	12.0379	0.0490	0.05	91.2
1987	144,368.6	3037.33	30.9377	11.9164	0.0500	0.058	89.1

Table A3: Continued

Year	Real annual Wage rate	Real Maize Price index	Seed use in kgs per ha	Fertilizer consumption kgs per ha	Labor use per ha	CPI 2010	REER
1988	143,221.5	4112.36	29.3603	8.9486	0.0506	0.07	81.0
1989	138,582.5	3017.57	29.1549	14.3925	0.0447	0.07	75.8
1990	131,572	2747.72	28.4783	19.3458	0.0493	0.08	67.6
1991	124,455.5	2681.04	32.2214	14.6495	0.0488	0.10	64.9
1992	118,939.4	2539.33	28.6461	17.5467	0.0472	0.19	56.5
1993	99,068.67	2981.36	33.4946	19.4428	0.0495	0.24	72.3
1994	96,349.74	3404.10	28.7747	20.3008	0.0474	0.25	73.9
1995	114,469.5	3281.28	31.0480	19.3968	0.0497	0.28	72.9
1996	129,280.7	3401.67	30.3190	21.4923	0.0588	0.31	82.7
1997	139,024.7	3802.13	29.4201	22.5849	0.0577	0.33	89.2
1998	155,527.8	5128.69	31.8600	18.4426	0.0599	0.35	80.2
1999	171,194.4	4493.00	28.7129	19.5064	0.0558	0.38	85.2
2000	176,071.8	4879.51	32.8000	20.2080	0.0581	0.40	90.1
2001	185,222.2	5167.41	29.1274	17.6542	0.0582	0.41	89.6
2002	203011.3	5211.69	31.4806	18.0505	0.0584	0.45	86.3
2003	210,010	192.49	24.2622	21.8813	0.0567	0.50	82.1
2004	246,585.7	180.59	39.3199	13.2477	0.0563	0.56	89.8
2005	235,154.4	176.31	29.9245	31.2172	0.0574	0.06	81.0

Table A3: Continued

Year	Real annual Wage rate	Real Maize Price index	Seed use in kgs per ha	Fertilizer consumption kgs per ha	Labor use per ha	CPI 2010	REER
2006	215,378.87	135.16	25.6643	25.3872	0.0582	0.63	96.9
2007	179,028.39	138.34	33.4302	24.6413	0.0589	0.70	100.0
2008	170,716.56	104.82	31.7647	26.5603	0.0585	0.88	105.8
2009	167,953.50	91.90	30.2489	27.1281	0.0569	0.96	108.2
2010	153,835.83	90.60	31.8456	27.0789	0.0571	1	105.8
2011	148,245.27	89.63	30.3862	25.8713	0.0539	1.14	100.3
2012	129,885.91	80.82	29.1758	64.7072	0.0551	1.24	117.4
2013	118,263.43	90.03	317.2205	59.8877	0.0559	1.32	147.64
2014	215,378.87	146.40	310.3448	51.1654	0.0544	1.41	152.65

Table A4: Rainfall Amount and Mean Temperature in Tea and Coffee Growing Areas.

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp - MAM	Mean temp - JJAS	Mean temp OND
1970	197.725	652.3	422.325	394.07	16.7	16.4	15.2	16.0
1971	96.66	895.0	536.62	367.08	15.9	16.1	14.9	16.2
1972	243.82	471.5	323.58	549.28	16.4	16.3	15.4	16.1
1973	226.5083	455.11	460.22	279.73	17.1	17.0	15.6	16.1
1974	41.35	549.36	471.65	309.08	17.4	17.7	16.2	17.0
1975	71.61667	560.28	539.16	310.18	17.5	17.6	15.8	16.8
1976	102.8857	485.39	404.95	295.3	18.7	19.0	17.4	18.7
1977	170.7843	704.25	450.14	556.85	18.6	18.9	17.5	18.3
1978	224.8829	688.51	375.45	435.29	18.3	18.4	17.1	18.0
1979	291.0557	545.91	285.61	337.14	18.7	19.2	17.8	19.2
1980	118.7857	489.76	343.56	361.28	19.5	19.8	18.0	19.0
1981	73.77	811.02	364.89	293.09	19.7	19.1	17.7	19.0
1982	90.12857	663.81	346.65	616.71	19.4	19.6	18.2	18.7
1983	111.5271	454.51	411.64	440.41	19.7	20.4	18.3	18.8
1984	43.6	313.47	303.72	511.85	18.9	20.0	18.0	18.6

Table A4 Continued:

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp - MAM	Mean temp - JJAS	Mean temp OND
1985	134.7429	694.48	404.69	281.3	18.9	19.0	17.5	18.8
1986	53.38571	683.34	272.29	366.21	19.5	19.3	17.5	19.0
1987	160.4271	548.82	350.94	328.79	19.6	20.1	18.5	19.8
1988	171.3986	784.76	469.51	466.76	20.2	20.0	18.0	18.6
1989	128.5143	604.54	330.48	508.51	18.8	19.0	17.4	18.6
1990	217.6429	700.38	297.07	397.32	19.1	19.3	17.6	18.6
1991	130.6179	599.32	305.92	394.6	19.1	19.6	17.6	18.7
1992	92.3	438.08	383.35	476.87	19.9	17.5	18.7	19.9
1993	269.2286	377.61	297.34	342.55	19.4	17.7	19.2	19.4
1994	75.85714	610.7571	342.2	594.7857	19.8	19.6	17.9	18.9
1995	109.0571	627.4	361.5714	507.7286	19.5	19.5	18.0	18.7
1996	170.3286	495.1857	371.4143	351.6571	18.9	19.7	17.7	19.1
1997	41.22857	579.6	245.1429	927.9429	20.0	19.8	18.4	19.0
1998	415.0143	584.7429	359.0429	288	19.9	20.2	17.8	19.1
1999	83.05714	528.7857	290.4714	485.1429	19.7	19.4	17.9	18.9
2000	48.47143	352.4714	320.3429	402.8571	19.3	19.9	18.1	19.4
2001	253.3714	606.4143	330.5714	435.6286	19.4	19.7	18.1	19.2
2002	129.9429	770.7857	275.6143	575.3857	19.9	19.9	18.1	19.4
2003	63.37143	630.5	422.4429	432.4429	20.0	20.3	18.2	19.2

Table A4 Continued:

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp - MAM	Mean temp - JJAS	Mean temp OND
2004	171.4143	487.0571	308.8857	456.2429	19.8	19.9	18.3	19.2
2005	89.67143	546.7714	336.2286	231.3714	20.3	20.3	18.1	19.6
2006	114.2	693.9857	333.9143	771.2143	20.4	19.7	18.5	19.2
2007	181.4286	508.4714	455.3143	351.9857	19.6	19.9	18.2	19.2
2008	111.8	495.6	351.5	426.6857	19.5	19.6	18.3	19.3
2009	138.4714	428.9571	270.9143	473.0714	19.8	20.2	18.9	19.6
2010	201.2857	689.6	345.6857	348.6	20.2	20.0	18.5	19.4
2011	71.2	449.1714	376.7714	648.5429	19.9	20.2	18.6	19.2
2012	34.85714	655.2857	409.3286	661.9857	19.7	20.1	18.3	19.3
2013	117.77	558.54	361.0986	480.2143	19.5	19.9	17.5	18.7
2014	123.2099	551.344	354.9641	484.9914	18.4	19.4	17.7	19.2

Table A5: Rainfall Amount and Mean Temperature in Maize Growing Areas.

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp - MAM	Mean temp - JJAS	Mean temp OND
1970	178.2455	536.3	309.3273	232.2182	18.78	18.61	17.04	17.90
1971	63.38333	603.7028	411.5667	295.825	18.23	18.40	16.58	17.58
1972	175.9333	324.0417	289.675	385	17.98	18.47	17.15	17.86
1973	186.025	307.6571	372.9589	198.8929	18.69	19.10	17.07	17.58
1974	35.27143	455.7214	410.1643	206.15	18.23	18.17	16.51	17.95
1975	45.31429	434.24	467.1857	236.8586	19.00	18.73	16.79	17.70
1976	76.53867	354.4285	368.106	250.3824	18.75	19.15	17.33	18.74
1977	139.9327	593.966	369.872	459.672	18.95	19.09	17.57	18.51
1978	224.6187	602.268	338.8793	323.152	18.59	18.65	17.39	18.31
1979	255.606	468.412	280.492	238.7793	18.85	19.13	17.90	19.21
1980	85.34667	431.9667	267.1187	256.2053	19.71	19.79	17.99	19.08
1981	49.326	656.2653	342.6387	210.1393	19.91	19.24	18.31	18.99
1982	66.90667	486.5053	307.538	520.1847	19.69	19.74	18.13	18.74
1983	105.6527	368.946	380.4453	344.446	19.84	20.38	18.26	18.66

Table A5 Continued:

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp -MAM	Mean temp -JJAS	Mean temp OND
1984	35.06667	223.0727	269.5053	397.566	18.80	19.92	18.00	18.50
1985	114.5533	608.3387	316.1193	209.0067	18.91	18.89	17.30	18.69
1986	46.88	521.1	276.798	274.0933	19.38	19.24	17.42	18.82
1987	125.8593	439.092	301.466	243.126	19.80	20.00	18.53	19.61
1988	132.3127	606.992	407.618	332.9853	19.96	19.57	17.68	18.35
1989	139.38	501.2933	288.5323	402.9733	18.57	18.74	17.32	18.59
1990	181.2733	588.5467	244.94	323.3123	19.11	19.11	17.57	18.60
1991	103.8817	460.0223	299.9633	289.5933	19.26	19.49	17.67	18.54
1992	63.09333	359.2867	370.2533	354.928	19.47	19.76	17.37	18.46
1993	251.1333	292.72	263.0967	251.5733	18.23	19.20	17.58	19.00
1994	64.28	498.2867	307.76	442.8267	19.57	19.41	17.71	18.56
1995	92.84	474.2667	307.5293	371.34	19.32	19.42	18.00	18.70
1996	136.3467	396.24	363.3867	261.9133	19.13	19.54	17.69	18.63
1997	29.86667	503.5333	236.8267	714.0533	19.44	19.41	18.10	19.03
1998	381.255	503.7467	362.6467	220.2467	19.50	20.08	17.81	18.76
1999	55.90667	431.9667	270.0533	384.6067	19.31	19.22	17.88	18.61
2000	32.56667	263.1267	291.5667	316.4067	19.05	19.75	18.05	18.98

Table A5 Continued:

YEAR	Rain JF	Rain MAM	Rain JJAS	Rain OND	Mean temp-JF	Mean temp -MAM	Mean temp -JJAS	Mean temp OND
2001	228.5733	461.8067	343.76	324.8533	19.23	19.48	17.94	18.87
2002	111.0733	607.1133	226.9333	467.4133	19.56	19.65	18.09	19.05
2003	57.9	549.8067	367.8	283.38	19.47	19.96	17.98	18.75
2004	139.1933	432.4133	265.18	352.6333	19.54	19.59	17.89	18.81
2005	71.2	454.2467	299.3733	167.4333	19.93	20.00	17.94	19.20
2006	94.65333	535.6667	308.6538	625.5067	19.89	19.37	18.16	18.91
2007	175.2867	399.5867	448.9267	228.3933	19.22	19.57	17.97	18.73
2008	87.38667	387.18	321.679	346.579	19.28	19.30	18.07	18.88
2009	97.75333	360.62	216.86	390.0733	19.63	20.15	18.71	19.35
2010	205.7667	589.0933	333.2867	268.0267	19.94	19.78	18.33	19.20
2011	59.46667	365.4	396.3333	483.2867	19.68	19.99	18.45	18.96
2012	33.07333	561.8133	375.4867	482.9267	19.38	19.81	18.05	19.15
2013	102.168	463.5827	333.358	362.8239	19.59	19.74	18.15	19.00
2014	106.5948	454.9603	329.9137	370.7683	19.60	19.75	18.16	19.00

Appendix 2: Unit Root Results

Table A6: Unit Root Results

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Log Of Maize Output	ADF	Intercept	-2.56	-2.93	Non Stationary
		Trend & Intercept	-2.89	-3.52	
		First difference	-8.91	-2.94	Stationary, therefore I(1)
	PP	Intercept	-2.54	-2.93	Non Stationary
	KPSS	Trend and Intercept	0.60	0.46	Non stationary
Log Of coffee Output	ADF	Intercept	-2.16	-2.93	Non stationary
		Trend & Intercept	-3.12	-3.52	
		First difference	-6.27	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.84	-2.93	Non stationary
	KPSS	Intercept	0.48	0.46	Non stationary
Log of Tea Output	ADF	Intercept	-4.67	-3.62	Stationary
		Trend & Intercept	-1.96	-3.54	Non stationary
		First difference	-6.68	-2.94	Stationary, therefore I(1)
	PP	Trend and Intercept	-2.18	-3.52	Non stationary
	KPSS	Intercept	0.80	0.46	Non stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
LOG area under coffee production	ADF	Intercept	-1.66	-2.93	Non stationary
		Trend & Intercept	-0.67	-3.52	
		First difference	-7.16	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.65	-2.93	Non stationary
	KPSS	Trend & Intercept	0.49	0.46	
Log area under maize production	ADF	Intercept	-1.05	-2.93	Non stationary
		Trend & Intercept	-3.29	-3.52	
		First difference	-9.56	-2.94	Stationary therefore I(1)
	PP	Intercept	-1.76	-2.93	Non stationary
	KPSS	Intercept	0.64	0.46	
Log area under tea production	ADF	Intercept	-2.60	-2.93	Non Stationary
		Trend & Intercept	-4.50	-3.52	stationary
	PP	Intercept	-2.02	-2.93	Non stationary
	KPSS	Intercept	0.84	0.46	Non stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Log Price of Tea	ADF	Intercept	-1.31	-2.93	Non stationary
		Trend And Intercept	-3.49	-3.52	Non stationary
		First difference	-6.52	-2.93	Stationary, therefore I(1)
	PP	Intercept	-1.05	-2.93	Non stationary
	KPSS	Intercept	0.79	0.46	Non stationary
Log Price of Maize	ADF	Intercept	-0.48	-2.93	Non Stationary
		Trend and Intercept	-2.95	-3.52	Non Stationary
		First Difference	-6.54	-2.94	Stationary, therefore I(1)
	PP	Intercept	-0.28	-2.93	Non stationary
	KPSS	Intercept	0.82	0.46	Non stationary
Log price of Coffee	ADF	Intercept	-1.20	-2.93	Non stationary
		Trend & Intercept	-2.72	-3.52	Non stationary
		First difference	-6.04	-2.93	Stationary, therefore I(1)
	PP	Intercept	-1.16	-2.93	Non stationary
	KPSS	Intercept	0.80	0.46	Non stationary
Log price of maize seed	ADF	Intercept	-0.83	-2.93	Non stationary
		Trend & Intercept	-2.55	-3.52	Non stationary
		First difference	-7.15	-2.93	Stationary, therefore I(1)
	PP	Intercept	-0.83	-2.93	Non stationary
	KPSS	Intercept	0.66	0.46	Non stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value At 5 %	Conclusion
Log price of Fertilizer	ADF	Intercept	-0.99	-2.93	Non stationary
		Trend & Intercept	-2.89	-3.52	Non stationary
		First Difference	-5.86	-2.94	Stationary, therefore I(1)
	PP	Intercept	-0.87	-2.93	Non Stationary
	KPSS	Intercept	0.77	0.46	Non Stationary
		Trend & Intercept	0.07	0.15	Stationary
Mean temperature in Maize growing areas(MGA)- JF	ADF	Intercept	-3.76	-2.93	Stationary
		Trend & Intercept	-4.75	-3.52	
	PP	Intercept	-3.63	-2.93	
	KPSS	Trend & Intercept	0.12	0.14	
Mean temperature in MGA-MAM	ADF	Intercept	-3.81	-2.93	Stationary
		Trend & Intercept	-5.10	-3.52	
	PP	intercept	-3.71	-2.93	
	KPSS	Intercept	0.65	0.46	
Log wage rate	ADF	Intercept	-1.83	-2.93	Non stationary
		Trend & Intercept	-1.78	-3.52	Non stationary
		First difference	-4.46	-2.93	Stationary, therefore I(1)
	PP	Intercept	-1.63	-2.93	Non stationary
	KPSS	Intercept	0.16	0.46	Stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Mean temperature in MGA -JJAS	ADF	Intercept	-2.79	-2.93	Non Stationary
		Trend & Intercept	-3.69	-3.52	Stationary
	PP	Intercept	-2.68	-2.93	Non stationary
	KPSS	Trend& Intercept	0.09	0.15	Stationary
Mean temperature (MGA) -OND	ADF	Intercept	-3.2	-2.93	Stationary
		Trend & Intercept	-4.3	-3.52	Stationary
	PP	Intercept	-3.2	-2.93	Stationary
	KPSS	Trend & Intercept	0.12	0.15	Stationary
Temperature variability in MGA	ADF	Intercept	-6.17	-2.93	Stationary
		Trend & Intercept	-6.09	-3.52	
	PP	Intercept	-7.36	-2.93	Stationary
	KPSS	Intercept	0.20	0.46	Stationary
Rainfall in MGA - JF	ADF	Intercept	-7.35	-2.93	Stationary
		Trend And Intercept	-7.25	-3.52	
	PP	Intercept	-7.45	-2.93	Stationary
	KPSS	Trend and Intercept	0.04	0.46	Stationary
Rainfall in MGA - MAM	ADF	Intercept	-6.02	-2.93	Stationary
		Trend and Intercept	-5.94	-3.52	Stationary
	PP	intercept	-7.36	-2.93	Stationary
	KPSS	Intercept	0.13	0.46	Stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Rainfall in MGA- JJAS	ADF	Intercept	-3.34	-2.93	Stationary
		Trend and Intercept	-3.59	-3.52	Stationary
	PP	intercept	-6.47	-2.93	Stationary
	KPSS	Intercept	0.29	0.46	Stationary
Rainfall in MGA- OND	ADF	Intercept	-8.13	-2.93	Stationary
		Trend & Intercept	-9.08	-3.52	
	PP	Intercept	-8.08	-2.93	Stationary
	KPSS	Trend & Intercept	0.55	0.46	Non stationary
Rainfall variability in MGA	ADF	Intercept	-6.59	-2.93	Stationary
		Trend & Intercept	-6.67	-3.52	Stationary
	PP	intercept	-6.59	-2.93	Stationary
	KPSS	Intercept	0.12	0.46	Stationary
Mean temperature in coffee and tea growing areas(CGA)- JF	ADF	Intercept	-2.56	-2.93	Non stationary
		Trend & Intercept	-2.89	-3.52	
		First Difference	-8.91	-2.94	Stationary, therefore I(1)
	PP	Intercept	-2.54	-2.93	Non stationary
	KPSS	Intercept	0.60	0.46	Non stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Mean temperature in CGA -MAM	ADF	Intercept	-2.78	-2.93	Non stationary
		Trend & Intercept	-3.19	-3.52	Non stationary
		First Difference	-4.68	-2.94	Stationary, therefore I(1)
	PP	Intercept	-4.03	-2.93	Stationary
	KPSS	Intercept	0.57	0.46	Non stationary
Mean temperature (CGA) -JJAS	ADF	Intercept	-2.80	-2.93	Non stationary
		Trend & Intercept	-2.81	-3.52	Non stationary
		First Difference	-6.09	-2.94	Stationary, therefore I(1)
	PP	Intercept	-2.80	-2.93	Non stationary
	KPSS	Intercept	0.58	0.46	Non stationary
Mean temperature (CGA) -OND	ADF	Intercept	-2.91	-2.93	Non stationary
		Trend & Intercept	-2.93	-3.52	
		First Difference	-9.24	-2.94	Stationary, therefore I(1)
	PP	Intercept	-3.22	-2.93	Stationary
	KPSS	Intercept	0.58	0.46	Non stationary
Log Maize Sales To Marketing Boards	ADF	Intercept	-3.552970	-2.933158	Stationary
		Trend and Intercept	-3.642774	-3.520787	Stationary
	PP	Intercept	-3.558625	-2.933158	Stationary
	KPSS	Intercept	0.134395	0.463000	Stationary
	ADF	Intercept	-3.552970	-2.933158	Stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Rainfall in CGA - JF	ADF	Intercept	-7.10	-2.93	Stationary
		Trend & Intercept	-7.06	-3.52	
	PP	Intercept	-7.11	-2.93	Stationary
	KPSS	Intercept	0.10	0.46	Stationary
Rainfall in CGA - MAM	ADF	Intercept	-6.79	-2.93	Stationary
		Trend &Intercept	-6.67	-3.52	Stationary
	PP	intercept	-9.01	-2.93	Stationary
	KPSS	Intercept	0.35	0.46	Stationary
Rainfall in CGA- JJAS	ADF	Intercept	-5.60	-2.93	Stationary
		Trend & Intercept	-6.25	-3.52	
	PP	intercept	-5.65	-2.93	Stationary
	KPSS	Intercept	0.29	0.46	Stationary
Rainfall in CGA- OND	ADF	Intercept	-8.03	-2.93	Stationary
		Trend & Intercept	-9.02	-3.52	Stationary
	PP	intercept	-8.03	-2.93	Stationary
	KPSS	Trend & intercept	0.14	0.15	Stationary
Rainfall variability in CGA	ADF	Intercept	-7.55	-2.93	Stationary
		Trend & Intercept	-7.48	-3.52	
	PP	Intercept	-7.55	-2.93	Stationary
	KPSS	Intercept	0.05	0.46	Stationary

.

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Temperature variability in CGA	ADF	Intercept	-4.56	-2.93	Stationary
		Trend & Intercept	-4.60	-3.52	Stationary
	PP	intercept	-4.55	-2.93	Stationary
	KPSS	Intercept	0.18	0.46	Stationary
Log effective exchange rate	ADF	Intercept	-1.330681	-2.933158	Non stationary
		Trend And Intercept	-1.218590	-3.520787	
		First difference	-6.734700	-2.935001	Stationary, therefore I(1)
	PP	Intercept	-1.192365	-3.520787	Non stationary
	KPSS	Intercept	3.100352	0.1460000	
Log Development Expenditure On Roads Transport And Communication	ADF	Intercept	-1.425527	-2.933158	Non stationary
		Trend and Intercept	-0.951802	-3.520787	
		First Difference	-7.838335	-2.935001	Stationary, therefore I(1)
	PP	Intercept	-1.345489	-2.604867	Non stationary
	KPSS	Intercept	0.243537	0.463000	Stationary

Table A6 Continued:

Variable	Type of Test	Form of Test	Test Statistic	Critical Value at 5 %	Conclusion
Log of maize yield	ADF	Intercept	-2.61	-2.93	Non stationary
		Trend & Intercept	-2.17	-3.52	
		First diffrence	-5.57	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.75	-2.93	Non stationary
	KPSS	Trend and Intercept	0.65	0.46	Non stationary
Log of coffee yield	ADF	Intercept	-0.08	-2.93	Non stationary
		Trend & Intercept	-3.50	-3.52	
		First difference	-8.08	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.20	-2.93	Non stationary
	KPSS	Intercept	0.73	0.46	Non stationary
Log of Tea yield	ADF	Intercept	-2.09	-3.62	Non stationary
		Trend & Intercept	-1.14	-3.54	Non stationary
		First difference	-9.86	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.57	-2.93	Non stationary
	KPSS	Intercept	0.20	0.46	Non stationary

Table A7: Estimation of Cointegrating Equations

Dependent Variable	Type of Test	Test Statistic	Asymptotic Critical Value at 5%[a]	Conclusion
maize output response	ADF	-5.91**	-4.71	Cointegration exists
Tea output response	ADF	-5.98**	-4.71	Cointegration exists
Coffee output response	ADF	-7.24**	-4.71	Cointegration exists

** significance at 5 % level

a: Asymptotic critical values are from Davidson and Mckinnon(1993)

Table A8: Lag Order Selection Criteria for Maize, Coffee and Tea Output Supply

Endogenous variables: log maize output, log price maize, logarea , log fertilizer price log seed price, log wage, log sales to marketing board, log transport, rain_cv, rain_jf, rain_jjas, rain_mam, rain_ond, mean_temp_jf, mean_temp_jjas, mean_temp_mam, mean_temp_ond temp_dvn.

Exogenous variables: C ; Sample: 1970 2014; Included observations: 43

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1167.400	NA	1.08e+09	54.85582	55.34732	55.03707
1	-855.3681	435.3936	551220.3	47.04038	53.42985*	49.39662
2	-641.0633	179.4180*	122027.7*	43.77039*	56.05783	48.30161*

Endogenous variables: log coffee output, log area, log transport, log coffee price, log reer, log wage, log fertilizer price, log wage, rain_cv, rain_jf, rain_jjas, rain_mam, rain_ond, mean_temp_jf, mean_temp_jjas, mean_temp_mam, mean_temp_ond temp_dvn.

Exogenous variables: C ; Sample: 1970 2014; Included observations: 43

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-192.7844	NA	2.22e-11	9.524855	10.01635	9.706104
1	134.9212	457.2636	5.47e-15	0.980410	7.369881*	3.336650
2	344.5537	175.5063*	1.50e-15*	-2.072267*	10.21518	2.458962*

Endogenous variables: log tea output, log tea area, log transport log tea price, logfertilizer price, log reer , log wage, rain_cv rain_jf rain_jjas rain_mam rain_ond mean_temp_jf mean_temp_jjas mean_temp_mam mean_temp_ond temp_dvn

Exogenous variables: C ; Sample: 1970 2014; Included observations: 43

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-602.4324	NA	1.57e-05	28.67127	29.24469	28.88273
1	-151.2274	587.6158	1.69e-10	16.80128	25.40249	19.97314
2	288.1492	286.1057*	7.62e-14*	5.481431*	22.11044*	11.61369*

* indicates lag order selected by the criterion

LR: sequential modified LR test statistic (each test at 5%level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

Appendix 3: Diagnostic Tests Results for Crop Output Response Equations

TableA9: Residual Properties of Maize Output Response Equation

Type of test	Test statistic	Test statistic value	Probability
Normality test-histogram	Jarque Berra	1.08	0.58
Breusch-Godfrey Serial Correlation LM Test	Obs*R-squared	3.63	0.16
Heteroskedasticity Test: ARCH	Obs*R-squared	0.22	0.63

Table A10: Residual Properties of Tea Output Response Equation

Type of test	Test statistic	Test statistic value	probability
Normality test-histogram	Jarque Berra	0.78	0.67
Breusch-Godfrey Serial Correlation LM Test	Obs*R-squared	0.34	0.84
Heteroskedasticity Test: ARCH	Obs*R-squared	0.07	0.79

Table A11: Residual Properties of Coffee Output Response Equation

Type of test	Test statistic	Test statistic value	probability
Normality test-histogram	Jarque Berra	0.02	0.99
Breusch-Godfrey Serial Correlation LM Test	Obs*R-squared	1.56	0.45
Heteroskedasticity Test: ARCH	Obs*R-squared	0.058	0.93

Table A12: Ramsey Reset Tests Results

Dependant variable	F statistic	Probability	conclusion
Log of maize output	0.06	0.80	No indication of misspecification error
Log of tea output	0.015	0.90	No indication of misspecification error
Log of coffee output	0.01	0.90	No indication of misspecification error

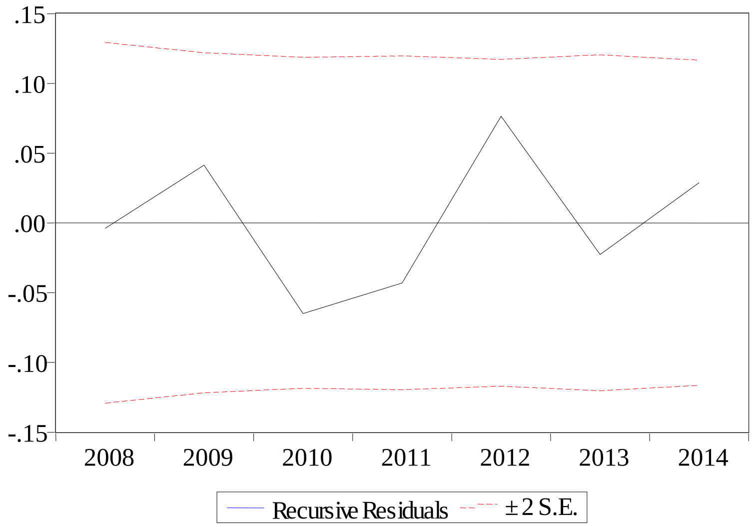

Figure A1: Recursive Residuals from the Maize Output Response Equation

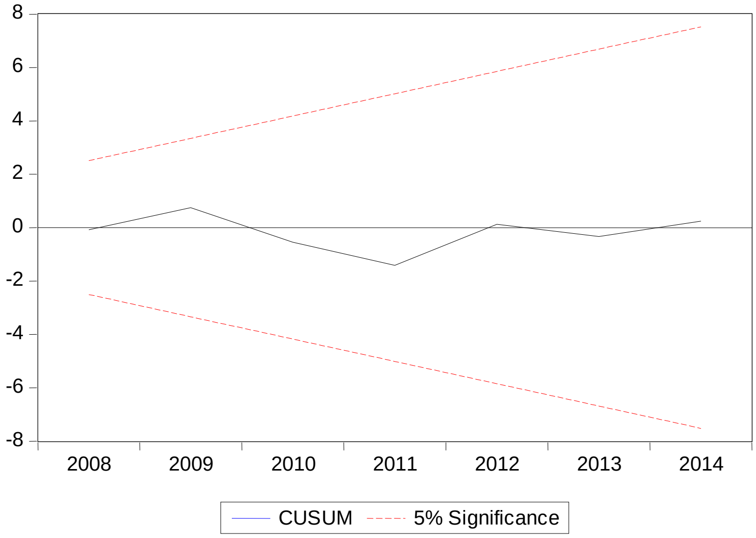

Figure A2: CUSUM Test from the Maize Output Long Run Response Equation

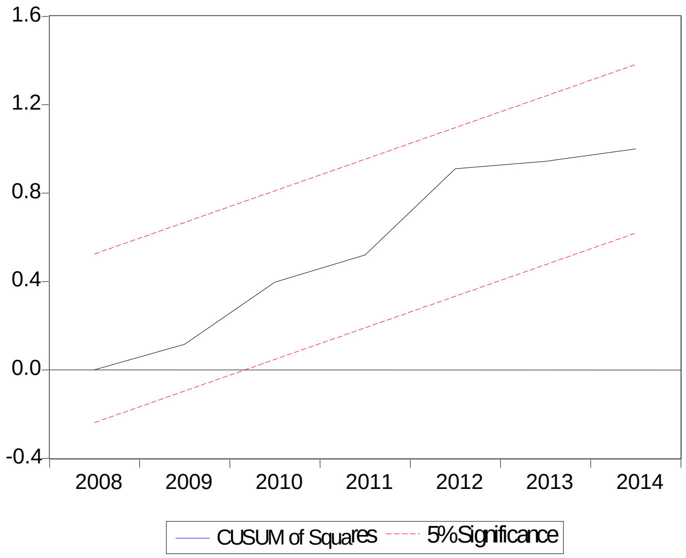

Figure A3: CUSUM of Squares from the Maize Output Response Equation

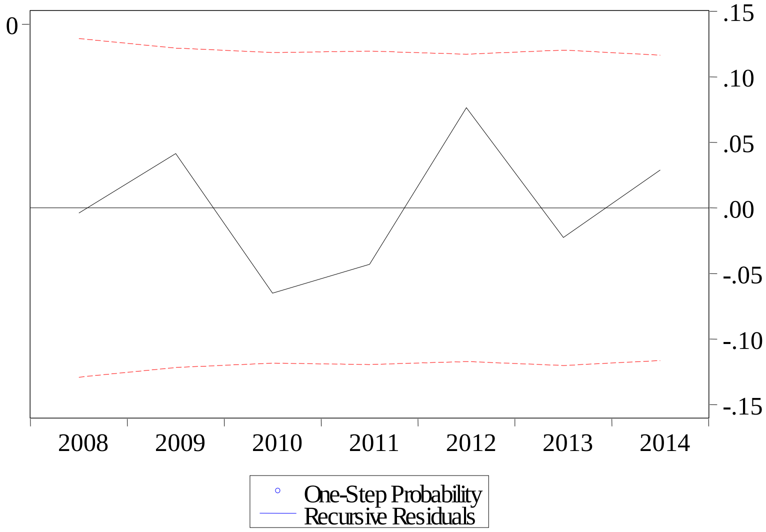

Figure A4: One Step Probability from the Maize Output Long Run Response Equation

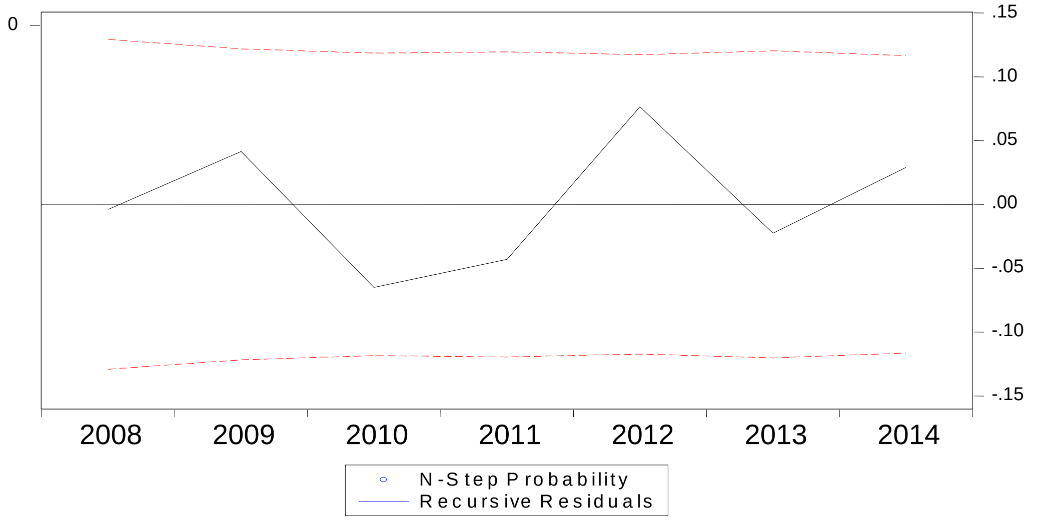

Figure A5: N – Step Probability from the Maize Output Long Run Response Equation

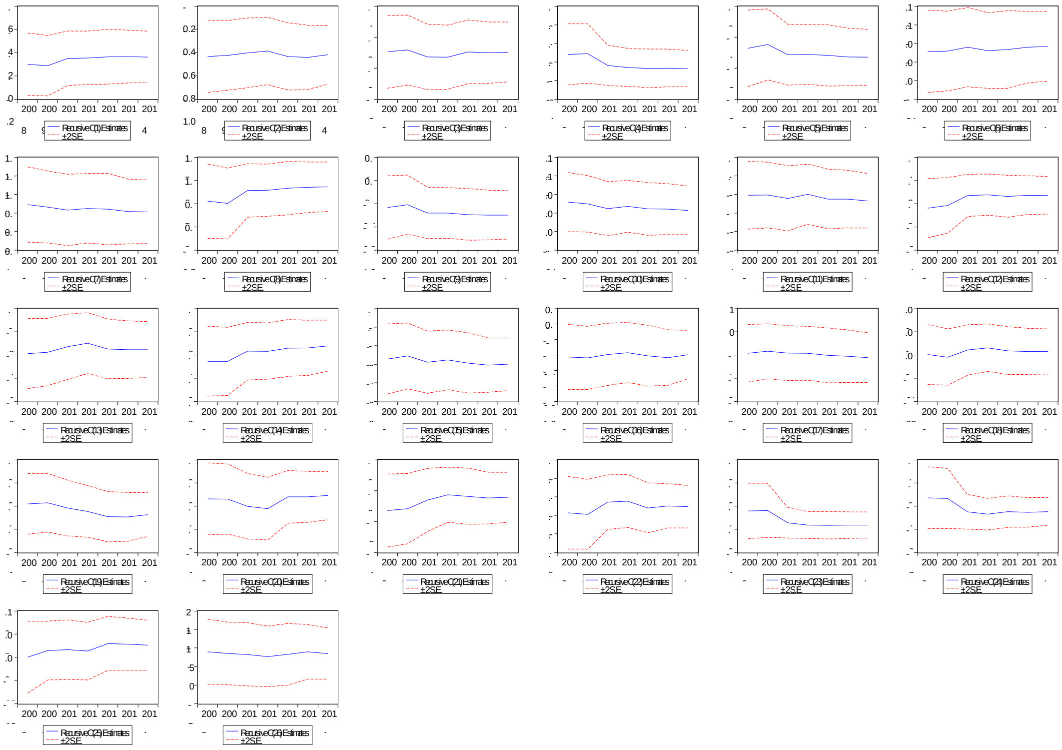

Figure A6: Recursive Coefficient Tests from the Maize Output Response Equation

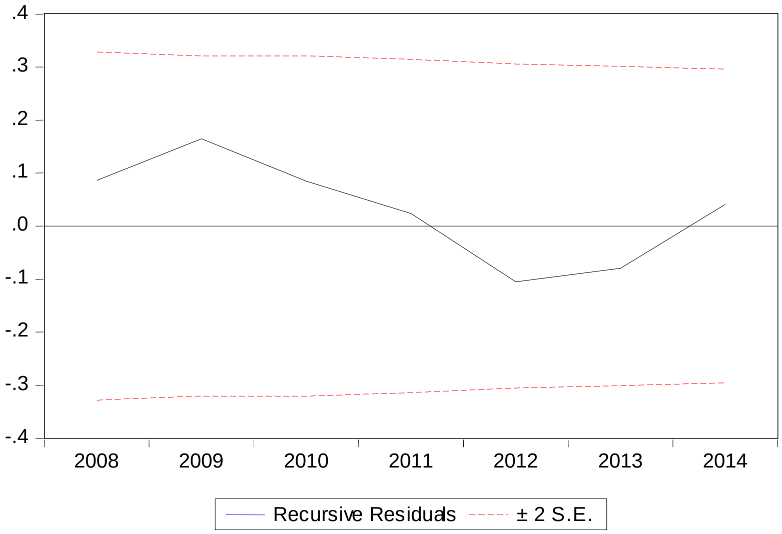

Figure A7: Recursive Residuals Coffee Output Response Equation

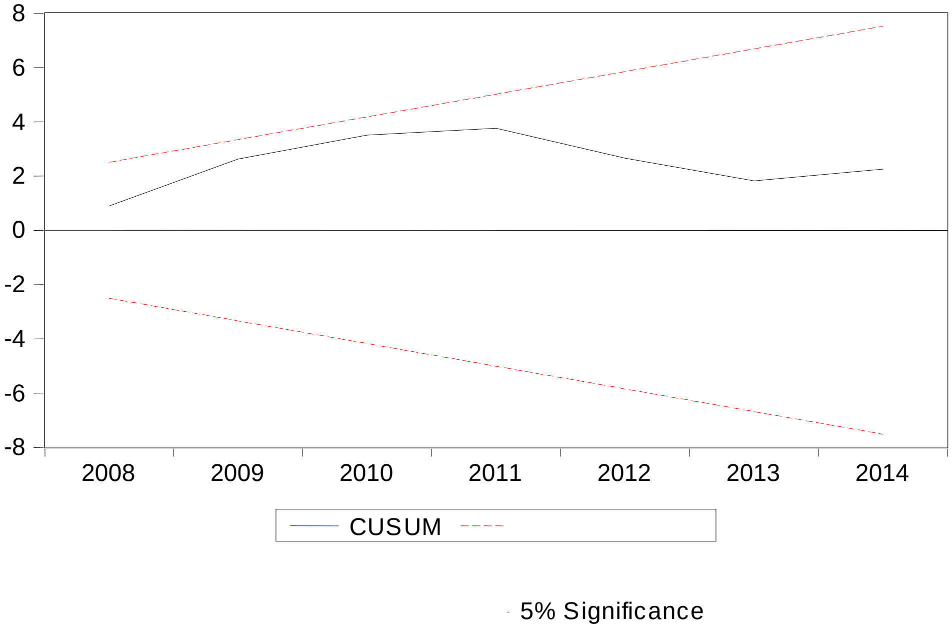

Figure A8: CUSUM Test from the Coffee Output Response Equation

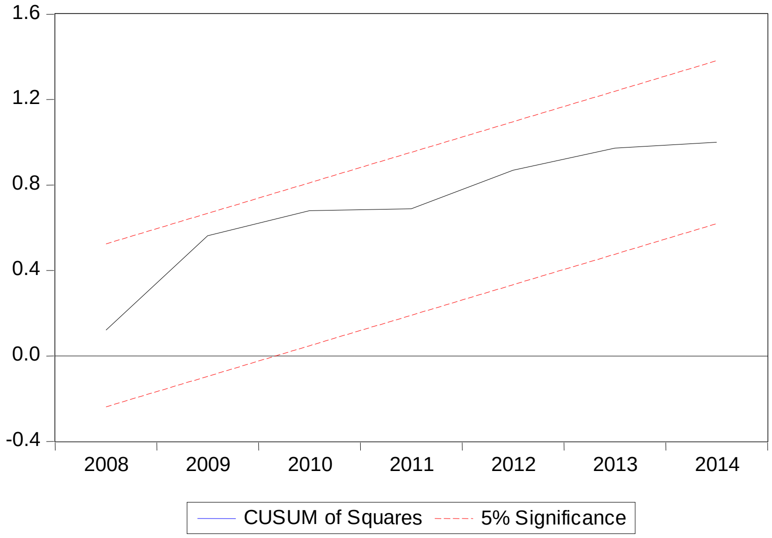

Figure A9: CUSUM of Squares from the Coffee Output Response Equation

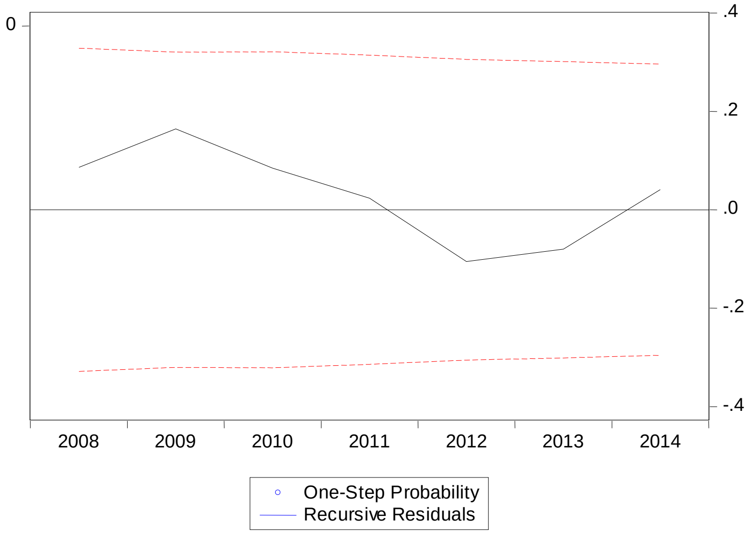

Figure A10: One –Step Probability from the Coffee Output Response Equation

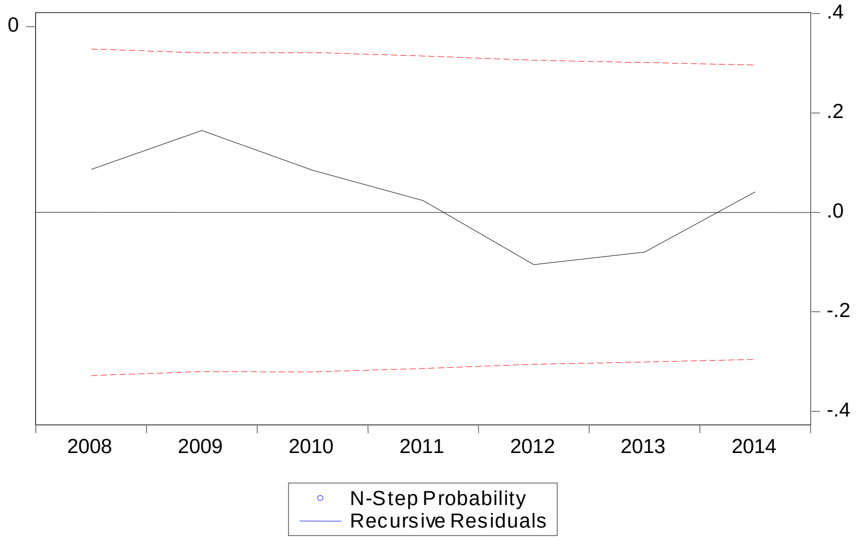

Figure A11: N-Step Probability from the Coffee Output Response Equation

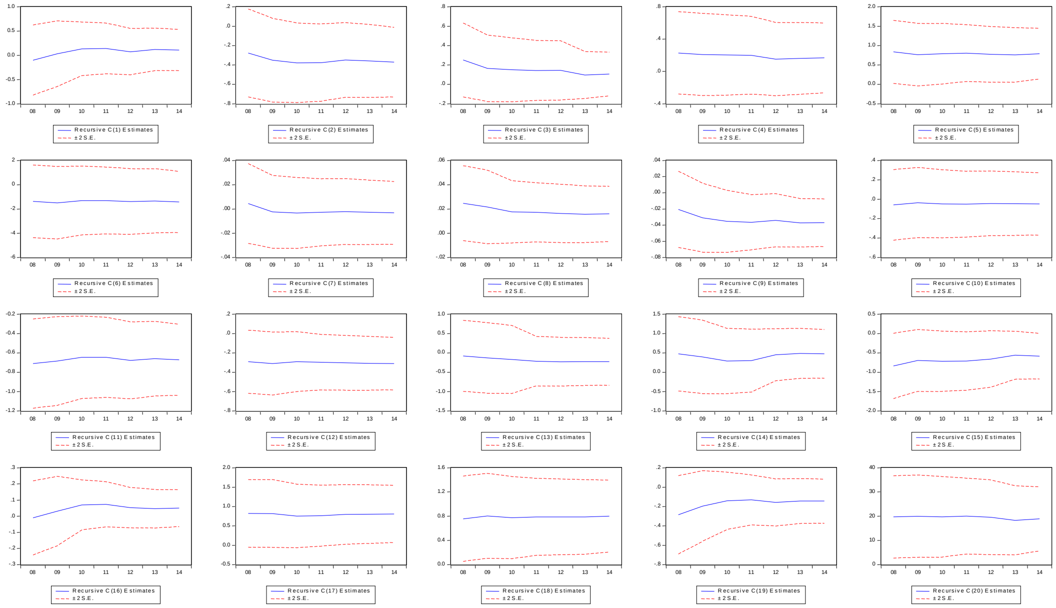

Figure A12: Recursive Coefficient Tests from the Coffee Output Response Equation

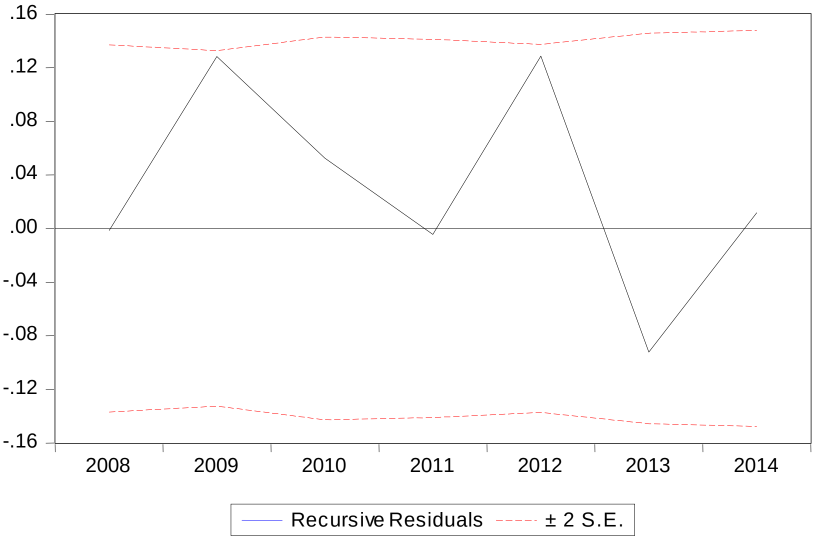

Figure A13: Recursive Residuals from the Tea Output Response Equation

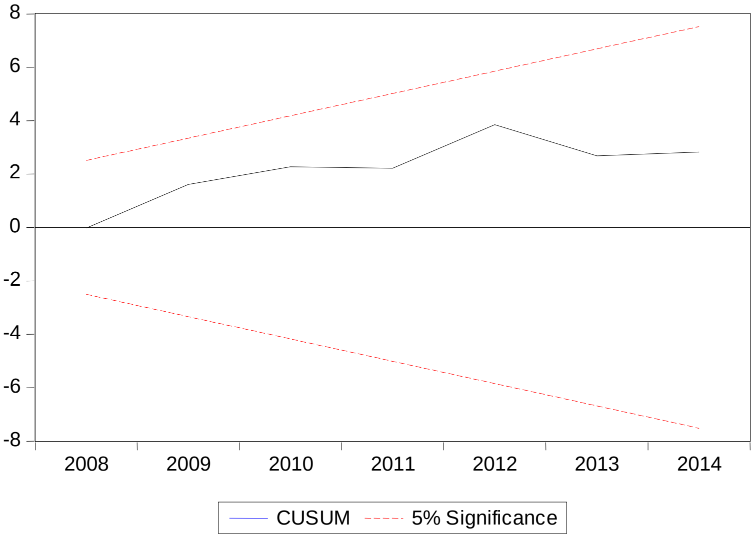

Figure A14: CUSUM from the Tea Output Response Equation

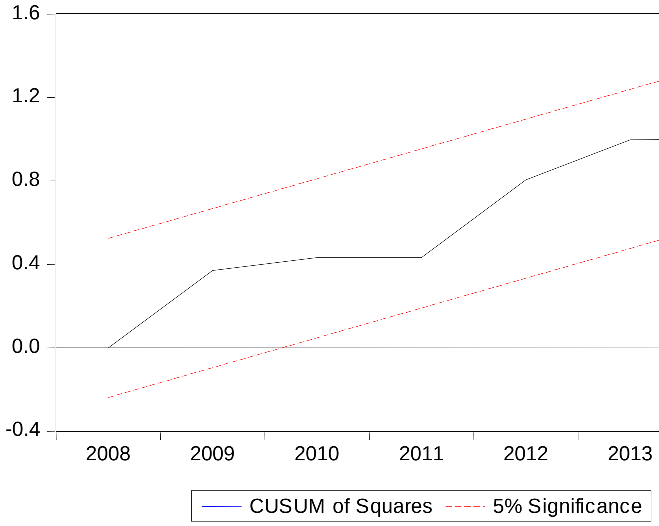

Figure A15: CUSUM of Squares from the Tea Response Equation

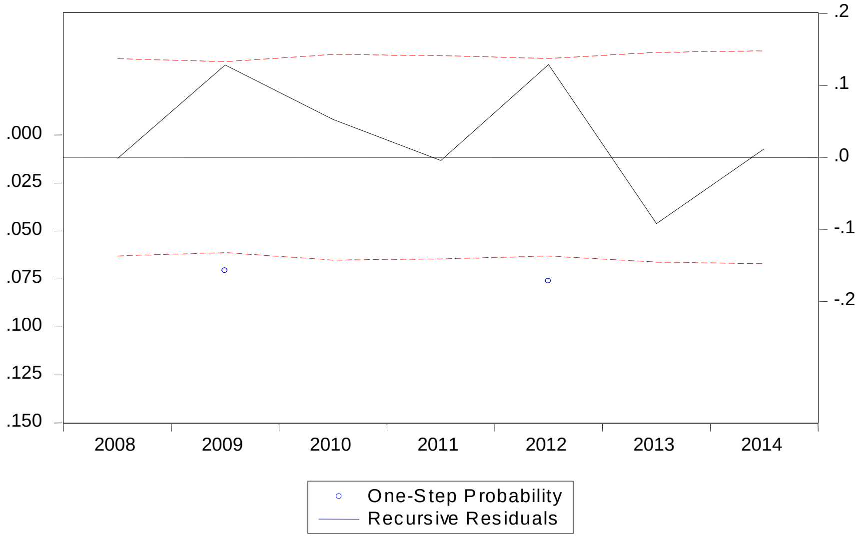

Figure A16: One Step Probability from the Tea Output Response Equation

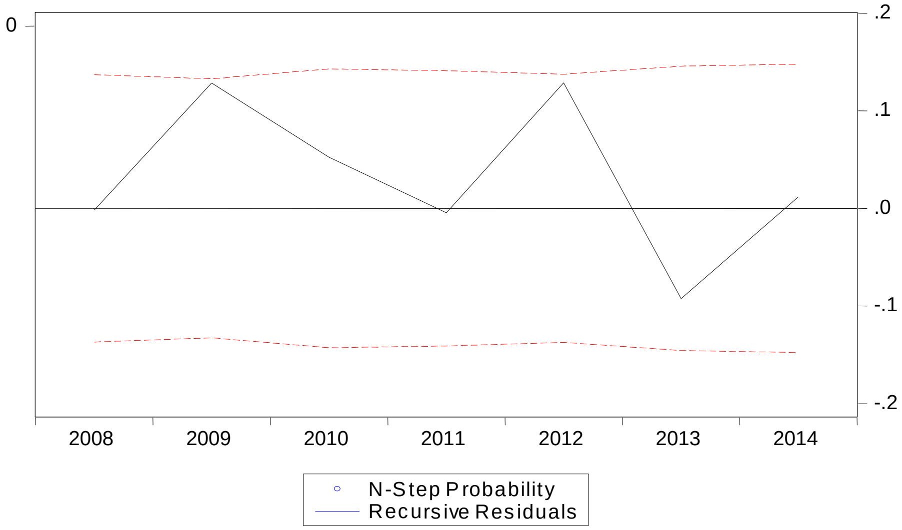

Figure A17: N- Step from the Tea output Response Equation

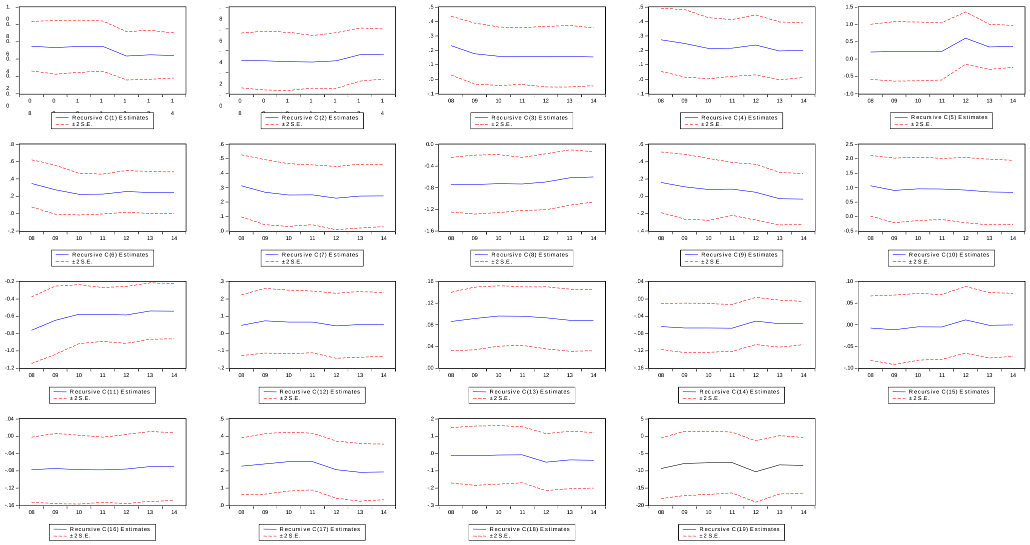

Figure A18: Recursive Coefficient Tests from the Tea Output Response Equation

Appendix4: Diagnostic Tests Results for Crop Yield Equations

TableA13: Residual Properties of Maize yield Equation

Type Of Test	Test Statistic	Test Statistic Value	Probability
Normality Test-Histogram	Jarque Berra	0.40	0.82
Breusch-Godfrey Serial Correlation LM Test	Obs*R-Squared	3.92	0.14
Heteroskedasticity Test: ARCH	Obs*R-Squared	1.43	0.23

TableA14: Residual Properties of Tea Yield Equation

Type Of Test	Test Statistic	Test Statistic Value	Probability
Normality Test-Histogram	Jarque Berra	0.34	0.84
Breusch-Godfrey Serial Correlation LM Test	Obs*R-Squared	0.46	0.79
Heteroskedasticity Test: ARCH	Obs*R-Squared	0.62	0.43

TableA15: Residual Properties of Coffee Yield Equation

Type Of Test	Test Statistic	Test Statistic Value	Probability
Normality Test-Histogram	Jarque Berra	0.56	0.75
Breusch-Godfrey Serial Correlation LM Test	Obs*R-Squared	3.20	0.20
Heteroskedasticity Test: ARCH	Obs*R-Squared	0.28	0.60

TableA16: Ramsey Reset Tests Results

Dependant Variable	F Statistic	Probability	Conclusion
D(Maize yield)	1.04	0.32	No Indication of Misspecification Error
D(Tea yield)	0.77	0.38	No Indication of Misspecification Error
D(Coffee yield)	0.78	0.39	No Indication of Misspecification Error