POTENTIAL EFFECTS OF CLIMATE CHANGE ON STAPLE CROPS IN WEST AFRICA

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MASTER OF ECONOMICS IN APPLIED ECONOMICS
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT
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ชื่อเรื่อง ผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศต่อพืชหลักในแอฟริกาตะวันตก
ชื่อผู้เขียน นายโอลาลิกน อิสราเอล ไออิคูโลลา
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บทคัดย่อ

การศึกษาครั้งนี้มุ่งเน้นไปที่ผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศต่อพืชหลักในแอฟริกาตะวันตก โดยการพิจารณาค่าเฉลี่ยและความแปรปรวนของตัวแปรสภาพภูมิอากาศที่ส่งผลต่อการผลิต โดยวิธีการทางเศรษฐมิติ จากแนวคิดฟังก์ชั่นการผลิตของ Just and Pope ซึ่งกำหนดรูปแบบฟังก์ชันการผลิตแบบสุ่ม (Stochastic Production Function) เพื่ออธิบายถึงผลกระทบของตัวแปรที่สังเกตได้ (อุณหภูมิและปริมาณน้ำฝน) ต่อการผลิตมันสำปะหลัง ข้าวโพด ข้าว และมันเทศ รวมทั้งตรวจสอบผลกระทบที่อาจเกิดขึ้นจากการเปลี่ยนแปลงสภาพภูมิอากาศในการผลิตพืชหลักในแอฟริกาตะวันตกในปีค.ศ. 2030, 2060 และ 2090 ภายใต้สถานการณ์ RCP 4.5 และ RCP 8.5

ผลการศึกษาผลกระทบของตัวแปรสภาพภูมิอากาศ (อุณหภูมิและปริมาณน้ำฝน) ต่อผลผลิตเฉลี่ย พบว่า ตัวแปรอุณหภูมิเฉลี่ยส่งผลกระทบทางบวกต่อผลผลิตเฉลี่ยของมันสำปะหลัง ข้าว และมันเทศ แต่มีเพียงมันเทศเท่านั้นที่ได้รับผลกระทบอย่างมีนัยสำคัญทางสถิติ ซึ่งหมายความว่า หากอุณหภูมิเฉลี่ยเพิ่มขึ้นร้อยละ 1 จะส่งผลให้ผลผลิตมันเทศเพิ่มขึ้นร้อยละ 4.3 แต่ในทางกลับกันข้าวโพดกลับได้รับผลกระทบทางลบจากการเพิ่มขึ้นของอุณหภูมิเฉลี่ย หมายความว่า หากอุณหภูมิเฉลี่ยเพิ่มขึ้นร้อยละ 1 จะส่งผลให้ผลผลิตข้าวโพดลดลงร้อยละ 1.2 ด้านตัวแปรปริมาณน้ำฝน พบว่าปริมาณน้ำฝนส่งผลกระทบทางบวกต่อผลผลิตเฉลี่ยของข้าวโพด ข้าว และมันเทศ แต่ข้าวโพดและข้าวได้รับผลกระทบอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 90 และ 99 ตามลำดับ หมายความว่า หากปริมาณน้ำฝนเพิ่มขึ้นร้อยละ 1 ผลผลิตข้าวโพดและข้าวจะเพิ่มขึ้นร้อยละ 0.6 และ 0.05 ตามลำดับ ในขณะเดียวกันมันสำปะหลังกลับได้รับผลกระทบทางลบจากการเพิ่มขึ้นของปริมาณน้ำฝน

ด้านความแปรปรวนของผลผลิต พบว่า การเพิ่มขึ้นของอุณหภูมิเฉลี่ยทำให้ความแปรปรวนของผลผลิตมันสำปะหลัง ข้าว และมันเทศ เพิ่มสูงขึ้น แต่อย่างไรก็ตามความแปรปรวนของผลผลิตข้าวโพดกลับลดลงอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 95 ด้านปัจจัยความแปรปรวนของอุณหภูมิเฉลี่ยที่เพิ่มขึ้นทำให้ความแปรปรวนของผลผลิตมันสำปะหลัง ข้าวโพดและมัน

เทศเพิ่มขึ้น อย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 99 ในขณะที่ความแปรปรวนของผลผลิตข้าวเพิ่มขึ้น อย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 90 ส่วนปัจจัยปริมาณน้ำฝนส่งผลกระทบทางลบต่อความแปรปรวนของผลผลิตข้าวโพด ข้าว และมันเทศ ยกเว้นมันสำปะหลัง ซึ่งได้รับผลกระทบในทางบวก อย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่นร้อยละ 99 แสดงให้เห็นว่าการเพิ่มขึ้นของปริมาณน้ำฝนทำให้ความแปรปรวนของผลผลิตมันสำปะหลังเพิ่มขึ้น แต่ลดความแปรปรวนของผลผลิตข้าวโพด ข้าวและมันเทศ ตามลำดับ

สำหรับผลกระทบที่อาจเกิดขึ้นในอนาคตจากการเปลี่ยนแปลงสภาพภูมิอากาศต่อการผลิตพืชหลักในแอฟริกาตะวันตก ภายใต้สถานการณ์ RCP 4.5 และ RCP 8.5 ในปีค.ศ. 2030, 2060 และ 2090 พบว่า ทั้งมันสำปะหลังและข้าวโพดจะได้รับผลกระทบในทางลบ จากการเปลี่ยนแปลงสภาพภูมิอากาศในแอฟริกาตะวันตก ในขณะที่ข้าวและมันเทศ กลับได้รับผลกระทบในเชิงบวก ภายใต้สถานการณ์ดังกล่าว ทั้งในปีค.ศ. 2030, 2060 และ 2090 ในภูมิภาคนี้

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ABSTRACT

This study focuses on the effect of climate change on staple foods in West Africa by considering the mean and variance of climate variables as well as the corresponding productions with the use of stochastic production function. Moreover, panel approach method is also being used for the West African countries. This study applies econometric approach by using the Just and Pope Production function to explain the effect of observed variables (Temperature and precipitation) on the production of Cassava, Maize, Rice and Yam. Then examined the potential effect of climate change on the production of staple crops in West Africa for 2030 2060 and 2090 under RCP 4.5 and RCP 8.5.

The results showed that, in relation to the effect of climate variables (temperature and precipitation), average temperature were positive on the mean production of cassava, rice and yam in the region. However, only yam was statistically significant. This implies that a one percent increase in average temperature leads to an increased production of yam at 4.3%. Meanwhile, maize was affected negatively from the effect of increase in average temperature, which implies that one percent increase in average temperature will result in 1.2% declination of maize production in the region. While the overall effect of an increase in total precipitation were, also positive on the mean production of maize, rice and yam, however, maize and rice were statistically significant at 90 and 99% respectively. This therefore implied that a one-percentage increase in total precipitation induces a 0.6 and 0.05% increase in the production of maize and rice respectively. At the same time, cassava received a negative impact on the effect of increase in total

precipitation.

The variance of the observed effect showed that higher average temperatures increase cassava, rice and yam production variability in the region. Only rice was statistically significant at 90%. While maize production variability decreased with a statistical significant of 95%. Cassava, maize and yam production variance increased with an increase temperature variability in the regions with 99% statistical significance for cassava and yam, whereby rice production variance decreases in the region. While total precipitation on production variability were all-negative at 99% statistical significance for maize and yam. Except for cassava, which was positive at 99%. Therefore, higher amount of total precipitation increase the variation of cassava production but decrease the variability of maize, rice and yam respectively.

The future potential effect of climate change on the production of staple crops in West Africa under RCP 4.5 and RCP 8.5 scenarios for years 2030, 2060 and 2090 showed that, both cassava and maize will be most threatened negatively by the effect of climate change in the region. While rice and yam showed a positive increase in production under both scenarios for years 2030, 2060 and 2090 in the region.

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I would like to thank my thesis advisor Asst. Prof. Dr. Nirote Sinnarong. The door to Prof. Sinnarong office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this research study to be my own work, but steered me in the right direction whenever he thought I needed it. Besides my advisor, I would like to thank the rest of my thesis committee: Dr. Ke Nunthasen and Dr. Siwarat Kuson, for their encouragement, insightful comments, and hard questions.

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Finally, I would like to express my profound gratitude to my parents and younger sisters, for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Olalekan Israel Aiikulola
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CHAPTER 1

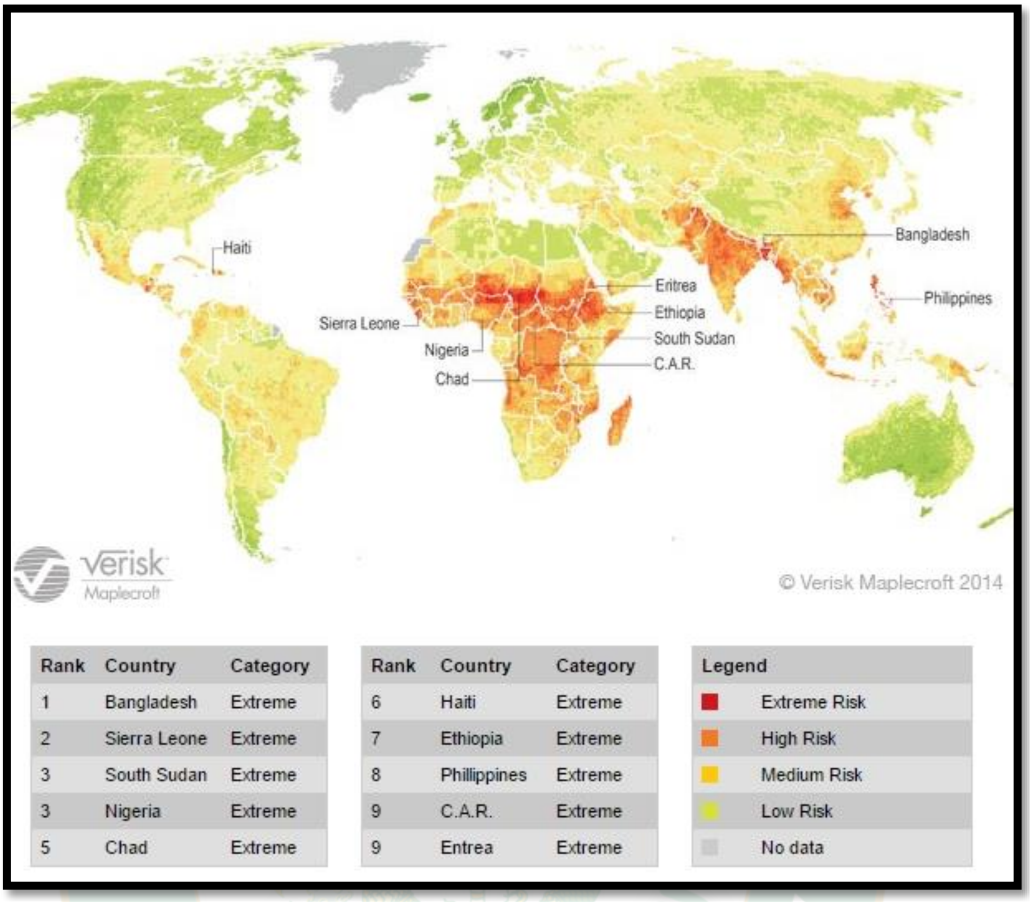
INTRODUCTION

The food production system in Africa is among the world’s most vulnerable system because of substantial reliance on rain-fed crop production, high intra- and inter-seasonal climate variability, frequent droughts and floods affect both crops and livestock, and persistent poverty limits the capacity to adapt (Boko et al., 2007). However, agriculture in Africa will face significant challenges in adapting to climate changes projected to occur by mid-century, as negative effects of high temperatures become increasingly prominent under an A1B scenario (Battisti and Naylor, 2009; Burke et al., 2009), therefore, increasing the possibility of diminished yield potential of major crops in Africa (Schlenker and Lobell, 2010; Sultan et al., 2013). Changes in growing season length are possible, with a tendency toward reduced growing season length (Thornton et al., 2009), Transition zones, where livestock keeping is projected to replace mixed crop-livestock systems by 2050, include the West African Sahel and coastal and mid altitude areas in eastern and southeastern Africa (Jones and Thornton, 2009)

Climate change is probably to have an overall negative effect on the yields of major cereal crops across Africa, with rigid regional variability in the degree of yield reduction (Liu et al., 2008; Roudier et al., 2011; Thornton et al., 2009; Walker and Schulze, 2008). Moreover, in eastern Africa, maize production could benefit from warming at high elevation locations (A1FI scenario) (Thornton et al., 2009) although the vast current maize production occurs at lower elevations, thereby implying a potential change in the distribution of maize cropping. Maize-based systems, particularly in southern Africa, are among the most vulnerable to climate change, simulations that combine all south regions of the Sahara suggest consistently negative effects of climate change on major cereal crops in Africa, ranging from 2% for sorghum to 35% for wheat by 2050 under an A2 scenario (Nelson et al., 2009).

Climate change will interact with non-climate drivers and stressors to worsen vulnerability of agricultural systems, particularly in the semi-arid areas. Increasing temperatures and changes in precipitation are probably to reduce cereal crop productivity. However, this will have rigid adverse effects on food security in the West Africa region. New evidence is also emerging that high-value perennial crops could also be adversely affected by temperature increase. Pest, weed, and disease pressure on crops and livestock are been expected to increase because of climate change along with other factors. Furthermore, fresh challenges to food security are rising in respect of strong increase on urbanization in the region and increased globalized food chains, which needs solid understanding of the multi-stressor context of food and livelihood security in both urban and rural contexts in the region. (Niang et al., 2014)

Agricultural production in most West African countries are sorely been affected by climate change. Agricultural losses are estimated to be possibly severe for several areas (like the Sahel, East Africa, and southern Africa) accompanied by changes in the length of growing periods impacting mixed rain-fed, arid and semi-arid structure under some climate projections. Currently, the effects of climate change are already being experienced by people in West Africa such as; Nigeria (the highest producer of cassava in the world). There has been claims that change in temperature and precipitation has affected the health, livelihoods, food productivity and water availability of the people in West Africa. According to the Climate Change Vulnerability Index for 2015, seven of the ten countries most at risk from climate change are in Africa. (Maplecroft, 2014). Including Nigeria and Sierra-Lone from West Africa. (See fig 1)



Rank	Country	Category
1	Bangladesh	Extreme
2	Sierra Leone	Extreme
3	South Sudan	Extreme
3	Nigeria	Extreme
5	Chad	Extreme

Rank	Country	Category
6	Haiti	Extreme
7	Ethiopia	Extreme
8	Phillippines	Extreme
9	C.A.R.	Extreme
9	Entrea	Extreme

Legend	
🟥	Extreme Risk
🟧	High Risk
🟨	Medium Risk
🟩	Low Risk
⬜	No data

Figure 1 *Climate Change Vulnerability Index 2015*

Source: Verisk Maplecroft (Nov 5, 2016)

Niang et al. (2014) cited (Hulme et al., 2001; Jones and Moberg, 2003; Kruger and Shongwe, 2004; Schreck and Semazzi, 2004; New et al., 2006; IPCC, 2007; Rosenzweig et al., 2007; Trenberth et al., 2007; Christy et al., 2009; Collins 2011; Grab and Craparo, 2011; Hoffman et al., 2011; Mohamed, 2011; Stern et al., 2011; Funk et al., 2012; Nicholson et al., 2013). That near surface temperatures have increased by 0.5°C or more during the last 50 to 100 years over most parts of Africa, with minimum temperatures warming growing faster than maximum temperatures. Near surface air temperature anomalies in Africa were significantly higher for the period 1995–2010 compared to the period 1979–1994.

In recent years, North African annual and seasonal observed trends in mean near surface temperature shows a significant overall warming above the range of changes due to natural (internal) variability (Barkhordarian et al., 2012). Evidence of warming over land regions across Africa, consistent with anthropogenic climate change, has increased. Moreover, Decadal analyses of temperatures strongly point to an increased warming trend across the continent over the last 50 to 100 years (Niang et al., 2014)

Niang et al. (2014) cited (Christensen et al., 2007; Joshi et al., 2011; Sanderson et al., 2011; James and Washington, 2013) that temperatures in Africa are projected to rise faster than the global average increase during the 21st century. Global average near surface air temperature is projected to move beyond 20th century simulated variability by 2069 (±18 years) under Representative Concentration Pathway 4.5 (RCP4.5) and by 2047 (±14 years) under RCP8.5. Nevertheless, in West Africa these unknown climates are been projected to occur some years faster than the global average, because the relatively small natural climate variability in this region generates limited climate bounds that can be exceeded by small climate changes. (Niang et al., 2014)

However, majority of the countries in West Africa lack inadequate observational data to draw out a summary on annual precipitation tendencies over the past years (Niang et al., 2014). In addition, most observed precipitation data sets are inconsistent (Kalognomou et al., 2013; Kim et al., 2013; Nikulin et al., 2012). Areas where there are sufficient data include very likely decreases in annual precipitation over the past century in the western and eastern Sahel region of northern Africa, along with very likely increases in eastern and southern Africa. Rainfall in the Sahel has encountered an overall declination over the course of the 20th century, with a recovery toward the last 20 years of the century (Battisti and Naylor, 2009; Lebel and Ali, 2009; Nicholson and Yin, 2001)

The increase of mean annual temperature over Africa, in relation to the late 20th century mean annual temperature, are probably to be above 2°C in the Special Report on Emissions Scenarios (SRES) A1B and A2 scenarios by the end of this century. (Medium confidence). (Niang et al., 2014) Warming projections under medium scenarios shows that most areas in Africa will be above 2°C by the last two decades of this century relative to the late 20th century mean annual temperature and all of Africa under high emission scenarios.

Precipitation projections are more unpredictable than temperature projections and showcase higher spatial and seasonal dependence than temperature projections (Orlowsky and Seneviratne, 2012). A reduction in rainfall in northern Africa foreseeable towards the end of the 21st century. Climate change projections for the 21st century under the A1B and A2 scenarios. West African precipitation projections in the CMIP3 and CMIP5 archives show inter-model variation in both the amplitude and direction of change that is partially attributed to the inability of GCMs to resolve convective rainfall (Biasutti et al., 2009; Roehrig et al., 2013). Projected rainfall change over sub-Saharan Africa in the mid- and late 21st century are uncertain. In regions of high or complex topography such as the Ethiopian Highlands, downscaled projections shows increases in rainfall and extreme rainfall by the end of the 21st century. (Niang et al., 2014)

West Africa particularly is a region of plains, the climates vary from arid to tropical and the region possesses important agriculture and mineral resources. The region comprises of four climatic zones. **(Sahelian a hot semi-arid climate)** an arid area in the Southern Sahara that spread across six countries from Senegal to Chad. **Sudanian** (precipitations ranging between less than 88 mm in the north of Nigeria and 1 000 mm in the north of Mali). **Tropical humid** (essentially described as wet and dry, where the wet areas are near the equatorial climate and the dry area near the desert climate with an annual rainfall ranging between 750mm - 1500 mm); and

Equatorial (a climate that's essentially hot and wet, no complete dry month; with a high temperature of 24^0C – 27^0C localized along the Gulf of Guinea. Most of the Economic activities in this area are Farming, Fishing and Tourism. (See Fig 2)

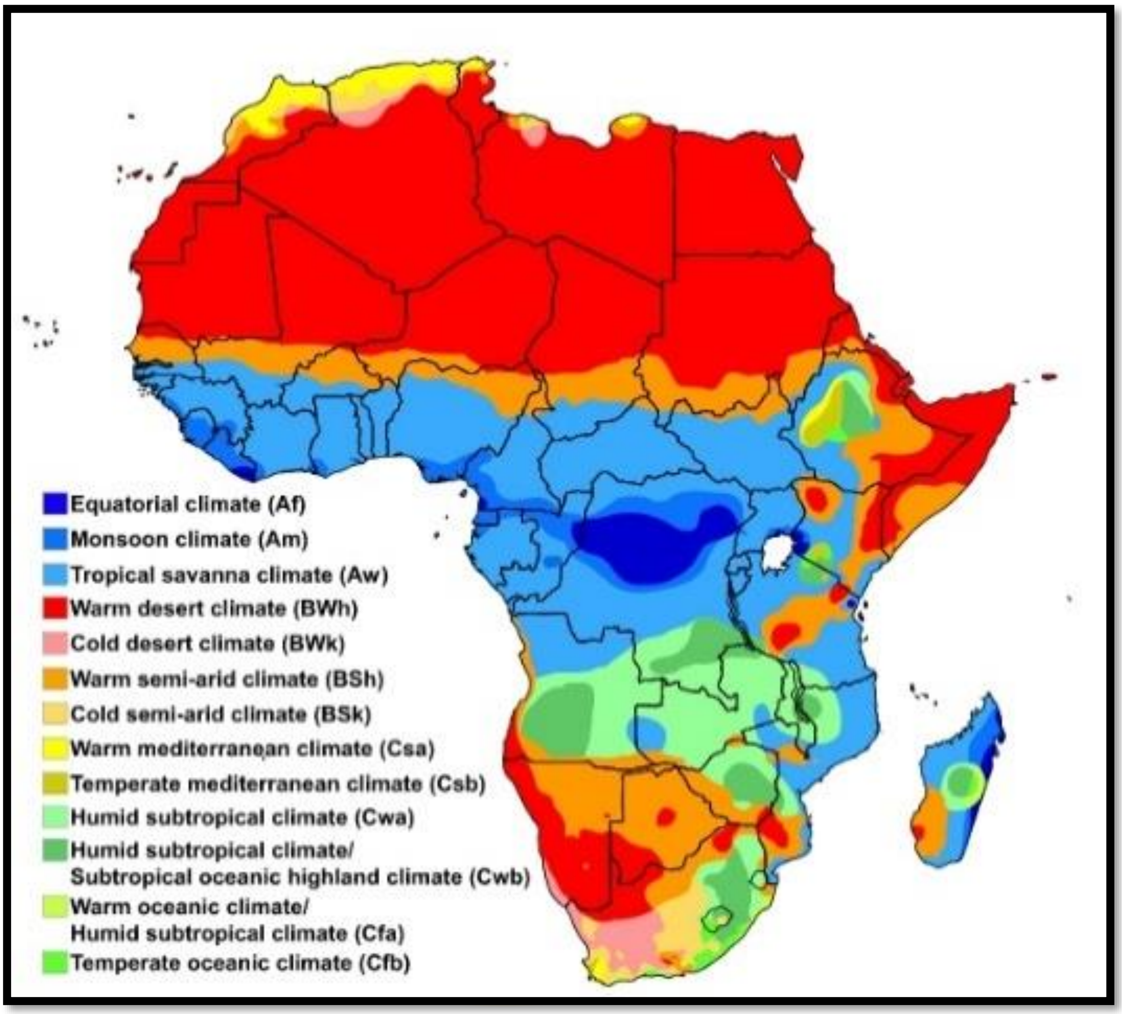


Figure 2 *Climatic zones of Africa showing West Africa*

Source: Wikipedia (2016)

Based on the current population of Western Africa as of October 2016, the region has about 365 million people from 16 different countries such as; Benin, Burkina-Faso, Cape Verde, Cote d' Ivore, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra-Leone and Togo. According to the latest United Nations estimates, the population of Western Africa is tantamount to 4.81% of the total world population, with population density of 60 per Km2 (155 people per mi^2). The total land area is 6,067,010 Km^2 (2,342,485 sq. miles) 44.6 % of the population is urban (164,351,190 people in 2016). (Worldometers, 2016). Poor economies and political instability are some of the well know situations in West Africa. According to The Technical Centre for Agriculture and Rural Co-operation (CTA) The agricultural sector forms an important part of the West African economy, contributing over 36% of regional GDP and accounting for more than 15% of export revenue, a figure potentially rising to 30% when Nigeria is excluded (CTA, 2011). Moreover, agriculture also provide a larger share in the GDP of its various countries. Except for Ghana and Nigeria that has now upgrade her economy diversely into manufacturing and exportation of digital technology, communication services, and entertainment industry respectively.

There are substantial varieties of staple foods within West Africa. Rice is one of the notable crop grown in West Africa and it has permanently become a major staple of West African diet. While some other continent uses corn as a major ingredient in most of their dishes, however, rice has become the most consumed staple in West Africa. Couscous is a common dish in North Africa. Starting from Côte d'Ivoire (Ivory Coast) to Nigeria and Cameroon, root crops, primarily varieties of yam and cassava, are common. Yam is a dominant crop in the region and is normally prepared in a variety of dishes, such like amala (pounded yam) and egusi (melon) sauce a favourable dish in Nigeria. Other locally grown foods such as onions, millet, sorghum, plantains, coconuts and peanuts are some of the other prevalent staples in West Africa.

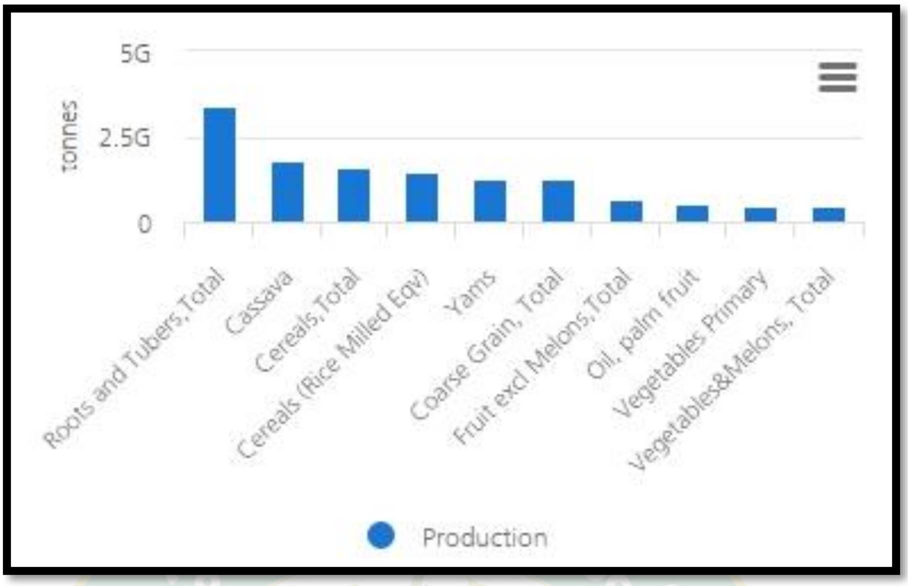


Figure 3 *Sum of most produced commodities in West Africa (1961 - 2014)*

Source: FOASTAT (Nov 16, 2016)

Fig 3 shows that root and tuber are the most produced crops in West Africa contributing a large share of consumed commodity in West Africa. However, main root and tubers crops produced in West Africa is cassava, which contributes a large share of total root and tuber production followed by yam and the others. However, poor agricultural practices and inadequate farming system has been one of the major reason why there was not much difference between total production and area harvested on cassava production in West Africa, (see appendix). However, since the introduction of some agricultural revolution the sector has started gaining more from total production than area harvested but that was due to the fact, that more farmers started giving interest to research and development in the enlargement of its total production by propagating its various species according to the current economic and climatic changes. **(See appendix for other crops).**

As aforementioned stated above, there are bundles of climatic change effect on agricultural production in West Africa. However, this study investigated the role precipitation and temperature played on the production of staple crops, which are predominantly been produced and consumed in West Africa. Such as; Cassava, Maize, Rice and Yam with a times series data from 1994 – 2014 also project the future effect temperature and precipitation will have on the production of these staples for the year 2030, 2060 and 2090. Because precipitation and temperature both have a sensational effect on agriculture systems. Moreover, rain-fed agriculture, which is mostly practiced in West Africa countries rely on rain as the most effective means of watering. Therefore, studies on the effect of climate variables on both past and future scenario of agricultural production in the region are been needed as a way of creating awareness on the effects of climate change relationship with crops productions along with preparation and adaptation for future production. This will however, help fill the poverty gap that has long existed in the West Africa.

1.1 IMPORTANT OF THE STUDY

Although, poverty and lack of educational skills has been the major problem in Africa, therefore, agriculture has now played a gigantic role in sustaining the people in the region including West Africa. Farming in West Africa, rely on rain-fed production, low fertilizer use, inadequate water management poor quality seeds and low soil fertility. Previous studies have focus on impact, vulnerability, adaptation, crop growth and trends of climatic condition on the yield and production of agricultural commodities, but none have looked at the effect of temperature and precipitation on the production of present and future production of cassava, maize, rice and yam. Therefore, this study will help create awareness and mitigate the effect of climatic variables on the production of future climate changes.

1.2 ADVANTAGE OF THE STUDY

1. This study will help offer recommendations to Western African countries that are already dealing with the vulnerabilities of climate change on staple crops production in the Region.

2. This study will also help decision makers and researchers find West African Agriculture and its climatic changes an essential tool in the making the proper adaptation policy for future changes.

1.3 OBJECTIVES OF THE STUDY

1. Analyze the production of staple crops in West Africa with a time-series data from 1994 – 2014.
2. Analyze the effects of observed climatic variables (temperature and precipitation) on the production of staple crops in West Africa.
3. Project future effect of climatic changes on staple crops in West Africa.

1.4 DEFINITION OF TERMS

1. **Climate Variable:** Climate variable in this study relates with the variable used in this study such as; **temperature and precipitation.**
2. **Climate change:** change in the usual weather over some period, due to natural variability or because of human activity. In this study climate change relates to the combination of both **temperature and precipitation**
3. **Staple Crops:** In this study are **Cassava, Maize, Rice and Yam.**
4. **West Africa:** In this study consists of 16 countries. **(Benin, Burkina-Faso, Cape Verde, Cote d' Ivore, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra-Leone and Togo)**

CHAPTER 2

LITERATURE REVIEW

Studying the potential effect of climate change on staple crops in West Africa, the researcher embark on the review of some notable literature reviews in order to pioneer the appropriate ways on making the objectives of this study justifiable. Most West African countries practice rain-fed system of Agriculture. Whereby, paving way for climate change in playing a vital role on crop yield. Different crops are been affected differently by climate of various countries in the world, in some countries, yields may rose above expectation, and for others it might reduce or get below expectation depending on the latitude of such country and the types of irrigation methods that are applied in crop production systems. Therefore, in this chapter, the researcher study palatable theories and model used in studying the effect of climate change on crop production, evidence temperature and precipitation has long been derailing agricultural activities, related risk and conceptual framework. Including theories behind the model used by the researcher in completing this study.

2.1 TYPES OF CROP YIELD MODELS

Depending upon the purpose for which it’s designed the models are been classified into different groups as explained below:

a. Statistical models: These models express the relationship between yield or yield components and weather parameters. In these models, relationships are measured using statistical techniques. Example: Step down regressions, correlation, etc.

b. Mechanistic models: These models explain not only the relationship between weather parameters and yield, but also explains the relationship of influencing dependent variables. These models base on physical selection.

c. Deterministic models: These models estimate the exact value of the yield or dependent variable. These models also have defined coefficients.

d. Stochastic models: A probability element is attach to each output. For each set of inputs, different outputs are been given along with probabilities. These models define yield or state of dependent variable at a given rate.

e. Dynamic models: Time is included as a variable. Both dependent and independent variables are having values, which remain constant over a given period.

f. Static: Time is not included as variables. Dependent and independent variables having values remain constant over a given period.

g. Simulation models: Computer models, in general, are a mathematical representation of a real world system. The uttermost priority of this model is to calculate agricultural production as a function of weather and soil conditions as well as crop management.

h. Descriptive model: A descriptive model defines the behaviour of a system in an easy approach. The model reflects little or none of the mechanisms that are the causes of phenomena. They consists of one or more mathematical equations. An example of such an equation is the one derived from successively measured weights of a crop. The equation is helpful to determine quickly the weight of the crop where no observation were been observed.

i. Explanatory model: This consists of quantitative description of the mechanisms and processes that cause the system conduct. To create this model, a system is analyze and its processes and mechanisms are been quantified discretely. (Murthy, 2002)

Different approaches have been used to measure the effect of climate change on agricultural production. According to (Hertel and Rosch, 2010) they classify these approaches into three sector; crop growth simulation model, hedonic or Ricardian approach, and lastly statistical or econometric approach.

2.1.1 CROP GROWTH SIMULATION MODEL

Crop growth model is an efficacious tool for predicting viable impacts of climatic change on crop growth and yield. Crop growth models are useful in solving assorted practical problems in agricultural production. Improvement are need on adequate human resource capacity in order to develop and validate simulation models across the globe. (Murthy, 2002).

Crop generally known as a plant grown for food, especially grain, fruit or vegetables. They can be for individual or commercial purpose in a unit area either for consumption or for economic purpose.

Growth is known as a process of Irreversible increase in size and volume in plants.

Simulation known as “Reproducing the essence of a system without reproducing the system itself”. In simulation, the essential characteristics of the system are been reproduced in a model, which is then studied in an abbreviated time scale.

A model is a system or methods used as an example to follow or imitate. They can be a simplified description, especially a mathematical equations or a system or process, which represents a behaviour and assist calculations and prediction. The objective of models are usually to help in explaining, understanding or improving performance of a mathematical or non-mathematical equation and system. (Murthy, 2002)

Models that deal with crop growth simulation are distinguish into two categories; Descriptive and Explanatory. (Singh). Crop models are being used to estimate the impact of increase in carbo dioxide and temperature on crop production (Matthews et al., 1995). It was been assumed that the trends in potential yields would also be shown in actual yield. These models can utilize the input from Global Circulation Models (GCM) to quantify the impact of climate changes.

2.1.2 RICARDIAN APPROACH

The Ricardian approach examines the impact of climate and other variables on land values and farm revenues. (Eid et al., 2007; Mendelsohn et al., 1994) describe Ricardian approach as a general cross-sectional model used to study agricultural production by measuring climate change damage as a reduction in net revenue or land value. In addition, it takes into account the costs and the benefits of different adaptation techniques used by farmers. According to (Kurukulasuriya et al., 2008) One of the setback in the Ricardian approach is that it cannot measure the effect of variables that do not vary across space. Specifically, this approach cannot detect the effect of different levels of carbon dioxide since carbon dioxide levels are generally the same across the world (Kurukulasuriya et al., 2008).

2.1.3 ECONOMETRICS OR STATISTICAL APPROACH

Econometric models are sets of mathematical equations or assumption built-up to provide a computable explanation of the behavior of some economic variables. Econometrics is the application of statistical and mathematical theories in economics to test hypotheses and forecast some reasonable future trends. Econometric takes economic models and tests them through statistical trials, compare and contrast the results against real-life examples. Currently, econometricians, statisticians, and climate scientists have analyzed some observed data on climate and results from climate models using econometric methods such as co-integration, change-point and transition analysis, dynamic panel methods, structural time series and so many other models.

2.1.4 JUST AND POPE PRODUCTION FUNCTION

In order to examine the effect of observed variables on both mean and variability of cassava, maize, rice and yam yield under heteroscedastic disturbances, stochastic production function is applied, a method that was developed by (Just and Pope, 1978, 1979). Followed by (Baltagi, 2008; Cabas et al., 2010; Chen et al., 2004; Guttormsen and Roll, 2014; Isik and Devadoss, 2006; Kumbhakar, 1997; McCarl et al., 2008) and (Nirote Sinnarong, 2013) The basic idea behind the Just and Pope production function encompasses around constructing the production function as a component of two functions. The first component of the function is related to the mean output, and the second one is related to the variability of the output (Just and Pope, 1979).

Where;

$$y_{it} = f(x_{itk}, \beta_k) + u_{it} = f(x_{itk}, \beta_k) + h(x_{itk}, \alpha_k)^{1/2} * \varepsilon_{it} \qquad 2.1$$

y_{it} is the production function

x_{itk} is the vector of k explanatory variables (temperature, Precipitation and area harvested)

$f(x_{itk}, \beta_k)$ is a function relating the mean level of production to x_{itk}

β and α are estimated parameters

$h(x_{itk}, \alpha_k)^{1/2}$ is a function relating to the standard deviation of production to the independent variables x_{itk}

ε_{it} is a random error term with zero mean and variance of σ^2

This specification is been estimated in a way that the explanatory variables such as climate influence both mean and the variance of crop production, as can be seen below

$$E(y_{it}) = f(x_{itk}, \beta_k) \text{ and Var } (y_{it}) = h(x_{itk}, \alpha_k)\sigma^2$$

The stochastic production function given by equation (2.1) has been estimated frequently using both maximum likelihood and feasible generalized least squares (FGLS) under heteroscedastic disturbances. But maximum likelihood estimation is more efficient and unbiased than FGLS estimation in a situation where we have smaller sample size (Saha et al., 1997). However, this study makes use of large sample size there is tantamount to make use of feasible generalized least squares under its heteroscedastic disturbance.

To estimate equation (2.1), the (Just and Pope, 1978, 1979) approach is used. Moreover, making using of panel data following (Chen et al., 2004) and others by assuming that all crops production and explanatory variables have relationship in form of log-linear or Cobb-Douglas Production function model. A panel data model for controlling intertemporal and regional differences

$$\ln(y_{it}) = \alpha + \ln(x'_{it})\beta + u_{it} = 1,\ldots N; t = 1,\ldots T \qquad 2.2$$

$$u_{it} = \mu_i + v_{it} \qquad 2.3$$

Where

y_{it} is the log of the production quantify observed for country i at time t

x'_{it} is a vector of explanatory variables for province i at time t as will be discussed below

β is a vector of estimated coefficients

u_{it} is the model residual

μ_i is the unobserved area-specific effect and v_{it} is the disturbance reminder.

2.1.5 PRE-ESTIMATION TEST

PANEL UNIT ROOT TEST

Panel unit root testing came apparent from time series unit root testing. The major difference to time series testing of unit roots is that we have to consider asymptotic behavior of the time-series dimension T and the cross-sectional dimension N. Whereby N and T are infinity, which make it critical in determining the asymptotic behavior of estimators and tests used for nonstationary panels. There are several possibilities that is used to deal with asymptotic: (Baltagi, 2008)

1. **Sequential limit theory** (one dimension is fixed, say N, and the other dimension T is allowed to be infinity and provides an intermediate limit; starting from this intermediate point, N is allowed to grow large)
2. **Diagonal path limits** (N and T go to infinity along a diagonal path—e.g., there is a monotonic increasingly connection between N and T)
3. **Joint limits** (N and T are allowed to go to infinity at the same time) (Levin et al., 2002)

Panel unit-root tests can have the mutual advantage of using a panel, by increasing the number of observations. In addition, (Levin et al., 2002) have shown that the panel approach substantially increases the power of the test relative to the time series ADF tests.

- The 1993 model takes the following form (to remove autocorrelation lagged dependent variables included):

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{p_i} \varphi_{iL} \Delta y_{i,t-L} + z'_{it}\gamma + u_{it}$$
$$z'_{it} - fixed \,/\, random\ effect \qquad 2.4$$

The error terms across the cross sections are assume independent. It assumed that ρ is the same across on all cross sections. The lag length for the lagged dependent variables are chosen in the usual way as with Augment Dickey-Fuller tests, a trend can also be included in the test.

LEVIN, LIN AND CHU TEST (LLC)

According to the published result of (Levin et al., 2002) where they argued that individual root test possess restricted power against alternative hypotheses with highly persistent deviations from equilibrium. Therefore, they suggested more reliable testing rather than embarking on individual testing for each cross-section. Whereof, individual testing is severe in small samples. The null hypothesis of the LLC unit root test states that each individual time series contains a unit root against the alternative that each time series is stationary. The maintained hypothesis state that:

$$\triangle y_{it} = py_{i,t-1} + \sum_{L=1}^{pi} \theta_{iL} \triangle y_{it-L} + \alpha_{mi} d_{mt} + \varepsilon_{it} \quad m = 1, 2, 3 \qquad 2.5$$

Where, d_{mt} indicates the vector of deterministic variables and α_{mi} do with the corresponding vector of coefficients for model m = 1, 2, 3. However, d_{lt} = {empty set}, d_{2t} = {1} and d_{3t} = {1,t}. Moreover, since the lag order pi is unknown, LLC suggest a three-step procedure to enforce their test.

1. Perform separate augmented Dickey-Fuller (ADF) regression for each cross-section.
2. Estimate the ratio of long run to short-run standard deviations. Under the null hypothesis of a unit root.
3. Compute the panel test statistics and run pooled regression. (Levin et al., 2002)

LLC suggest that using their panel unit root test for moderate panel size with N between 10 and 250 and T between 25 and 250. They argue that the standard panel procedures may not be computationally feasible or sufficiently powerful for panels of this size. However, for very large T, they argue that individual unit root time series tests will be sufficiently powerful to apply for each cross-section. In addition, for very large N and very small T, they recommend the usual panel data procedures. (Baltagi, 2008)

The proposed LLC test has its limitations. The test crucially depends upon the independence assumption across cross-sections and is not applicable if cross sectional correlation is present. Second, the assumption that all cross-sections have or do not have a unit root is restrictive. (Baltagi, 2008)

IM PESARAN AND SHIN TEST

- The Im Pesaran and Shen test is alternative example to the Levin and Lin test, instead of assuming a common unit root process, where all the ρ are identical; it tests for individual unit root processes.
- This in effect tests for all i cross-sections to be stationary.
- The Im Pesan and Shin test averages all the individual ADF test statistics.
- The null hypothesis in this case is that each series contains a unit root for all i cross-sections.

The Im Pesaran and Shin test in effect follows the model below:

$$\Delta y_{it} = \rho_i y_{i,t-1} + \sum_{L=1}^{p_i} \varphi_{iL} \Delta y_{i,t-L} + z_{it}'\gamma + u_{it}$$
$$z_{it}' - \textit{fixed / random effect} \qquad 2.6$$

Im Pesaran and Shin and Levi Lin tests Compared

The main difference between the tests, is that one assumes a common unit root, the other individual unit root, also the Im Pesaran and Shin has an alternative hypothesis stating that at least one of the I cross section series is stationary, so Levi and Lin requires all to be stationary, Im Pesaran and Shin require some to be stationary. Both suffer from the assumption that the error terms across the cross sections are independent, which rules out any co-integration between them. This may not always be the case, particularly where the cross sections are financial markets or banks. Depending on different values of the N and T components, the two test statistics can give different results (Levin et al., 2002)

HETEROSCEDASTICITY TEST

Heteroscedasticity assumes that the residual ε_i were identically distributed with mean zero and equal variance $\sigma^2 (i.e., E(\varepsilon_i | \ X_i) = 0,$ and Var $(\varepsilon_i | \ X_i) = \sigma^2,$ where X_i means
$\{X_{i2}, ..., X_{ik}\}$, for i = 1, 2, ..., n).

Because the variance is a measure of dispersion of the observed value of the dependent variable (y around the regression line $\beta_1 + \beta_2 X_2 + ... + \beta_k X_k$), homoscedasticity means that the dispersion is the same across all observations. However, in many situations, this assumption might be false.

Consequences of Ignoring Heteroscedasticity

$$yi = \beta_1 + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i \tag{2.7}$$

Where Var $(\varepsilon_i | \ X_i) = \sigma^2$, for $i = 1, ..., n$ That is, the error variances are different for different values of i are unknown. In the presence of heteroscedasticity, the Ordinary Least Square estimator b is still unbiased, consistent and asymptotically normally distributed.

Moreover, if heteroscedasticity is been ignored and continue with the usage of ordinary least square to estimate $\beta 's,$ the properties of unbiasedness and consistency are still not violated. However, ordinary least square estimation is no more efficient. It is possible to find an alternative unbiased linear estimation that has a lower variance than ordinary least square estimator (Gau, 2002)

Effects of Heteroscedasticity on Forecasting

Forecast based on ordinary least square estimation will be unbiased. But forecasts are inefficient because the estimates are inefficient (Gau, 2002)

Properties of OLS with heteroscedasticity Errors:

1. The estimates and forecasts based on OLS will still be unbiased and consistent.
2. The OLS estimates are no longer BLUE and will be inefficient. Forecasts will also be inefficient.
3. The estimated variances and covariance of the regression coefficient will be biased and inconsistent, and hence tests of hypotheses are in valid.

There are various ways in which we can use in testing for heteroscedasticity such as (Goldfeld-Quandt Test which is based on the ration of variance, Lagrange Multiplier Test or Breusch-Pagan Test which is sensitive to any violation of the normality assumption and White Test which has been found useful as large sample test of more than 30 samples. (Gau, 2002).

GOLDFELD-QUANDT TEST

The idea behind this test is that, If the error variances are equal across observations (i.e., homoscedastic), then the variance for one part of the sample will be the same as the variance for another part of the sample. Divide the sample of observations into three parts, and then discard the middle observations. Estimate the model for each of the two other sets of observations and compute the corresponding residual variances. Use an F -test to test for the equality of these two variances. (Gau, 2002).

BREUSCH-PAGAN TEST / COOK-WEISBERG TEST

The LM statistic of the test is actually called the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity (BP test). Breusch-Pagan test is aversion of LM statistic for the hypothesis $\alpha_2 = \cdots = \alpha_k = 0$. The LM test consists of an auxiliary regression and using it to construct a test statistic. While embarking on using this test, consider the following, Breusch-Pagan shown to be sensitive to any violation of the normality assumption. Breusch-Pagan test also requires a prior knowledge of what might be causing the heteroscedasticity. (Gau, 2002).

WHITE TEST

A direct test for heteroscedasticity, which relates to the Breusch-Pagan test but does not assume any prior knowledge of the heteroscedasticity. White's test is a large sample LM test with a particular choice for the Z's, but it does not depend on the normality assumption. Although White's test is a large sample test, it had been useful in samples of 30 or more. If the null is not rejected, it implies that the residuals are homoscedastic. (Gau, 2002).

The standard error component model given by equations (2.2) and (2.3) assumes that the regression disturbances are homoscedastic with the same variance across time and country. This may be a restrictive assumption for panels, where the cross sectional units may be of varying size and as a result may exhibit different variation. Assuming homoscedastic disturbances when heteroscedasticity is present will still result in consistent estimates of the regression coefficients, but these estimates will not be efficient. Also, the standard errors of these estimates will be biased and one should compute robust standard errors correcting for the possible presence of heteroscedasticity. (Baltagi, 2008) Heteroscedasticity test are been used to test the effect of both precipitation and temperature on staple crops in West Africa. Heteroscedasticity causes our Ordinary Least Square estimator to be unbiased.

FIXED AND RANDOM EFFECT TEST

The rationale behind random effects model is that, the variation across entities is assume a random and uncorrelated with the predictor or independent variables that are included in the model. (Greene, 2008) the crucial distinction between fixed and random effects is whether the unobserved individual effect embodies elements that are correlated with the regressors in the model, not whether these effects are stochastic or not. The random effect is been used when there are difference across entities, which influence some of the dependent variable. One benefit of the random effect is that it can add time invariant variables.

$$Y_{it} = \beta X_{it} + \alpha + u_{it} + \varepsilon_{it} \qquad 2.8$$

The Random effects assume that the entity's error term are not been correlated with the predictors, which allows time-invariant variables to play a role as explanatory variables. Those individual characteristics that may or may not influence the predictor variables needs to be specify in the random effect. The problem with this is that some variables may not be available therefore leading to omitted variable bias in the model.

The Hausman test is been used to decide and differentiate between fixed and random effect. Statistically, fixed effects are always a reasonable thing to do with panel data. Random effects give better P-values as they are a more efficient estimator.

2.2 CLIMATE CHANGE

Lasco et al. (2011) Climate change, defined as any change in the average daily weather pattern over a continued period whether due to natural instability or as a result of human activity (Easterling WE et al., 2007; IPCC, 2007), climate change is happening now, and is already affecting many natural systems around the world (IPCC, 2007). In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) declared that climate change is indisputable (IPCC, 2007), evidenced by observed changes in several global and regional climatic indicators. The Food and Agriculture Organization (FAO) expects that considerable efforts would be required to prepare developing countries to deal with climate-related impacts, particularly in agriculture (FAO, 2007). However, the IPCC also notes that recent studies show a high confidence that there are viable adaptation options that can be implemented at low cost and/or with high benefit-cost ratios (IPCC, 2007)

At the country level, climate change refers to observable changes and permutations of temperature, rainfall and extreme climate events and their single or aggregated impacts on various agricultural production and harvesting activities (Lasco et al., 2011). Temperature escalation would have whole year and day-to-day on-site impacts that accelerate the changes/decomposition of soil organic matter and loss of soil fertility, which ultimately affects the overall health of crops and livestock. Soil temperature and organic matter are useful indices of ecosystem recovery after disturbance of natural vegetation (Aust and Lea, 1991). The varying intensity and patterns of rainfall and extreme climate events (typhoons and El Niño) during the remaining periods of rainy season would have broaden the coverage of climate change off-site impacts which include massive soil erosion and irreversible loss of sloping land soil fertility and life threatening floods and landslide (Lasco et al., 2011).

2.3 EVIDENCE OF TEMPERATURE AND PRECIPITATION ON AGRICULTURAL PRODUCTION

Temperature and precipitation are examine as a major climate condition, which will require farmers to adapt to its changing conditions. Major factor of adaptation breadth to climate change include; changes in agricultural practices, changes in agricultural water management, agricultural diversification, agricultural science and technology development, agricultural insurance and risk management. Generally, these measures are intended to increase flexibility on farming practice, improve crops and livestock through breeding and investing in innovative technologies and infrastructure (Cruz et al., 2007)

Existing results shows that rise in precipitation will increase crop yield, moreover, crop yield is more sensitive to the precipitation than temperature. If water availability reduced in the future, soils with higher water holding capacity will be better to reduce the impact of drought while maintaining crop yield, with increase temperature and fluctuations in precipitation, water availability, and crop production will probably decrease in the future. If the irrigated areas expands, the total crop production will escalate; however, food and environmental quality may degrade. (Kang et al., 2009)

Bannayan et al. (2011) investigated the role played by precipitation, temperature and three climate indices [Arctic Oscillation (AO), North Atlantic Oscillation (NAO) and NINO 3.4] in historically observed rain-fed crop yields between 1983–2005 of both barley and wheat in the northeast of Iran. The results revealed differences in the association between crop yield and climatic factors at different locations. The south of the study area is a very hot location, and the maximum temperature proved to be the limiting and determining factor for crop yields; temperature variability resulted in crop yield variability.

Mereu et al. (2015b) Changes in climatic conditions are very likely to decline cereal crop productivity in Sub-Saharan Africa, with high differences in yield projections according to regional variability. (Lobell and Burke, 2008; Nelson et al., 2009; Roudier et al., 2011; Thornton et al., 2009; Webber et al., 2014) analyzed simulations for all Sub-Saharan Africa regions, highlighting climate change impacts on cereal crop yields, ranging from 2 % for sorghum to 35 % for wheat by 2050. Similarly, the highest yield reductions are projected for wheat (-21 %) in the study of (Ringler et al., 2010), while yields for millet and sorghum are projected to be slightly higher (1–2 %). On the contrary, crop yield reductions in Sub-Saharan Africa are projected by mid-century for sorghum and millet (-17 %), in the study of (Schlenker and Lobell, 2010)

Mereu et al. (2015b) Study the Impact of climate change on staple food crop production in Nigeria. Their study presents a multi-model approach to analyzing climate change impacts and associated risks for staple food crops in Nigeria. They discovered that Large uncertainties in yield projections are recognizable in the Sahel region (the northern part of the states of Borno, Yobe and Sokoto), where yields are expected to increase in the short period for sorghum, millet and rice, whereas in the medium-term appreciable increases in yield are expected only for millet. On the contrary, for the other Agro-Ecological Zones there is a good consensus among climate models, with changes in crop yields ranging from 0 to -20 % for sorghum and maize, from +20 to -40 % for millet, and from +8 to -25 % for rice. For Cassava, yield changes from +20 to -24 % are projected, with increases expected especially in the Northern drier Agro-Ecological Zones (Sudan and Northern Guinea Savanna), although affected by large uncertainties linked to climate change projections for this part of the Country.

Nirote Sinnarong (2013) study the potential impacts of climate change on agricultural production based on econometric panel data model. Including the impact of drought phenomenon on rice production in Asia using a stochastic production function as a moment based model for the production of rice in Asia. The study shows that both temperature and precipitation have a significant impact in the production of rice in Thailand. Whereby drought phenomenon projection for 2020s to 2060 revels that the mean production of rice in Asia will decrease by 6.92 to 13.18% respectively.

Sultan et al. (2013) studied the climate change impacts on sorghum and millet yields in the Sudanian and Sahelian Savannas of West Africa. They applied the process-based crop model SARRA-H calibrated and validated over multi-year field trials and surveys at eight contrasting sites in terms of climate and agricultural practices in Senegal, Mali, Burkina Faso and Niger. The model gives a reasonable correlation with observed yields of sorghum and millet under a range of cultivars and traditional crop management practices. They also applied the model to more than 7000 simulations of yields of sorghum and millet for 35 stations across West Africa and under very different future climate conditions. Moreover, they also took into account 35 possible climate scenarios by combining precipitation anomalies from -20% to 20% and temperature anomalies from C0 to C6 °C. They found that most of the 35 scenarios (31/35) showed a negative impact on yields, up to -41% for C6 °C= - 20% rainfall. Moreover, the potential future climate impacts on yields are very different from those recorded in the recent past.

The Earth's land resources are finite, whereas the number of people that the land must support continues to grow rapidly. This creates a major problem for agriculture. The production (productivity) must increase to meet rapidly growing demands while there is uttermost need to protect natural resources. New agricultural research is needed to supply information to farmers, policy makers and other decision makers on how to accomplish sustainable agriculture over the wide variations in climate around the world. In this direction, explanation and prediction of growth of managed and natural ecosystems in response to climate and soil-related factors are increasingly important as objectives of science. a change in weather to warm and humid may lead to the more rapid development of a plant disease, a loss in yield of a crop, and consequent financial adversity for individual farmers and so for the people of a region.

2.4 STAPLE CROPS RISK TO CLIMATE CHANGES

According to the most recent literature review, climate changes for the past 30 years have already reduced world agricultural production in the range 1-5 % per decade internationally, most especially some negative effects on tropical cereal (West Africa) crops such as maize and rice (Porter et al., 2014). Moreover, there are now explicit evidence suggesting that even at low (+2 °C) levels of warming, agricultural production is likely to decrease across the world, but most especially in tropical areas (West Africa) (Challinor et al., 2015)

If no adaptation actions are taken for tropical areas in West Africa, average maize production could reduce by 5-10%, whereas rice production could reduce by 2-5% degree of warming during the 21st century. (Ramirez-Villegas and Thornton, 2015). Adaptation process only can reduce some of the negative impact of climatic changes on the production of these crops.

(Ramirez-Villegas and Thornton, 2015) projected that during the 21st century, the total maize output will decline at a rate of 3-5 tonnes per decade from historical levels as a result of climate change. According to these projections, if there is no adaptation by the end of the 21st century, the total maize production of Africa will decrease from ~42 to ~37 million tonnes per year (12%) in the best scenario, and if the situation get worse the maize production could be as low as 25 million tonnes per year (40% reduction). (Ramirez-Villegas and Thornton, 2015). These projections are vigorous, therefore, adaptation of maize production should be a priority for many African countries, most especially countries in the Sahel.

Cassava is a plants which has been a major staple across West Africa are at risk from disease as regional temperatures rise, as the trend goes on. cassava, has been a significant source of food and income in the economy of most west Africa countries, according to the current climatic trend, high temperature will cause cassava a disease popularly known as (Cassava Brown Streak Disease) transmitted by insects whose numbers are surging with rising temperature and this will cause serious food shortages may worsen poverty worsen.

Maize and rice are crops that can’t stand drought well and maize can easily rot during storage in tropical climates. Although according to previous literature, it was said that maize could do well in a wetter atmosphere that hotter one, but the climatic trend of West Africa puts maize on the Vulnerability list. Although, lack of sunshine and nitrogen can reduce the production ability of maize in West Africa.

The projections herein analyzed explicitly shows that impacts of climate change on staple crops in West Africa in a different way. For some countries such as those along the Sahel, climate change means that most of the crops that are presently climatically suitable can no longer be planted in the area. Indeed, previous literature suggests that in some areas of these countries a livelihood change from crops production to livestock is required (Jones and Thornton, 2009; Thornton et al., 2009).

After thorough literature reviews and research on climate change and food agricultural production, the researcher hereby summarized in the table below showing an explicit result of scholars whose research also justify climatic variability pose both negative and positive result on the yield of agricultural production. Although the increase or decrease in yield might be different for each geographical region and based on each kinds of crops.

Table 1 *Summary of related literature reviews*

Author (Year)	Title	Result
Niang et al (2014)	Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects	Evidence of increased temperature in most parts of Africa.
Battisti and Naylor (2009) Lebel and Ali (2009) Nicholson and Yin (2001)	Historical warnings of future food insecurity with unprecedented seasonal heat. Recent trends in the Central and Western Sahel rainfall regime (1990–2007). Rainfall conditions in equatorial East Africa during the nineteenth century as inferred from the record of Lake Victoria.	Evidence of decline on precipitation in Africa
Boko et al (2007) Liu et al (2008) Roudier et al (2011) Thornton et al (2009) Nelson et al (2009) Cruz et al (2007)	Climate Change 2007: Impacts, Adaptation and Vulnerability A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change. The impact of future climate change on West African crop yields: What does the recent literature say? Spatial variation of crop yield response to climate change in East Africa. Climate change: Impact on agriculture and costs of adaptation. Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability.	Food production system in Africa is among the world's most vulnerable system because of substantial reliance on rain-fed crop production
Schlenker and Lobell (2010) Sultan et al (2013)	Robust negative impacts of climate change on African agriculture. Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa	Evidence of diminished yield of major crops in Africa
Kang et al (2009)	Climate change impacts on crop yield, crop water productivity and food security–A review.	Crop yield is more sensitive to the precipitation than temperature. Therefore, extended irrigated areas will lead to higher total crop production.
Bannayan et al (2011)	Effects of precipitation and temperature on crop production variability in northeast Iran.	Maximum temperature limits and determine factor

		for crop yield. Variability in temperature amount to yield variability
Mereu et al (2015)	Impact of climate change on staple food crop production in Nigeria.	Changes in climatic conditions are likely to decline cereal production.
Lobell and Burke (2008) Nelson et al (2009) Roudier et al (2011) Thornton et al (2009) Webber et al (2014) Ringler et al (2010)	Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Climate change: Impact on agriculture and costs of adaptation. The impact of future climate change on West African crop yields: What does the recent literature say? Spatial variation of crop yield response to climate change in East Africa. What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa? Climate change impacts on food security in sub-Saharan Africa.	Reduction on the future simulation of cereal production.
Nirote Sinnarong (2013)	Essays on the Impacts of Climate Change in Agricultural Production.	Temperature and precipitation have a significant impact in the production of rice in Thailand
Nirote Sinnarong (2013)	Essays on the Impacts of Climate Change in Agricultural Production.	Drought phenomenon projection for 2020 to 2060 shows a decrease in mean rice production.
Sultan et al (2013)	Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa.	Temperature and precipitation anomalies showed a negative impact on yield.

2.5 CONCEPTUAL FRAME WORK

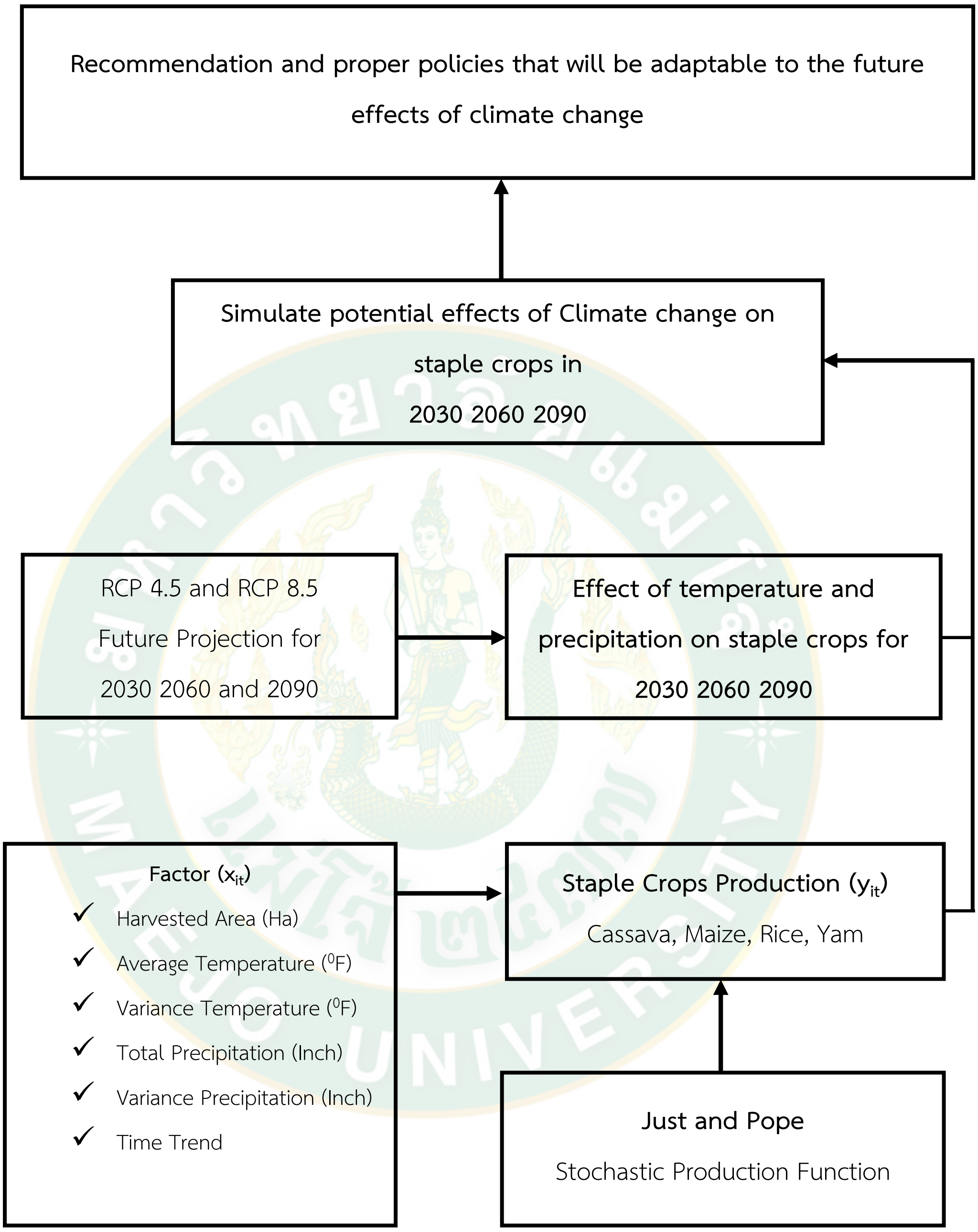


Figure 4 *Conceptual framework*

CHAPTER 3

METHODOLOGY

This study focuses on the effect of climate change on staple foods in West Africa by considering the mean and variance of climate variables as well as the corresponding productions with the use of stochastic production function with a panel data. This study specifically, also intends to answer the following open questions based on the methodologies that was applied.

1. How does the change in the observed variable affect staple food (Cassava, Maize, Rice and Yam) mean production and variability?
2. How will the projection of future climate variable affect the production of staple crops?

This study also applies econometric approaches as an alternative to the crop simulation approach, because crop simulation explains how the crops function in a quantitative manner. Therefore, statistical function of Just and Pope is been used to explain the effect of observed variables (temperature and precipitation) on the production of Cassava, Maize, Rice and Yam. Instead of the Ricardian approach that is just a cross-sectional technique used to determine net revenues to farmers. The Just and Pope production function in this study examine the effect of precipitation and temperature on the mean and variance of the production of Cassava, Maize, Rice and Yam in West Africa. Then, a projection technique is used to show the potential simulation effects of both temperature and precipitation on the staple crops (Cassava, Maize, Rice and Yam) production in West Africa for 2030 2060 and 2090.

3.1 DATA SET

Data from 1994 – 2014 yearly agricultural production of Cassava, Maize, Rice and Yam for the 16 countries in West Africa are been collected from the Food and Agriculture Organization of the United Nation (FAOSTAT, 2016). Consisting of area harvested, yield and Production quantity. Two climate data sets (Temperature and Precipitation) were used. A set for 1994 –2014, compiled from 323 meteorological stations with time series at daily resolution located in 16 countries across West Africa. However, only data from stations that is located in regions where these staple crops are been mostly planted were used. National Environmental Satellite, Data, and Information Service have compiled these data sets. (NERDIS) NOAA Satellite and Information Service.(NOAA, 2016) The daily elements included in the dataset (as available from each station) are: Mean temperature. (.1 Fahrenheit) Mean dew point (.1 Fahrenheit). Mean sea level pressure (.1 mb). Mean station pressure (.1 mb). Mean visibility (.1 miles). Mean wind speed (.1 knots). Maximum sustained wind speed (.1 knots). Maximum wind gust (.1 knots). Maximum temperature (.1 Fahrenheit). Minimum temperature (.1 Fahrenheit). Precipitation amount (.01 inches). Snow depth (.1 inches). Indicator for occurrence of: Fog, Rain or Drizzle, Snow or Ice Pellets, Hail, Thunder, Tornado/Funnel Cloud. (NOAA, 2016).

Figure 5 *Territorial boundaries of West African countries*

Source: Map of Worlds (Nov 19, 2016)

In terms of the projected future changes, data were statistically downscaled Couple Model Inter-comparison Project (CMIP5) for two different Representative Concentration Pathways (RCP 4.5 and RCP 8.5) under the IPCC 4th Assessment Report. RCP 4.5 is a scenario of long-term, global emissions of greenhouse gases, short-lived species, and land-use-land cover, which stabilizes radiative forcing at 4.5 Watts per meter squared (W m2, approximately 650 ppm CO2-equivalent) in the year 2100 without ever exceeding that value (Thomson et al., 2011). RCP8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high-energy demand and GHG emissions in absence of climate change policies. (Riahi et al., 2011) Table 6 shows the average temperature and precipitation of 2030, 2060 and 2090 for each growing season in the region.

3.2 EMPIRICAL MODELS AND ANALYZES

In order to construct efficiently the estimated parameters on the error component model with cross-section heteroscedasticity, panel unit-root test and heteroscedasticity test were performed. To prevent the issue of spurious correlation, the test for the presence of unit root for each variable is necessary step prior to process the FGLS estimation (Chen et al., 2004). Thereafter, carry out some other tests, in order to confirm that the variance component of production function is been reflected in the presence of heteroscedasticity in the production function. Such tests may include Glejser test, which regresses the absolute residuals on the original regressors as well as ARCH test that regresses the squared residuals on lagged square residuals and constant.

The panel data model can be estimated using either a fixed effects (FE) model, which controls for omitted variables that differ between countries but are constant over time, or a random effects (RE) model, which considers that some omitted variables, may be constant over time but vary between countries. Therefore, to determine the appropriate model specification, this study uses Fixed Effects Tests, based on the test result shown by Hausman Test, which signify its more effective for the dataset.

The empirical model for mean production equation is been estimated for cassava, maize, rice and yam are constructed for each crop

$$PROD_{it} = \beta_0 + \beta_1 HAREA_{it} + \beta_2 ATEM_{it} + \beta_3 VTEM_{it} + \beta_4 TPRE_{it} + \beta_5 VPRE_{it} \beta_6 T_{it} + \mu_i + v_{it} \qquad 3.4$$

Where:

$PROD_{it}$ is the natural logarithm of cassava, maize, rice and yam production (in tons),

$HAREA_{it}$ is the natural logarithm of harvested area (in hectare),

$ATEM_{it}$ is the natural logarithm of monthly average temperature for the growing season (in °F)

$VTEM_{it}$ is the natural logarithm of variation of temperature for the growing season and is been used to capture the effects of temperature variability on yield,

$TPRE_{it}$ is the natural logarithm of monthly total precipitation for growing season (in inches.)

$VPRE_{it}$ is the natural logarithm of variation of precipitation for the growing season and is been used to capture the effects of variance variability on yield,

T_{it} is a time–trend variable that represents the effect of technological progress

In order to estimate the marginal effects of explanatory variables on the variance of cassava, maize, rice and yam production (α) with the σ^2 is unobservable, this step can use the OLS residuals from Step2 as a consistent estimator of u_{it}. Then, $u_{it}{}^2$ is regress on its asymptotic expectation, $h(x_{itk}, \alpha)$ with h(.) assumed to be exponential function, $E(\sigma^2_{it}) = \exp(z'_{it}\alpha)$. After taking logs on both sides, it can be rewritten as $\ln\sigma^2_{it} = z'_{it}\alpha$ which z'_{it} elements are non-linear transformations of explanatory variables (x_{it}') as same as the explanatory variables used in equation (3.4). Then, apply panel least square data to estimate the following non-linear regression;

$$\ln\ (u_{it})^2 = \alpha_0 + \alpha_1 HAREA_{it} + \alpha_2 ATEM_{it} + \alpha_3 VTEM_{it} + \alpha_4 TPRE_{it} + \alpha_5 VPRE_{it} + \alpha_6 T_{it} + e_{it} \qquad 3.5$$

Even though Just and Pope production function seems perfect in a way that it was able to point out the effect of climate variables and other inputs on mean yield and yield variance at the same time, it is criticized for its attempt to link variance with risk. Therefore, according to (Zellner and Rossi, 1984) argued that an increase in variability of output does not correspond to increased risk, and increased usage of an input may not, necessarily enlarge the variance of output. Therefore, the researcher utilized the Just and Pope Production function as the main model of this study.

CHAPTER 4

RESULT AND DISCUSSION

The result of studying the potential effect of climate change on staple crops in West Africa using a data for the period of 1994 – 2014 is been displayed below. The result were been divided into three sections according to the objective of this research study.

1. Descriptive statistics showing the analysis of staple crop production in West Africa.
2. Pre-estimation test and estimated parameter result for mean and variance production on staple crops in West Africa. This section also answer the open question on how observed variable (temperature and precipitation) affect the production of staple crops in West Africa.
3. The last section deals with the projection of future climate change on staple crops in West Africa for 2030, 2060 and 2090. Thereby, answering the second open question on how will the forecast of future climate variable affect the production of staple crops in West Africa.

4.1 DESCRIPTIVE STATISTICS OF PRODUCTION OF STAPLE CROPS IN WEST AFRICA

This section shed more light on the puzzle behind the first objective of this study, showing the past production of the observed crops in the region. Table 2 shows descriptive data results for all observed variables.

Table 2 *Descriptive statistics of production of staple crops in West Africa (1994 – 2014)*

Variable		Cassava	Maize	Rice	Yam
Production (Tons/Ha)	Mean	3894412	810359.7	610872.4	4228105
	Std. Dev.	9942301	1669642	992031	9063596
	Minimum	1000	951	5400	2454
	Maximum	54800000	10800000	6734000	45000000
Harvested Area (Ha)	Mean	382240.9	532929.3	334646.3	426019.5
	Std. Dev.	1006279	1057497	576639.8	957103.5
	Minimum	163	1186	5300	400
	Maximum	7102300	5849800	3095800	5416400
Average Temperature (°F)	Mean	81.33433	81.58715	81.37601	81.63476
	Std. Dev.	2.822447	3.065823	2.86531	2.271034
	Minimum	75.32571	72.68159	75.08508	76.38
	Maximum	91.37558	89.88928	92.07843	89.38867
Variance Temperature (°F)	Mean	13.59081	12.37844	13.65812	17.59742
	Std. Dev.	11.27914	6.107659	11.66619	13.70124
	Minimum	2.935851	2.935851	2.959102	2.935851
	Maximum	54.4042	43.38509	67.15084	72.90551
Total Precipitation (Inch)	Mean	23.78182	21.85616	20.06337	33.08412
	Std. Dev.	20.55727	18.30179	16.39693	21.46974
	Minimum	0.1231912	0.12	0.2	0.9
	Maximum	130.7	130.7	120.37	130.7
Variance Precipitation (Inch)	Mean	0.2107016	0.2524572	0.2418004	0.2426327
	Std. Dev.	0.3132366	0.3933299	0.396143	0.2678242
	Minimum	0.0001847	0.0003017	0.0003754	0.0211599
	Maximum	2.424916	2.927796	2.765367	2.424916

These include the production of each staple crops output in tons per hectares, Temperature in degree Fahrenheit and precipitation in inches. The descriptive statistics summary shows that tuber crops are predominant in the region. Yam and cassava are leading the production in the region with a mean of 4,228,105 ton/ha and 3,894,412 respectively. The harvested area for each crops in the region were explicitly at 532,929.3/ha and 426,019.5/ha respectively for both yam and maize. While yam took the lead position. The average temperature during the growing season for the observed crops in the region were relatively the same at 81.33^{0}F, 81.59^{0}F, 81.38^{0}F and 81.63^{0}F respectively. Total precipitation is the region ranges between 20.06 – 33.08 inches, which varied between the growing seasons of each crops across the region.

4.2 PRE-ESTIMATION SPECIFICATION TEST

Table 3 presents stationarity test results of all observed variables. In all cases, null hypothesis, which carries panel, unit root were been rejected for all variables.

Table 3 *Pre-Estimation Specification Test Results for Staple crops in West Africa*

Variable	Cassava	Maize	Rice	Yam
Panel Unit Root Test				
Production (Tons/Ha)	-5.3346***	-3.3418***	-0.2382	-2.1814
	0.0000	0.0004	0.4059	0.0146
Harvested Area (Ha)	-2.1984****	-2.2105***	-2.6792***	-2.4579***
	0.0140	0.0135	0.0037	0.0070
Average Temperature (^{o}F)	-5.1452***	-5.4499***	-5.3972***	-4.7899***
	0.0000	0.0000	0.0000	0.0000
Variance Temperature (^{o}F)	-6.6553***	-5.8363***	-6.7942***	-3.6755***
	0.0000	0.0000	0.0000	0.0001
Total Precipitation (Inch)	-4.2571***	-4.3580***	-4.4019***	-1.6295**
	0.0000	0.0000	0.0000	0.0516
Variance Precipitation (Inch)	-6.7719***	-5.7918***	-6.2267***	-4.9283***
	0.0000	0.0000	0.0000	0.0000
Heteroscedasticity				
Breusch-Pagan / Cook-Weisberg test	2431.62***	1174.42***	371.90***	931.94***
Hausman Statistic for Fixed vs. Random Effect test	61.58***	32.80***	37.57***	255.06***
	0.0000	0.0000	0.0000	0.0000

H0: Panels Contain Unit Roots; H1: Panels are Stationary

Note: Numbers in parentheses are Statistical value. ***, ** and * denotes significance at 1%, 5% and 10% respectively.

Husman Test: H0: Random Effect model is appropriate; H1: Fixed effect model is appropriate.

In order to construct efficiently estimated parameters on the error component model with cross-section heteroscedasticity, the researcher conducted Levin-Lin-Chu panel unit root (LLC). To determine the stationarity at level $(\mathrm{I}(0))$ or otherwise of all the variables used in the analysis. The researcher performed Breusch-Pagan / Cook-Weisberg heteroscedasticity test to prevent the issue of spurious correlation. Therefore, correct panel data model was determined by testing the random effects model (RE) versus the fixed effects model (FE) using Hausman statistics test. The Hausman statistic test is distributed asymptotically as chi-squared with m (explanatory variable) degrees of freedom under the null hypothesis that the random effects estimator is consistent and more efficient (Baltagi, 1995). The Hausman test statistics rejected the null hypothesis that the random effects estimator is consistent and efficient for cassava, maize, rice and yam estimations. Thus, Hausman test result shows FE is more appropriate in order to estimate Feasible General Least Square (FGLS) estimation.

4.3 ESTIMATED PARAMETER FOR MEAN PRODUCTION FUNCTION ON STAPLE CROPS IN WEST AFRICA

This study uses models, which differ in estimation techniques to examine the sensitivity of estimated explanatory variables impact on cassava, maize, rice and yam production. The estimation results were been summarized in table 4 in two specification models. The first model is panel least square, the second model is cross-section FE with FGLS. The second model estimates a FGLS specification correcting for both cross-section heteroscedasticity and contemporaneous correlation. Table 4 presents result of estimated comparison and the final estimates of proposed production functions parameters. The parameters listed in both tables are estimated elasticities for cassava, maize rice and yam production in West Africa.

Prior to the fitting of cross section FE with FGLS model, the researcher conducts a Panel Least Square regression on the mean production of observed crops in the region and the result was explicitly shown in table 4. The panel least square result shows that only total precipitation was significant on the mean production of cassava and rice in the region and average temperature proof insignificant on all observed crops in the region. However, the effect of total precipitation was negative on the mean production of cassava, while the result of rice was positive on mean production of rice in the region. Although time trend tend to be significant on the rice production too.

Table 4 shows a comparison of estimated results. The researcher chooses the best model, which carries highest adjusted R^2 and lowest root mean squared error (RMSE) in explaining the impact of temperature and precipitation on the production of staple crops in West Africa. The chosen FGLS results are consistent and asymptomatically efficient under the conditions for stochastic production functions with cross section heteroscedastic disturbance term.

Table 4 Estimated parameters for staple crops on mean production in West Africa

Variables	Cassava	Maize	Rice	Yam
Panel Least Square				
Harvested Area (Ha)	9.676869***	1.54831***	1.652457***	9.312941***
	(0.1205793)	(0.0160486)	(0.02489)	(0.1476403)
Average Temperature (^{o}F)	84641.02	4441.464	-659.0759	101167.7
	(63724.92)	(5909.52)	(6852.208)	(88014.78)
Variance Temperature (^{o}F)	-17580.67	1111.148	3131.294*	-18965.02
	(16096.91)	(3006.455)	(1731.927)	(14980.45)
Total Precipitation (Inch)	-14442.18**	-1103.117	2160.69**	-12078.93
	(7480.767)	(1259.498)	(1106.303)	(8074.132)
Variance Precipitation (Inch)	100718.5	1987.908	-65622.96	-249822.2
	(474056.3)	(56050.93)	(41143.5)	(588790.6)
Time Trend	5328.339	13147.55	14308.91***	-31800.64
	(20872.31)	(2987.337)	(2475.456)	(22852.62)
Constant	-6186140	-511915.9	-116131.9	-6854407
	(4994880)	(470357.3)	(542148.6)	(7023598)
Adjusted R-Squared	0.9544	0.9684	0.9376	0.9538
Root Mean Squared error	2.1000	3.0000	2.500	1.9000
FGLS				
Harvested Area (Ha)	0.9863275***	1.063952***	0.9311821***	0.9800811***
	(0.008836)	(0.0104471)	(0.0107725)	(0.0088701)
Average Temperature (^{o}F)	1.425514	-1.211721*	0.6703018	4.327606***
	(0.9531392)	(0.6494511)	(0.6524222)	(1.122857)
Variance Temperature (^{o}F)	0.1084523**	0.0018354	0.1963496***	0.1181887***
	(0.0524369)	(0.0414045)	(0.036612)	(0.0361551)
Total Precipitation (Inch)	-0.1214914***	0.0607875*	0.0535662***	0.0433741
	(0.0308502)	(0.0322035)	(0.0201762)	(0.0429753)
Variance Precipitation (Inch)	0.0587944**	-0.0059673	-0.0184857	-0.0054372
	(0.0250826)	(0.024507)	(0.0152861)	(0.0311114)
Time Trend	0.013441***	0.0101047***	0.0221087***	0.0069764***
	(0.0042239)	(0.0031889)	(0.0028232)	(0.0034158)
Constant	-3.790955	4.520902	-2.313266	(-16.92475)
	(4.119345)	(2.882962)	(2.835939)	(4.928109)
Adjusted R-Squared	0.9815	0.9788	0.9621	0.9848
Root Mean Squared error	0.39325	0.30399	0.27258	0.28525

Note: Numbers in parentheses are standard errors. *, ** and * denotes significance at 1%, 5% and 10% respectively.**

The results of mean production function on cassava, maize, rice and yam on harvested area elasticities are all positive and statistically significant at 99%. This implies that an increased in harvested area prompt an increase per hectare in the production of cassava, maize, rice and yam in West Africa respectively. Which literally implies that one percent increase in harvested area induces an increase of 0.93 to 1.06% increase in the production of cassava, maize, rice and yam across countries in West Africa. Time trend coefficients were all positives and statistically significant at 99% for cassava, maize, rice and yam production in West Africa. It is to be noted that time trend stood as a surrogate for technical change in crop production technology such as development of new varieties and farm management practices, which generally increase crop yields overtime. Therefore, technological progress are positive significant influence.

In relation to the effect of climate variables, the effect of increase in average temperature were positive on the mean production of cassava, rice and yam in the region, while only yam was statistically significant at 99%. Which implies that a one percent increase in average temperature leads to and increased production of yam at 4.3%. Meanwhile, maize was affected negatively from the effect of increase in average temperature, which implies that one percent increase in average temperature will result in 1.2% declination of maize production in the region. The result obtained from the relationship of increased average temperature and maize is justifiable, from the research study of (Wang et al., 2008) where they analyze the effect of temperature and precipitation on net crop revenues using a cross section data on both rain-fed and irrigated farms in China. Using a Ricardian analysis, they find higher temperatures to be harmful. In contrast, their most disaggregated results show that “marginal increases in temperature and rainfall have different effects on different kinds of crops in West Africa”. Climate change is probably to have an overall negative effect on the yields of major cereal crops across Africa, with rigid regional variability in the degree of yield reduction (Liu et al., 2008; Roudier et al., 2011; Thornton et al., 2009; Walker and Schulze, 2008). Moreover, in eastern Africa, maize production could benefit from warming at high elevation locations (A1FI scenario) (Thornton et al., 2009) although the vast current maize production occurs at lower elevations, thereby implying a potential change in the distribution of maize cropping. Maize-based systems, particularly in southern Africa, are among the most vulnerable to climate change, simulations that combine all south regions of the Sahara suggest consistently negative effects of climate change on major cereal crops in Africa, ranging from 2% for sorghum to 35% for wheat by 2050 under an A2 scenario (Nelson et al., 2009).

For the variability in temperature, the estimated elasticities for variation in temperature were all positive and the effect of change in variation were statistically significant on cassava, rice and yam production in the region at 95 and 99% respectively. This implies that higher variability in temperature increase cassava, rice and yam production.

While the overall effect of increase in total precipitation were, also positive on the mean production of maize, rice and yam, however, maize and rice were statistically significant at 90 and 99% respectively. This therefore implies that a one-percentage increase in total precipitation induces a 0.6 and 0.05% increase in the production of maize and rice respectively. (Wang et al., 2008) analyze the effect of temperature and precipitation on net crop revenues using a cross section data on both rain-fed and irrigated farms in China. Using a Ricardian analysis, they find increased precipitations more beneficial to agricultural production.

However, cassava receives a negative impact on the effect of increase in total precipitation; therefore, one percent increase in total precipitation induces a 0.12% decrease in the production of cassava in the region. This was because cassava generally thrives in challenging environments, particularly under hot, dry conditions, and that is why it has become such an important component of food security in West Africa. Some agriculture experts suggest those traits could make cassava an adaptive strategy for farmers seeking to maintain food security in areas where the arrival of hotter, dryer weather makes current staples, like maize, less viable.

For the variability in total precipitation, the estimated elasticities for variation in total precipitation were all negative and only cassava was positive and statistically significant at 95%. This implies that higher variability in temperature increase the production of cassava in the region, while high variability in temperature induces a decrease in the production of maize, rice and yam respectively.

4.4 ESTIMATED PARAMETERS FOR VARIANCE FUNCTION ON STAPLE CROPS IN WEST AFRICA

The impacts of precipitation and temperature on the variance production of cassava, maize, rice and yam are been reported in Table 5. Which shows that, estimated coefficients that are positive and statistically significant indicates an increase on the variance of observed crops. While negative coefficient that are negative and statistically significant indicates a reduction on the variance of observed crops.

***Table 5** Estimated parameters for Variance function on Staple crops in West Africa*

	Cassava	Maize	Rice	Yam
Harvested Area (Ha)	-0.0521598	-0.190845**	-0.3870411***	0.1283678***
	(0.0550714)	(0.0898686)	(0.0935103)	(0.0406644)
Average Temperature (°F)	1.35667	-10.60044**	10.39778*	5.86235
	(5.917051)	(4.730688)	(5.589312)	(5.337644)
Variance Temperature (°F)	0.8512304***	0.465632	-0.3446569	0.8235144***
	(0.3132517)	(0.3224002)	0.2864359	(0.2060431)
Total Precipitation (Inch)	0.3445525***	-0.544025***	-0.0019092	-0.4959949***
	(0.122636)	(0.1344106)	(0.1422029)	(0.1511104)
Time Trend	-0.0123477	0.1259545***	0.0602492*	-0.0062897
	(0.0242174)	(0.0252864)	(0.0231036)	(0.0172183)
Constant	-10.84273	44.30001**	-44.43444*	-29.23213
	(25.45079)	(20.95026)	(24.4616)	(23.33959)
Adjusted R-Squared	0.0710	0.0968	0.0781	0.2376

Note: Numbers in parentheses are standard errors. *, ** and * denotes significance at 1%, 5% and 10% respectively.**

Time-trend coefficient shows a negative impact on cassava and yam production variance. However, cassava and yam are not statistically significant. Whereby maize and rice were positive and statistically significant at 99% and 90 respectively. Therefore, the result explicitly induces an increase in the production variance of maize and rice in the region.

Harvested area coefficient result shows negativity and statistically significant on the production variance of maize and rice, while yam is statistically significant at 99% which signifies an increase in the production variance of yam.

For the independent variables related to temperature, higher average temperatures increase cassava, rice and yam production variability in the regions. Only rice is statistically significant at 90%. While maize production variability decreases with a statistical significant of 95%. Cassava, maize and yam production variance increases with an increase temperature variability in the regions with 99% statistical significance for cassava and yam, whereby rice production variance is decreases in the region.

Finally, the effect of changes in total precipitation on production variability are all-negative at 99% statistical significance for maize and yam. Except for cassava, which is positive at 99%. Therefore higher amount of total precipitation increase the variation of cassava production, while higher amount of total precipitation decrease the variation of maize, rice and yam production respectively.

4.5 CLIMATE CHANGE SCENARIOS

Two climate scenarios are been applied to generate percentage change effect of climate variable (temperature and precipitation) on the future production of staple crops observed in this study. The observed and downscaled climate projections are for 2030, 2060 and 2090 for the growing season of each crops. The data were been retrieved from Climate System Analysis Group (CSAG) from the University of Cape

Town South Africa. The projected future changes were statistically downscaled Couple Model Inter-comparison Project (CMIP5) for two different Representative Concentration Pathways (RCP 4.5 and RCP 8.5) under the IPCC 4th Assessment Report.

Table 6 *Future Climate Change Projection in West Africa for 2030, 2060 and 2090*

	Scenario	Cassava	Maize	Rice	Yam
2030 Temperature (^{0}F)	**RCP 4.5**	84.3424	84.4908	84.3081	84.2601
	RCP 8.5	85.0868	85.4114	85.2019	85.3806
2030 Precipitation (Inch)	**RCP 4.5**	36.3251	35.4291	32.6404	42.6140
	RCP 8.5	38.9082	35.5386	34.2621	43.3425
2060 Temperature (^{0}F)	**RCP 4.5**	85.0364	85.3623	85.1762	84.9582
	RCP 8.5	86.6522	86.8523	86.5541	86.6381
2060 Precipitation (Inch)	**RCP 4.5**	37.5082	34.6646	33.8726	42.2683
	RCP 8.5	38.9081	35.9394	45.5957	45.5466
2090 Temperature (^{0}F)	**RCP 4.5**	85.6771	85.8747	85.7335	85.7466
	RCP 8.5	89.5264	89.8356	89.8289	89.7794
2090 Precipitation (Inch)	**RCP 4.5**	41.6578	39.3891	36.4781	45.8042
	RCP 8.5	38.5103	34.6341	33.0567	45.1946

RCP 4.5 is a scenario of long-term, global emissions of greenhouse gases, short-lived species, and land-use-land cover, which stabilizes radiative forcing at 4.5 Watts per meter squared (W m2, approximately 650 ppm CO2-equivalent) in the year 2100 without ever exceeding that value (Thomson et al., 2011). RCP8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high-energy demand and GHG emissions in absence of climate change policies. (Riahi et al., 2011) Table 6 shows the average temperature and precipitation of 2030, 2060 and 2090 for each growing season in the region. The projected climate change scenarios related with the temperature and precipitation as presented in Table 6 shows an increased trend for both average temperature and total

precipitation throughout the region, when compare to the average temperature and total precipitation of the used base year in this study (1994 - 2014).

4.6. FUTURE CLIMATE CHANGE EFFECT ON STAPLE CROPS IN WEST AFRICA FOR 2030, 2060 AND 2090

Climate change effect on staple crops in the region were been analyzed as follows:

1. Specify the main driver of climate variable; average temperature and total precipitation, followed by selecting future project values for both variables for the year 2030, 2060 and 2090 in each growing region and seasons of observed staple crops (Cassava, Maize, Rice and Yam). The average was then calculated and further taken for continuous analyzation as shown in table 6 for each scenarios (RCP 4.5 and RCP 8.5).

2. The percentage change of average temperature and total precipitation were been carried out accordingly for each scenarios (RCP 4.5%Δ and RCP 8.5%Δ). The percentage changes were been compared with the temperature and precipitation baseline used in the study (1994 – 2014) as shown in table 7.

3. Simulation for future effect of climate change were been carried out by using the elasticity (elastic) value obtained from FGLS regressing for temperature and precipitation of the baseline, which is previously explained in table 4 as future percentage change of both climatic variables. In order to get temperature and precipitation effect, the elastic temperature and precipitation were multiplied by the %Δ for each crops and scenarios.

4. The potential effect of climate change (CC-effect) was been achieved by adding both temperature and precipitation effects for the projected years 2030, 2060 and 2090 under both scenarios.

Table 7 Climate Change Effect on Staple Crops in West Africa for 2030, 2060 and 2090

	Scenario	Cassava	Maize	Rice	Yam
Elastic Temperature		1.4255	-1.2117	0.6703	4.3276
Elastic Precipitation		-0.1214	0.0607	0.0535	0.0433
Temperature Baseline [^{0}F]		81.3343	81.5871	81.3760	81.6347
Precipitation Baseline [Inch]		23.7818	21.8561	20.0633	33.0841
2030 Temperature [^{0}F]	RCP 4.5 (%Δ)	3.6980	3.5590	3.6030	3.2160
	RCP 8.5 (%Δ)	4.6140	4.6870	4.7020	4.5890
2030 Precipitation [Inch]	RCP 4.5 (%Δ)	52.7430	62.1010	62.6870	28.8050
	RCP 8.5 (%Δ)	63.6050	62.6030	93.9270	31.0070
Temperature Effect [^{0}F]	RCP 4.5	5.2720	-4.3120	2.4150	13.9180
	RCP 8.5	6.5770	-5.6800	3.1520	19.8570
Precipitation Effect [Inch]	RCP 4.5	-6.4080	3.7750	3.3580	1.2490
	RCP 8.5	-7.7270	3.8050	5.0310	1.3450
CC – Effect	**RCP 4.5**	**-1.1360**	**-0.5370**	**5.7730**	**15.1670**
	RCP 8.5	**-1.1510**	**-1.8740**	**8.1830**	**21.2020**
2060 Temperature [^{0}F]	RCP 4.5 (%Δ)	4.5520	4.6270	4.6700	4.0710
	RCP 8.5 (%Δ)	6.5380	6.4530	6.3630	6.1290
2060 Precipitation [Inch]	RCP 4.5 (%Δ)	57.7180	58.6040	68.8280	27.7601
	RCP 8.5 (%Δ)	63.6050	64.4360	93.9260	37.6690
Temperature Effect [^{0}F]	RCP 4.5	6.4880	-5.6070	3.1301	17.6180
	RCP 8.5	9.3210	-7.8200	4.2650	26.5240
Precipitation Effect [Inch]	RCP 4.5	-7.0120	3.5620	3.6870	1.2040
	RCP 8.5	-7.7270	3.9170	5.0310	1.6340
CC – Effect	**RCP 4.5**	**-0.5240**	**-2.0440**	**6.8170**	**18.8220**
	RCP 8.5	**1.5930**	**-3.9030**	**9.2970**	**28.1580**
2090 Temperature [^{0}F]	RCP 4.5 (%Δ)	5.3390	5.2550	5.3550	5.0370
	RCP 8.5 (%Δ)	10.0720	10.1100	10.3880	9.9770
2090 Precipitation [Inch]	RCP 4.5 (%Δ)	75.1670	80.2200	81.8150	38.4480
	RCP 8.5 (%Δ)	61.9320	58.4640	91.9440	36.6050
Temperature Effect [^{0}F]	RCP 4.5	7.6110	-6.3680	3.5890	21.7980
	RCP 8.5	14.3580	-12.2510	6.9630	43.1760
Precipitation Effect [Inch]	RCP 4.5	-9.1320	4.8760	4.3830	1.6680
	RCP 8.5	-7.5240	3.5540	4.9250	1.5880
CC – Effect	**RCP 4.5**	**-1.5210**	**-1.4920**	**7.9720**	**23.4660**
	RCP 8.5	**6.8340**	**-8.6970**	**11.8880**	**44.7640**

The potential effect of climate change on the production of Cassava and Maize in West Africa under RCP 4.5 and RCP 8.5 scenarios for 2030 shows that both cassava and maize are threatened negatively by the effect of climate change in the region at -1.136 and -0.537 for RCP 4.5, then -1.151 and -1.1874 for RCP 8.5 respectively. Thereby, indicating a reduction on the production of both crops under the specified simulation. (Mereu et al., 2015a) used a multi-model approach to analyzing climate change impacts and associated risks for staple food crops in Nigeria. The result shows that, projected increase in temperature and changes in precipitation patterns could determine reasonable reductions in crop yields.

However, for the same period the potential effect of climate change on the production of Rice and Yam in the region were positive at 5.773 and 15.167 for RCP 4.5 and 8.183 and 21.202 for RCP 8.5 respectively. Thereby, indicating an increase in the production of both crops under the specified simulation.

In 2060 the projected effect of climate change on the production of Cassava and Maize in West Africa under RCP 4.5 and RCP 8.5 scenarios also prove to possess a negative effect in the region at -0.524 and -2.044 for RCP 4.5, then -3.903 for RCP 8.5. Thereby, indicating a reduction on the production of both crops under the specified scenario. However, on a contrast Cassava projection tend to be positive at 1.593 for RCP 8.5. Climate impacts on the main crops for West Africa are controversial and projected to be either positive or negative depending on the scenario and crop modelling approach considered (Roudier et al., 2011)

Under the same period, climate change effect on the production of Rice and Yam in the region were positive at 6.817 and 18.822 for RCP 4.5 and 9.297 and 28.158 for RCP 8.5 respectively. Thereby, indicating an increase in the production of both crops under the specified scenarios.(Mereu et al., 2015a) did a climate impact assessment using an ensemble of future climate projection, to include uncertainty related to climate projections. Even if precipitations could increase in most parts of their studied area, it is not likely to offset crop yield reduction due to the increase in temperatures, particularly over the medium-term period (2050), with yield decreases projected especially for cereals.

Finally, in 2090 the projected effect of climate change on the production of Cassava and Maize in West Africa under RCP 4.5 and RCP 8.5 scenarios have a negative effect in the region at -1.521 and -1.492 for RCP 4.5, then -8.697 for RCP 8.5. Thereby, indicating a reduction on the production of both crops under the specified scenario. However, cassava projection tend to be positive at 6.894 for RCP 8.5.

Under the same period, climate change effect on the production of Rice and Yam in the region were positive at 7.972 and 23.466 for RCP 4.5 and 11.888 and 44.764 for RCP 8.5 respectively. Thereby, indicating an increase in the production of both crops under the specified scenarios. Changes in climatic conditions are very likely to reduce cereal crop productivity in Sub-Saharan African countries, with high differences in yield projections according to regional variability (Lobell and Burke, 2008; Roudier et al., 2011; Thornton et al., 2009; Webber et al., 2014). Notwithstanding a good consensus among climate models in predicting increases in temperatures for West Africa, there is large uncertainty in projections of precipitations (Niang et al., 2014). These results are consistent with other studies conducted in West African Countries, even if the comparison is difficult due to the different methods considered in each analysis: different crop simulation models, climate models, emission scenarios, downscaling methods, geographic locations, time and spatial scales.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This research study uses an econometric model to estimate a stochastic production functions and evaluate the impacts of temperature and precipitation on the mean and variance for cassava, maize, rice and yam production in West Africa. The estimated production functions are then, used to explain future impacts of temperature and precipitation in the region agricultural production. Then proceeds to project potential climate change effect of temperature and precipitation in the region. The results from the econometric model, which employs the historical temperature and precipitation data on the production of cassava, maize rice and yam production for the observed year shows that the impacts of temperature and precipitation on tuber production vary between cassava and yam. The impact of increase in average temperature were positive on the mean production of cassava and yam in the region. In addition, variation in temperature were all positive and the effect of change in variation were statistically significant on cassava and yam production in the region. Therefore, higher variability in temperature increase the production of both crops in the region. While the overall effect of increase in total precipitation shows positivity on the mean production of yam but cassava receives a negative impact on the effect of increase in total precipitation, therefore, increase in total precipitation induces a decrease in the production of cassava in the region. However, the variability in total precipitation, were negative and only cassava was positive and statistically significant. This implies that higher variability in temperature increase the production of cassava in the region, while high variability in temperature induces a decrease in the production of yam.

However, impacts of temperature and precipitation on rice and maize production varies too. The impact of average temperature and its variance were positive on mean production of rice but was negative on the mean and variance production of maize in the region. However, the impact of precipitation was positive on the mean production but was negative on variance production of both crops in the region.

The future potential effect of climate change on the production of staple crops in West Africa under RCP 4.5 and RCP 8.5 scenarios for years 2030, 2060 and 2090 shows that, both cassava and maize will be most threatened negatively by the effect of climate change in the region. While rice and yam shows a positive increase in production under both scenarios for years 2030, 2060 and 2090 in the region.

Existing results shows that rise in precipitation will increase crop yield, moreover, crop yield is more sensitive to precipitation than temperature. If the reduction of water availability occurs in the future, soils with higher water holding capacity will be better to reduce the impact of drought while maintaining crop yield. As temperature is increasing and precipitation varies, water availability and crop production are likely to decrease in the future. Therefore, if irrigated areas are been expanded, the total crop production will increase rapidly; however, food and environmental quality may degrade. (Kang et al., 2009).

5.2 RECOMMENDATION

Agricultural sector and its stakeholder challenges from unstable climatic conditions, which are growing faster and posing a critical threat to the welfare of people in West Africa, especially farmers. Although higher temperatures are likely to occur in the future based on the data comparison of future projection and the baseline data used in this study, but the enormity of the increase is uncertain, and the effects will vary across regions depending on which climate scenario eventually occurs. Precipitation outcomes are even more uncertain. However, the effects of changes in climate on the limits of tolerance of existing varieties as well as the possible emergence of diseases and pests will be a challenge. However, possible avenues for adaptation must include dealing with drought, floods, high temperatures, waterlogging, new and increasing incidence of plant pests and diseases. A shorter growing season, which might help mitigate the treat pose by climatic change on the production of cassava and maize in the future based on the result of this study, and related human health concerns such as; malaria and sleeping sickness in the Sahel due to wetter conditions favorable to mosquitoes and tsetse flies. Selection and breeding of appropriate varieties will be crucial in any adaptation venture. Developing appropriate management practices of such varieties is essential on a large scale.

5.2.1 POLICY RECOMMENDATION

Temperature and precipitation are been examined to be the major climate conditions, which will require farmer's adaptation to its changing conditions, especially those who grows cassava and maize in the West Africa. Major factor of adaptation breadth to climate change include; changes in agricultural practices, changes in agricultural water management, agricultural diversification, agricultural science and technology development, agricultural insurance and risk management. In summary, the proposed measures are to increase versatile on farming practice, improved crops through breeding and investing in innovative technologies and infrastructure.

However, it is important to recognize that the impacts of climate change (temperature and precipitation) are not going to be the same for countries in West Africa or even for each region inside a country. It is however important to note that this impacts will depend greatly on current local climate for each countries, and other conditions of such as soil conditions, farmers skills and methods of farming. Some countries might benefit from increase and decrease in temperature because it will gives them the opportunity to divert or shift into other plants that are resistance to hot temperature or even inventing of new varieties to withstand their current climatic conditions. Moreover global climate change could have significant effects on West Africa agriculture. Hence, mitigation and adaptation strategies to curb these effects are necessary especially for cassava and maize production such as provision of tolerant improved varieties to climatic changes, adequate and proper planning such that growing season should be during the raining season of each country in the region.

Vast farmers in West Africa are resource poor. In addition to biophysical constraints to their farming pursuits, lack of access to funds as well as markets drastically limits their potential to break out of the vicious circle of poverty. In view of their scale of production, targeted subsidies coupled with microcredit with practical and reasonable collateral requirements will go a long way toward enabling small-scale farmers to acquire vital inputs required for boosting production of agricultural crops in the region especially on the production of cassava and maize. In addition, access to payments for carbon credits will encourage farmers to join hands in the global effort to meet the challenges of climate change.

It is critical that appropriate technologies be available for farmers to enable them, effectively undertake adaptation and mitigation measures. There is also a need for appropriate awareness raising to inform mostly illiterate farmers about how use technologies efficiently as well as to ensure that they are aware of their rights and are able to negotiate for benefits.

5.2.1 RECOMMENDATION FOR FURTHER STUDIES

However, the results of this study raises several issues, which could be further investigated. The main contribution of this study has focused on future potential effects of temperature and precipitation on cassava, maize, rice and yam production in West Africa, but does not consider other input factors, which relates to the production of agricultural commodity. Future studies should attempt to collect more data with regard to the conventional cassava, maize, rice and yam production factors. Such as; labor, machinery, fertilizer, irrigation system etc. However, this study focuses only on the use of Cobb-Doulas functional form. Future research should try extending to additional functional form in existing literatures. Comparison of more functional form will effectively be of more support by theoretical foundation and existing empirical evidence.

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APPENDIX

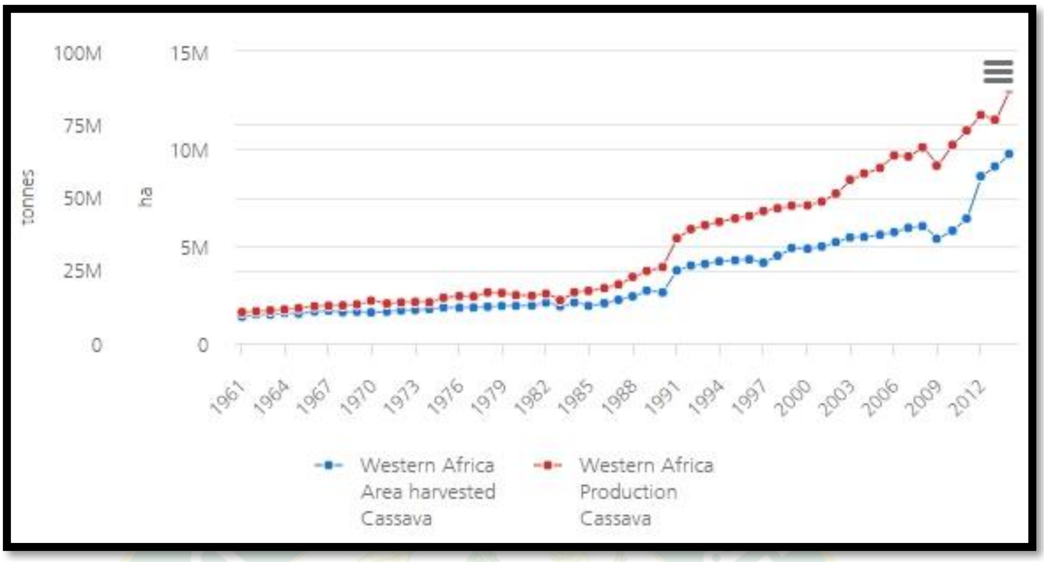
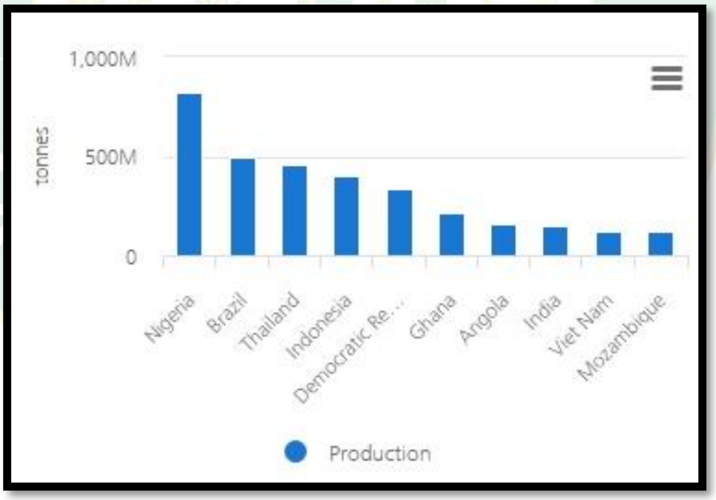


Figure 6 Sum Production/yield quantities of Cassava in West Africa (1961 – 2014)

Source: FOASTAT (Nov 16, 2016)



Source: FOASTAT (Nov 16, 2016)

Figure 7 *Top ten producers of cassava in the world (1994 – 2014)*

Cassava rich in carbohydrates and low in vitamins and minerals it is a poor source of protein. It is mostly cultivated in tropical and sub-tropical regions of the world it is mainly cultivated in Africa, Asia and Latin America, according to the fig above, It is estimated that African countries are producing more than half of the total world production of Cassava, followed by Latin America and Asia, Nigeria is the highest producer of cassava with its annual production of over 500 million tonnes produced from 1994 – 2014, followed by Brazil and Thailand respectively.

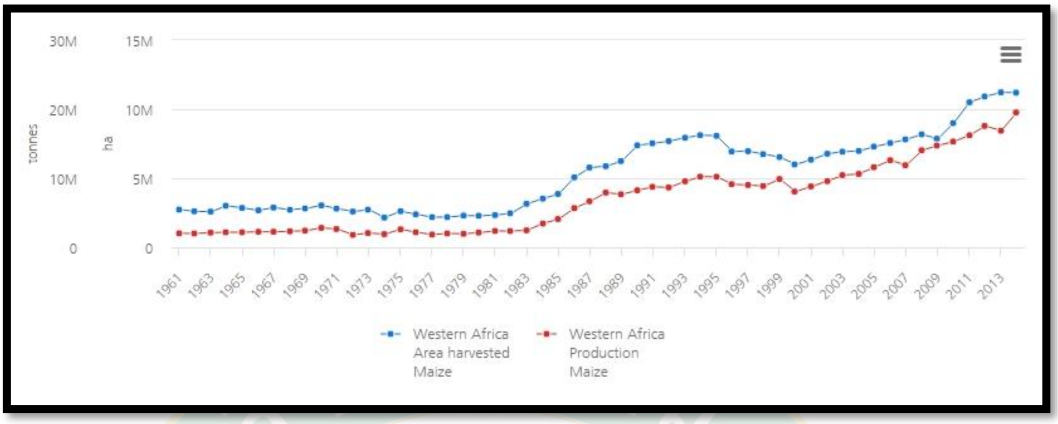


Figure 8 *Production/yield quantities of maize in West Africa (1961 – 2014)*

Source: FOASTAT (Nov 16, 2016)

Maize is a vulnerable crop. Research has shown that geographically, the majority (~90%) of cropped maize area are expected to experience negative impacts, with decline production (Ramirez-Villegas and Thornton, 2015). According to Climate Change and Agricultural Food Security (2005) West African countries will in particular feel the negative impacts, with mean production losses between 20 and 40% by 2050s, while other countries, such as Kenya, Mozambique, Botswana will face less severe declination in production. With maize being one of the greatest sources of calories, while being grown across the greatest area on the continent, adaptation measures, especially for the Sahel, are pivotal. Figure above show something of such.

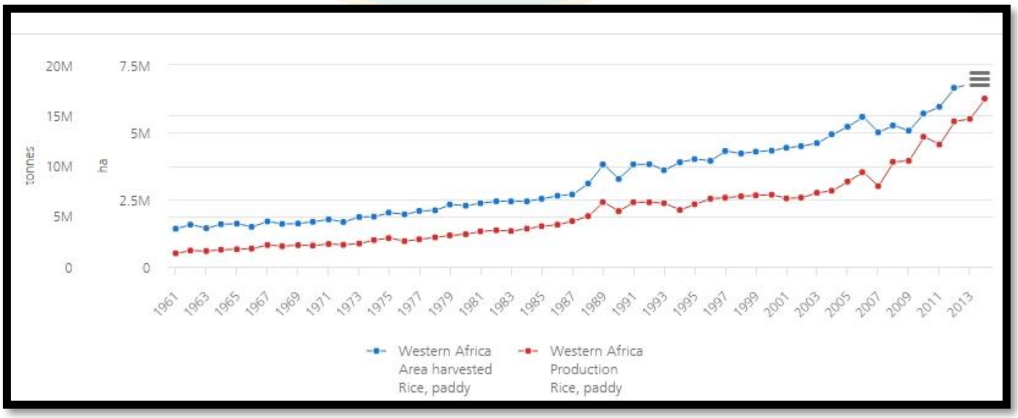


Figure 9 *Production/yield quantities of rice in West Africa (1961 – 2014)*

Source: FOASTAT (Nov 16, 2016)

According to Global Rice Science Partnership (Ricepedia, 2015). Revolutionary change in the preferences of West African consumers has created a wide and growing imbalance between regional rice supply and demand. Since 1973, regional demand has grown at 6.0% annually, driven by a combination of population growth (2.9% growth rate) and substitution away from the region's traditional coarse grains. The consumption of traditional cereals, mainly sorghum and millet, has fallen by 12 kg per capita, and their share in cereals used as food from 62% in the early 1970s to 50% in the early 1990s. In contrast, the share of rice in cereals consumed grew from 15% to 25% over the same period, and from 12% to 18% in calorie terms from the 1960s to the end of the 1990s. Much of this dramatic shift occurred in the late 1970s and 1980s. Per capita rice consumption has been increasing at more than 3% annually since the late 1990s. Accounting for population growth, this suggests that total rice consumption increased at nearly 6% per year during 2006-2010. Figure above shows the area harvested and total production of rice in West Africa from 1961 – 2014.

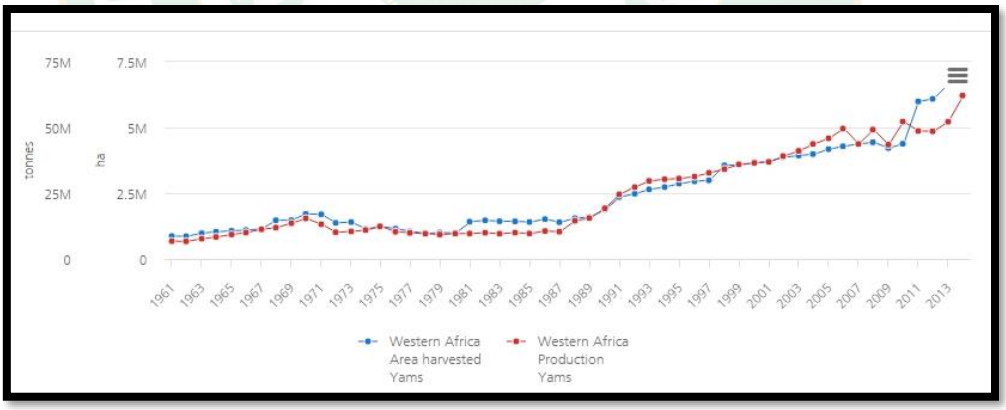


Figure 10 *Production/yield quantities of yams in West Africa (1961 – 2014)*

Source: FOASTAT (Nov 16, 2016)

The yam sector in the West Africa sub region, however, is plagued by low on-farm productivity, high production costs and frequent climatic condition, high losses due to pests and diseases, and unsustainable production practices. High production costs are primarily driven by the high costs of seed and labor, with potential profit margins further reduced by moderate yields and postharvest losses. The figure above shows a large imbalance between the area harvested and the production of yam in West Africa since 1961 – 2014.

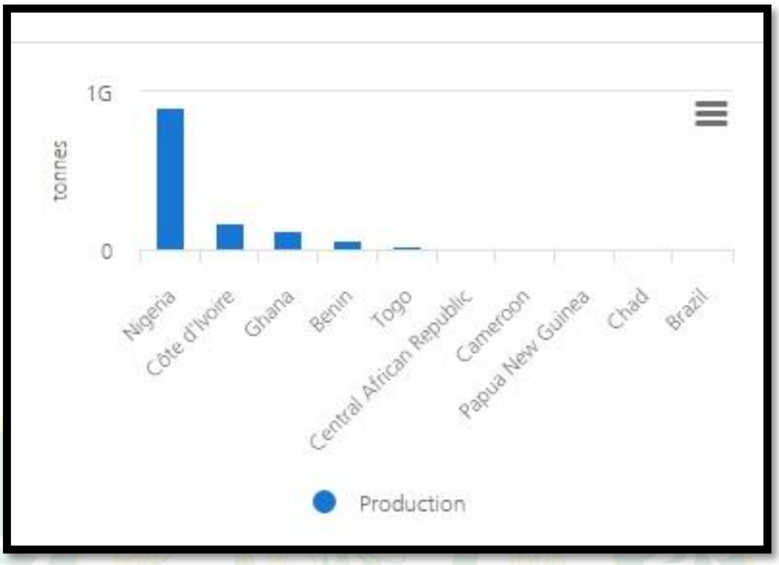


***Figure* 11** *Top ten producers of Yam in the world (1961 – 2014)*

Source: FOASTAT (Nov 16, 2016)

As represented in the figure above Nigeria is the world's largest producer of yams, accounting for over 70–76 percent of the world production. According to the Food and Agricultural Organization report, in 1985, Nigeria produced 18.3 million tonnes of yam from 1.5 million hectares, representing 73.8 percent of total yam production in Africa. According to 2008 figures, yam production in Nigeria has nearly doubled since 1985, with Nigeria producing 35.017 million metric tonnes. In perspective, the world's second and third largest producers of yams, Côte d'Ivoire and Ghana respectively. According to the International Institute of Tropical Agriculture, Nigeria produced about 70 percent of the world production.

Figure 12 *Territorial boundaries of West African countries*

Source: Map of Worlds (Nov 19, 2016)

Descriptive Statistics for Cassava production in West Africa

Variable	Mean	Std. Dev.	Min	Max
Production (Tons/Ha)	3894412	9942301	1000	5.48e+07
Harvested Area (Ha)	382240.9	1006279	163	7102300
Average Temperature	81.33433	2.822447	75.32571	91.37558
Variance Temperature	13.59081	11.27914	2.935851	54.4042
Total Precipitation	23.78182	20.55727	0.1231912	130.7
Variance Precipitation	0.2107016	0.3132366	0.0001847	2.424916
Time Trend	11	6.064935	1	21

Pre-Estimation Specification Test Results for Cassava Production in West Africa

Variable	Production (Tons/Ha)	Harvested Area (Ha)	Average Temperature	Variance Temperature	Total Precipitation	Variance Precipitation	Time Trend
Statistic	-5.3346	-2.1984	-5.1452	-6.6553	-4.2571	-6.7719	-47.3622
P-Value	0.0000	0.0140	0.0000	0.0000	0.0000	0.0000	0.0000

H0: Panels Contain Unit Roots

H1: Panels are Stationary

OLS Regression for Cassava mean production in West Africa

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	9.676869	0.1205793	80.25	0.000***	9.439605	9.914132
Average Temperature	84641.02	63724.92	1.33	0.185	-40750.26	210032.3
Variance Temperature	-17580.67	16096.91	-1.09	0.276	-49254.49	14093.15
Total Precipitation	-14442.18	7480.767	-1.93	0.054**	-29162.06	277.6916
Variance Precipitation	100718.5	474056.3	0.21	0.832	-832080.2	1033517
Time Trend	5328.339	20872.31	0.26	0.799	-35742.02	46398.69
Constant	-6186140	4994880	-1.24	0.216	-1.60e+07	3642266
Adjusted R-Squared	0.9544					
Root Mean Squared error	2.1e+06					

Estimated parameters for Mean function on Cassava Production under Cobb-Douglas functional forms

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	0.9863275	0.008836	111.63	0.000***	0.9689409	1.003714
Average Temperature	1.425514	0.9531392	1.50	0.136	-0.4499745	3.301002
Variance Temperature	0.1084523	0.0524369	2.07	0.039**	0.0052725	.2116321
Total Precipitation	0.1214914	0.0308502	-3.94	0.000***	-0.1821952	-.0607877
Variance Precipitation	0.0587944	0.0250826	2.34	0.020**	0.0094395	.1081493
Time Trend	0.013441	0.0042239	3.18	0.002***	0.0051296	.0217525
Constant	-3.790955	4.119345	-0.92	0.358	-11.89657	4.314664
Adjusted R-Squared	0.9815					
Root Mean Squared error	0.39325					

Estimated parameters for Variance function on Cassava Production in West Africa

Variance Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	-0.0521598	0.0550714	-0.95	0.344	-0.1605222	0.0562025
Average Temperature	1.35667	5.917051	0.23	0.819	-10.28614	12.99948
Variance Temperature	0.8512304	0.3132517	2.72	0.007***	0.2348541	1.467607
Total Precipitation	0.3445525	0.122636	2.81	0.005***	0.1032453	0.5858597
Time Trend	-0.0123477	0.0242174	-0.51	0.611	-0.0599996	0.0353041
Constant	-10.84273	25.45079	-0.43	0.670	-60.92152	39.23606
Adjusted R-Squared	0.0710					

Descriptive Statistics for Maize production in West Africa

Variable	Mean	Std. Dev.	Min	Max
Production (Tons/Ha)	810359.7	1669642	951	1.08e+07
Harvested Area (Ha)	532929.3	1057497	1186	5849800
Average Temperature	81.58715	3.065823	72.68159	89.88928
Variance Temperature	12.37844	6.107659	2.935851	43.38509
Total Precipitation	21.85616	18.30179	0.12	130.7
Variance Precipitation	0.2524572	0.3933299	0.0003017	2.927796
Time Trend	11	6.064935	1	21

Pre-Estimation Specification Test Results for Maize Production in West Africa

Variable	Production (Tons/Ha)	Harvested Area (Ha)	Average Temperature	Variance Temperature	Total Precipitation	Variance Precipitation	Time Trend
Statistic	-3.3418	-2.2105	-5.4499	-5.8363	-4.3580	-5.7918	-47.3622
P-Value	0.0004	0.0135	0.0000	0.0000	0.0000	0.0000	0.0000

H0: Panels Contain Unit Roots

H1: Panels are Stationary

OLS Regression for Maize mean production in West Africa

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	1.54831	0.0160486	96.48	0.000***	1.516732	1.579889
Average Temperature	4441.464	5909.52	0.75	0.453	-7186.674	16069.6
Variance Temperature	1111.148	3006.455	0.37	0.712	-4804.64	7026.937
Total Precipitation	-1103.117	1259.498	-0.88	0.382	-3581.426	1375.191
Variance Precipitation	1987.908	56050.93	0.04	0.972	-108303.3	112279.1
Time Trend	13147.55	2987.337	4.40	0.000	7269.382	19025.72
Constant	-511915.9	470357.3	-1.09	0.277	-1437436	413604.3
Adjusted R-Squared	0.9684					
Root Mean Squared error	3.0e+05					

Estimated parameters for Mean function on Maize Production under Cobb-Douglas functional forms

Mean Function	Coef.	Std. Err.	T	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	1.063952	0.0104471	101.84	0.000***	1.043396	1.084509
Average Temperature	-1.211721	0.6494511	-1.87	0.063*	-2.489644	.066201
Variance Temperature	0.0018354	0.0414045	0.04	0.965	-.079636	.0833069
Total Precipitation	0.0607875	0.0322035	1.89	0.060*	-.0025792	.1241541
Variance Precipitation	-0.0059673	0.024507	-0.24	0.808	-.0541896	.042255
Time Trend	0.0101047	0.0031889	3.17	0.002***	.0038299	.0163795
Constant	4.520902	2.882962	1.57	0.118	-1.151892	10.19369
Adjusted R-Squared	0.9788					
Root Mean Squared error	0.30399					

Estimated parameters for Variance function on Maize Production in West Africa

Variance Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	-0.190845	0.0898686	-2.12	0.034**	-.3676767	-.0140132
Average Temperature	-10.60044	4.730688	-2.24	0.026**	-19.90887	-1.291999
Variance Temperature	0.465632	0.3224002	1.44	0.150	-.1687455	1.100009
Total Precipitation	-0.544025	0.1344106	-4.05	0.000***	-0.8085007	-0.2795492
Time Trend	0.1259545	0.0252864	4.98	0.000***	0.0761991	0.1757099
Constant	44.30001	20.95026	2.11	0.035**	3.076783	85.52323
Adjusted R-Squared	0.0968					

Descriptive Statistics for Rice production in West Africa

Variable	Mean	Std. Dev.	Min	Max
Production (Tons/Ha)	610872.4	992031	5400	6734000
Harvested Area (Ha)	334646.3	576639.8	5300	3095800
Average Temperature	81.37601	2.86531	75.08508	92.07843
Variance Temperature	13.65812	11.66619	2.959102	67.15084
Total Precipitation	20.06337	16.39693	0.2	120.37
Variance Precipitation	0.2418004	0.396143	0.0003754	2.765367
Time Trend	11	6.064935	1	21

Pre-Estimation Specification Test Results for Rice Production in West Africa

Variable	Production (Tons/Ha)	Harvested Area (Ha)	Average Temperature	Variance Temperature	Total Precipitation	Variance Precipitation	Time Trend
Statistic	-0.2382	-2.6792	-5.3972	-6.7942	-4.4019	-6.2267	-47.3622
P-Value	0.4059	0.0037	0.0000	0.0000	0.0000	0.0000	0.0000

H0: Panels Contain Unit Roots

H1: Panels are Stationary

OLS Regression for Rice mean production in West Africa

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	1.652457	0.02489	66.39	0.000***	1.603481	1.701433
Average Temperature	-659.0759	6852.208	-0.10	0.923	-14142.14	12823.99
Variance Temperature	3131.294	1731.927	1.81	0.072*	-276.6112	6539.2
Total Precipitation	2160.69	1106.303	1.95	0.052**	-16.17856	4337.559
Variance Precipitation	-65622.96	41143.5	-1.59	0.112	-146580.9	15334.94
Time Trend	14308.91	2475.456	5.78	0.000***	9437.965	19179.85
Constant	-116131.9	542148.6	-0.21	0.831	-1182915	950651.7
Adjusted R-Squared	0.9376					
Root Mean Squared error	2.5e+05					

Estimated parameters for Mean function on Rice Production under Cobb-Douglas functional forms

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	0.9311821	0.0107725	86.44	0.000***	.9099852	.9523791
Average Temperature	0.6703018	0.6524222	1.03	0.305	-.6134668	1.95407
Variance Temperature	0.1963496	0.036612	5.36	0.000***	.1243084	.2683909
Total Precipitation	0.0535662	0.0201762	2.65	0.008***	.0138656	.0932667
Variance Precipitation	-0.0184857	0.0152861	-1.21	0.227	-.0485641	.0115928
Time Trend	0.0221087	0.0028232	7.83	0.000***	.0165536	.0276638
Constant	-2.313266	2.835939	-0.82	0.415	-7.893531	3.266999
Adjusted R-Squared	0.9621					
Root Mean Squared error	0.27258					

Estimated parameters for Variance function on Rice Production in West Africa

Variance Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	-0.3870411	0.0935103	-4.14	0.000***	-0.5710385	-0.2030436
Average Temperature	10.39778	5.589312	1.86	0.064*	-0.6001511	21.3957
Variance Temperature	-0.3446569	0.2864359	-1.20	0.230	-0.9082684	0.2189546
Total Precipitation	-0.0019092	0.1422029	-0.01	0.989	-0.2817176	0.2778992
Time Trend	0.0602492	0.0231036	2.61	0.010***	0.0147889	0.1057094
Constant	-44.43444	24.4616	-1.82	0.070*	-92.56681	3.697937
Adjusted R-Squared	0.0781					

Descriptive Statistics for Yam production in West Africa

Variable	Mean	Std. Dev.	Min	Max
Production (Tons/Ha)	4228105	9063596	2454	4.50e+07
Harvested Area (Ha)	426019.5	957103.5	400	5416400
Average Temperature	81.63476	2.271034	76.38	89.38867
Variance Temperature	17.59742	13.70124	2.935851	72.90551
Total Precipitation	33.08412	21.46974	0.9	130.7
Variance Precipitation	0.2426327	0.2678242	0.0211599	2.424916
Time Trend	11	6.06977	1	21

Pre-Estimation Specification Test Results for Yam Production in West Africa

Variable	Production (Tons/Ha)	Harvested Area (Ha)	Average Temperature	Variance Temperature	Total Precipitation	Variance Precipitation	Time Trend
Statistic	-2.1814	-2.4579	-4.7899	-3.6755	-1.6295	-4.9283	-38.6711
P-Value	0.0146	0.0070	0.0000	0.0001	0.0516	0.0000	0.0000

H0: Panels Contain Unit Roots

H1: Panels are Stationary

OLS Regression for Yam mean production in West Africa

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	9.312941	0.1476403	63.08	0.000***	9.021836	9.604046
Average Temperature	101167.7	88014.78	1.15	0.252	-72372.74	274708.1
Variance Temperature	-18965.02	14980.45	-1.27	0.207	-48502.26	10572.21
Total Precipitation	-12078.93	8074.132	-1.50	0.136	-27998.85	3840.983
Variance Precipitation	-249822.2	588790.6	-0.42	0.672	-1410752	911107.2
Time Trend	-31800.64	22852.62	-1.39	0.166	-76859.58	13258.29
Constant	-6854407	7023598	-0.98	0.330	-2.07e+07	6994154
Adjusted R-Squared	0.9538					
Root Mean Squared error	1.9e+06					

Estimated parameters for Mean function on Yam Production under Cobb-Douglas functional forms

Mean Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	0.9800811	0.0088701	110.49	0.000***	0.9625918	.9975703
Average Temperature	4.327606	1.122857	3.85	0.000***	2.113648	6.541564
Variance Temperature	0.1181887	0.0361551	3.27	0.001***	0.0469011	.1894763
Total Precipitation	0.0433741	0.0429753	1.01	0.314	-0.041361	0.1281093
Variance Precipitation	-0.0054372	0.0311114	-0.17	0.861	-0.06678	0.0559057
Time Trend	0.0069764	0.0034158	2.04	0.042***	0.0002414	0.0137115
Constant	-16.92475	4.928109	-3.43	0.001***	-26.6416	-7.207907
Adjusted R-Squared	0.9848					
Root Mean Squared error	0.28525					

Estimated parameters for Variance function on Yam Production in West Africa

Variance Function	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
Harvested Area (Ha)	0.1283678	0.0406644	3.16	0.002***	0.0481914	0.2085442
Average Temperature	5.86235	5.337644	1.10	0.273	-4.661673	16.38637
Variance Temperature	0.8235144	0.2060431	4.00	0.000***	0.4172673	1.229762
Total Precipitation	-0.4959949	0.1511104	-3.28	0.001***	-0.7939334	-0.1980564
Time Trend	-0.0062897	0.0172183	-0.37	0.715	-0.0402384	0.0276589
Constant	-29.23213	23.33959	-1.25	0.212	-75.24989	16.78563
Adjusted R-Squared	0.2376					

Future Projection of Temperature Change Effect on Cassava

1	Temperature	Baseline 1994 - 2014	2030	2060	2090
	RCP 4.5	**81.33433**	84.34241001	85.03640001	85.67715501
	%		**3.698**	**4.552**	**5.339**
Mean	**Elas-casava**		1.425514	1.425514	1.425514
	% Effect		**5.272**	**6.488**	**7.611**
Variance	**Elas-N**		1.35667	1.35667	1.35667
	% Effect		**5.018**	**6.175**	**7.244**
	RCP 8.5	**81.33433**	85.086815	86.652275	89.52641001
	%		4.614	6.538	10.072
Mean	**Elas-N**		1.425514	1.425514	1.425514
	% Effect		**6.577**	**9.321**	**14.358**
Variance	**Elas-N**		1.35667	1.35667	1.35667
	% Effect		**6.259**	**8.870**	**13.665**

Future Projection of Precipitation Change Effect on Cassava

2	Precipitation	Baseline 1994-2014	2030	2060	2090
	RCP 4.5	**23.78182**	36.32511811	37.50821522	41.65787402
	%		**52.743**	**57.718**	**75.167**
Mean	**Elas-N**		-0.1214914	-0.1214914	-0.1214914
	% Effect		**-6.408**	**-7.012**	**-9.132**
Variance	**Elas-N**		0.3445525	0.3445525	0.3445525
	% Effect		**18.173**	**19.887**	**25.899**
	RCP 8.5	**23.78182**	38.9082677	38.90818898	38.5103937
	%		**63.605**	**63.605**	**61.932**
Mean	**Elas-N**		-0.1214914	-0.1214914	-0.1214914
	% Effect		**-7.727**	**-7.727**	**-7.524**
Variance	**Elas-N**		0.3445525	0.3445525	0.3445525
	% Effect		**21.915**	**21.915**	**21.339**

Future Projection of Climate Change Effect on Cassava

3	CC	Based 1994 - 2014	2030	2060	2090
	RCP 4.5				
Mean	% Effect		**-1.136**	**-0.524**	**-1.521**
Variance	% Effect		23.190	26.062	33.143
	RCP 8.5				
Mean	% Effect		**-1.151**	**1.593**	**6.834**
Variance	% Effect		28.174	30.786	35.003

Future Projection of Temperature Change Effect on Maize

1	Temperature	Baseline 1994 - 2014	2030	2060	2090
	RCP 4.5	81.58715	84.49081	85.36231	85.87479
	%		**3.559**	**4.627**	**5.255**
Mean	Elas-casava		-1.211721	-1.211721	-1.211721
	% Effect		**-4.312**	**-5.607**	**-6.368**
Variance	Elas-N		-10.60044	-10.60044	-10.60044
	% Effect		**-37.727**	**-49.050**	**-55.708**
	RCP 8.5	81.58715	85.41148	86.85235	89.83568
	%		**4.687**	**6.453**	**10.110**
Mean	Elas-N		-1.211721	-1.211721	-1.211721
	% Effect		**-5.680**	**-7.820**	**-12.251**
Variance	Elas-N		-10.60044	-10.60044	-10.60044
	% Effect		**-49.689**	**-68.410**	**-107.171**

Future Projection of Precipitation Change Effect on Maize

2	Precipitation	Baseline 1994-2014	2030	2060	2090
	RCP 4.5	21.85616	35.42911	34.66467	39.38911
	%		**62.101**	**58.604**	**80.220**
Mean	Elas-N		0.0607875	0.0607875	0.0607875
	% Effect		**3.775**	**3.562**	**4.876**
Variance	Elas-N		0.3445525	0.3445525	0.3445525
	% Effect		**21.397**	**20.192**	**27.640**
	RCP 8.5	21.85616	35.53869	35.93942	34.63417
	%		**62.603**	**64.436**	**58.464**
Mean	Elas-N		0.0607875	0.0607875	0.0607875
	% Effect		**3.805**	**3.917**	**3.554**
Variance	Elas-N		0.3445525	0.3445525	0.3445525
	% Effect		**21.570**	**22.202**	**20.144**

Future Projection of Climate Change Effect on Maize

3	CC	Baseline 1994 - 2014	2030	2060	2090
	RCP 4.5				
Mean	% Effect		**-0.537**	**-2.044**	**-1.492**
Variance	% Effect		-16.330	-28.858	-28.069
	RCP 8.5				
Mean	% Effect		**-1.874**	**-3.903**	**-8.697**
Variance	% Effect		-28.119	-46.208	-87.027

Future Projection of Temperature Change Effect on Rice

1	Temperature	Baseline 1994 – 2014	2030	2060	2090
	RCP 4.5	**81.37601**	84.30814	85.1763	85.73352
	%		**3.603**	**4.670**	**5.355**
Mean	Elas-casava		0.6703018	0.6703018	0.6703018
	% Effect		**2.415**	**3.130**	**3.589**
Variance	Elas-N		10.39778	10.39778	10.39778
	% Effect		**37.465**	**48.558**	**55.678**
	RCP 8.5	**81.37601**	85.202	86.55419	89.82895
	%		**4.702**	**6.363**	**10.388**
Mean	Elas-N		0.6703018	0.6703018	0.6703018
	% Effect		**3.152**	**4.265**	**6.963**
Variance	Elas-N		10.39778	10.39778	10.39778
	% Effect		**48.886**	**66.164**	**108.007**

Future Projection of Precipitation Change Effect on Rice

2	Precipitation	Baseline 1994-2014	2030	2060	2090
	RCP 4.5	**20.06337**	32.64042	33.87268	36.47816
	%		**62.687**	**68.828**	**81.815**
Mean	Elas-N		0.0535662	0.0535662	0.0535662
	% Effect		**3.358**	**3.687**	**4.383**
Variance	Elas-N		10.39778	10.39778	10.39778
	% Effect		**651.802**	**715.663**	**850.692**
	RCP 8.5	**20.06337**	38.90827	38.90819	38.51039
	%		**93.927**	**93.926**	**91.944**
Mean	Elas-N		0.0535662	0.0535662	0.0535662
	% Effect		**5.031**	**5.031**	**4.925**
Variance	Elas-N		10.39778	10.39778	10.39778
	% Effect		**976.631**	**976.627**	**956.011**

Future Projection of Climate Change Effect on Rice

3	CC	Baseline 1994 - 2014	2030	2060	2090
	RCP 4.5				
Mean	**% Effect**		**5.773**	**6.817**	**7.972**
Variance	% Effect		689.267	764.221	906.370
	RCP 8.5				
Mean	**% Effect**		**8.183**	**9.297**	**11.888**
Variance	% Effect		1025.517	1042.791	1064.018

Future Projection of Temperature Change Effect on Yam

1	Temperature	Baseline 1994 - 2014	2030	2060	2090
	RCP 4.5	**81.63476**	84.26013	84.9582	85.74668
	%		**3.216**	**4.071**	**5.037**
Mean	Elas-casava		4.327606	4.327606	4.327606
	% Effect		**13.918**	**17.618**	**21.798**
Variance	Elas-N		5.86235	5.86235	5.86235
	% Effect		**18.853**	**23.866**	**29.529**
	RCP 8.5	**81.63476**	85.38062	86.63812	89.77941
	%		**4.589**	**6.129**	**9.977**
Mean	Elas-N		4.327606	4.327606	4.327606
	% Effect		**19.857**	**26.524**	**43.176**
Variance	Elas-N		5.86235	5.86235	5.86235
	% Effect		**26.900**	**35.930**	**58.488**

Future Projection of Precipitation Change Effect on Yam

2	Precipitation	Baseline 1994-2014	2030	2060	2090
	RCP 4.5	**33.08412**	42.61409	42.26835	45.80421
	%		**28.805**	**27.760**	**38.448**
Mean	Elas-N		0.0433741	0.0433741	0.0433741
	% Effect		**1.249**	**1.204**	**1.668**
Variance	Elas-N		5.86235	5.86235	5.86235
	% Effect		**168.867**	**162.740**	**225.394**
	RCP 8.5	**33.08412**	43.34252	45.54665	45.19469
	%		**31.007**	**37.669**	**36.605**
Mean	Elas-N		0.0433741	0.0433741	0.0433741
	% Effect		**1.345**	**1.634**	**1.588**
Variance	Elas-N		5.86235	5.86235	5.86235
	% Effect		**181.774**	**220.830**	**214.593**

Future Projection of Climate Change Effect on Yam

3	CC	Based 1994 - 2014	2030	2060	2090
	RCP 4.5				
Mean	**% Effect**		**15.167**	**18.822**	**23.466**
Variance	% Effect		187.720	186.606	254.923
	RCP 8.5				
Mean	**% Effect**		**21.202**	**28.158**	**44.764**
Variance	% Effect		208.674	256.760	273.082

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