Impact of Climate Variability on Crop Diversification in West African Countries

ABOUA Angui Christian Dorgelès Kevin

Research Paper 480

Bringing Rigour and Evidence to Economic Policy Making in Africa

AFRICAN ECONOMIC RESEARCH CONSORTIUM
CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

Impact of Climate Variability on Crop Diversification in West African Countries

By

ABOUA Angui Christian Dorgelès Kevin

AERC Research Paper 480
African Economic Research Consortium, Nairobi
October 2021

THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are, however, those of the author and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 - City Square
Nairobi 00200, Kenya

ISBN 978-9966-61-179-6

Contents

List of tables

List of figures

Abstract

This paper analyses the impact of climate variability on cereal, root and tuber crops diversification for selected West Africa countries during the period 1965-2014. Crop diversification index, lumping together cereal, root and tuber crops, was calculated through the Composite Entropy Index. Climate variability is measured by the coefficient of variation of temperature and precipitation. A Seemingly Unrelated Regression was used to estimate the relationship between climate variability and crop diversification by controlling for supply and demand side factors of crop diversification. Overall, the results reveal that variability in temperature and precipitation over decades did not have an adverse effect on cereal root and tuber crops diversification. A detail analysis showed that Niger and Togo have been the most adapted to climate variability while Ghana was the most affected, mainly by precipitation variability. The results also indicated that, on the supply side, the availability of agricultural land contributed to crop diversification. Productivity, which is expected to increase crop diversification, was positive and significant in very few countries. In the others, it was not enough to improve crop diversification. On the demand side, population growth and consumption led to crop diversification, particularly in consumption of roots and tuber crops. This study suggests that greater diversification would mitigate the negative impact of climate variability. Therefore, regional and national agricultural policies aimed at increasing productivity are necessary to encourage farmers to diversify food crops under climate variability.

Keywords: Climate variability, Crop diversification, Seemingly Unrelated Regression, West Africa

1. Introduction

Literature related to the impact of climate change in West Africa shows that for some years, there have been signs that temperature and rainfall have changed significantly (De Bruijn and Van Dijk, 2006; FAO, 2008; Brown and Crawford, 2009; Jalloh et al., 2013). A substantial body of empirical research reveals that climate change and variability threaten agriculture and food production (Parry et al., 2004; Lobell et al., 2008; Schlenker and Lobell, 2010; Müller et al., 2011). Reviewing these studies and other country-specific studies, Roudier et al. (2011) found that the negative impact of climate change results mainly from temperature, and it is much larger relative to change in precipitation. Furthermore, the predicted potential impact of climate change showed that the median values of country-average yield loss of cereal crop would be 13% and 18% in the southern (Guinean countries) and northern (Sudano-Sahelian countries) parts of West Africa, respectively. Consequently, regions most vulnerable to food insecurity will be affected by a severe food deficit. To address this situation, farmers need to find solutions to enable them produce enough food for their home consumption or even for the market. One possible solution is crop diversification.

Crop diversification is about crop area allocation and cropping pattern (FAO, 2001). In the context of growing uncertainties, crop diversification is a potential strategy to cope with weather, market and environmental risks. Crop diversification can improve yield stability and crop resilience under changing climatic conditions (Bradshaw et al., 2004; Seo, 2010; Lin, 2011, Bezabih and Sarr, 2012; Njeru, 2013; Huang et al., 2014; Roesch-McNally et al., 2018). Indeed, as climate variability increases, the value of resilience will also increase, especially in production systems sensitive to climate variation. A farmer's decision to move towards diversified agricultural systems will be highly influenced by the ability of the diversification strategy to support the economic resilience of farms (Lin, 2011). Crop diversification can also manage market risks (McGuire, 1980; Dilley et al., 2005; Kahan, 2008; Mukherjee, 2010). Price variability strongly influences an individual farmer's planting decision. They diversify their production to reduce the risk of income volatility. Moreover, climate change is likely to reduce food safety due to environmental risks resulting from increased temperatures or weather events (Miraglia et al., 2009; Tirado et al., 2010; Liu et al., 2013; Hammond et al., 2015; Campbell et al., 2016). In such situations, farmers may diversify crops to mitigate potential losses due to climate change.

In West Africa, agriculture plays a key role in the national economies and is the major source of livelihood (Jalloh et al., 2013). Several cereal, root and tuber crops are widely grown in the region. The major crops grown and consumed are sorghum, millet, maize, rice and fonio (cereals), cassava, sweet potato, yams and taro (roots and tubers). They are the most important staple crops and are rich sources of protein, minerals and vitamins. Therefore, the abundance and diversification of these crops are essential for ensuring food security and improving nutrition. Moreover, cereal-root crops mix is one of the dominant systems farming in West Africa (Dixon et al., 2001; World Bank, 2009; Callo-Concha et al., 2012; Benin, 2016). At the production level, the total areas harvested for cereal, root and tuber crops have grown. From the 1960s to the 2010s, the area harvested increased from 20 million hectares to more than 50 million hectares for cereals and from 2.7 million hectares to more than 20 million hectares for roots and tubers.[2] Furthermore, area allocation (i.e. the share of area harvested of individual crop to total harvested area of crop category) changed during this period.[3] The share of areas harvested of some major food crops decreased to the benefit of some minor food crops. These changes occurred from the 1980s, when the total areas harvested have also increased. At the same time, it is known that the climate has varied significantly. These observations lead us to ask the following questions: Does climate variability adversely affect the diversification of cereal, root and tuber crops? If yes, what is the strength of the relationship?

Recent studies in West Africa *(Parry et al., 2004; Lobell et al., 2008; Schlenker and Lobell, 2010; Müller et al., 2011; Roudier et al., 2011)* have analyzed the long-term impact of climate variability on individual crops. They found that climate variability negatively affected crop yields. However, the exploitation of food crop diversification as a strategy to adapt to long-term climate variability has not been critically examined. This study intends to show if or not climate variability influences crop diversification in West Africa, particularly for cereal, root and tuber crops. The aim of this study is to investigate the link between climate variability and crop diversification, lumping together cereal, root and tuber crops in eleven countries of West Africa using dynamic panel data model. Specifically, land allocated to each individual crop is aggregated to calculate the level of crop diversification by country using the Composite Entropy Index (CEI). Secondly, the strength of the relationship between interannual variability of temperature and precipitation and crop diversification are estimated by controlling for supply and demand side factors of crop diversification. We also take account of the interaction between temperature and precipitation variabilities to capture a simultaneous long-term change in these two climatic variables. Having a long panel data with small cross section units and large time period, we applied a Seemingly Unrelated Regression (SUR) technique that is more appropriate than fixed or random effects panel data. Indeed, the SUR method proposed by Zellner (1962) is a way of estimating panel data models that are long (large T) but not wide (small N). It enables an efficient joint estimation of all the regression parameters and accounts for heteroskedasticity and contemporaneous correlation in the errors across equations.

The paper is organized as follows. The sections 2 and 3 provide an overview of climate variability and changing land use pattern among cereal, root and tuber crops in West Africa, respectively. Section 4 presents the review of literature. Section 5 describes the methodology and the data of the study. The empirical results and discussion are presented in section 6. The final section 7 is devoted to the conclusion and some policy implications.

2. Climate Variability in West Africa

Several studies (De Bruijn and Dijk, 2006; FAO, 2008; Brown and Crawford, 2009; Jalloh et al, 2013; Riede et al., 2016) and climate data in West Africa (Figure 1) reveal that temperature and rainfall have changed considerably. The period 1930-1960 was characterized by a wet climate, followed by droughts in 1970-1980 and a return of rainfall in the 1990s and 2000s, affecting Sahel's population (FAO, 2008). De Bruijn and Dijk (2006) found that climate variability is the most significant problem in the region. The variability of rainfall is enormous, sometimes up to 40-80% and increases with decreasing annual rainfall totals and especially in marginal areas such as the Sahara Desert where unpredictability of rainfall poses enormous threats to food security. Brown and Crawford (2009) revealed that at the end of the century, global temperature in the region will rise by around 1.8°C, which will lead to a 20-30% decrease in water availability in some vulnerable regions of the world. Côte d'Ivoire, Ghana, Guinea, Nigeria and Togo have experienced a reduction of at least 50-100 millimetres of rainfall per year, whereas rainfall is predicted to increase substantially in the Sahelian countries such as Burkina Faso, Niger and Senegal. Moreover, temperature increases by an average of 2°C in the region. The 5th Intergovernmental Panel on Climate Change report warns that West Africa is expected to be strongly impacted by temperature increase ranging between 3 and 6°C above the late 20th century baseline (Riede et al., 2016). Figure 1 confirms these observations; it shows that the average annual rainfall and temperature in West Africa countries have changed over the last 50 years (1960-2015). Over this period, temperature has shown an upward trend while up and down situations were observed for rainfall in the countries. The consequences are that climate vulnerability has negatively affected food crops and food security, as it has been demonstrated in some studies (Parry et al., 2004; Butt et al. 2005; Lobell et al., 2008; Paeth et al., 2008; Müller et al., 2011; Schlenker and Lobell, 2010; Roudier et al., 2011).

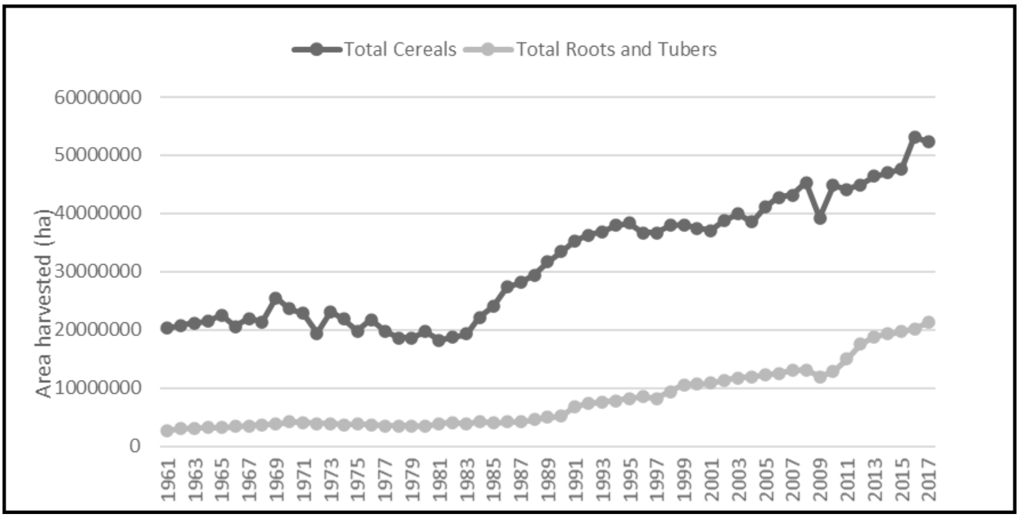
Figure 1: Average annual temperature and rainfall for 11 West African countries, 1960-2015

Source: Elaborated by author from Climatic Unit Research (CRU) database

3. Changing Land Use Pattern among Cereal, Root and Tuber Crops in West Africa

West Africa has an advantage of growing diversified food crops in view of its land availability. First, the FAO's data show that over the period 1961-2017, the areas harvested for cereal and tuber crops have grown (Figure 2). The harvested area more than doubled from 20 million hectares to more than 50 million hectares, while that of root and tuber crops has increased almost tenfold from 2.7 million hectares to 20.0 million hectares. The trends show that during the 1960s and 1970s, the harvested area of cereal crops has evolved into a saw tooth trend while the harvested area of root and tuber crops remained constant. It is from the 1980s that the areas harvested of both groups of crops increased sharply. However, the area of cereal crops showed a more rapid growth than that of roots and tubers.

Figure 2: Trend of total area harvested for cereal, root and tuber crops from 1961-2017



Source: Elaborated by author from FAO database

Secondly, the distribution of individual cereal, root and tuber crops (i.e. the share of area harvested of individual crop in total harvested area of crop category) changed during 1961-2017. Table 1 shows that in the 1960s, millet and sorghum occupied about 41.8% and 36.8%, respectively, of total harvested area under cereals, while maize and rice represented only 12.7% and 7.3%, respectively. The share of area harvested for millet and sorghum decreased from about 41.8% to 27.8% and 36.8% to 29.3% during the 1960s and 2010s, respectively, while in the same period, the share of area for maize and rice increased from about 12.7% to 23.9% and 7.3% to 17.1%, respectively. The figures point out that the cropping pattern for cereals tend to diversification.

Table 1: Trend of land use pattern for cereal crops in West Africa, 1961-2017

Cereal Crops	**Share of harvested area (%)**					
	1960s	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**
Millet	41.81	44.26	39.27	37.56	36.92	27.80
Sorghum	36.75	33.30	31.78	30.59	32.06	29.34
Maize	12.70	11.94	16.46	20.17	17.67	23.92
Rice	7.31	9.30	11.32	10.64	12.05	17.07
Fonio	1.32	1.04	0.93	0.87	1.09	1.61
Wheat	0.06	0.06	0.15	0.10	0.15	0.20
Other cereals	0.15	0.09	0.09	0.07	0.06	0.06

Source: Author’s own calculation from FAO database

For tuber and root crops, cassava and yams are the crops with the largest share of area harvested during the 1960s and 2010s and represent more than 45% and 30%, respectively (Table 2). Changes were also observed in taro, sweet potatoes and potatoes. During the same period, the area harvested for taro decreased from about 16.6% to 5.3% while harvested area of sweet potatoes and potatoes increased from about 2.6% to 9.6% and 0.1% to 1.9%, respectively.

Table 2: Trend of land use pattern for root and tubers crops in West Africa, 1970-2014

Root and Tuber Crops	**Share of harvested area (%)**					
	1960s	**1970s**	**1980s**	**1990s**	**2000s**	**2010-2017**
Cassava	47.05	47.13	51.47	51.51	45.66	46.40
Yams	33.45	33.50	34.39	35.26	34.04	36.74
Taro	16.62	17.05	12.10	8.70	8.15	5.33
Sweet potatoes	2.57	2.03	1.66	3.98	9.91	9.55
Potatoes	0.09	0.12	0.21	0.42	2.11	1.88
Other roots and tubers	0.20	0.17	0.18	0.12	0.12	0.10

Source: Author’s own calculation from FAO database

4. Literature Review

4.1 Drivers of Crop Diversification

Crop diversification is referred to as useful means to increase crop output under different situations and is characterized as an important risk management strategy against the shocks affecting agriculture (FAO, 2001; Kahan, 2008). The notable reasons in favour of crop diversification are to increase farm income, generate employment and ensure food security. Crop diversification can be analyzed as a changing allocation of area under crops and the diversification in the cropping pattern under the influence and interaction of many factors such as resources-related factors (irrigation, rainfall and soil fertility); technology-related factors (seed, fertilizers, water, marketing and processing); food security, price and trade policies; institutional and infrastructure factors and government regulatory policies (Ghosh et al., 2015). Their influences can be analyzed at micro-level (farm level) or macro-level (country or regional level). At farm level, crop diversification is supposed to increase farm income against changes in crop prices and climate risks. At the country level, diversification is supposed to increase the extent of self-sufficiency for the country. At the regional level, diversification is being promoted to mitigate negative externalities associated with mono-cropping (Abro, 2012). Some authors have classified these factors as either as economic and non-economic factors or as supply and demand side factors, including climate variables (Kebebe et al., 2000; Joshi et al., 2004, 2006; Ashfaq et al., 2008; Jha et al., 2009; Mukherjee, 2010; Acharya et al., 2011; Abro, 2012).

The demand side forces that have been hypothesized to influence the diversification include per capita income, urbanization, changing consumer demand, high value crops, etc. On the supply side, the diversification is largely influenced by infrastructure (markets, roads and transportation), technology (irrigation), resource endowments (water, land and labour), agricultural inputs (fertilizers), socio-economic variables and shocks related to climatic conditions.

Experiences in Asian countries show that crop diversification has been mainly driven by economic and demand factors. Farmers shifted towards high value commodities such as fruits, vegetables and flowers (van den Berg et al., 2007; Birthal et al., 2007; Bhattacharyya, 2008; Abro and Sadaqat, 2010). Indian agriculture has been diversifying from cereals to high-value crops and livestock products in accordance with the changing consumption pattern in favour of livestock, fruits and vegetables without the country sacrificing the basic obligation of ensuring food security (Ghosh et al., 2015). Abro et al. (2012) argued that agriculture in Pakistan is diversifying towards High Value Commodities (HVCs) in response to rising per capita income, changing food consumption, increasing urbanization, unfolding globalization, improving infrastructure and reforming policies. The HVCs yield higher, more regular and earlier returns compared to food grains (cereals). Joshi et al. (2004) and Pingali (2004) found that expanding urbanization, increasing infrastructural development, and liberalization of trade policies are factors that caused the process of agricultural diversification in India. Beyond economic factors, agriculture diversification has been possible through the green revolution that the government has put in place by creating core infrastructure such as irrigation projects, rural roads, rural electrification and agricultural markets (Karmakar and Sahoo, 2015). Rahman and Kazal (2015) also found relative prices of vegetables and urea fertilizer, extension expenditure, labour stock per farm, average farm size, irrigation and a reduction in livestock per farm significantly increasing crop diversity in Bangladesh. These studies show that the nature of crop diversification in Asia countries is that farmers shifted from less profitable to more profitable crops, with the goal of increasing exports and competitiveness in both domestic and international markets.

In some developing countries, exposure to fluctuations in commodity prices, demand and climate change and variability (higher temperatures, shifting seasons, more frequent and extreme weather events, flooding, and drought) have motivated the diversification of food crops (Cunguara et al., 2013). Seo (2012) found that in Sub-Saharan Africa (SSA), particularly in lowland savannahs and arid zones in the Sahel, where climate risks are high, farmers will adapt by switching to an integrated system.

The findings of these studies are not surprising since Asian countries are basically rice producing countries, which have achieved a very high level of productivity in rice cultivation and are self-sufficient in rice. The situation might be different in some SSA countries where there is potential to diversify food crops based on cereals and tubers. Crop diversification is expected to contribute towards a higher nutrition level, and food security in vulnerable regions affected by climate risks, poverty and unemployment.

4.2 Empirical Evidence on the Impact of Climate on Crop Diversification

Palanisami et al. (2009) showed that crop diversification is considered as a resilience mechanism adopted by farmers in different regions. The socio-ecological systems of coastal areas are more vulnerable to the impact of climatic changes. In his paper, he used the Modified Entropy Index to rank the different districts and found that there is wide spatio-temporal disparity in the diversification of crops in the coastal districts of Tamil Nadu State, India. He also found that some regions are more vulnerable to climate change, and thus more diversification of crops must be attempted to avoid risk of crop failure and loss of income and employment to the rural people. Acharya et al. (2011) used a Composite Entropy Index (CEI) and multiple linear regression analysis to analyze the nature and extent of crop diversification in Kartanaka states in the period 1982-2008. He computed CEI for different crops and showed that almost all the crop groups have a higher crop diversification index, except for oilseed and vegetable crops. His results showed that rainfall affects positively the level of cereal crop diversification, but the effect is not significant.

Abro (2012) applied a Generalized Least Squares (GLS) technique with fixed effect model to examine the impact of different forces on crop diversification in Pakistan for the period 1980-2011 using the index of output values of high value commodities (IHVC). He found that rainfall was significant, with a negative sign, indicating that crop diversification was limited in areas with higher rainfall. The author also showed that farmers in these areas naturally preferred cultivating rice, and it was only in the medium and low rainfall that farmers wanted to diversify crops to increase their income and minimize risks. In India, Joshi et al. (2004) also confirmed this result. Huang et al. (2014) examined whether farmers adapt to extreme weather events through crop diversification, and which factors influence farmers' decisions on crop diversification against extreme weather events in China. They found that farmers respond to extreme weather events by increasing crop diversification, and their decision to diversify crops is significantly influenced by their experiences of extreme weather events in the previous year. In Bangladesh, Rahman and Kazal (2015) measure the level of crop diversity and identify factors influencing diversification using a panel data of 17 regions. They found insignificant negative effect of rainfall variability on crop diversity, and insignificant positive effect of temperature variability and crop diversity.

All these studies were very important in understanding the significant effect of climate variability on crop diversification. Empirical studies that examine the relationship between climate variability and crop diversification in West Africa are rare. This current study may be among the few early contributors to understanding this link. Firstly, we determine the extent of the diversification of cereal, root and tuber crops in each of the selected 11countries. Secondly, we apply dynamic panel data model to estimate the effect of climate variables and other controls on crop diversification.

5. Methodology

5.1 Econometric Specification

Based on the literature on the rationale and the factors influencing the extent of crop diversification, discussed above, the econometric model to be estimated is formulated as follows:

$$D_{i,t} = \gamma D_{i,t-1} + \alpha C_{i,t} + \beta X'_{i,t} + u_i + \varepsilon_{i,t} \tag{1}$$

where $D_{i,t}$ is crop diversification index for country i at time t; $D_{i,t-1}$ is the lagged of crop diversification index. $C_{i,t}$ is a set of climate variables (our interest variables), $X'_{i,t}$ represents a vector of control variables capturing supply and demand side factors of crop diversification; u_i represents the unobservable country-specific effect, and $\varepsilon_{i,t}$ is the idiosyncratic error components that are independently and identically distributed $N(0,\sigma^2)$. γ, α and β are the coefficients of the variables to be estimated. The dynamic form of the model to be estimated is motivated by the fact that crop diversification can involve dynamic adjustment; the past values of crop diversification index can affect the present ones due maybe to suitable climate, continuous improvement and stability in productivity, remunerative prices, and above all, the major staple foods (Singh and Sidhu, 2004).

In the literature, crop diversification is measured through a variety of indices indicating the extent of dispersion and concentration of activities in a given time and space. Among these indices, Herfindahl Index, Simpson Index and the Entropy Indices are widely used in the agricultural literature for diversification (Maji et al., 2015). In the case of this study, the Composite Entropy Index (CEI) is used. The choice of this index is motivated by the fact that it considers two components: the distribution and the number of crops. Moreover, the CEI possesses all desirable properties of Modified Entropy Index and is used to compare diversification across situations having different and large numbers of crops. In fact, the number of crops cultivated differs from one country to another. Cereal, root and tuber crops are lumped together to calculate the crop diversification index. The value of CEI increases with decrease of concentration and rises with the number of crops. It ranges between zero and one. A zero value indicates a specialization in a single crop and a value above zero signifies crop diversification. The formula of the CEI is given by:

$$CEI = -\left(\sum_{i=1}^{N} p_i \log_N p_i\right) \times \left\{1 - \left(\frac{1}{N}\right)\right\} \tag{2}$$

where, N is the total number of crops and is the average proportion of i^{th} crop in the total harvested area. Cereal, root and tuber crops include millet, sorghum, maize, rice, fonio, wheat, other cereals, cassava, yams, taro, sweet potatoes, potatoes, other roots and tubers.

Interest variables are the coefficient of variation of temperature and precipitation and their interaction. The coefficient of variation measures the interannual variation of temperature and precipitation and are computed as the ratio of standard deviation and the mean. It is written as follows:

$$Temperature\ CV = \frac{STD_{Temp}}{Average\ Annual\ Temp};\ Precipitation\ CV = \frac{STD_{Prec}}{Average\ Annual\ Prec} \tag{3}$$

In empirical studies, the coefficient of variation is often used to measure climate variability and the long-term climate variation (Ochieng et al., 2016; Ncube et al., 2012; Seo, 2012; Alem et al., 2009). Control variables include technology and supply side factors, and demand side factors.

Since the dependent variable (crop diversification index) aggregates harvested area of individual cereal, root and tuber crops, aggregate cereal yield (tonnes per hectare) and also aggregate root and tuber yield (tonnes per hectare) are used as proxies to capture technology. They can also capture the efficient use of irrigation water and fertilizer use in cereal and root and tuber farms. It will be better to directly include these variables in the model; however, the data on irrigated areas and quantities of fertilizer effectively used in cereal and tuber farms are not available. As supply side factors, we considered agricultural land representing total arable land (area under permanent crop and permanent pastures measured as a percentage of total land area); and agricultural labour measured as the number of active persons in the agricultural sector. The demand side factors are population, Gross Domestic Product per capita used as a proxy of income, and apparent consumption also used as proxy to measure the changing demand in cereal, root and tuber crops.

This study uses panel data over the period 1965-2014 covering 11 countries in West Africa: Benin, Burkina Faso, Côte d'Ivoire, Guinea, Mali, Niger, Nigeria, Ghana, Sierra Leone, Senegal and Togo. The countries have been chosen based on available data. The data set is constructed from several data sources. We used seven cereal crops (millet, sorghum, maize, rice, fonio, wheat, other cereals) and seven root and tuber crops (cassava, yams, taro, sweet potatoes, potatoes, others roots and tubers). We collected the data on area harvested for crops from the FAO database. The temperature and precipitation data are collected from Climatic Research Unit (CRU) database. The other variables are from World Development Indicators and FAO database.

5.2 Estimation Strategy

We have a long panel data with small number of individual units (N) and large time series (T). Time dimension is large enough (50 years) to run separate regression for each individual country. For this purpose, we adopt the Seemingly Unrelated Regression Equations (SURE) model proposed by Zellner (1962). The SURE method consists of several individual relationships that are linked by the reason of their disturbances being correlated. This method allows for estimation of the parameters of a system, accounting for heteroskedasticity and contemporaneous correlation in the errors across equations. We use Feasible Generalized Least Squares (FGLS) method that leads to more efficient estimations. Zellner (1962) opined that the jointly estimated equation models (SURE method) are more efficient than the independent equation solution methods where contemporaneous correlation is present because independent equation solution methods such as multiple regression models will suffer from simultaneous bias. Indeed, in the absence of contemporaneous correlation between errors in different equations, the OLS equation-by-equation is fully efficient. To make sure that the SURE is valid and has yielded a significant gain in efficiency, we test for diagonality of the covariance matrix proposed by Breusch and Pagan (1980). The null hypothesis of diagonality states zero contemporaneous covariance between the errors of different equations.

5.3 Descriptive Statistics

Table 3 reports the summary statistics of the key variables used in the study. Crop diversification index across countries ranges from 0.841 to 0.243, with an average value of 0.540 for the entire sample while 0.617 was for tropical countries and 0.405 for Sahelian countries. These values show that crops were less diversified in the region. However, it is observed that crops are more diversified in the tropical countries than the Sahelian countries. The low level of the crop diversification index means that land area allocated among crops is unequally distributed. Indeed, a zero value of the index indicates a specialization in the country (few numbers of crops are dominant) and a value greater than zero signifies crop diversification. A value close to one means that the country better diversifies its crops.

Table 3: Definition and descriptive statistics of the variables used in the econometric model

Variables	Description	Obs	Min	Max	Mean		
					All sample	Tropical countries	Sahelian countries
CEI	Crop diversification index	550	0.243	0.841	0.540 (0.153)	0.617 (0.124)	0.405 (0.095)
Temperature	Average annual temperature in °C	550	25.2	29.7	27.3 (0.932)	26.9 (0.718)	28.2 (0.640)
Precipitation	Average annual precipitation in mm	550	5.55	277.9	89.2 (41.98)	118.1 (39.76)	38.6 (22.06)
Temperature CV	Coefficient of variation of annual temperature	550	0.028	0.217	0.082 (0.045)	0.056 (0.010)	0.126 (0.047)
Precipitation CV	Coefficient of variation of annual precipitation	550	0.533	1.962	1.063 (0.322)	0.856 (0.152)	1.425 (0.196)
Cereal Yield	Output in tonnes per hectare	550	0.257	2.721	1.000 (0.381)	1.154 (0.377)	0.729 (0.295)
Root and Tuber Yield	Output in tonnes per hectare	550	2.627	22.21	7.885 (3.476)	7.706 (2.583)	8.198 (4.634)
Agricultural Land	Total arable land and land under permanent crops in hectare	550	7.37E+07	1522000	1.87E+07 (1.80E+07)	1.68E+07 (1.99E+07)	2.22E+07 (1.34E+07)
Agricultural Labour	Number of persons	385	7.14E+05	1.26E+07	3.53E+06 (3.12E+06)	3.73E+06 (3.77E+06)	3.16E+06 (1.30E+06)
Population	Number of persons	550	1.70E+06	1.76E+08	1.68E+07 (2.90E+07)	2.12E+07 (3.55E+07)	9.04E+06 (3.68E+06)
GDP (%)	Gross national product per capita in (constant 2010 US$)	527	782.6	248.04	782.6 (487.9)	929.1 (534.7)	539.2 (253.4)
Cereal consumption	Apparent per capita consumption (cereals) in kg	539	35.99	229.8	131.2 (44.28)	104.1 (24.63)	178.5 (28.40)
Root and tuber consumption	Apparent per capita consumption (roots and tubers) in kg	539	2.28	434.5	140.9 (122.9)	211.3 (100)	17.64 (11.99)

Source: Computation from data set of countries (1960-2015)

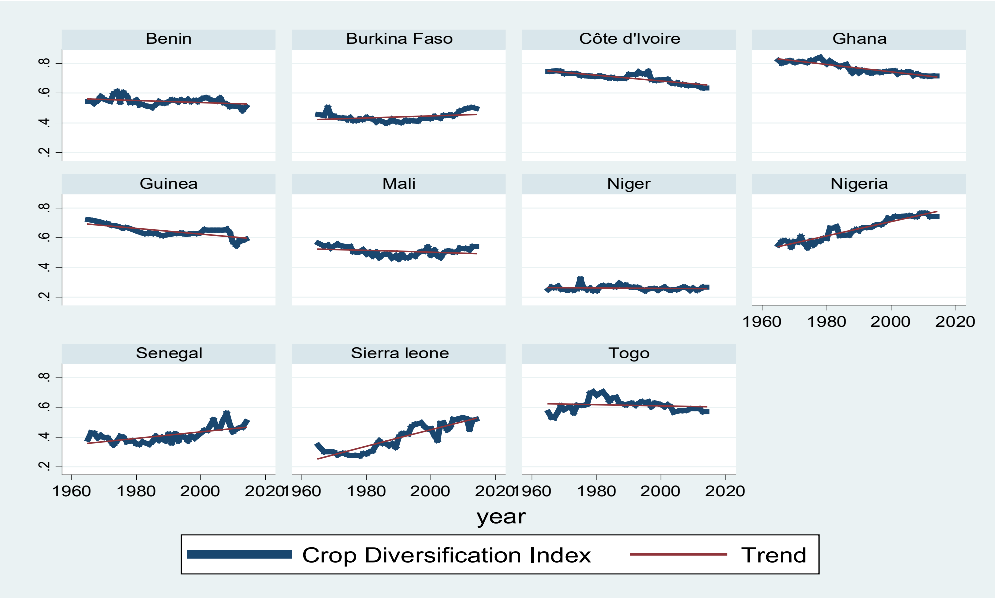
Table 4 shows that, at country level, on average, Ghana is the most diversified in cereal, root and tuber crops with an index value of 0.768 followed by Côte d'Ivoire (0.702), Nigeria (0.658), Guinea (0.648), and Togo (0.614). The less diversified countries are Senegal (0.421), Sierra Leone (0.391) and Niger (0.261). After the 1990s, Nigeria became the most diversified. Figure 3 shows the evolution of the diversification index for each country. We observe three types of trend: (i) an increasing trend of the index in Nigeria, Sierra Leone and Senegal; (ii) a consistent trend in Benin, Burkina Faso, Mali, Niger and Togo; and (iii) a decreasing trend in Côte d'Ivoire, Ghana and Guinea.

Table 4: Diversification index by country

Countries	1960s	1970s	1980s	1990s	2000s	2000-2014	Average
Ghana	0.812	0.818	0.782	0.742	0.736	0.714	**0.768**
Côte d'Ivoire	0.746	0.724	0.704	0.719	0.669	0.642	**0.702**
Nigeria	0.563	0.571	0.635	0.682	0.744	0.751	**0.658**
Guinea	0.713	0.676	0.628	0.626	0.649	0.574	**0.645**
Togo	0.562	0.622	0.659	0.626	0.591	0.582	**0.614**
Benin	0.549	0.565	0.525	0.548	0.548	0.504	**0.542**
Mali	0.548	0.530	0.483	0.488	0.499	0.529	**0.508**
Burkina Faso	0.416	0.428	0.415	0.416	0.448	0.497	**0.437**
Senegal	0.409	0.381	0.370	0.396	0.479	0.463	**0.412**
Sierra Leone	0.314	0.282	0.335	0.453	0.471	0.507	**0.391**
Niger	0.262	0.259	0.273	0.257	0.255	0.259	**0.261**

Source: Computation from data set of countries (1960-2015)

Figure 3: Trend in crop diversification index



Source: Computer output from computed data set of countries (1960-2015)

Average annual temperature and precipitation, and the coefficient of variation of temperature and precipitation are the interest variables. From Table 3, the average annual temperature and precipitation over the period of analysis was around 27.3°C and 89.2 mm for the entire sample. The annual temperature is higher in the Sahelian countries than in the tropical countries, with an average value of 28.2°C and 26.9°C, respectively. The annual precipitation is higher in the tropical countries than Sahelian countries, with an average value of 118.1 mm and 38.6 mm, respectively. The coefficient of variation of temperature and precipitation for the entire sample was 0.082 and 1.063, respectively. The CV of temperature and precipitation are higher in Sahelian countries than in tropical countries. Temperature variability was 0.126 and 0.056 for Sahelian countries and tropical countries, respectively. Table 5 shows that Côte d'Ivoire, Ghana and Togo are experiencing the lowest variability in temperature and precipitation. Niger has the highest coefficient of variation of temperature and precipitation.

Table 5: Temperature and precipitation variability by country over the period 1965-2014

Countries	Temperature variation	Countries	Precipitation variation
Sierra Leone	0.040	Côte d'Ivoire	0.656
Côte d'Ivoire	0.049	Ghana	0.699
Ghana	0.053	Togo	0.774
Togo	0.056	Benin	0.919
Guinea	0.062	Nigeria	0.920

Benin	0.063	Sierra Leone	0.979
Nigeria	0.068	Guinea	1.042
Senegal	0.076	Burkina Faso	1.208
Burkina Faso	0.088	Mali	1.378
Mali	0.155	Senegal	1.460
Niger	0.187	Niger	1.655

Source: Computation from data set of countries (1960-2015)

With respect to yield, Table 3 shows that the average yield of cereal crops is 1.00 tonnes per hectare with a minimum value of 0.257 tonnes per hectare and a maximum value of 2.721 tonnes per hectare. With respect to roots and tubers, the yield is 7.88 tonnes per hectare, with a minimum value of 2.62 tonnes per hectare and 22.21 tonnes per hectare. Cereal yield is higher in tropical countries (1.154 tonnes per hectare) than in Sahelian countries (0.729 tonnes per hectare). The situation is the opposite for roots and tubers with an average yield of 7.706 for tropical countries and 8.198 for Sahelian countries. The average apparent per capita consumption is 131.2 for cereals and 140.9 for roots and tubers. Sahelian countries consume more cereals (178.5kg per capita) than tropical countries (104.1kg per capita). Consumption of roots and tubers is still very low in the Sahelian countries (17.64kg per capita) against 211.3kg per capita in tropical countries.

6. Empirical Results and Discussion

Table 6 shows the results of the estimated coefficients, Breusch-Pagan test for independent equations and diagnostic statistics. As the results indicate, the null hypothesis that the coefficients in each respective regression are zero is rejected at 1% significance level. For most equations, the R-squared value exceeds 70%. The Breusch-Pagan test confirms the existence of contemporaneous correlation between the equation errors of each country at 5% level of significance. Moreover, F-value is higher than its critical value, suggesting a good overall significance of the estimated model for all the eleven (11) countries. The SUR estimation is more appropriate than the OLS equation-by-equation procedure.

From the econometric results, we found a positive and significant relationship between crop diversification index and its lag in Burkina Faso, Nigeria, Sierra Leone and Togo. This relationship is also positive in Benin, Ghana and Guinea but not significant. A negative effect is observed in Côte d'Ivoire, Mali, Niger and Senegal. The effect is only significant in Côte d'Ivoire. These results demonstrate that crop diversification is a dynamic process, thus implying that past diversification level of crops increases (or decreases) the current diversification, and which can be explained by the increase or decrease in crop productivity. Banerjee et al. (2015) explained that the dynamic effect of crop shifts captures the concomitant movement of yield and change in cropping pattern.

The results show a negative relationship between temperature variability and crop diversification in most countries except Benin, Ghana, and Mali. There is a positive and significant effect in Mali, implying that temperature variability did not have a significant adverse effect on the diversification of crops. The results also reveal that in most countries, precipitation variability has negative and non-significant effect on crop diversification. Precipitation variability was significantly favourable for crop diversification in Burkina Faso, and significantly unfavourable in Ghana. The results confirm the findings that the negative impact of climate variability on agriculture in West Africa is driven mainly by increase in temperature, while rainfall has the potential to exacerbate or mitigate this impact depending on whether rainfall decreases or increases (Sultan and Gaetani, 2016 ; Roudier et al., 2011).

We also look at what would be the effect of the interaction between temperature and precipitation variability to capture a simultaneous long-term change in these two climatic variables. We did not find adverse effect of climate variability on crop diversification in most Sahelian countries experiencing high variability in temperature and rainfall, except in Senegal where the coefficient is negative but not significant.

This result agrees with that of Huang et al. (2014) in China, who found that in areas where extreme climatic events occur, agriculture adapts by diversifying, and the decision to diversify is influenced by their experience of extreme weather events in the previous year.

Table 6: Empirical parameter estimates of the impact of climate variability on food crops diversification in West Africa

	Tropical Countries							Sahelian Countries			
Variables	Benin	Côte d'Ivoire	Ghana	Guinea	Nigeria	Sierra Leone	Togo	Burkina Faso	Mali	Niger	Senegal
CEI_{t-1}	0.322 (0.198)	-0.508*** (0.179)	0.141 (0.094)	0.177 (0.156)	0.353*** (0.127)	0.528*** (0.164)	0.434*** (0.143)	0.333*** (0.098)	-0.222 (0.196)	-0.099 (0.129)	-0.045 (0.120)
Climate Variables											
CV Temp	0.287 (0.275)	-0.097 (0.248)	0.272 (0.220)	-0.338 (0.207)	-0.315** (0.143)	-2.587*** (0.918)	-0.805** (0.331)	-0.243** (0.119)	0.502*** (0.220)	-0.038 (0.082)	-0.889** (0.431)
CV Prec	-0.067 (0.037)	-0.008 (0.018)	-0.046** (0.018)	0.096 (0.026)	0.002 (0.026)	-0.041 (0.054)	0.031 (0.029)	0.033** (0.016)	-0.027 (0.029)	-0.005 (0.008)	-0.027 (0.039)
CV Temp × CV Prec	0.164 (0.198)	-1.005 (0.399)	-0.777*** (0.182)	-0.087 (0.145)	0.111 (0.115)	-0.031 (0.746)	0.819** (0.347)	0.030 (0.048)	0.025 (0.107)	0.068** (0.027)	-0.091 (0.159)
Supply side factors											
$\text{Cereal Yield}_{t-1}$	-0.025 (0.028)	0.005 (0.010)	0.007 (0.013)	0.105** (0.053)	0.025 (0.030)	-0.112* (0.059)	-0.080*** (0.022)	-0.004 (0.011)	0.052*** (0.0.16)	-0.010 (0.023)	-0.017 (0.031)
$\text{Root\&Tuber Yield}_{t-1}$	-0.001 (0.002)	-0.013 (0.004)	0.001 (0.002)	-0.053 (0.007)	0.001 (0.002)	-0.0003 (0.004)	0.015*** (0.003)	0.001 (0.001)	-0.005*** (0.001)	0.003*** (0.0007)	-0.0001 (0.003)
Agri land	0.105** (0.050)	-0.197 (0.204)	0.602*** (0.132)	0.5188** (0.219)	-0.283*** (0.089)	0.447*** (0.196)	0.114 (0.063)	0.055 (0.044)	-0.045 (0.121)	0.071 (0.050)	-0.101 (0.121)
Agri labour	0.159 (0.079)	0.839*** (0.129)	-0.645** (0.247)	-1.638*** (0.816)	-2.730*** (0.636)	0.333 (0.502)	-0.955** (0.438)	-1.121* (0.622)	0.153 (0.545)	-1.106*** (0.356)	0.648 (0.772)
Demand Side Factors											
Population	-0.271*** (0.091)	-0.290*** (0.046)	0.221 (0.216)	1.463*** (0.739)	0.250*** (0.049)	-0.189 (0.389)	0.630 (0.296)	1.278** (0.631)	0.095 (0.398)	0.972*** (0.335)	-0.538 (0.728)

GDP per capita	0.138 (0.116)	-0.136*** (0.033)	0.056* (0.030)	-0.203 (0.114)	-0.086*** (0.016)	-0.039 (0.080)	-0.110 (0.025)	-0.034 (0.038)	-0.017 (0.055)	0.087** (0.038)	-0.158 (0.201)
Cereal Consump	0.0006* (0.0003)	0.001*** (0.0006)	0.0001 (0.0002)	-0.0001 (0.0004)	-0.0009 (0.0004)	0.007** (0.002)	0.0003 (0.0004)	0.0003 (0.0002)	-0.001 (0.0005)	0.00001 (0.0002)	0.0004 (0.0004)
Root&Tuber Consump	0.0001 (0.0001)	-0.0001 (0.0002)	0.0001** (0.00007)	-0.0002 (0.0005)	0.0002** (0.001)	-0.0009 (0.001)	0.0003** (0.0001)	0.002*** (0.0004)	0.0008* (0.0004)	0.001*** (0.0002)	0.006*** (0.0009)
Constant	-0.130 (0.418)	-2.296 (2.477)	-3.536*** (1.117)	-5.329 (3.913)	46.183 (11.200)	-8.505 (2.804)	2.745 (1.548)	-4.075 (1.308)	-2.090 (2.071)	-0.772 (0.636)	2.103 (2.905)
R – Squared R-Squared	0.775	0.957	0.896	0.902	0.983	0.821	0.881	0.971	0.731	0.774	0.919
F-Statistic	125.55	732.92	301.07	285.87	1796.95	143.51	367.51	1084.31	87.13	124.33	338.94
Prob(F-Statistic)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Breusch-Pagan test of Independence: Chi^2 (55) = 75.403 Prob=0.0353											

*Figures in parenthesis are standard error. ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. The variables Agricultural Land, Agricultural Labour, Population and apparent consumption are in logarithmic form.*

The results also reveal that climate variability had adversely affected crop diversification in Côte d'Ivoire, Ghana and Sierra Leone, but was favourable in Benin, Nigeria and Togo. A significant effect is found in Ghana (negatively) and in Niger and Togo (positively). Looking at these results, it seems that Niger and Togo have been the most adapted to climate variability while Ghana was the most affected, mainly by precipitation variability. The econometric results are consistent with what we observed with the diversification index data. Ghana had experienced a downward trend in its diversification index while the trend has remained constant in Niger and Togo. Indeed, Ghana had a better diversification of food crops until 1980s, with a predominance of maize, millet and sorghum (for cereals) and cassava, yams and taro (for tubers). After this period, maize and cassava remained dominant as the major food basket of the country, accounting respectively for nearly half of total cereal production and root and tuber production. Moreover, recent research has shown that maize yield has been significantly affected by climate variability (Acquah and Kweku, 2012; Tachie-Obeng et al., 2013; and Fosu-Mensah, 2013). Although cereals and tubers have the lowest level of diversification in Niger and the region, millet and sorghum, which are crops particularly adapted to the drastic conditions of climatic variability, have remained predominant with diverse varieties. In addition, the country has diversified root and tuber crops. It was previously dominated by cassava production, but sweet potato and potato production has been growing in recent years. Regarding Togo's experience, she has maintained a constant diversification with a predominance of maize and sorghum for cereals and cassava, yams and taro for roots and tubers. The results suggest that better diversification has the advantage of mitigating the effect of climate variability.

The effect of supply and demand side factors was estimated on crop diversification index. The results indicate that agricultural land is positively and significantly associated with crop diversification, mainly in most tropical countries. Indeed, the abundance of agricultural land can stimulate crop diversification. This relationship can be explained by the fact that an increase in agricultural land favours an increase in the area allocated to crops. A plausible mechanism by which the allocated area increases is that the farmers next to their current crops, practice other crops or new crops. In addition, new farmers have access to land to grow food crops. The results are consistent with the finding of (Rahman and Kazal, 2015; Huang et al., 2014; Joshi et al., 2004), who found that increase in farm size is positively and significantly associated with crop diversification.

Productivity is used as proxy to capture technology, such as the efficient use of irrigation water and fertilizer use in cereal and root and tuber farms. Productivity, which is expected to increase crop diversification, has been positive and significant in very few countries. In the others, it was not enough to improve crop diversification. A positive sign of technology variables is confirmed by some researchers (Acharya et al., 2011; Abro, 2012; Rahman and Kazal, 2015), showing that use of fertilizers, and irrigation play a key role in crop diversification. This involves investing in research to promote new varieties and also access to fertilizers and irrigation. On the demand side, population growth and consumption led to crop diversification, particularly the roots and tuber crops consumption.

7. Conclusion

In this paper, we have examined the impact of climate variability on cereal, root and tuber crops diversification for eleven (11) selected countries in West Africa over the period 1965-2014. Indeed, cereal, root and tuber crops are the most important staple crops grown and consumed in the region. They are not only essential to food security, but are a rich source of proteins, minerals and vitamins needed to ensure children's nutrition. Over the last decades, there is evidence that climate variability adversely affected crop yield, and the negative impact results mainly from temperature. In this paper, we have shown that climate variability characterized by long-run change interannual temperature and precipitation negatively affect cereal, root and tuber crop diversification. A seemingly unrelated regression was used to estimate a dynamic panel data. The results reveal that, in many cases, variability in temperature and precipitation over decades did not have an adverse effect on cereal root and tuber crops diversification. The results also indicate that an increase in demand for cereals, roots and tubers, and population, are positively associated with crop diversification in most countries. However, the productivity of these crops is not yet sufficient to promote great diversification.

One of the limitations of the study is that it did not consider prices. Price variability can influence the farmer's decision to diversify or not. We wanted to include producer prices, but the data is not available over a long period. This study suggests that greater diversification would mitigate the negative impact of climate variability. Therefore, regional and national agricultural policies aimed at increasing productivity are necessary to encourage farmers to diversify food crops under climate variability. In particular, it is necessary to invest in research to promote new varieties, and ensure access to fertilizers and irrigation.

References

Abro, A.A. 2012. "Determinants of crop diversification towards high value crops in Pakistan". *International Journal of Business Management and Economic Research*, 3(3): 536-545.

Abro, A.A. and Sadaqat, M. 2010. "Poverty alleviation through diversifying towards high value crops in Pakistan". *International Journal of Business Management and Economic Research,* 1(1): 1-8.

Acharya, S.P., Basavaraja, H., Kunnal, L.B., Mahajanashetti, S.B. and Bhat, A.R.S. 2011. "Crop diversification in Karnataka: An economic analysis". *Agricultural Economics Research Review,* 24: 351-357.

Acquah, H. D. and Kyei, C. K. 2012. "The effects of climatic variables and crop area on maize yield and variability in Ghana". *Russian Journal of Agriculture and Socio-Economic Sciences*, 10(10): 10-13.

Alem, Y., Bezabih, M., Menale, K. and Zikhali, P. 2010. "Does fertilizer use respond to rainfall variability? Panel data evidence from Ethiopia". *Agricultural Economics*, 41(2): 165-175.

Ashfaq, M., Hassan, S., Naseer, M.Z., Baig, I.A. and Asma, J. 2008. "Factors affecting farm diversification in rice–wheat". *Pakistan Journal of Agricultural Science*, 45(3): 91-94.

Banerjee G. and Banerjee S. 2015. "Crop diversification: An exploratory analysis". In M. Ghosh, D. Sarkar and B. Roy, eds., *Diversification of agriculture in Eastern India. India Studies in Business and Economics*. New Delhi: Springer.

Benin, S. 2016. *Agricultural productivity in Africa: Trends, patterns, and determinants*. Washington DC: International Food Policy Research Institute.

Bezabih, M. and Sarr, M. 2012. "Risk preferences and environmental uncertainty: Implications for crop diversification decisions in Ethiopia". *Environmental and Resource Economics*, 53(4): 483–505.

Bhattacharyya, R. 2008. Crop diversification: A search for an alternative income of the farmers in the state of West Bengal in India. Proceedings of the international conference on applied economics (ICOAE), Kastoria, Greece, 15-17 May.

Birthal, P.S., Joshi, P.K., Devesh, R. and Amit, T. 2007. *Diversification in Indian agriculture towards high value crops: The role of smallholders*. Washington DC: International Food Policy Research Institute.

Bradshaw, B., Dolan, H. and Smit, B. 2004. "Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian Prairies". *Climatic Change*, 67(1): 119-141.

Breusch, T. S. and Pagan, A.R. 1980. "The Lagrange Multiplier Test and its applications to model specification tests in econometrics". *Review of Economic Studies*, 47(1): 239-53.

Brown, O. and Crawford, A. 2009. Rising temperatures, rising tensions. climate change and the risk of violent conflict in the Middle East. Winnipeg: International Institute for Sustainable Development.

Butt, T. A., McCarl, B. A., Angerer, J., Dyke, P. T. and Stuth, J. W. 2005. "The economic and food security implications of climate change in Mali". *Climatic Change,* 68(3): 355-378.

Callo-Concha, D., Gaiser, T. and Ewert, F. 2012. Farming and cropping systems in the West African Sudanian Savanna, WASCAL research area: Northern Ghana, Southwest Burkina Faso and Northern Benin. ZEF Working Paper Series, 100.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A.M. and Wollenberg, E. 2016. "Reducing risks to food security from climate change". *Global Food Security*, 11: 34-43.

Cunguara, B., Garrett, J., Donovan, C. and Cassimo, C. 2013. Analise situacional, construangimentos e oportunidades para o crescimento agrario em Moçambique Relatorio de Pesquisa #73P. Maputo, Mozambique: Ministry of Agriculture.

De Bruijn, M.E. and van Dijk, J.W.M. 2006. *Climate change and climate variability in West Africa*. Leiden: African Studies Centre.

Dilley, M., Chen, R. S., Deichmann, U., Lerner-Lam, A. L. and Arnold, M. 2005. "Natural disaster hotspots: A global risk analysis". *Disaster Risk Management Series*, Vol. 5. Washington DC: World Bank.

Dixon, J., Gulliver, A. and Gibbon, D. 2001. *Farming systems and poverty: Improving farmers' livelihoods in a changing world*. Rome and Washington DC: FAO and World Bank.

FAO. 2001. *Crop diversification in Asia-Pacific region*, Bangkok, Thailand.

FAO. 2008. Climate change and biodiversity for food. Technical background document, HLC/08/BAK/3.

Fosu-Mensah, B.Y. 2013. Modelling the impact of climate change on maize (Zea mays L.) yield under rainfed conditions in sub-humid Ghana. UNU-INRA Working Paper 1. Accra: United Nations University-Institute for Natural Resources in Africa.

Ghosh, M., Sarkar, D. and Roy, B. C. 2015. Diversification of agriculture in Eastern India. New Delhi: Springer.

Hammond, S.T., Brown, J.H., Burger, J.R., Flanagan, T.P., Fristoe, T.S., Mercado-Silva, N. and Okie, J.G. 2015. "Food spoilage, storage, and transport: Implications for a sustainable future". BioScience, 65(8): 758-768.

Huang, J., Jiang, J., Wang, J. and Hou, L. 2014. "Crop diversification in coping with extreme weather events in China". Journal of Integrative Agriculture, 13(4): 677-686.

Jalloh, A., Nelson, G., Thomas, T., Zougmoré, R.B. and Roy-Macauley, H. 2013. West African agriculture and climate change: A comprehensive analysis. Washington DC: International Food Policy Research Institute.

Jha, B.N., Kumar, N. and Mohanty, B. 2009. Pattern of agricultural diversification in India. Working Paper No. E/302/2009. New Delhi: Institute of Economic Growth.

Joshi, P.K., Gulati, A., Birthal, P.S. and Tewari, L. 2004. "Agriculture diversification in South Asia: Patterns, determinants and implications". Economic and Political Weekly, 39(24): 2457-2467.

Joshi, P.K., Tewari. L. and Birthal, P.S. 2006. "Diversification and its impact on smallholders: Evidence from a study on vegetable production". *Agricultural Economics Research Review*, 19(2): 219-236.

Kahan, D. 2008. Managing risk in farming. Food and Agriculture Organization (FAO), Rome (Retrieved from http://www.fao.org/uploads/media/3- ManagingRiskInternLores.pdf).

Karmakar K. and Sahoo, B. 2015. "Green revolution in Eastern India". In M. Ghosh, D. Sarkar and B. Roy (eds), *Diversification of agriculture in Eastern India*. India Studies in Business and Economics. New Delhi: Springer.

Kebebe, E., Mehta, V.P. and Dixit, P.N. 2000. "Diversification of agriculture in Haryana: An empirical analysis". *Agricultural Situation in India*, 57(8): 459-463.

Lin, B. B. 2011. "Resilience in agriculture through crop diversification: Adaptive management for environmental change". *BioScience*, 61(3): 183-193.

Liu, C., Hofstra, N. and Franz, E. 2013. "Impacts of climate change on the microbial safety of pre-harvest leafy green vegetables as indicated by Escherichia coli O157 and Salmonella spp". *International Journal of Food Microbiology*, 163(2-3): 119-128.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. 2008. "Prioritizing climate change adaptation needs for food security in 2030". *Science*, 319(5863): 607–610.

Maji, S., Jha Chakraborty, A., Bera, B. and Nandi, A. 2015. "A study on the extent of crop diversification in West Bengal". In M. Ghosh, D. Sarkar and B. Roy, eds., *Diversification of agriculture in Eastern India*. India Studies in Business and Economics. New Dheli: Springer.

McGuire, R. A. 1980. "A portfolio analysis of crop diversification and risk in the cotton South". *Explorations in Economic History*, 17(4): 342-71.

Miraglia, M., Marvin, H. J., Kleter, G.A., Battilani, P., Brera, C., Coni, E. and Vespermann, A. 2009. "Climate change and food safety: An emerging issue with special focus on Europe". *Food and Chemical Toxicology*, 47(5): 1009-1021.

Mukherjee, S. 2010. Crop diversification and risk: An empirical analysis of Indian states. MPRA paper. Retrieved from http://mpra.ub.uni-muenchen.de/35947/1/MPRA_paper_35947.pdf.

Muller, C., Cramer, W., Hare, W.L. and Lotze-Campen, H. 2011. Climate change risks for African agriculture. *Proceedings of the National Academy of Sciences*, 108(11) 4313–4315.

Ncube, M., Zikhali, P. and Musango, J.K. 2012. "The impact of climate variability on water and energy demand: The case of South African local governments". *Water and Environment Journal*, 27: 29-41.

Njeru, E.M. 2013. "Crop diversification: A potential strategy to mitigate food insecurity by smallholders in Sub-Saharan Africa". *Journal of Agriculture, Food Systems, and Community Development*, *3*(4): 63-69.

Ochieng', J., Kirimi, L. and Mathenge, M. 2016. "Effects of climate variability and change on agricultural production: The case of small-scale farmers in Kenya". *NJAS - Wageningen Journal of Life Sciences*, 77: 71-78.

Paeth, H., Capo-Chichi, A. and Endlicher, W. 2008. "Climate change and food security in tropical West Africa: A dynamic-statistical modelling approach". *Erdkunde*, 62: 101-115.

Palanisami, K., Ranganathan, C. R., Senthilnathan, S. and Umetsu, C. 2009.

Diversification of agriculture in coastal districts of Tamil Nadu: A spatio-temporal analysis. Japan: Inter-University Research Institute Corporation, National Institute for the Humanities. Research Institute for Humanity and Nature, 130-137.

Parry, M.L., Rosenzweig, C., Iglesias, A. and Livermore, M.G.F. 2004. “Effects of climate change on global food production under SRES emissions and socio-economic scenarios”. *Global Environmental Change*, 14(1): 53-67.

Pingali, P. 2004. Agricultural diversification: Opportunities and constraints. FAO Rice Conference, 12-13 February 2004. Agricultural and Development Economics Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

Rahman, S. and Kazal, M. M. H. 2015. “Determinants of crop diversity in the regions of Bangladesh (1990-2008)”. *Singapore Journal of Tropical Geography*, 36(1): 83-97.

Riede, J.O., Posada, R., Fink, A.H. and Kaspar, F. 2016. “What’s on the 5th IPCC Report for West Africa?”. In J. Yaro and J. Hesselberg (eds.), *Adaptation to climate change and variability in rural West Africa*. Cham: Springer.

Roesch-McNally, G. E., Arbuckle, J. G. and Tyndall, J. C. 2018. “Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt”. *Global Environmental Change*, 48: 206-215.

Roudier, P., Sultan, S., Quirion, P. and Berg, A. 2011. “The impact of future climate change on West African crop yields: What does the recent literature say?”. *Global Environmental Change*, 21(3): 1073-1083.

Sarr, B. 2012. “Present and future climate change in the semi-arid region of West Africa: A crucial input for practical adaptation in agriculture”. *Atmospheric Science Letters*, 13(2): 108-112.

Schlenker, W. and Lobell, D.B. 2010. “Robust negative impacts of climate change on African agriculture”. *Environmental Research Letters*, 5(1): 1-8.

Seo, S.N. 2010. “Is an integrated farm more resilient against climate change? A micro-econometric analysis of portfolio diversification in African agriculture”. *Food Policy*, 35(1): 32-40.

Singh, J. and Sidhu, R.S. 2004. « Factors in declining crop diversification: Case study of Punjab ». *Economic and Political Weekly,* 39(52): 5607-5610.

Sultan, B. and Gaetani, M. 2016. “Agriculture in West Africa in the twenty-first century climate change and impacts scenarios, and potential for adaptation”. *Frontier in Plant Science* 7: 1-20.

Sylla, M.B., Pal, J.S., Faye, A., Dimobe, K. and Kuntsmann, H. 2018. “Climate change to severely impact West African basin scale irrigation in 2°C and 1.5°C global warming scenarios”. *Scientific Report*, 8: 14395.

Tachie-Obeng, E., Akponikpè, P. and Adiku, S. 2013. “Considering effective adaptation options to impacts of climate change for maize production in Ghana”. *Environmental Development*, 5: 131-145.

Tirado, M.C., Clarke, R., Jaykus, L.A., McQuatters-Gollop, A. and Franke, J.M. 2010. “Climate change and food safety: A review”. *Food Resource International*, 43(7): 1745-1765.

Van den Berg, M.M., Hengsdijk, H., Wolf, J., Ittersum, M.K.V., Guanghuo, W. and Roetter, R.P. 2007. “The impact of increasing farm size and mechanization on rural income and rice

production in Zhejiang Province, China". *Agricultural Systems*, 94(3): 841-850.
World Bank. 2009. Awakening Africa's sleeping giant: Prospects for commercial agriculture in the Guinea Savannah Zone and beyond. Washington DC: World Bank.
Zellner, A. 1962. "An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias". *Journal of the American Statistical Association*, 57(298): 348-368.

Notes

1 Faculty of Economics and Management, Lecturer at the University Jean Lorougnon Guede of Daloa (Cote d'Ivoire)
Researcher at the CAPEC, Tel: (+225) 07 01 07 34 / (+225) 03 14 84 64;
E-mail: *christy.aboua@yahoo.fr*
2 Figure 2 (FAO data).
3 Table 1 & 2 (FAO Data).

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

www.aercafrica.org

Learn More

www.facebook.com/aercafrica

www.instagram.com/aercafrica_official/

twitter.com/aercafrica

www.linkedin.com/school/aercafrica/

Contact Us
African Economic Research Consortium
Consortium pour la Recherche Economique en Afrique
Middle East Bank Towers,
3rd Floor, Jakaya Kikwete Road
Nairobi 00200, Kenya
Tel: +254 (0) 20 273 4150
communications@aercafrica.org