Journal of Agriculture and Environmental Sciences
December 2019, Vol. 8, No. 2, pp. 66-74
ISSN: 2334-2404 (Print), 2334-2412 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jaes.v8n2a9
URL: https://doi.org/10.15640/jaes.v8n2a9

Climate Variability Effect on Food Crop Yield among the Smallholder Farmers in Lower *Offin* River Basin, Ghana

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Abstract

The study assesses the effects of climate variability on food crop yield of the smallholder farmers in the Lower *Offin* River Basin, Ghana. Spline Interpolation and Spearman rank correlation coefficient were employed to examine the spatial and seasonal distribution of climate variables. Yield anomaly index and multiple linear regression models were used to assess the effect of climate variability on food crop yield. The results showed that the higher values of seasonality and replicability indices of rainfall indicate that rainfall is concentrated within few months causing prolonged dry spells and frequent droughts during the cropping period. The regression analysis revealed that climate variability has had differential impacts on the yield of maize, rice, cassava, yam, cocoyam and plantain ranging from 18.4 % in the case of plantain to 80.0 % in the case of cocoyam. Also, cocoyam, yam and rice were much more affected by climatic conditions in contrast with maize, cassava and plantain. Therefore, there is the need to adopt drought-resistant high-yielding crop varieties to sustain high crop yield. Again, cassava and plantain have the potential to withstand climate variability which is very significant in the Lower *Offin* River Basin.

Keywords: Lower Offin River Basin, climate variability, smallholder farmers, crop yield

1.0 Introduction

Crop yield is inherently susceptible to climate variability. Climate variables like temperature and rainfall are primary determinant of crop yield. Increased rainfall variability (Rowhani *et al.*, 2011), prolonged dry spells and droughts have great effects on food crop yield (Laux *et al.*, 2010). Increased temperature leads to increased evapotranspiration and affects soil moisture availability, which is important in the processes of photosynthesis (Dawyer *et al.*, 2006). High temperature accelerates phenological growth, which results in shortening crop growth periods and hastens heat stress (Tubiello *et al.*, 2007) which limits crop growth, development and yield (Prasad and Staggenborg, 2008). According to Liu *et al.* (2010), increased climate variability influences phenological phases of food crop growth from germination through vegetative to reproductive phase. For instance, during the early growth phase of maize, climate variability limits the size of leaves and suppresses photosynthetic activities. In the later phase, climate variability lessens the number of silks, resulting in poor pollination of the ovules and restricting the number or the size of the developing kernels (Ritchie *et al.*, 1993).

Globally, climate variability accounts for about a third of observed crop yield variability (Lobell and Field, 2007;Ray *et al.*, 2015). At the continental level climate variability is a major driver of yield variability mostly in Africa, where crop production is largely rain-fed. Rowhani *et al.* (2011) in Tanzania reported that climate variability has had negative effect on crop yield. In Nigeria, rainfall variability has been found to have a significant impact on crop yield (Akinseye *et al.*, 2013; Yamusa *et al.*, 2015).

In Ghana, there has been a great concern that climate variability has created uncertain conditions for food crop production (Yaro, 2013). Nevertheless, to what extent has a climate variability impact on food crop yield in the Lower *Offin* River Basin has not received much research attention.

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This paper examines the effects of climate variability on major food crop yield which could provide viable options for enhancing farmers' adaptive capacity and food security.

2.0 Materials and Methods

2.1 Study area

The study area lies within Latitude 5° 30' to 6°54' N and Longitude 1°30' to 2°15'W. A large population in the basin lives in rural communities, with food crop production as their main economic activity. The annual rainfall is 1,432 mm and maximum and minimum temperature is 33.2°C and 22°C respectively.

2.2 Climate data

Climate data from six weather stations within the Lower *Offin* River Basin obtained from Ghana Meteorological Service Department, Regional Office, Kumasi, between 1983 and 2012 were used for the study. The climate data were mapped in ArcGIS version 10.1 with spline interpolation techniques. The Seasonality Index (SI_i), indicating the spread of monthly rainfall (Celleri *et al.*, 2007) was estimated using equation 1:

$$SI_i = \frac{1}{R_i}\sum_{n=1}^{12}\left|X_{in} - \frac{R_i}{12}\right| \qquad (1)$$

Where, $R_i$is the total annual rainfall for the particular year i and $X_{in}$is the actual monthly rainfall for month n. The accumulated SI_i was used to calculate a long-term mean $\overline{SI_i}$ using Equation 2.

$$\overline{SI_i} = \frac{1}{30}\sum_{j=1}^{30} SI_{ij} \qquad (2)$$

Another seasonality index $\overline{SI}$ was also calculated in order to estimate the mean seasonality over the study period by using directly long-term average monthly rainfall using Equation 3 in Lower *Offin* River Basin.

$$\overline{SI} = \frac{1}{R_i}\sum_{n=1}^{12}\left|\overline{X_n} - \frac{\overline{R}}{12}\right| \qquad (3)$$

Where, $\overline{X_n}$ is the mean rainfall of month n *and* $\overline{R}$ is the mean annual rainfall. To determine whether or not the rainfall period occurs over a small range of months or in any month during the year the Replicablity Index (RI) was estimated using Equation 4

$$RI = \frac{\overline{SI}}{\overline{SI_i}} \qquad (4)$$

Yield of major food crops (maize, rice, cassava, yam, cocoyam and plantain) from the Basin between 1983 and 2012 obtained from Ministry of Food and Agriculture Regional Office, Kumasi were used to determine crop yield responses to climate variability. In the *Offin* River Basin the crop yield anomaly was estimated using equation 5

$$YAI = \frac{Y - \mu}{\sigma} \qquad (5)$$

Where,YAI is the yield anomaly index*,* Y is the crop yield, μ is the long term average crop yieldand σ = is the standard deviation of the crop. Negative yield anomalies indicate negative effect of climate variability on food crop yield and vice versa. The higher the values of crop yield anomaly, the higher the effect of climate variability.

Multiple Linear Regression (MLR) model was used to determine the effect of climate variability on food crop yields in the *Offin* River Basin. Using crop yield as dependent variable (Y) and climate variables (X) as independent variables, the multiple linear regression model was expressed using Equation 6:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 .... + \beta_n X_n + \ell \qquad (6)$$

Where,

Yis the yield of food crops (maize, rice, cassava, plantain, yam and cocoyam) in (kg/ha); β_0 = Y intercept and β1, β2, β3, β4, · · βn = partial regression coefficient of the independent variables; X_1, X_2, X_3, X_4, · · Xn is the independent variables (maximum and maximum temperatures, annual rainfall, major and minor season rainfall); e = the residual term/error). Statistical Package for Social Sciences (version 20) was used for in

3.0 Results and Discussion

3.1 Spatial and seasonal rainfall pattern in the Lower *Offin* river basin

Dry season (December to February), Minor season (September to November) and major season (March to July rainfall) comprised 7.6 % (115.0 mm), 35.7 % (502 mm) and 56.7 % (803 mm) of annual rainfall respectively. The mean annual rainfall varies from 1124.7 mm to 1748.0 mm (Figure 1). Dunkwa and Nyinahin received the highest rainfall while Ashanti Bekwai recorded lowest rainfall. The southwestern part of the basin received the largest amount of annual and seasonal rainfall while northeastern part received the least amount of rainfall which could influence the agronomic activities.

3.2 Variations in rainfall characteristics in the Lower *Offin* River Basin

The Seasonality (SI) and Replicability (RI) indices and Hydrologic ratio (HR) results are presented in Table 1. The results showed that Dunkwa and Nyinahin fell within seasonality index value of 0.40-0.59 with low replicability index. This implies that the areas have seasonality of rainfall regime with wettest month of the year being evenly spread which is good for rain -fed food crop production. In contrast, Nkawie and Manso Adubia fell within the class of 0.60-0.69 with high replicability index. Thus, confines rainfall season in the *Offin* River Basin into few months. These will most likely have a negative impact on onset and cessation of rainfall, length of cropping season, optimum planting period and food crop yield in the *Offin* River Basin. A study by (McCarl *et al.*, 2001)in Texas noted that rainfall concentrated in few months has a negative effect on food crop yield.

Hydrologic ratio ranged from 0.94 in Manso Adubia to 1.32 in Dunkwa. Hydrologic ratio value in the Manso Adubia was high making the area prone to soil moisture stress and most crops will not thrive well especially at rain-fed conditions. Negative rainfall anomalies were found most in 1983-1986, 1988-1992, 1994-1997, 2000-2001 and 2005 period (Figure 2). These trigger soil moisture stress and high incidence of crop pests and diseases and eventually affect the food crop yields. Rainfall anomalies were more positive in 2000s which could have positive impact on soil moisture availability and promote good crop yields among the smallholder farmers.

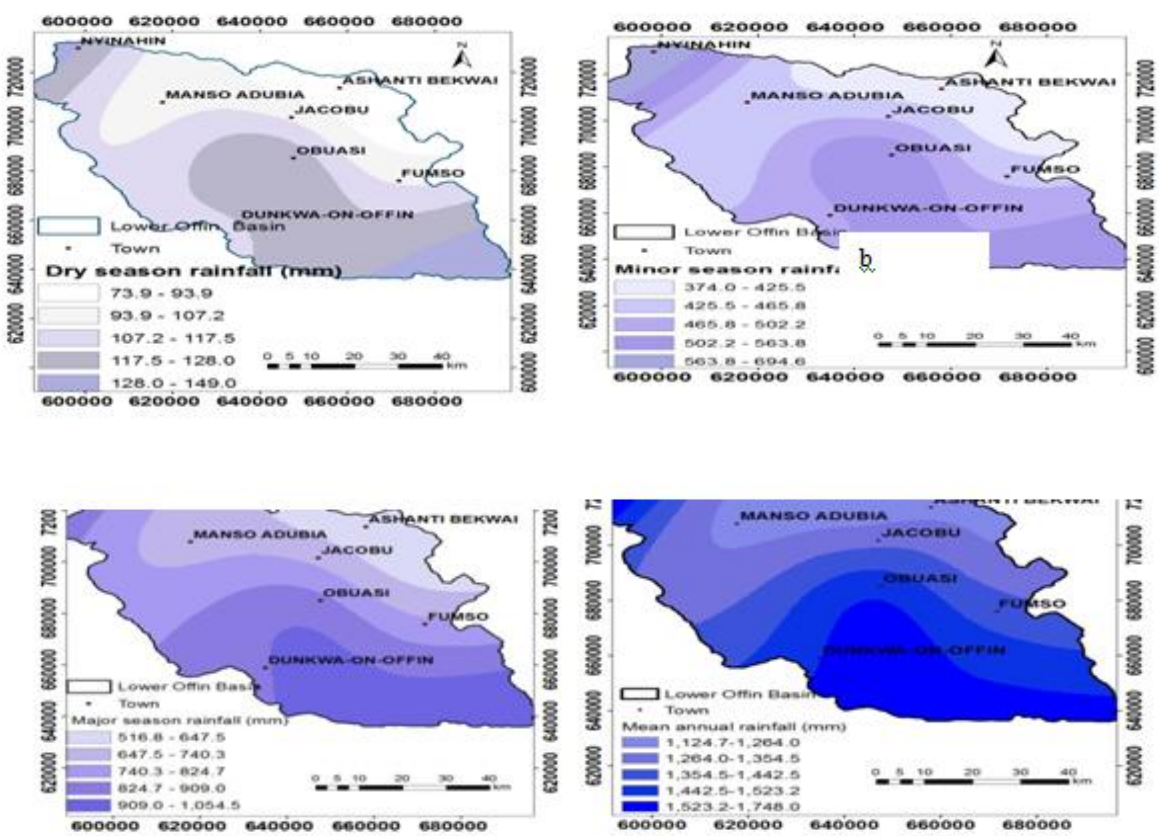

Figure 1:Spatial pattern of (a) dry season (December-February); (b) major season (March-July); (c) minor season (September-November); (d) annual rainfall between 1983-2012 in Lower *Offin*.

Table 1: Seasonality, replicability and hydrological indices of rainfall in the Lower *Offin* River Basin

Station	Seasonality Indice (SI)			Replicability Indice (RI)	Hydrologic Ratio (HR)
	Mean	Lowest (Year*)	Highest (Year*)		
Nkawie	0.66	0.32(1984)	0.92 (1984)	1.14	0.95
Nyinahin	0.40	0.30 (1998)	1.38 (2005)	0.87	1.21
Manso Adubia	0.67	0.28(1984)	0.78 (1994)	1.22	0.94
Sefwi Bekwai	0.63	0.43(2008)	0.71(1994)	1.16	1.01
Obuasi	0.60	0.39(2010)	1.44(1997)	1.03	1.21
Dunkwa-on- Offin	0. 56	0.40 (2010)	1.33(1990)	0.99	1.32

*Year of occurance

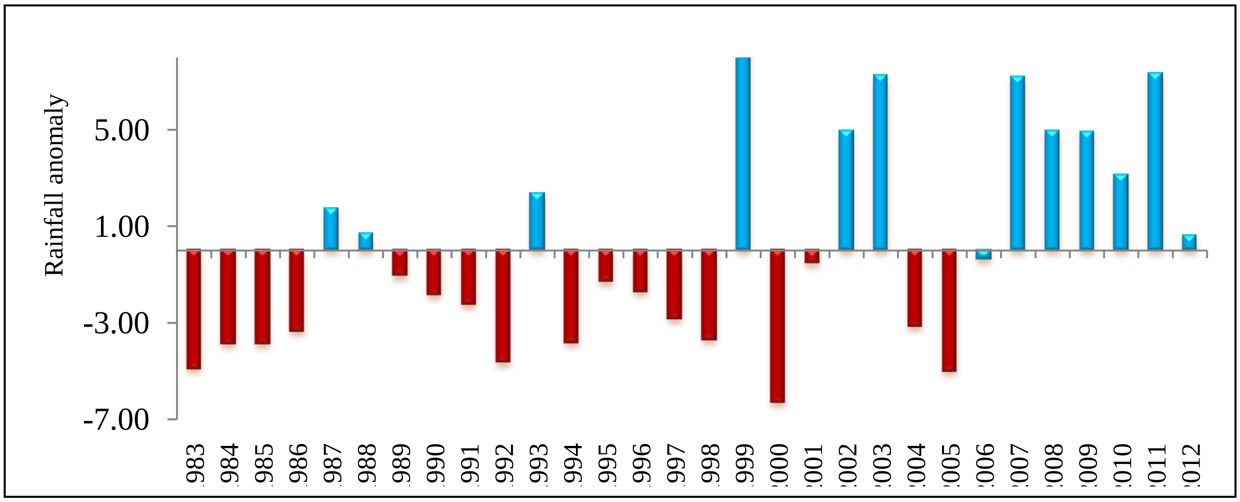

Figure 2: Growing season rainfall anomaly in the Lower *Offin* River Basin (1983-2012)

3. 3 Spatial and seasonal temperature in the Lower *Offin* River Basin

The increasing trend of temperatures was found in all the cropping seasons (Figure 3). The increasing trend in temperature observed in the Lower *Offin* River Basin supports (Agyeman-Bonsu *et al.*, 2008) and (Yaro, 2013) that temperature continues to rise in all the agro-ecological zones in Ghana.The increasing temperatures in the Lower *Offin* River Basin will most likely increase evapotranspiration, decrease soil moisture availability and increase heat stress on the food crop. Generally increased temperature has a tendency to accelerate the loss of water from the root zone thereby affecting crop growth from germination to vegetative growth and grain filling. An increase in temperature determines the length of the growing season of a crop by determining the crop's germination, vegetative and reproductive stages (FAO, 2009). Mall and Aggarwal (2002) indicated that increase in temperature leads to a decrease in length of the growing season.

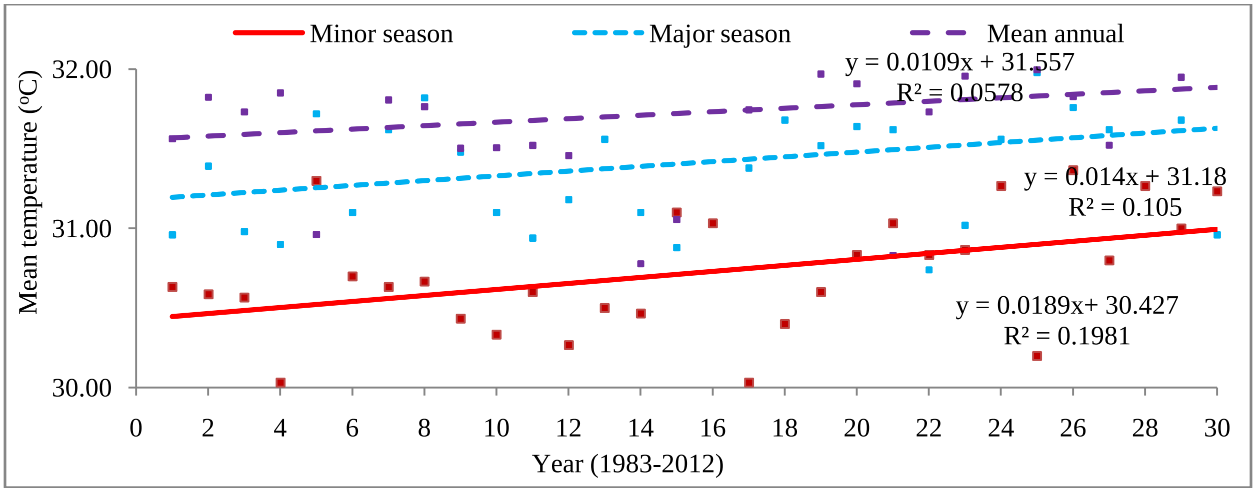

Figure 3: Seasonal temperature trends in the Lower *Offin* River Basin (1983 - 2012)

More positive temperature anomalies were found between the periods 1983-1986, 1989-1992, 1994-1995, 1998-2002 and 2005-2012 (Figure 4) which translated into intermittent dry spell and prolong drought periods with negative impact on the soil moisture, heat stress, crop pests and diseases and food crop yield. Kangalawe *et al.* (2017)observed that, rising temperature leads to heat stress, increasing sterility and thus affects crop yield. Longer drought periods increase water stress on crops by reducing the crop growing period and crop productivity. The view that outbreak of crop pests and diseases are influenced by increasing temperatures are consistent with the studies by Gregory *et al.* (2009) who have showed that temperature rise expands the range of crop pests and diseases by increasing their abilityto survive and affect food crops.

3.4 Yields of major crops among smallholder farmers in the Lower *Offin* River Basin

Yields of the six major food crops cultivated in the Lower *Offin* River Basin were lower than national average and their potential or achievable yield (Table 2).Yield gap, that is, the difference between actual and potential yields were found in all the major food crops. A similar observation was made in Kenya, South Africa, Mali and Tanzania (Conceição *et al.*, 2016; Mkonda and He, 2017).

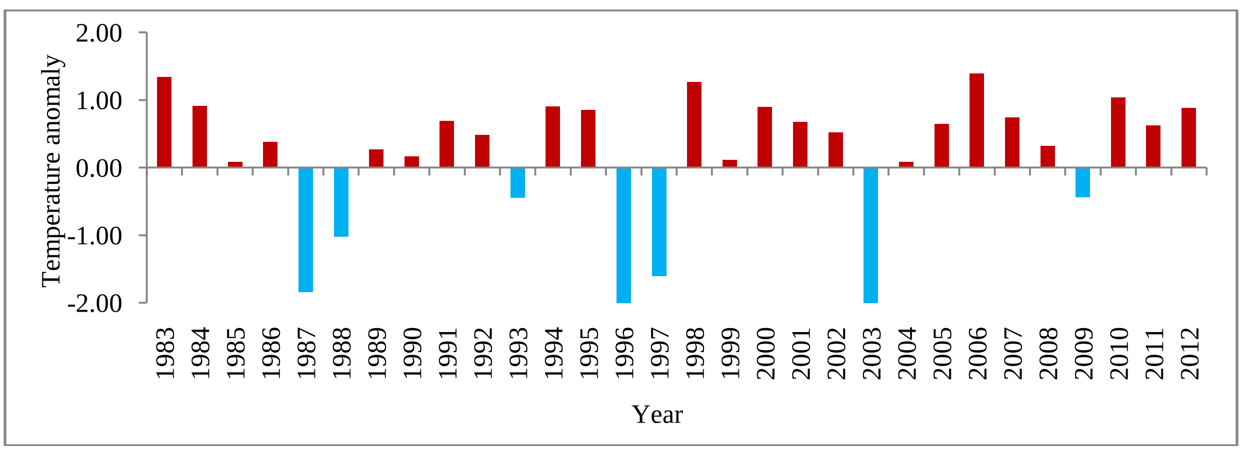

Figure 4: Growing season temperature anomaly in the Lower *Offin* River Basin (1983-2012)

Table 2: Crop yield (tonnes/ha) among farmers in the Lower *Offin* River Basin (1983-2012)

Major Crop yield	Lower *Offin* Basin	Towns				Average national yield	Achievable / Potential yield
		Nyinahin	Manso	Jacobu	Dunkwa		
Rice	1.3(*15)	1.4 (15)	1.3 (14.1)	1.2 (12)	1.4 (15)	2.0	6.5
Maize	1.6 (9)	1.9 (22)	1.5 (21.5)	1.5 (25)	1.7 (26)	2.5	5.0
Plantain	9.0 (5)	11.2 (11)	6.9 (8.6)	8.2 (11)	9.3 (9.1)	9.7	10.0
Cassava	10.4 (11)	10.5 (16)	10.4 (19.2)	10.4 (20)	10.3 (11)	12.7	28.0
Yam	8.5 (14)	8.9 (20.1)	8.1 (23.8)	8.3 (22)	8.8 (25)	13.0	20.0
Cocoyam	3.6 (8.3)	4.3 (17)	3.0 (16.2)	3.3 (13)	4.0 (15)	6.5	8.0

Values in bracket are the coefficient of variation

Maize and rice had 19 and 25 years of negative yield anomalies as against 11 and 5 years of positive yield anomalies respectively (Figure 5). Root and tuber crops (cocoyam, yam, cassava and plantain) had 26, 25, 20 and 21 years of negative yield anomalies as against 4, 5, 10, 9 years of positive yield anomalies respectively (Figure 5). Positive years of yield anomalies imply that there have been affirmative effects of climate variability on food crop yield in the *Offin* River Basin. On the other hand, negative years indicate negative effects of climate variability on the crop yield during the periods in *Offin* River Basin. The study revealed that the more the climate variability, the greater the yield anomalies and the less reliable the crop yields in the Basin. A study by (Thornton *et al.*, 2009) indicated that variation in temperature and rainfall increased crop variability in East Africa.

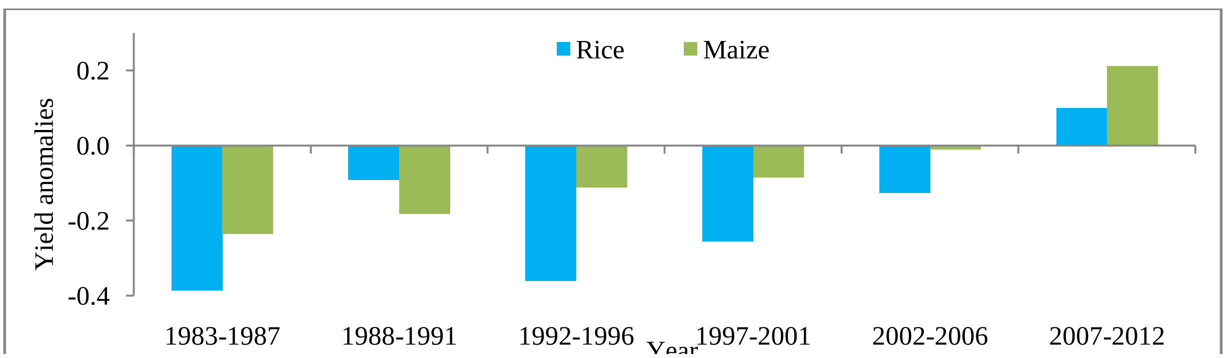

Figure 5: Anomalies of rice and maize crop yields in the Lower *Offin* River Basin

The fluctuations in the yield of food crops in the Lower *Offin* River Basin, particularly in 1980s and 1990s corresponds to the periods when rainfall registered most negative anomalies (Figure 2) and temperature had more positive anomalies (Figure 4). The finding of this study is supported the study by (Yaro, 2013). He observed that climate variability has a severe negative effect on crop yield in Ghana. Studies in Nigeria (Akinseye *et al.*, 2013; Yamusa *et al.*, 2015), Kenya (Omoyo *et al.*, 2015) and Nepal (Joshi *et al.*, 2011) similarly noted that climate variability induces year to year fluctuation in food crop yield.

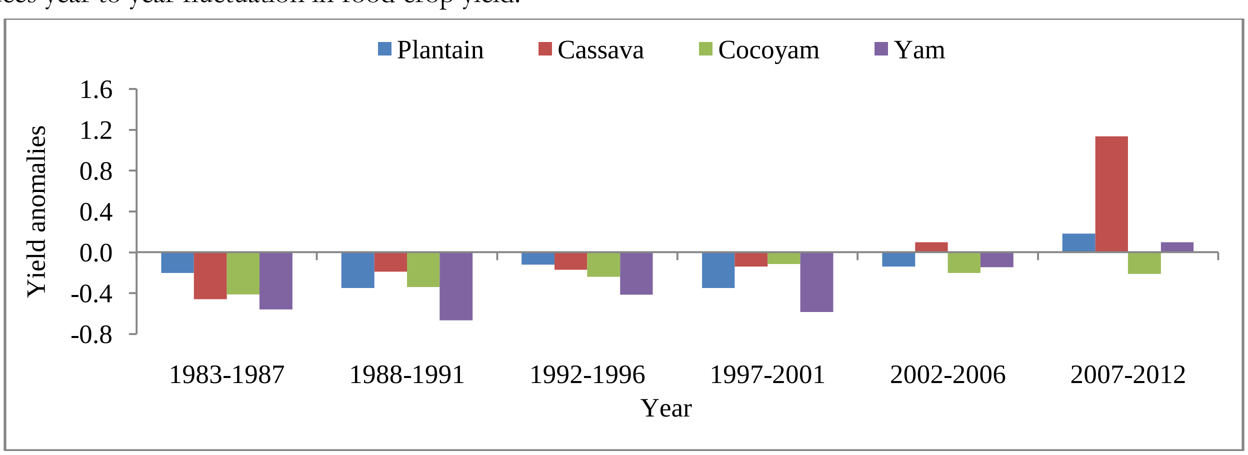

Figure 6: Anomalies of root and tuber crop yields in the Lower *Offin* River Basin

3.5 Climate-crop yield relationship in the Basin

Multiple linear regression analysis of crop yield with climatic variables is presented in Table 4. The results showed that changes in yield of food crops were influenced differently by climate variability, ranging from 18.4 % in the case of plantain to 80.0 % in the case of cocoyam. In fact Miloševic *et al.* (2015) in Serbia and Eregha *et al.* (2014) in Nigeria noted that climate variability revealed varied effects on crop yield depending on crop type. In Kwara State of Nigeria, (Tunde *et al.*, 2011) found that climatic variables accounted for 43 % to 79 % of crop yield.

Maize had R^2 value of 0.655, indicating that larger proportion of variation (65.5%), in maize yield was mainly due to climate variability. Previous study in Ghana (Amikuzuno and Donkoh, 2012) indicated that variability in rainfall leads to fluctuations in maize yields. Studies in Nigeria (Akinseye *et al.*, 2013; Akintunde, 2013)Kenya (Omoyo *et al.*, 2013) and Pakistan (Ali *et al.*, 2017) similarly indicated that rainfall variability caused severe effect on maize yield. Rice had R^2 value of 0.704, showing 70 % variation in rice yield was associated with climate variability. Studies in Nigeria (Tiamiyu *et al.*, 2015) Bangladesh (Amin *et al.*, 2015; Rahman *et al.*, 2017), India (Elbariki *et al.*, 2014) and Pakistan (Shakoor *et al.*, 2015) noted similarly that climate variability affects rice yield.

Cassava and plantain were found to be less sensitive to climate variability. Hence, the low R^2 values of 0.239 and 0.184 for cassava and plantain respectively. This finding gives empirical evidencethat sensitivity of cassava and plantain crop to changes in climatic conditions is less than that of other food crops. The findings are in line with similar studies in Nigeria (El-Sharkawy, 2007; Adewuyi *et al.*, 2014) that cassava is less affected by climate variability. Study by (Jarvis *et al.*, 2011)noted that planting of cassava could be the answer to climate variability adaptation in Africa, because cassava is "often the food crop that continues toprovide food in periods of the year when other food sources are not available" and it can also withstand drought conditions.

Table 4: Regression between climate variables and food crop yield in the Lower *Offin* River Basin

Climate variables	Maize	Rice	Plantain	Yam	Cocoyam	Cassava
Minor season rainfall	0.001	0.00	0.000	0.000	0.003	0.436
	(3.958)*	(0.579)*	(1.162)*	(1.830)**	(3.564)**	(0.799)**
Major season rainfall	0.004	0.004	0.002	0.000	0.001	0.002
	(3.333)*	(3.350)*	(0.312)	(5.241)*	(5.675)**	(1.767)**
Annual rainfall	0.000	0.000	0.000	0.774	0.001	0.004
	(0.085)**	(0.514)	(0.306)	-0.293*	(-0.645)*	(0.743)
Maximum temperature	0.242	0.000	0.199	0.973	0.243	0.676
	(-1.215)*	(-1.290)*	(-1.339)*	-0.034*	(-1.213)	(-0.426)*
Minimum temperature	0.950	0.410	0.567	0.795	0.754	0.020
	(-0.064)	(0.840)*	(0.584)*	(-0.264)	(-0.319)	(2.572)*
Model R^2	0.655	0.704	0.184	0.727	0.797	0.239
F-statistics	6.478	7.091	0.602	6.339	10.448	2.150

** Significant at 1 % level * Significant at 5 % level Numbers in brackets refer to *t* values

Yam and cocoyam were found to be more susceptible to climate variability. Yam and cocoyam had high R^2 values of 0.704 and 0.797 respectively, indicating that the impact of climatic factors accounted for 70 % and 80 % of variance in yields of these crops. Similar studies in Nigeria (Adewuyi *et al.*, 2014; Ganiyu *et al.*, 2013; Zakari *et al.*, 2014)observed an adverse effect of climate variability on yam and cocoyam yield.

Maximum temperature affected all food crop yields negatively (Table 3). Previous studies by (Rowhani *et al.*, 2011; Awotoye and Matthew, 2010; Al-Masud *et al.*, 2014) found that high temperature has a negative effect on maize and rice yield. This agrees with the findings by (Nguyen, 2006) that a higher temperature causes the yield of rice and some other crops to decline.

4.0 Conclusion

The higher values of Seasonality and Replicability indices of rainfall and more negative rainfall anomaly have shrank the length of growing season rainfall making planning for rain-fed agronomic activities rather difficult among farmers in the Basin.

Climate variability has had a major impact on yield of food crops with minor and major season rainfall being the most important determinants of food crop yields. Cocoyam, yam and rice had the highest magnitude of negative yield anomaly making these crops more vulnerable to climate variability than the other crops. Overall, 18, 24, 66, 70, 73 and 80 % of variance in plantain, cassava, maize, rice, yam and cocoyam yield were respectively explained by climate variables. Therefore, plantain and cassava are more adaptable to climate variation. Hence, there is the need to adopt drought tolerant food crop varieties as well as soil moisture retention management practices to enhance soil moisture availability, improve soil health and crop production in the basin.

Acknowledgements

We are grateful to the Directors and staff of Ghana Meteorological Department Service, Regional Office, Kumasi and Ministry of Food and Agriculture in Kumasi for providing climate data and crop yield data respectively for this study.

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