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Influence of Climate Change on Food Crop Yield in Benin Republic

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Abstract

World climate is projected to be more harmful and unforeseeable. A threefold combination of temperature, precipitation and potential evapotranspiration leads to climate change with a negative effect on staple food crop production. To understand the sensitivity of staple food crop yield to future change in climate, this paper uses the feasible generalized least square (FGLS) and heteroskedasticity and autocorrelation (HAC) consistent standard error techniques function to quantify the effects of climate variables on the mean and variance of crop yields. Data from FAOSTAT website and national institutions such as temperature, precipitation and crop areas cultivated for period 1961-2015 for Benin country are used. Climate variables are computed according to each crop growing season. The results showed that climate change could significantly influence the mean crop yields and could significantly affect the crop yield variability. The contribution of climate variables to crop yield varies across staple crop yields and they were predicted to decrease about 2025. In order to ensure food availability in the context of climate change, support to agricultural sector and especially to staple food crops production should be focused on seeds improvement by generating, developing and extending drought and flood-tolerant varieties. The results also implicate the promoting of irrigated agriculture.

Keywords: crop yield, crop yield variability, climate change, time series, effect, Benin Republic

1. Introduction

Crop production and crop yield in particular are controlled by the combination of climate factors, soil fertility, land use decisions, agricultural practices through innovative use of tools, and access and utilization of high yielding varieties among other factors (Kulcharik & Serbin, 2008; Epule & Bryant, 2015). Despite technological advances around the world, the agricultural sector remains strongly dependent on climate (Gourdji, Laderach, Valle, Martinez, & Lobell, 2015), particularly in developing countries where temperature, sunlight, water, relative humidity are the main drivers of crop growth and yield. Climate change has become more threatening for sustainable development where extreme climate conditions such as severe winds, heavy rains, extreme heat and cold could result in flooding, landslides, droughts and sea-level rise (Emaziye, 2015). Everywhere in the world, plants, animals, and ecosystems are adapted to the prevailing climate conditions (FAO, 2008). For these reasons, it does not matter whether climate conditions change, even slightly, even in favor of life growing, plants and animals are impacted, some of them become less productive, or even disappear. Change in climate conditions from year to year is one of the major determinants of crop yield fluctuations (Isik & Devadoss, 2006). The changing precipitation in terms of patterns is likely to affect crop yields depending on when the crop is grown, crop water requirements, critical periods of water stress, and crop's ability to withstand water stress (Huang, Duiker, Deng, Fang, & Zeng, 2015). Considering Emaziye's (2015) point of view, crop production requires optimum conditions during crop growing for maximum yields, where an excess or a deficit in temperature and/or precipitation results in poor harvests and even total losses. This exactly applies in Benin according to Hounnou and Dedehouanou (2018). In the same vein, climate change is considered to have direct and indirect effects on the existing agricultural production systems, potentially threatening local, national, regional, and/or global food security (Ajadi, Adeniyi, & Afolabi, 2011).

Agricultural production is important to ensure food security by increasing rural incomes and lowering food prices. Benin's rural households are vulnerable to chronic food shortages, poor food quality, volatility in food prices and irregular supply of foodstuffs (INSAE [Institut National de la Statistique et de l'Analyse Economique], WFP [World Food Program], & MAEP [Benin Ministry of Agriculture, Livestock and Fisheries], 2015). Understanding the relationship between climate parameters and crop yields is important in order to enhance resilience of agriculture production systems to climate change (Leng & Huang, 2017).

The existing scientific works are unanimous in the fact that high temperatures and changes in the precipitation model due to climate change will be unfavorable for crop growth in many regions and particularly in Africa (Awoye, Pollinger, Agbossou, & Paeth, 2017). The effects of change in climate on crop yield are becoming increasingly significant in some part of the world, particularly in Africa where 66% of the total land area is concerned (Molua, Benhin, Kabubo, Ouedraogo, & El-Marsafawy, 2010). According to UNDP [United Nations Development Program] and MEPN [Benin Ministry of Environment and Nature Protection] (2008), four agro-ecological zones in Benin are highly influenced by temperature and precipitation changes. Although the view on temperature and precipitation changes was embedded in a perceptive approach, Hounnou and Dedehouanou (2018) recently demonstrated statistically that temperatures rather than precipitations changed over the last sixty years. Many crops are produced in Benin either in all agro-ecological zones, *i.e.*, maize, cassava, cowpea, *etc.* or in few zones i.e. sorghum, millet, etc. Empirical models that rely on past observations of climate and crop yields are recognized as efficient tools and have been extensively used in previous studies (Lobell & Burke, 2010). Among crops produced in Benin, maize crop is the main staple and most preferred food in Benin, and is becoming increasingly commercial (Houndetondji, Biaou, & Zannou, 2014; Toleba, Biaou, Saidou, & Zannou, 2015). The work of Korogone, Adamou, and Primavera (2008) showed that the annual production of maize corresponds to 80% of the total cereal production and its consumption represents 70% of the basic food basket for cereals. Maize and sorghum are integrated with more than 50% in poultry feed in intensive poultry farming and other short-cycle species (rabbits, pigs, *etc.*) that are developed nowadays in all suburbs (WAAPP [West Africa Agricultural Productivity Program], 2012). As climate factors can result in dissimilar effects on crop performance, across agro-ecological zones, these effects are much likely to differ among various crop species as well (Kukal & Irmak, 2018). As such, the study of climate effects on crop yields requires analyses at small scales, assessing yield and yield variability for each crop at its own. Six major staple food crops are used in the present study. The purpose here is to analyze the effect of climate variables on the yields and also assess yield variability in Benin based on historical data. Understanding of the effects of previous climate behavior on major food crops would help to anticipate influences of future climate events on country food self-sufficiency (Joshi, Maharjan, & Piya, 2011). Likewise, the study of the relationship between climate and crop yield is fundamental (Bhatt, Maskey, Babel, Uhlenbrook, & Prasad, 2014) with a view to identify possible effects of future climate change and to initiate adaptation strategies.

2. Methodology

This study follows the ex-post facto and longitudinal processes based on the analysis of secondary serial data for the years 1961 to 2015.

2.1 Study Area

For this study, national level which is composed by eight different agro-ecological zones is considered in fact to analyze the special effect of climate variability on major staple crop yields (maize, rice, cowpea, sorghum, cassava and yam) in Benin. According to UNDP and MEPN (2008), four out of eight agro-ecological zones are faced to climate variability threats, namely extreme north-Benin zone, west Atacora zone, cotton zone of center Benin and zone of the fisheries.

2.2 Data Collection and techniques of Analysis

Data on annual yields of major crops (maize, rice, sorghum, cowpea, cassava and yam) are obtained from Food and Agricultural Organization website (FAOSTAT) and Agricultural Statistical Direction (DSA), subdivision of MAEP [Ministry of Agriculture, Livestock and Fisheries] of Benin, from 1961 to 2015. Furthermore, data on climate, *i.e.* precipitation and temperature, are obtained with the Agency for the Safety of Air Navigation in Africa and Madagascar (ASECNA) and Smallholder farmers Productivity Improvement Project (PAPAPE) of National Agricultural Research Institute of Benin (INRAB).

Temperature, precipitation and solar radiation are the three most widely used climate variables to assess climate change and its impacts (Joshi et al., 2011). A solar radiation has a closer positive correlation with maximum temperature. In general, higher (lower) solar radiation leads to a higher (lower) maximum (minimum) temperature as a matter of fact of radiation heating (cooling). In this sense, there is a direct correlation between temperature and solar radiation. Then, to eliminate the possible correlation among the independent variables, this study takes into account only temperature and precipitation, where each was considered according to crops growing season. Climate variables (temperature and precipitation) and crop area cultivated are used as independent variables (Sarker, Alam, & Gow, 2012; Shabnam, Bansal, & Dabas, 2013; Afzal, Ahmed, & Ahmed, 2016; Leng & Huang, 2017; Ali et al., 2017). This paper uses an average growing season temperature variable with the total growing season precipitation variable. The average growing season climate is able to capture the net effect of the entire range of the development process by which yields are affected by climate (Lobell & Field, 2007; Sarker et al., 2012). Moreover, the average growing season temperature is a key determinant of average yield (Cabas, Weersink, & Olale, 2010). The monthly average growing season maximum and minimum temperatures and the total growing season rainfall have been used in previous studies (Lobell et al., 2008; Boubacar, 2012; Aye & Ater, 2012; Sounders, Sunjo, & Mbella, 2017).

Six crops considered in this study were the main staple crops cultivated for subsistence in western Africa and particularly in Benin. The descriptive statistics (means, standard deviation, maximum and minimum) of all the variables in regressions estimate are presented in Table 1. Crop yields are expressed in kg/ha and the yield of six major crops considered were directly obtained from FAOSTAT (2018). These yields were generally low compared to what was expected according to experimental work and compared to developed countries.

In the case of yields, the average crop yields varied from low of about 545.21 kg/ha for sorghum to high of about 10791.47 kg/ha for yam over 1961-2015 period as shown in Table 1. Variables used as independent can be categorized into two parts: climate and non-climate variables. The non-climate variable in this study is area cropped expressed in ha. Regarding the average of the production area, maize areas rank first, and cassava area, cowpea area, yam area, sorghum area, and rice area stand second, third, fourth, fifth and sixth, respectively. Area cultivated for each crop is hypothesized to have negative effect on all crop yields because of diminishing returns to using additional land in farming (in fact of productive land shortage).

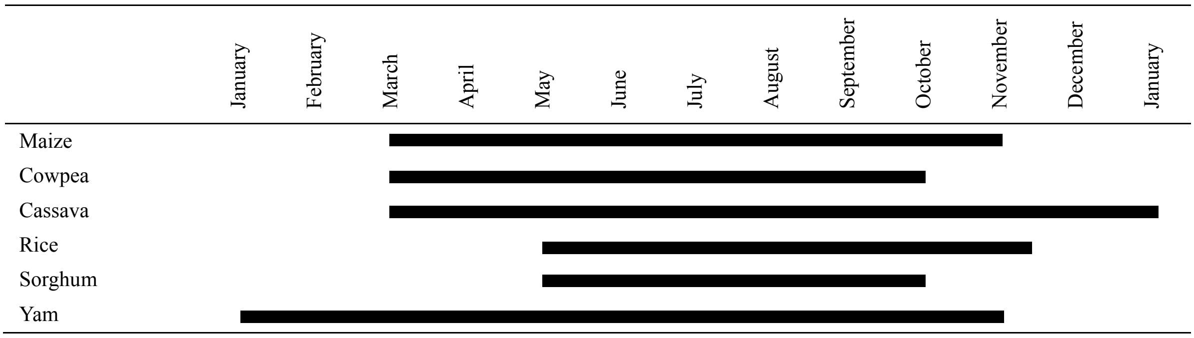
The precipitation data are the time series of the total precipitation within a year and reflect precipitation falling directly on a crop within the year. The temperature data include the average observations for the growing seasons. The growing seasons differ from agro-ecological zone to zone and from crop to crop (Table 2). For each crop, the growing seasons in the southern parts of the country were joined to those of the northern parts. Some crops with a short growing cycle are produced twice per year in the south of Benin because of the bimodal distribution of the precipitation in that part of the country. Considering precipitation in each crop growing season, the cassava and yam growing seasons receive the highest mean precipitation while rice growing season receives the lowest. The highest growing temperatures are noticed in the yam growing season and the lowest temperatures are observed in rice, maize, sorghum and cowpea growing seasons. From Table 1, the mean temperatures indicate two pieces of information. First, the mean temperature of crops growing period is superior to 25 °C, which is a little high. Second, there is slight difference between the maximum and the minimum temperatures for each crop growing period, exhibiting that Benin is a slightly hot country. It is hypothesized that high temperatures impact negatively on crop yields. Considering precipitation, Table 1 shows a large variability between the high and the low values. These statistics on precipitation suggest that the data used for precipitation variability may explain the decreasing of agricultural yields faced by Beninese farmers (Alle et al., 2013).

This paper also determines which climate variable affects more severely staple crops in Benin. Notice that before being used in the model crop yields, all variables are transformed logarithmically in order to enhance model fit.

Table 1. Descriptive statistics

	N	Mean	Standard Deviation	Minimum	Maximum
Maize data					
Yield (kg/ha)	55	907.06	282.37	494.4	1421.6
Area (ha)	55	536735.9	198716.2	261700	1006289
Precipitation (mm)	55	1027.4	118.1	744.9	1362
Temperature (degree Celsius)	55	27.7	0.5	26.7	28.8
Rice data					
Yield (kg/ha)	55	1720.11	887.25	355.8	3936.2
Area (ha)	55	17608.6	21590.0	1558	110009
Precipitation (mm)	55	814.8	109.3	561.6	1148.9
Temperature (degree Celsius)	55	26.6	0.5	25.5	27.6
Sorghum data					
Yield (kg/ha)	55	545.21	194.48	227.0	864.2
Area (ha)	55	93971.1	24612.3	51400	169483
Precipitation (mm)	55	994.2	115.6	730.8	1322.4
Temperature (degree Celsius)	55	27.4	0.5	26.4	28.5
Cowpea data					
Yield (kg/ha)	55	785.58	216.49	483.1	1499.4
Area (ha)	55	122276.0	31006.0	57970	193106
Precipitation (mm)	55	934.4	110.8	698.6	1264.8
Temperature (degree Celsius)	55	26.9	0.5	25.9	28.0
Cassava data					
Yield (kg/ha)	55	8682.30	3466.38	3783.8	17377.1
Area (ha)	55	148991.3	69340.4	70000	296641
Precipitation (mm)	55	1040.2	120.4	761	1374.4
Temperature (degree Celsius)	55	27.6	0.5	26.6	28.6
Yam data					
Yield (kg/ha)	55	10791.47	1754.73	7390.9	15046.0
Area (ha)	55	108259.2	52578.5	42000	214054
Precipitation (mm)	55	1039.4	119.8	746	1391.2
Temperature (degree Celsius)	55	27.8	0.5	26.7	28.8

Table 2. Crop growing seasons in Benin



Source: Awoye et al. (2017).

2.3 Model Specification

Each crop needs certain conditions for growth and survival, these are soil moisture (water), optimum temperature, adequate sunshine, and atmospheric humidity (Ali et al., 2017). According to Sombroek and Gommes (2018), temperature enhances photosynthesis as it increases and leads to an increase in crop yield. But Mathur and Jajoo (2014) stated that extremely high temperatures negatively affect the process of metabolism in plants, such as protein stability and reactions (enzymatic) in cells, leading to metabolic imbalance. It is noticed that photosynthesis reductions can be caused by high temperatures while the extremely low temperatures may lead to injury of chilling in plants (Bhandari & Nayyar, 2014). In the rainy season, intense precipitation can be a serious problem for the farmers. It can lead to soil erosion, washing out of soil surface, and depleting potential nutrients of the soil (Ali et al., 2017). Kabir and Golder (2017) mentioned that flooding can affect negatively crops and reduce farmer foods or leave them without food, and thus can trigger production and food security problems. In the same order, sunshine also plays a crucial role in crop yield due to its photosynthesis process implication. As certified by Ali et al. (2017), plants directly depend on sunshine for their healthy growth and development, completion of their life cycle, and most importantly, food preparation. In contrast, excessive sunshine has similar negative effects on crops (*e.g.*, extreme temperatures). In sum, change in climate parameters is expected to affect significantly crop yields.

To analyze the effects of climate change on crop yields, an econometric model which depends on the climate variables is developed using regression models and time series data at an aggregate level. Three main types of model (time-series models using time series data from a single locality, cross-sectional models using spatial variations data and panel models using spatio-temporal variation data) are used to establish the relationship between climate parameters and crop yields (Lobell & Burke, 2010). In terms of performance of the three models, the difference of results is not obvious (Schlenker & Roberts, 2009). But Schlenker and Lobell (2010) mentioned that the errors obtained from the panel regression method are less than those obtained in time-series regression method. This paper uses the time-series model to fit the crop yields and climate factors because of the unavailability of panel data. Regression analysis is often used to relate crop yield data to climate variables considering the information from the same geographical zone (Mahmood, Ahmad, Hassan, & Bakhsh, 2012; Sarker et al., 2012; Leng & Huang, 2017; Shakoor et al., 2017). Regression analysis approach is helpful by providing quite effective estimates of crop yield when this is affected by weather factors such as precipitation or temperature (Parry, Carter, & Konjin, 1988).

Two steps and computations are involved in quantifying the contribution of climate towards trends in crop yields. The first step concerns the climate effect on the mean of crop yields and the second is related to the climate effect on crop yields variability. It is more likely that relationship between climate variables and crop yield is non-linear as crop growth increases with a rise in precipitation and temperature up-to a certain limit, after that, crop growth may be adversely affected by an increase in the precipitation and the temperature. That is to indicate that crops require optimal conditions for their growing. Considering this kind of relationship, non-linear form of regression analysis is used. Based on the common non-linear functional form and following Wooldridge (2015), Amin, Zhang, and Yang (2015) and Ali et al. (2017), the feasible generalized least square (FGLS) and heteroskedasticity and autocorrelation (HAC) consistent standard error techniques are used, keeping in view the nature of the dependent and independent variables.

$$Y_{it} = \beta_0 + \beta_t Trend + \prod_{k=1}^{k} \beta_k X_{it} + \varepsilon_{it} \quad (1)$$

Where, Y_{it} represents yield (kg/ha) of crop i in year t; β_0 and β_t represent the intercept and trend coefficient respectively; β_k represents coefficient to be estimated for independent variables; X_{it} represent average monthly temperature (degree Celsius) during growing season for crop i in year t, total precipitation (mm) during growing season for crop i in year t, area cultivated of crop i in year t; ε_{it} error term for crop i model.

$$\varepsilon_{it} = \alpha_0 + \alpha_t Trend + \prod_{k=1}^{k} \alpha_k X_{it} + \xi_{it} \quad (2)$$

Based on Kukal and Irmak (2018), the yield residuals are regressed against the same independent variables as in Equation (1) to evaluate the sensitivity or variability of yields to individual climate variables. The following equation is to be used:

With ε_{it} Yield variability (kg/ha) of crop i in year t; α_0 and α_1 represent the intercept and trend coefficient respectively; α_k represents coefficient to be estimated for independent variables; X_{it} represent average monthly temperature (degree Celsius) during growing season for crop i in year t, total precipitation (mm) during growing season for crop i in year t, area cultivated of crop i in year t; ξ_{it} error term for crop i model.

To simulate the impact of future change in climate or its variability on the yield of major crops, the coefficients of the model estimated or elasticity in Equations (1) and (2) together with projected changes in temperature and precipitation is used like the following equation adopted by Issahaku (2015):

$$\%\Delta\hat{Y} = 100 \times [\exp(\beta_t \Delta T) - 1] + 100 \times [\exp(\beta_p \Delta P) - 1] \qquad (3)$$

Where, $\%\Delta\hat{Y}$ is the predicted percentage change in each crop yield, β_t is the coefficient of temperature and β_p the coefficient of precipitation; ΔT and ΔP are climate change projection scenarios respectively for temperature and precipitation. Ministry of the Environment, Habitat and Urban planning [MEHU] (2011) projected climate change in different horizons. Then, mean precipitation scenario for years 2025, 2050, 2075 and 2100 predicts an increase of about 1.56, 3.69, 5.69 and 8.25%, respectively for Benin. With respect to mean temperature, the forecasted values for the same period will increase by 2.52, 5.79, 8.17 and 9.9%, respectively.

The presence of unit root is tested using the unit root test proposed by Dickey and Fuller (1979). This test helps to check the presence of unit roots for each variable and the results are reported in Table 3. The null hypothesis is that data series contain a unit root and the alternative is that series are stationary. Using time series needs unit root test because of possible correlation between variables even when they increase or decrease for different reasons. Then, the correlation between variables of interest will be spurious, which in turn will produce unreliable estimates (Boubacar, 2012). Also, any series extending 20 years of observations requires testing for stationary (Chen, McCarl, & Schimmelpfennig, 2004). According to the later authors, this kind of correlation between variables may be introduced through either deterministic or stochastic trend. To take account of this possibility, Augmented Dickey-Fuller (ADF) unit root test is conducted to examine the time series properties of the variables of study.

3. Results and Discussion

3.1 Panel Unit Root Test

The Table 3 showed that variables of cowpea and yam model are stationary at level or integrated of order zero I (0). The Table 3 also showed that areas cultivated for maize, rice, sorghum and cassava are integrated of order one I (1). In addition, the rice model had two other variables (yield and temperature) stationary at first difference. However, the rest of variables were integrated of order zero. When all or most of the variables were not integrated at the same order under each model, Sarker et al. (2012) mentioned that co-integration test is not necessary. In the same direction, a causality analysis was not performed. Yield changes were assumed to be caused by climate variations rather than the reverse, as proposed by Lobell and Field (2007). Also, the variables with I (1) were differenced first before computation (McCarl, Villavicencio, & Wu, 2008; Amin et al., 2015). The detailed results of the unit root tests for the variables are displayed in Table 3.

Table 3. Augmented Dickey-Fuller (ADF) test for determining the stationary of the data series

Variable	Maize	Rice	Sorghum	Cowpea	Cassava	Yam
Yield						
Adjusted t statistic	-5.448	-2.275	-4.503	-4.985	-4.184	-4.293
P-value	0.000*	0.180[a]	0.001*	0.000*	0.005*	0.003*
Area cultivated						
Adjusted t statistic	-2.657	-1.968	-3.166	-4.609	-3.142	-3.635
P-value	0.254[a]	0.619[a]	0.091[a]	0.001*	0.097[a]	0.027*
Temperature						
Adjusted t statistic	-4.233	-2.829	-4.235	-4.481	-4.306	-4.441
P-value	0.004*	0.186[a]	0.004*	0.001*	0.003*	0.002*
Precipitation						
Adjusted t statistic	-5.436	-5.404	-5.232	-5.249	-5.310	-5.534
P-value	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*

Note. * indicates that the test statistics are significant at 5% level and integrated for order zero, I (0); [a] stationary at first difference or integrated of order I (1).

After examining the time trend, the feasible generalized least square (FGLS) and heteroskedasticity and autocorrelation (HAC) estimations were run (Equation 1). The crop yield variability was carried out by fitting Equation (2) for six staple crops cultivated (maize, rice, sorghum, cowpea, cassava and yam) in Benin and the results were summarized in Tables 4 and 5.

3.2 Estimation of Functions

3.2.1 Maize Yield Function

In maize model, the test result of F-statistics showed a well-behaved function. Climate variables tended to have mixed effects on maize yields. The results showed that precipitation and temperature affect differently the mean of maize yields. Precipitation had positive effect and temperature had negative effect on the mean of maize yield. Climate variables influenced negatively the yield variability. The elasticity of climate variables indicates that 1% increase in precipitation will increase the maize yield by 0.14% and 1% increase in temperature will decrease the maize yield by 1.819%. The estimated coefficients in the variance function indicate that increases in precipitation and temperature tend to reduce the variability of maize yields. These results implied that the climate variables were risk-increasing. These results are also similar to the findings of Boubacar (2012), Acquah and Kyei (2012), Issahaku (2015), and Adisa et al. (2017), where temperature and precipitation intensity variables were negatively related to the mean of maize yields. Ropo and Ibraheem (2017) conversely concluded that as temperature decreases, the yield of maize increases in Port Harcourt, Nigeria.

The trend had a significant effect on both the mean yield and yield variability though only positive effect in the mean yield functions. This implies that while the maize yield increases over time because of the technological progress, maize yield variability decreases in the same time. These results confirmed the findings of Boubacar (2012) who found that the improved technology augmented the mean of maize yield and diminished its variability. Other researchers like Isik and Devadoss (2006), Aye and Ater (2012) and Ali et al. (2017) found the positive impact of the mean of maize yields over time. In the maize area cropped side, the mean function of maize yields indicates that 1% increase in the maize area will decrease significantly the mean maize yield by 0.159%. This result meant that extending the cultivated area could not help to increase maize yield. Inversely, Acquah and Kyei (2012) and Boubacar (2012) found the positive relationship between mean maize yields and areas allocated to cultivate maize.

3.2.2 Rice Yield Function

The estimated equations for rice showed that the effects of precipitation were observed to be non-significant for the mean of rice yields. But temperature had a negative and significant effect on the mean of rice yields. Precipitation caused a positive effect, on the contrary. The elasticity in mean of rice yields function indicated that when temperature increases by 1%, the mean of rice yield will be expected to decrease by 4.04%. These results are similar to the findings of Afzal et al. (2016), where they revealed that minimum and maximum temperatures, rainfall and humidity had influenced negatively the mean of rice yields. In contrast, only precipitation negatively and significantly contributed to the variability of rice yields. The coefficient of the trend variables is positive for mean of rice yield function and is negative for rice yield variability function, and both coefficients are significant. These results indicate that the technological progress leads to higher yields and lower variability. Isik and Devadoss (2006) found the similar results. The rice areas cultivated were found to influence positively and significantly the mean of rice yields. The value of F-statistic of the model showed that rice yield variability could be explained by climate factors.

Many studies were conducted in which it was found that temperature, precipitation, humidity and sunshine significantly affect the yield of rice, but vary among different rice crops. Moreover, according to Sarker et al. (2012), the effects of temperature were pronounced as compared to precipitation. Ali et al. (2017) confirmed that rising mean temperature would result in a decrease in rice production. Other studies also stated that an increase in temperature and precipitation negatively affects rice production (Siddiqui, Samad, Nasir, & Jalil, 2012; Issahaku, 2015; Afzal et al., 2016). Mahmood et al. (2012) also analyzed the impact of minimum temperature during the first stage on rice production and they concluded that minimum temperature in first stage impacted the rice crop. Sarker et al. (2012) concluded that maximum and minimum temperatures and rainfall affect in different ways (sign and varieties) the rice yields.

3.2.3 Cowpea Yield Function

The relationship was developed to determine the mean of cowpea yield change and its variability associated to climate conditions during 1961-2015, using the time series method analysis. The findings showed that precipitation and temperature were found to be in disfavor of the cowpea crop yields (Table 4). The coefficient of trend was found to be positive and significant in mean yield function and negative in variability function. These results mean that the technological progress contributes to cowpea yield improvement and at the same time, the cowpea yield variability decreases. The climate variables affected negatively the mean of cowpea yields. It meant that 1% increase in temperature leads to the diminishing of cowpea yields by 3.045% and 1% increase in precipitation diminishes the cowpea yield by 0.274%. In the cowpea yield variability side, all the climate variables affected significantly but temperature influenced positively and precipitation negatively the variance of the cowpea yields.

3.2.4 Sorghum Yield Function

The results presented in Table 5 demonstrated that the temperature was observed to be detrimental for the sorghum mean yield and its variability. Temperature was statistically significant and had negative effect on the mean of the sorghum yield function, while the areas cultivated had negative effect on it. Precipitation influenced positively and was non-significant to the sorghum mean yield while it had negative and significant effect on sorghum variability. Specifically, the estimated coefficient for temperature indicated that if temperature augments by 1%, mean sorghum yield would decrease by 1.63%. Sorghum areas cultivated appeared to have adverse effect on sorghum mean yield. When sorghum areas increase by 1%, sorghum mean yield decreases by 0.217%. The findings of this paper are also congruent with the past studies. Boubacar (2012) recorded the same effect of temperature on sorghum yield in America. Also, Issahaku (2015) showed that temperature affects negatively the sorghum, whereas the precipitation affects it positively. Results of Amikuno and Donkoh (2012) revealed that the temperature could appear to have the effect on sorghum yield in both senses. The trend, however, impacted positively on sorghum mean yield which implied the sorghum yield improvement through the time by using improved seeds and best cropping practices.

3.2.5 Cassava Yield Function

Results revealed that precipitation and temperature showed adverse influences on mean of cassava yield with statistically significant coefficients (Table 5). Also, the variability of cassava yields was significantly influenced by temperature in a negative term and precipitation in a positive term. Trend had a positive influence on cassava mean yield and negative influence on the variability of cassava yields. The areas cultivated for cassava were found to affect negatively the yield but were statistically non-significant.

The p-value revealed that the contribution of temperature to the yields is significant at 1% level and showed the harmful effect of temperature to the yield of cassava. By considering elasticity value, respective increase of precipitation and temperature by 1% brings cassava yields to decrease by 3.07% and 0.117%. With respect to the variability of cassava yield, the results showed that an increase of temperature by 1% leads to the reduced variability of cassava yield by 0.09%. In contrast, when precipitation increases by 1%, the variability of cassava yield is expected to increase by 0.003%. The results implied that the response of cassava mean yields and variability to the change in precipitation level is inelastic. The estimated elasticity of the temperature for mean yields was elastic while the one for variability was inelastic. The literature review also explored the same justification that high temperature is one of the major abiotic stresses that have negative effects on growth, development and finally cassava yield (Ropo & Ibraheem, 2017). These authors revealed that the temperature had a negative relationship with the yield of cassava. These results do not confirm the findings of Issahaku (2015) who showed that the relationship between cassava yield and temperature is positive while that of precipitation is negative.

3.2.6 Yam Yield Function

The effect of climate variables on yam yield shown in Table 5 indicated that climate variables tend to have mixed effect on yam yield and its variability. Temperature had significant negative effect on mean yield but its effects on yam variability were significantly positive. If temperature increases by 1%, yam yield will decline by 0.75% and the variability of the yield will increase by 0.08%. This implied that yam yield is more susceptible to increase with certain temperature and that additional warming would adversely affect yam yields. The coefficient of precipitation is positively related to yam mean yield but negatively to its variability. Positive effect of additional precipitation on yam yield confirmed the fact that yam requires enhanced soil moisture to ensure smooth plant ant tuber development. When precipitation increases by 1%, the mean yam yield will increase by 0.32% while yam yield variability will decline by 0.01%. The coefficient of trend variable was positive and statistically significant at 5% level in the mean yield function showing that the technological progress brings higher yield and lower variability.

Table 4. Influence of climate variables on maize, rice and cowpea yields in Benin

	Maize			Rice			Cowpea		
	Coeff	Std err	P-value	Coeff	Std err	P-value	Coeff	Std err	P-value
Mean yield									
Trend	0.023	0.001	0.000	0.017	0.002	0.000	0.024	0.000	0.000
Area	-0.159	0.021	0.000	0.266	0.029	0.000	0.095	0.011	0.000
Precipitation	0.141	0.034	0.000	0.110	0.070	0.113	-0.274	0.037	0.000
Temperature	-1.819	0.351	0.000	-4.045	1.055	0.000	-3.165	0.183	0.000
Intercept	-30.451	1.105	0.000	-13.761	4.532	0.002	-27.680	0.774	0.000
Yield variability									
Trend	-0.000	0.000	0.000	-0.001	0.000	0.000	-0.000	0.000	0.054
Area	-0.001	0.000	0.013	0.012	0.001	0.000	0.002	0.001	0.024
Precipitation	-0.008	0.000	0.000	-0.018	0.002	0.000	0.0002	0.001	0.827
Temperature	-0.031	0.006	0.000	-0.046	0.035	0.190	-0.019	0.008	0.027
Intercept	0.300	0.014	0.000	2.049	0.123	0.000	0.095	0.026	0.000
Prob > chi2	0.000			0.000			0.000		

Note. Coeff = coefficient; Std err = standard error.

Table 5. Influence of climate variables on sorghum, cassava and yam yields in Benin

	Sorghum			Cassava			Yam		
	Coeff	Std err	P-value	Coeff	Std err	P-value	Coeff	Std err	P-value
Mean yield									
Trend	0.017	0.000	0.000	0.028	0.001	0.000	0.013	0.001	0.000
Area	-0.217	0.023	0.000	-0.045	0.026	0.084	-0.138	0.020	0.000
Precipitation	0.042	0.043	0.335	-0.117	0.025	0.000	0.315	0.022	0.000
Temperature	-1.630	0.357	0.000	-3.070	0.238	0.000	-0.758	0.377	0.044
Intercept	-17.782	1.280	0.000	-32.187	0.946	0.000	-12.46	1.894	0.000
Yield variability									
Trend	0.0002	0.000	0.000	0.000	0.000	0.004	-0.002	0.000	0.000
Area	-0.014	0.001	0.000	0.001	0.000	0.150	0.006	0.001	0.000
Precipitation	-0.007	0.001	0.000	0.003	0.001	0.000	-0.008	0.000	0.000
Temperature	0.030	0.007	0.000	-0.090	0.007	0.000	0.080	0.002	0.000
Intercept	-0.185	0.024	0.000	0.365	0.024	0.000	0.175	0.041	0.000
Prob > chi2	0.000			0.000			0.000		

Note. Coeff = coefficient; Std err = standard error.

3.3 Possible Effects of Temperature and Precipitation Change on Crop Yield and Yield Variability in the Future

At this level, the estimated production function parameters (variable elasticities) for maize, rice, cowpea, sorghum, cassava and yam yields were used to examine the implications of the different long-term climate change scenarios for crop yields and variability. According to MEHU (2011), temperature was expected to change by 2.52, 5.79, 8.17 and 9.9%, respectively in 2025, 2050, 2075 and 2100. In the same vein, precipitation was also expected to change by 1.56, 3.69, 5.69 and 8.25% in the same period. The percentage changes in the mean crop yields and yield variability were calculated for four climate change scenarios and the results are presented in Table 6. It can be seen from this Table that in 2025, temperature and precipitation changes will affect negatively yields of maize, rice, cowpea, sorghum, cassava and yam. Then, the projected climate change in 2025 would decrease maize, rice, cowpea, sorghum, cassava and yam yields by about 4.23, 9.45, 8.03, 7.57 and 1.38%, respectively. The findings of past studies mentioned that for Africa, maize and sorghum yields are set to decline significantly during the 21st century (Knox, Hess, Daccache, & Wheeler, 2012). Also, Ramirez-Villegas and Thornton (2015) found that during the 21st century and with any adaptation strategies, maize productivity could decrease by about 10% whereas rice productivity could decrease by about 5%. These authors recorded that in the case of maize yields, these would show large decreases in suitable areas across the Sahel, particularly in

Senegal, Mali, Burkina Faso, and Niger, and to some extent also in humid West Africa which contains Benin. Cairns et al. (2012) justified the crop yield losses in West Africa mostly by the shortened cropping seasons and the heat stress during the crop's reproductive period. After rice, the crop yield falls were ordered decrescendo as follows: cowpea, cassava, maize, sorghum and yam. With cross-sectional data, Issahaku (2015) found the similar results. The author indicated that yam yields would decrease by 6.43%. MEHU's (2011) climate change projection would also considerably affect the crop yield variability (Table 6). The variability of sorghum and yam would respectively expand by 0.06 and 0.18% for the period 2025. But, the variability of maize, rice, cowpea, and cassava yields is expected to decline. The decrease is higher for cassava yields and lower for cowpea yields. The future trend of crop yields is also shown by Table 6. Combined effects of precipitation and temperature indicated a decrease in major-crop yields. Crops with the highest losses were rice, sorghum and cowpea where their yields could decline by 27.6, 22.92 and 24.41%, respectively in 2075; 32.09, 27.17 and 29.13%, respectively in 2100. However, the lowest crop yield losses are expected from yam with 4.22 and 4.60% yield decreases in 2075 and 2100, respectively. These results are in line with those of Awoye et al. (2017) who revealed negative effects of climate change on pineapple, maize, groundnuts, cassava and cowpea yields in Benin while the same conditions are beneficial to rice, sorghum and yam. Many studies in West Africa linked trend and extent of crop yields to climate change, while discriminating effects from one crop to another. Of course, the methodologies put to use varied across studies (Roudier, Sultan, Quirion, & Berg, 2011). From 2050, some crop yields, *i.e.*, maize, sorghum, cowpea, cassava and yam, are expected to decrease by 10 to 40% (Knox et al., 2012; Jalloh, Nelson, Thomas, Zougmore, & Roy-Macauley, 2013; Sultan et al., 2013; Tesfaye et al., 2015). But divergent results were found in some previous studies which predicted increases of crop yields in response to future climate change. For instance, Jarvis, Ramirez-Villegas, Campo, and Navarro-Racines (2012) projected increases of cassava and yam yields; accordingly, Gerardeaux et al. (2013), Daccache, Sataya, and Knox (2014), and Awoye et al. (2017) predicted increases of rice and yam yields subsequent to climate change.

By considering previous studies in Benin, climate variables present different trends during the last decades (Amoussou, Camberlin, & Mahe, 2012 and Boko, Amoussou, Totin, & Sejame, 2014). Recently, Hounnou and Dedehouanou (2018) indicated that, in Benin, the mean state of annual precipitation of 1960-1988 and that of 1989-2016 are statistically identical. Contrasting with MEHU (2011), it is performed the single effect of mean temperature on food crop yields in order to highlight the significant statistical change in temperature alone on crop yields (Table 7). Obviously, temperature rise is harmful to future crop yields. The single effect of temperature rise on crop yields is higher than the combined effect with precipitation. The rationale is that precipitation rise is beneficial to all crop yields and reduces the negative effect of temperature rise. Therefore, irrigated systems can help farmers to mitigate or minimize the effect of temperature rise.

Table 6. Percentage change in crop yield means and yield variability for mean temperature and precipitation change projections in Benin

	Maize	Rice	Cowpea	Sorghum	Cassava	Yam
Period 2025						
Meanyields	-4.23	-9.45	-8.03	-3.93	-7.57	-1.38
Variance	-0.09	-0.14	-0.05	0.06	-0.22	0.18
Period 2050						
Meanyields	-9.50	-20.50	-17.78	-8.87	-16.74	-3.13
Variance	-0.21	-0.33	-0.11	0.15	-0.51	0.44
Period 2075						
Meanyields	-13.06	-27.60	-24.41	-12.27	-22.92	-4.22
Variance	-0.30	-0.48	-0.15	0.21	-0.72	0.61
Period 2100						
Meanyields	-15.33	-32.09	-29.13	-14.51	-27.17	-4.60
Variance	-0.37	-0.60	-0.19	0.24	-0.86	0.73

Table 7. Percentage change in crop yield means and yield variability for only mean temperature change projections in Benin

	Maize	Rice	Cowpea	Sorghum	Cassava	Yam
Period 2025						
Meanyields	-4.45	-9.62	-7.61	-3.98	-7.39	-1.88
Variance	-0.08	-0.11	-0.05	0.08	-0.22	0.20
Period 2050						
Meanyields	-10.02	-20.91	-16.77	-8.99	-16.31	-4.30
Variance	-0.18	-0.27	-0.11	0.17	-0.52	0.47
Period 2075						
Meanyields	-13.86	-28.23	-22.86	-12.48	-22.26	-6.03
Variance	-0.25	-0.38	-0.16	0.25	-0.74	0.66
Period 2075						
Meanyields	-13.49	-33.00	-26.90	-14.86	-26.21	-7.23
Variance	-0.31	-0.45	-0.19	0.30	-0.89	0.80

4. Conclusion

Apart from non-climate factors such as demographic pressure, fertility degree, technological progress, plant management, and insect, disease and weeds management that affect crop yields, there is no ambiguity that temperature and precipitation constitute the important climate factors which determine crop yields, particularly in agricultural rain-fed system. The temperature and precipitation level predictions affect the mean and variability of crop yields. This study develops the FGLS and HAC model to estimate stochastic production functions and determine the effects of temperature and precipitation on mean and variability of maize, rice, cowpea, sorghum, cassava, and yam yields in Benin. The results from estimated functions using time series data of climate variables and crop yields reveal that the effects of temperature and precipitation on crop yields differ across crops. The increasing trend affects positively the mean yields of all crops considered and negatively the crop yield variability except for sorghum and cassava. Projection of crop yields in the future indicates that the mean yields of six crops studied in this paper will register yield decreases of about quarter due to increases in both temperature and precipitation levels. Also, climate change would likely influence significantly the yield variability. Maize, rice, cowpea and cassava yield variability would decrease while sorghum and yam yield variability would increase. However, a single effect of temperature rise alone on crop yields leads to much more yield losses. To cope with climate change, farmers should adjust to the distributional effect of precipitation while policy makers, financial and technical partners should invest in agricultural sector through introducing adapted irrigation systems.

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