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Exploring the Relationship between Climate Variability and Crop Yields in Niger State, Nigeria

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Abstract

The study examined the impact of climate variability and its consequences on crop yields to achieve this, the study assessed the relationship between climate variables (rainfall, temperature and relative humidity) and crop yields in Niger State, Nigeria. The study utilized daily temperature and rainfall data for 30 years (1988-2018) The annual series of crop yields per unit area during 1997–2018(21 years) was collected from Nigeria Meteorological Agency (NIMET) and Agricultural Development Project (ADP) Niger Stat. *Linear regression model was used to analyze the relationship between crop yields and climatic variables. The result reveals that for every unit increment in rainfall there is a 29.9% positive effect on the yield of cassava, 36.50% positive effect in the yield of yam, 87.5% positive effect on the yield of rice, 0.07% positive effect on the yield of sweet potato, and 0.01% positive effect on the yield of millet. For temperature there is a 0.01% positive effect on the yield of cassava, 37.62% positive effect in the yield of sweet potato, and on humidity there is a 1.20% positive effect on the yield of yam. 2.0% positive effects on the yield of beans, 2.30% positive effect on the yield of sweet potato, and 3.40% positive effect on the yield of millet during the study period in Niger State. The study recommended that* the result therefore, has much to offer in terms of far- level decision making policies on agricultural production, *in Niger State.*

Keywords: *Climate variability, Crop yield, agriculture productivity and food security*

Introduction

Climate variability is one of the most pressing global challenges, particularly in sub- Saharan Africa, where agriculture is a vital sector of the economy (IPCC, 2019). Thus, climatic parameters (rainfall, temperature, relative humidity) have an influence on various stages of agricultural production chain including land preparation, sowing, crop yield and management, harvesting, storage, transport, and marketing (Ayinde *et al*., 2011; Popova *et al*., 2014). Climate affects agriculture and determines the adequacy of food supplies in two major ways. One is through the negative effect of climatic hazards (drought, flood) to crops and the other is through the control exercised by the environment on the type of crops feasible or viable in a given area (Eze, 2018, Shi *et al.*, 2013;). The varying incidence, reliability and magnitude of climate variables play a significant role in explaining the differences in cropping patterns, crop growth, and crop yields across different ecological zones in Nigeria (Ayinde *et al*., 2011). Jones and Thornton (2003) argued that climate variability has a direct effect on crop yields and farm management and that variation in climatic parameters will have subsequent effects on the implementation of new economic policies and adaptation strategies. The most direct impact of climate variability in Nigeria stems from water shortages or drought, leading to an increasing dependence on imported foodstuffs (Boubacar, 2010; Shittu *et al*., 2017; Eze, 2018). Moreover, the changing climatic conditions are likely to impose additional pressure on water availability, reducing the length of the growing season and forcing large regions of marginal agriculture out of production (IPCC, 2007). However, climate variability possesses significant threat to agricultural productivity, food security, and the livelihood of rural communities (Eze *et al*, 2022). Understanding the relationship between climate and crop yield is crucial for developing effective adaptation strategies to mitigate the impact of climate change. Climate variables such as temperature, precipitation and humidity significantly impact crop yields, influencing the productivity of staple crops like maize, millet, rice yam, beans, soya beans, cassava and sweet potato.

Despite the critical importance of climate-crop yield relationships and researches carried out by some major scholars like (Gadgil *et al*., 2002; Popova *et al*., 2014; Van der Pol *et al*., 2015; Tiamiyu *et al.* 2015), there is little research focusing on the yield of some crops in Niger State, Nigeria. Therefore, it is against this back ground that this study seeks to bridge the gap in the knowledge and exploring the relationship between climate variability and crop yields in Niger State.

The Study Area

This study was conducted in Niger State, which lies between Longitude 3^{0E} and 7^{0}E of the prime meridian, and Latitude 8^{0N} and 9^{0}N of the equator, and cover a land area of about 86000km representing approximately 9.3percent of the total land area of Nigeria. It is located in the North central geopolitical zones of Nigeria where it shares borders with a republic of Niger (West), Zamfara (North), Kebbi, (North-west). Kogi (South), Kwara (South-west), Kaduna (North-East) and FCT (South-East). The State has 25 local Government Areas, with Minna as the State capital. Niger State has the Niger valley terrain covering 18,007.38 km^2 (24.94 percent), the plains covering 24,181.04 km^2 (33.49 percent), upland covering 20616.09 (28.55 percent) while the remaining 9593.3 km^2 (13.01 percent) are made up of highlands. Today, the area known as Niger State was originally part of the defunct North-Western State, one of the twelve states initially created in 1967. The old state was later divided into two by late General Murtala Muhammed's regime in 1976. This brought about Sokoto and Niger States. The present Niger State is the largest in the country regarding landmass and is referred to as the "Power State" because of three hydro-electric power stations, namely the Shiroro, Kainji and Jebba power stations in the state. Niger State, located in the savannah region, is characterized by a fragile ecosystem, vulnerable to climate variability. The State's agricultural sector is predominantly rain-fed, making it highly susceptible to climate-related risks.

Climate of the study Area

Niger State is directly characterized by two seasons (rain and dry seasons). The mean annual rainfall is 1,334mm. The highest mean monthly rainfall is 300mm in September, and the lowest is in November, which is 5mm. The highest mean monthly temperature is in April (30 ^{0}C) and Augusts' mean minimum (25 ^{0}C). Temperature generally increases during the dry season due to clear skies and intense solar radiation. With the onset of the rainy season between June and September, the temperature is reduced. The lowest temperature in December and January are due to the influences of the north-east trade winds from the Sahara Desert

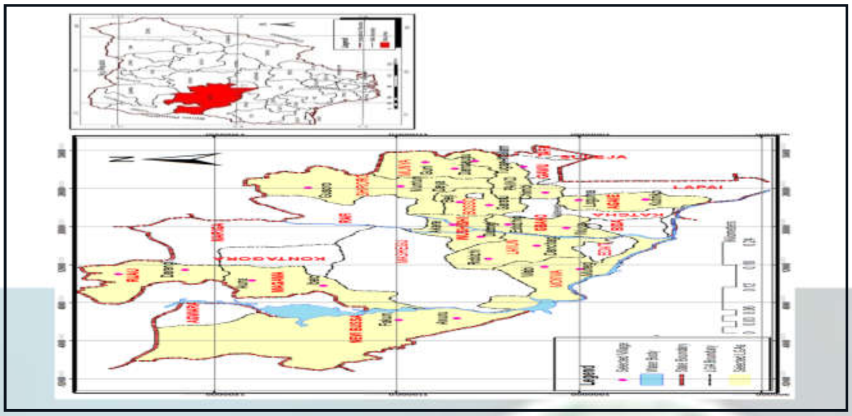

Figure 1 Map of the study Area.

Source; Ministry of Land and Survey

Materials and Methods

Rainfall data were obtained from the Nigerian Meteorological Agency, Abuja (NIMET) Also, data on crop yields (beans, soybean, maize, rice, millet, cassava, sweet potato and yam,) were collected from the Niger State Agricultural Development Programme (NADP) for twenty-one years (1997-2018). Only 9 crops (yam, cassava, sweet potato, rice, millet, maize, beans, and soya beans) were selected due to unavailability of complete data on other crops cultivated in the study area. Data collected were analysed using mean, standard deviation, regression analysis.

Data Analysis

Regression analyses i.e. (Linear, Semi-log, Double-log) was used to analyzed the relationship between the crop yields and climatic variables, this incorporates with the given variables (Constant, mean rainfall, mean temperature, mean relative humidity) along with R2, Adjusted R2, and F-value.

(R2= Regression coefficient of determination, F- value= Frequency value)

Linear Regression Model is expressed as follows $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_i x_i + \varepsilon$

Where, I is the number of observations, $\beta_0$is the y-intercept, which is a constant term, $\beta_n$represents the slope coefficients for each input variable, and ε is the model deviation.PR is a nonlinear regression model in which the output (response variable) is modeled in proportion to a power (polynomial) of the inputs (explanatory variables). These formulas can be used to estimate the crop yield (Y) based on the given climatic variables in each regression model. The coefficients provide insights into the strength and direction of the relationships. The R2 and F-value help assess the overall fit and significance of the regression model.

Results

Effect of Temperature, Rainfall and Relative humidity on Some Crops in the Study Area.

Climate variables like temperature, rainfall and humidity have positive/negative effects on the growth and yield of selected crops. The relationship between climate variables (temperature, rainfall and humidity) and the following staple crops (yam, cassava, sweet potato, rice, millet, maize, beans, and soya beans) are discussed in Tables 1-10 below:

Table 1 Effect of Rainfall, temperature, relative humidity on cassava yield

Variable	Linear	Semi-log	Double-log
Constant	4.098 (27.889)	2.253(1.409)	-0.665(5.77)
Mean rainfall	0.004(0.002)	0.000(0.000)	0.351(0.212)
Mean temperature	0.299(0.566)	0.015(.029)	0.357(0.694)
Mean relative humidity	0.010(0.267)	0.000(0.014)	-0.031(1.024)
R^2	0.207	0.197	0.190
Adjusted R^2	0.049	0.037	0.028
F-value	1.307	1.230	1.170

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 1 shows the regression results of the effects of mean annual rainfall, temperature and relative humidity on the yield of cassava in the study area. The result from the linear regression analysis showed that the regression coefficient of determination R^2 was 0.207, it can be noted that about 20.7% of variation in cassava yields could be explained by means of rainfall, relative humidity and mean temperature. The remaining 79.3% were largely due to other variables like wind velocity soil that were outside the regression model that also reveals that for every unit increment in rainfall there is a 29.9% positive effect on the yield of cassava during the study period. The implication of these findings is that the volume of rainfall, mean temperature and relative humidity may not necessarily determine the output of cassava in the study area. The important determinant is the spread of the rainfall within the year. According to Suleiman, (2019), one-month drought when cassava is tasseling can result in serious reduction in the output of maize, and thus the same principles apply to the other climatic variables

Table 2: Effect of Rainfall, Temperature, Relative Humidity on Beans Yield

Variable	**Linear**	**Semi-log**	**Double-log**
Constant	-823 (4.010)	-2.092(3.018)	-11.524(11.773)
Mean rainfall	0.001(.000)	0.000(.000)	0.761(.455)
Mean temperature	0.017(.081)	0.017(.061)	0.394(1.492)
Mean relative humidity	0.020(.038)	0.015(.029)	1.121(2.201)
R^2	0.268	0.201	0.187
Adjusted R^2	0.121	0.041	0.025
F-value	1.829	1.257	1.153

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 2 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yield of beans in the study area. The result form the linear regression analysis showed that the regression coefficient of determination R^2 was 0.268, it should be noted that about 26.80% of variation of beans could be explained by means of rainfall, relative humidity and temperature. The remaining 73.20% were largely due to other variables like wind, soil water, and soil air that were outside the regression model that also has effect on the beans yield in the study area. The regression results also reveal that for every unit increment in temperature there is a 0.01% positive effect in the yield of beans, and for every unit increment in the relative humidity there is a 2.0% positive effect on the yield of beans during the study period in Niger State.

Table 3: Effect of Rainfall, Temperature, Relative Humidity on Yam Yield

Variable	Linear	Semi-log	Double-log
Constant	2.536 (21.986)	1.906(1.370)	-0.850(5.317)
Mean rainfall	0.003(0.002)	0.000(.000)	0.282(.205)
Mean temperature	0.365(.446)	0.026(.028)	0.615(.674)
Mean relative humidity	-0.012(.211)	-0.001(.013)	-0.116(.994)
R^2	0.186	0.193	0.188
Adjusted R^2	0.023	0.031	0.025
F-value	1.144	1.195	1.154

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 3 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yields of yam in the study area. The result from the linear function was chosen as the lead equation. The result from the regression analysis showed that the regression coefficient of determination R^2 was 0.186. It should be noted that about 18.60% of variation in yam could be explained by means of rainfall, relative humidity and temperature, the remaining 81.40% were largely due to other variables like soil capillary water and soil turbidity that were outside the regression model that also affects the yield of yam in the study area. The regression result also reveals that for every unit increment in temperature there is 0.03% positive effect on the yield of yam, also for every unit increment in rainfall there is a 36.50% positive effect in the yield of yam, and for every unit increment in the relative humidity there is a 1.20% positive effect on the yield of yam during the study period in Niger State. This conformed with Obafemi and Adebolu (2018) study that variations in rainfall, temperature and relative humidity were found to have effects on cassava, yam, pepper and tomatoes yield by 20.7%, 18.6%, 26.8% and 15.5%, respectively.

Table 4: Effect of Rainfall, Temperature, Relative Humidity on Millet Yield

Variable	Linear	Semi-log	Double-log
Constant	2.523 (22.874)	1.917(1.260)	-0.861(5.321)
Mean rainfall	0.004(0.003)	0.000(0.000)	0.279(0.208)
Mean temperature	0.371(0.346)	0.027(0.027)	0.635(0.663)
Mean relative humidity	-0.013(0.212)	-0.001(.016)	-0.107(0.874)
R^2	0.155	0.193	0.188
Adjusted R^2	0.033	0.040	0.034
F-value	1.126	1.189	1.168

Note: Figure in parenthesis indicates T-value

Table 4 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yields of millet in the study area. The result from the regression analysis showed that the regression coefficient of determination R2 was 0.155. It should be noted that about 15.50% of variation in millet could be explained by means of rainfall, relative humidity and temperature. The remaining 84.50% were largely due to other variable wind and air that were outside the regression model that has effect on the yield of millet in the study area. The regression results also reveal that for every unit increment in rainfall there is a 0.01% positive effect on the yields of millet, also for every unit increment in the relative humidity there is a 3.40% positive effect on the yield of millet during the study period in Niger State.

Table 5 : Effect of Rainfall, Temperature and Relative Humidity on Ground Nut Yields

Variable	Linear	Semi-log	Double-log
Constant	4.077 (27.993)	2.2713(1.511)	-0.553(5.83)
Mean rainfall	0.005(0.013)	0.000(0.000)	0.342(0.320)
Mean temperature	0.278(0.521)	0.016(.026)	0.329(0.721)
Mean relative humidity	0.021(0.245)	0.000(0.017)	-0.041(1.052)
R^2	0.305	0.172	0.171
Adjusted R^2	0.059	0.042	0.036
F-value	1.406	1.310	1.162

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 5 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yield of groundnut in the study area. The result from the linear regression analysis showed that the regression coefficient of determination R^2 was 0.305%, it should be noted that about 25.8% of variation in groundnut could be explained by means of rainfall, relative humidity and mean temperature.

The remaining 74.2% were largely due to other variables soil water outside the regression model that also reveals that for every unit increment in rainfall there is a 30.5% positive effect on the yield of groundnut during the study period. The implication of these findings is that the volume of rainfall, mean temperature and relative humidity may not necessarily determine the output of groundnut in the study area.

Table 6: Effect of Rainfall, Temperature, Relative Humidity on Maize Yield

Variable	Linear	Semi-log	Double-log
Constant	-721 (4.032)	-3.072(3.022)	-10.531(11.781)
Mean rainfall	0.001(0.000)	0.001(0.001)	0.726(0.461)
Mean temperature	0.018(.072)	0.024(.058)	0.373(1.523)
Mean relative humidity	0.026(.037)	0.016(.031)	1.142(2.310)
R^2	0.361	0.322	0.188
Adjusted R^2	0.134	0.050	0.037
F-value	1.737	1.266	1.161

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 6 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yields of maize in the study area. The result form the linear regression analysis showed that the regression analysis showed that the regression coefficient of determination R^2 was 0.361%, it should be noted that about 27.75% of variation of beans could be explained by means of rainfall, relative humidity and temperature. The remaining 72.25% were largely due to other variables wind and air outside the regression model that also has effect on the maize yield in the study area. The regression results also reveal that for every unit increment in temperature there is a 0.02%

positive effect in the yield of maize, and for every unit increment in the relative humidity there is a 3.0% positive effect on the yields of maize during the study period in Niger State. This finding is in line with Ajetomobi (2016) research work which shows weak but positive relationship between the yields of maize and average precipitation. The marginal relationship with growing degree days (GDD) is also weakly positive but that with heat degree days (HDD) is strongly negative.

Table 8: Effect of Rainfall, Temperature, Relative Humidity on Sorghum Yield

Variable	**Linear**	**Semi-log**	**Double-log**
Constant	2.572 (24.861)	1.816(1.720)	-0.721(5.341)
Mean rainfall	0.006(0.007)	0.001(0.001)	0.285(0.274)
Mean temperature	0.392(0.363)	0.028(0.038)	0.662(0.721)
Mean relative humidity	0.014(0.225)	0.002(.018)	0.204(0.692)
R^2	0.273	0.193	0.188
Adjusted R^2	0.041	0.052	0.047
F-value	1.132	1.187	1.182

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 8 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yields of sorghum in the study area. The result from the regression analysis showed that the regression coefficient of determination R^2 was 0.273. It can be noted that about 16.85% of variation in sorghum could be explained by means of rainfall, relative humidity and temperature. The remaining 83.15% were largely due to other variable like air and minimum temperature that were outside the regression model that has effect on the yield of sorghum in the study area. The regression results also reveal that for every unit increment in rainfall there is a 0.01% positive effect on the yield of millet, also for every unit increment in the relative humidity there is a 3.40% positive effect on the yield of sorghum during the study period in Niger State. The result was contrary to the study of Ajetomobi (2016) which showed that the relationship of the yield with vapor pressure deficit was strongly negative and significant. As an increase in soil moisture is desirable in order to stimulate increase in the yield of sorghum.

Table 9: Effect of Rainfall, Temperature, Relative Humidity on sweet Potato Yield

Variable	Linear	Semi-log	Double-log
Constant	2.734 (22.935)	2.922(2.340)	0.862(5.610)
Mean rainfall	0.007(0.005)	0.001(.001)	0.274(.275)
Mean temperature	0.728(.531)	0.067(.083)	0.683(.629)
Mean relative humidity	-0.016(.232)	-0.001(.042)	-0.163(.987)
R^2	0.425	0.953	0.199
Adjusted R^2	0.042	0.073	0.062
F-value	1.173	1.195	1.199

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 9 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yield of sweet potato in the study area. The result from the linear function was chosen as the lead equation. The result from the regression analysis showed that the regression coefficient of determination R^2 was 0.425, it should be noted that about 19.80% of variation in sweet potato could be explained by means of rainfall, relative humidity and temperature, the remaining 80.20% were largely due to other variables like soil water that was outside the regression model that also affects the yield of sweet potato in the study area. The regression result also reveals that for every unit increment in rainfall there is 0.07% positive effect on the yield of sweet potato, also for every unit increment in temperature there is a 37.62% positive effect in the yield of sweet potato, and for every unit increment in the relative humidity there is a 2.30% positive effect on the yields of sweet potato during the study period in Niger State. This conformed with Obafemi and Adebolu (2018) studies that variations in rainfall, temperature and relative humidity were found to have effects on cassava, yam, pepper and tomatoes yield by 20.7%, 18.6%, 26.8% and 15.5%, respectively.

Table 10: Effect of Rainfall, Temperature, Relative Humidity on Rice Yield

Variable	Linear	Semi-log	Double-log
Constant	3.078 (27.993)	3.2715(1.532)	-0.546(5.62)
Mean rainfall	0.006(0.014)	0.001(0.001)	0.347(0.340)
Mean temperature	0.269(0.535)	0.018(.032)	0.387(0.741)
Mean relative humidity	0.046(0.252)	0.001(0.019)	0.062(1.070)
R^2	0.597	0.278	0.283
Adjusted R^2	0.084	0.058	0.074
F-value	1.657	1.362	1.452

Note: Figure in parenthesis indicates T-value

Source: Field Work, 2023

Table 10 shows the regression result of the effect of mean annual rainfall, temperature and relative humidity on the yields of rice in the study area. The result from the linear regression analysis showed that the regression coefficient of determination R^2 was 0.597, it should be noted that about 66.7% of variation in rice could be explained by means of rainfall, relative humidity and mean temperature. The remaining 33.3% were largely due to other variables like soil water that was outside the regression model that also reveals that for every unit increment in rainfall there is 87.5% positive effect on the yields of rice during the study period. The implication of these findings is that the volume of mean temperature and relative humidity may not necessarily determine the output of rice in the study area. The important determinant is the spread of the amount of rainfall within the year.

Conclusion and Recommendation

In conclusion, the climate variability has affected agricultural production, particularly, low crop yields were observed in the study area. However, the crop yield and climate variables (rainfall, temperature and relative humidity) in the study area show a generally weak positive correlation. The study concludes that rainfall, mean temperature and relative humidity has positive impact on the yield of selected staple crops during the study period in Niger State. This implies that the variations in soya beans, beans and cassava yield are due to other causes or reasons, such as soil type, application of fertilizers, farming methods etc. Moreover, rainfall amount has significant effect on the yields of rice, yam and maize in the study area. The extent of rainfall deviation from its normal occurrence, therefore, has a great implication for the yield and agricultural production in general. Finally, the result therefore, has much to offer in terms of far- level decision making policies on agricultural production. The result can be used for the reduction of the potential damage of climate variability and crop production by integrating climate smart agricultural practices in crop production.

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