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MODELLING RELATIONSHIP BETWEEN RAINFALL VARIABILITY AND MILLET (*Pennisetum americanum* L.) AND SORGHUM (*Sorghum bicolor* L. *Moench.*) YIELDS IN THE SUDAN SAVANNA ECOLOGICAL ZONE OF NIGERIA

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ABSTRACT

This study models the relationship between rainfall variability parameters and millet (Pennisetum americanum L.) and sorghum (Sorghum bicolor L. Moench.) yields in the Sudan Savanna ecological zone of Nigeria. Daily rainfall data recorded by the nearby stations for the period between 1981 and 2010 as well as millet and sorghum yield data were used as inputs in the model. It attempts to develop model for predicting millet and sorghum yields based on rainfall variables. The analytical tools used in developing and testing the model performance include ogive of cumulative pentad rainfall, product-moment correlation coefficient (r), stepwise multiple regression analysis and coefficient of determination (R^2). The study produced four yield forecast models; three for millet at Kano, Katsina and Potiskum and the last for sorghum at Potiskum. Model accounted for 61.7% of variation in millet yield due to total annual rainfall and 68.1% in sorghum yield due to total rainfall in may assume the best-fitted yield forecast models. The unaccounted variation of 38.3% in millet yield and 31.9% in sorghum indicate other factors could influence the yield variability of the two crops. It is recommended that based on holding annual and may totals rainfall constant, the two best-fitted crop yield models should be used for planning and forecasting the yield of millet and sorghum in the study area.

Key words: modelling, rainfall, yields, millet, sorghum

INTRODUCTION

Meteorological variables, such as rainfall parameters, temperature, sunshine hours, relative humidity, and wind velocity and soil moisture are some of the most important factors, which affect crop yield. Most of the developed forecasting models for crop yield are on weather variables (Amrender, 2005). Few of these models are the ones developed by Agrawal *et al.* (1980), Adebayo and Adebayo (1997), Adejuwon (2005), Abdullahi *et al.* (2006), Sawa (2010), Sawa and Ibrahim (2011). An exception to these is that of Prasad and Dudhane (1989) who developed a forecast model for rice yield in the Gangetic Bengal using rainfall and agricultural technology including trend variables in the model as a measure of technological change.

Agrawal *et al.* (1980) developed a model for forecast of rice yield using climatic variables and found out that rainfall and temperature are critical factors to rice yield. Adebayo and Adebayo (1997) developed double log multiple regression model to predict rice yield in Adamawa State, Nigeria. The general form of the model expressed as*:*

$$Y = a + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_4 \log x_4 + b_n \log x_n \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where Y is predicted yield in kg/ha ($\log_{10}$), x_1 is hydrological ratio, x_2 is onset of the rain, x_3 is number of pentad dry spells between May and September and x_4 is total rainfall in June, a, b_1, b_2, b_3, b_4- - - - - b_n are the coefficients of double log multiple regression.

Adejuwon (2005) in the study of food crop production and present effects of climatic variables in Nigeria adopted a forecast model for the yields of cowpeas, groundnut, millet, maize and sorghum in Potiskum and Maiduguri using bivariate correlation and stepwise multiple regression analysis techniques. The form of the model is mathematically expressed as:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 \ b_nx_n \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where Y is crop yield, a, b_1, b_2, b_3, b_4,b_5-b_n are the coefficients of stepwise multiple regression, x_1, x_2, x_3, x_4, x_5, ------------ x_n are rainfall parameters (predictors variables). This equation used to develop four yields forecast models of cowpea, groundnut, millet and sorghum in the Nigerian Arid Zone. The study reported that the predicted models generated for the yield of cowpeas, groundnut, millet and sorghum were statistically significant with $\alpha \leq 0.05$. Among most powerful determinants

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of crop yield were rainfalls at the onset and at the cessation of months of the growing season.

Abdullahi *et al.* (2006) in their study on econometric analysis of the relationship between drought and millet production in the Arid Zone of Nigeria: A case study of Borno and Yobe States, used a supply response model. They used this model to isolate the systematic effect of rainfall on millet production using ordinary lease squares (OLS) estimate. Linear and double log functions were lead equations for the production and yield, with coefficient of determination (R^2_s) of 0.86 and 0.77 respectively. They observed that rainfall and trend variables were significant ($p \leq 0.01$) for both production and yield function. Recently, Sawa and Ibrahim (2011) adopted a forecast model for the yield of millet and sorghum in Sami-Arid region of northern Nigeria using the occurrence of dry spells of 5, 7, 10 and equal or greater than 15 consecutive days during the growing season. Bivariate correlation analysis, stepwise (forward selection) and double log multiple regressions were then used to develop models for the prediction of the yield of the two crops. This research assumes that total monthly rainfall amounts during months of the growing season, total annual rainfall and the length of growing season were not fully explored in developing the yield forecast model for millet (*Pennisetum americanum* L.) and sorghum (*Sorghum bicolor* (L) Moench) in the Sudan Savanna Ecological Zone of Nigeria. This is a research gap, which need to be bridged. The aim of this paper is to model the relationship between rainfall variability parameters and millet (*Pennisetum americanum* L.) and sorghum (*Sorghum bicolor* (L) Moench) yields in the Sudan Savanna ecological zone of Nigeria. The aim achieved by the following objectives:

i. identify the rainfall variables that influence yields;
ii. develop a model for predicting the yield of millet and sorghum at each location base on rainfall parameters; and
iii. to determine the best fitted yield models for the study area.

MATERIALS AND METHODS:

Study Area

The study area is Sudan Savannah ecological zone of Nigeria. It approximately lies between Latitudes 100^0 and 120^0 N and Longitudes 40^0 and 150^0 E (Fig. 1). It stretches from the Sokoto plains in the west through the northern section of the High Plains of northern Nigeria in the east to the Chad Basin. It thus includes the state of Kaduna, Katsina, Kano, Jigawa, Zamfara, Sokoto, Kebbi, and Borno.

Study Locations

Six (6) locations selected for this study include Kano, Katsina, Maiduguri, Potiskum, Sokoto and Gusau. The locations were chosen based on availability of meteorological stations within the climatic zone. These meteorological stations are synoptic stations that have long period of daily rainfall records. They are consistent in location since their establishment; have no significant missing rainfall records and geographically well distributed within the area.

Types of Data Needed

For this type of empirical study, two types of data are required: the first are daily rainfall records, and the second are the crop yield/values for millet and sorghum (metric tons/ha) or kg/ha. The analysis covers the growing season – 01 May to 31 October, as it coincides the period when all the stations in this climatic zone receive about 95% of their total annual rainfall (Anyadike, 1993). Relating millet and sorghum yields with the rainfall effectiveness indices in each location was based on the availability of yields data for these crops. The basis of this is because no location in the area has crop yield data that matches rainfall records to the end of the study. The yields data obtained for these crops in each of the six locations range between 11 and 29 years.

Sources of Data

Rainfall data for each of the six (6) locations were sourced from the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos. Most of the annual yields of millet and sorghum for each of the six locations were sourced from the respective State Agricultural Development Programs (ADPs).The rest were sourced from National Food Reserve Agency (NFRA). The period for millet and sorghum yield data, however, varied among these locations. This was due to irregularities in available yield records of these crops. The records of rainfall and crop yield data used presented are in Table 1.

Derivation of Onset Dates, Cessation Dates and Length of Growing Season (LGS)

Daily rainfall data for the period between 1981 and 2010 for the six selected locations and the method of Adefolalu (1993) which was based on relative definition adopted in the derivation of onset and cessation dates of rains and length of growing season in the study area. The study reported that, the length of growing season could be obtained by subtracting the onset pentad from the cessation pentad. The onset and cessation dates of the growing season was determined by dividing each year into pentads making 72 pentads, and using the pentad calendar, Pentad rainfall was then obtained for each pentad. Pentads rainfall then plotted against the number of pentad giving an ogive for each year in the study area. The points on the pentad axis corresponding to the first and last points of the maximum inflexion on the rainfall ogive correspond to the onset and cessation pentads,

Table 1: Rainfall and crop yield in the study area

Location	Rainfall	Millet Yield	Sorghum Yield
Gusau	30 years (1981-2010)	11 years (1999-2009)	11 years (1999-2009)
Kano	30 years (1981-2010)	29 years (1982-2010)	29 years (1982-2010)
Katsina	30 years (1981-2010)	11 years (1991-2001)	11 years (1991-2001)
Maiduguri	30 years (1981-2010)	17 years (1993-2009	17 years (1993-2009)
Potiskum	30 years (1981-2010)	11 year (1999-2009)	11 years (1999-2009)
Sokoto	30 years (1981-2010)	16 years (1993-2008)	16 years (1993-2008)

Source: NIMET, States` ADPs, NFRA, 2013

and multiplied by 5. The last date in the onset pentad gives the exact onset date and the first date in the cessation pentad gives the cessation date of the rainy season. The gap between onset and cessation pentads gives the length of growing season. The derived onset and cessation dates then converted to Julian days using Julian day calendar and obtained the length of growing season for each year in the study period. This method adopted in the derivation of onset and cessation dates of rains and length of growing season in the study area. The method utilizes daily rainfall data and makes it more accurate and precise method for determining the onset, cessation date and the length of growing season than other method.

Derivation of Monthly Rainfall Amounts during the Growing Season and Annual Rainfall (AR)

Daily rainfall data cumulated from onset pentad to cessation pentad to give monthly rainfall totals in months of the growing season. Daily rainfall data cumulated from January to December to give annual rainfall total for each station in the study period.

Relationship between Crop Yield and Rainfall Parameters

The Product moment correlation coefficient (r) is the ratio of the joint variation of two variables to the total variation (David, 1977). The technique assumes that both variables have come from normally distributed populations. The Product Moment Correlation Coefficient (r) used to test the relationship between crop yields and monthly rainfall amounts during months of growing season, length of growing season and annual rainfall. The product moment correlation coefficient (r) between two variables mathematically expressed as:

$$r = \sum xy / N - \bar{x}\ \bar{y} / s_x s_y \quad \ldots\ldots\ldots\ldots (3)$$

where r is the product moment correlation coefficient, x is the rainfall effectiveness parameter for each location, y refers to total crop yields of each crop for each location, $\bar{x}$ is the mean rainfall effectiveness parameter for each location, $\bar{y}$ is the mean total yield of each crop for each location and N is the study period. S_x is the standard deviation of rainfall total for each location; S_y is the standard deviation of total crop yields for each location. S_x and S_y calculated by the following equations:

$$S_x = \sqrt{\left(\sum x^2 / N\right) - \bar{x}^2} \quad \ldots\ldots\ldots\ldots (4)$$

$$S_y = \sqrt{\left(\sum y^2 / N\right) - \bar{y}^2} \quad \ldots\ldots\ldots\ldots (5)$$

Models for Predicting Crop Yield

The identified crops yield Ton/hectare (millet and sorghum) and rainfall effectiveness parameters are harmonized to common base ($\log_{10}$) using MINITAB Software of the computer. Later, rainfall amounts during growing season, annual rainfall and length of growing season correlated with the yields of the two crops in each location. These parameters are then subjected to stepwise multiple regression analysis using SPSS Software of the computer to develop yield forecasting models for the two crops station wise. The best-fitted yield forecast models of the two crops chosen among the six locations for the study area. The method of Adebayo and Adebayo (1997) adopted to develop yield forecast models for millet and sorghum yields using the rainfall parameters identified in the study. The general form of the model expressed as:

$$Y = a + b_1\log x_1 + b_2\log x_2 + b_3 \log x_3 + b_4\log x_4 + b_5 \log x_5 + b_6\log x_6 + b_7\log x_7 + b_8\log x_8 + bn\log x_n \ldots\ldots\ldots\ldots 6$$

where Y is yield ton/yr; X_1, X_2, X_3, X_4, X_5 and X_6 are May, Jun., Jul., Aug., Sep. and Oct. rainfall, respectively; X_7 is AR (annual rainfall) and X_8 is LGS (length of growing season). To check the appropriateness of the developed model, the residuals were examined. Residual is the difference between the observed and predicted value. The goodness fit of the models verified by coefficient of determination (R^2). The accuracy of this forecast model checked by the forecast error percentage, which computed by the equation:

$$FE = \frac{\text{Observed Yield} - \text{Forecast Yield}}{\text{Observed}} \times 100 \quad (7)$$

For goodness of fit, the percentage errors should not vary significantly one from another. The FE should not be greater than 25% otherwise, the model is not appropriate for forecasting the yield of crops (Sawa, 2010).

RESULTS AND DISCUSSION

Onset Dates, Cessation Dates and Length of Growing Season

Results for onset dates, cessation dates and length of growing season in 1981 for Kano presented in Fig. 2. As shown in Fig. 2, the onset pentad falls on pentad 29. Using Pentad Calendar, the onset date of rainfall corresponds to 21 May 1981. The cessation pentad falls on pentad 53 and the cessation date of rainfall corresponds to 25-September. The other onset and cessation dates and length of growing season for the study period between 1981 and 2010 for each location were obtained using similar methods with pentad and Julian day calendars.

Monthly Rainfall Amounts in Length of the growing Season and Annual Rainfall

The monthly rainfall amounts during the growing season and annual rainfall for Katsina in 1981are determined and presented in Table 2. Results of other locations in the study period between 1981 and 2010 also obtained using similar method.

Length of the Growing Season

Results for length of growing season at Potiskum in 1981 obtained and presented in Table 3. Results for each location in the study period were also obtained using similar method.

Test of Relationship

Results on test of relationship between rainfall variability parameters using the Product Moment Correlation Coefficient(r) indicates that at Kano millet yield is significantly correlated with July rainfall, annual rainfall and length of growing season at 0.01 significant levels. At Katsina, millet yield significantly correlated with annual rainfall at 0.05 significant levels. At the 0.05 significant levels, Sorghum yield correlated with August rainfall in Maiduguri. In Potiskum, at 0.05 significance levels, millet yield significantly and negatively correlated with annual rainfall and the length of growing season. Sorghum yield also significantly and negatively correlated with May rainfall at the 0.01 significant levels. There is no significant correlation found between millet and sorghum yields with the identified rainfall variability parameters in Gusau and Sokoto.

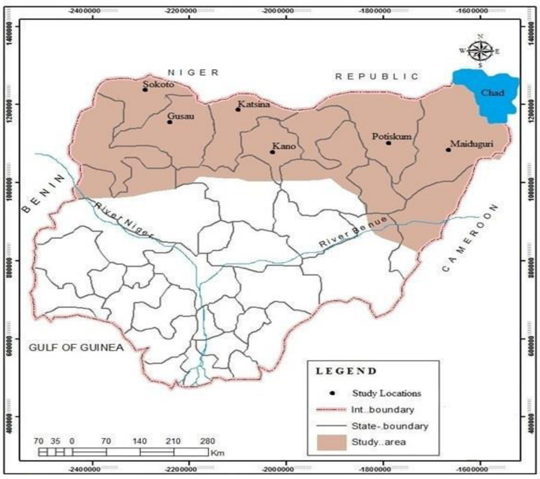

Fig. 1: Study area showing the location of the study sites.
Source: Les (2006)

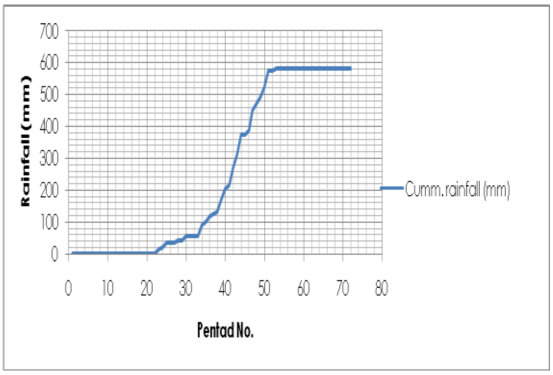

Fig. 2: Ogive of cumulative pentad rainfall at Kano (1981) for determination of onset, cessation dates and length of growing season

Table 2: Monthly rainfall (mm) of the growing season and annual rainfall (AR) at Kano (1981-2010)

Year	May	Jun.	Jul.	Aug.	Sep.	Oct	AR
1981	20.7	62.1	152.8	199.9	111.8	00	582
1982	25.7	62.3	152.9	283.8	60.5	1.3	606
1983	26.2	47.4	82.4	266.1	37	00	460
1984	42.7	114.9	198.7	53.6	118.7	17.3	547
1985	27	165.6	169.8	162.2	110.1	00	656
1986	00	135.2	258.9	157.5	105.8	4.2	676
1987	00	68.9	164.5	110.1	65.5	14.8	515
1988	00	139.2	147.1	488.5	154.1	00	1038
1989	00	32.6	142.4	382.1	84	45.3	700
1990	00	54.3	233.1	142.4	89.2	00	532
1991	104.8	148.6	287.3	455.2	26.9	00	1088
1992	122.1	45.1	191.4	324.8	205.6	0.7	927
1993	28	222.3	174.9	406.9	67.3	0.6	920
1994	00	00	146.1	325.2	156.3	00	652
1995	25.4	145	218.9	145	173.5	3.5	719
1996	12.2	143.1	253.8	392.8	235.5	4.7	1104
1997	100.6	161.4	243.9	451.4	252.1	40	1280
1998	96.6	170.1	525.4	571.8	414.1	26.6	1822
1999	44.5	101.3	527.5	466.3	223.4	5.1	1348
2000	93.5	100.2	364.2	281.8	174.4	64	1115
2001	00	231.1	604.7	521.1	205.6	00	1614
2002	00	83.6	274.9	376.6	199.9	54.1	993
2003	65.3	247.2	394	465.4	227.4	13	1424
2004	166.3	255.2	265.2	275.7	233.9	00	1206
2005	119.7	188	422	437.9	120.3	39.6	1329
2006	149.7	114.9	373.5	328.4	346	00	1313
2007	107.3	329.3	158.4	430	189.5	8.1	1280
2008	00	171.7	424.2	276.8	146.8	8.1	1039
2009	00	167.6	375.3	520.8	174.7	2.2	1266
2010	43.6	172.8	294.8	306.8	393.2	57.4	1335
Mean	47.4	136.0	274.1	333.6	170.1	14	1003

Source: Fieldwork, 2013

Forecast Models for Millet and Sorghum Yields Based on Rainfall Parameters

The method of Adebayo and Adebayo (1997) adopted to develop yield forecast models for the two crops in each location. Rainfall parameters significantly correlated with the yield of the two crops (millet and sorghum) in the six locations subjected to Stepwise Multiple Regression Model (SMRM). In Kano, total rainfall in June and July, annual rainfall and length of growing season subjected into SMRM. At Katsina, annual rainfall total subjected into SMRM. In Maiduguri, total rainfall in May subjected into SMRM. At Potiskum, annual rainfall total, length of growing season and total rainfall in May subjected into SMRM. At the three locations of Kano, Katsina and Potiskum only

Table 3: Length of growing season at Potiskum (1981-2010)

Years	LGS (Days)
1981	161
1982	115
1983	76
1984	105
1985	125
1986	120
1987	125
1988	105
1989	161
1990	105
1991	146
1992	95
1993	70
1994	120
1995	110
1996	151
1997	146
1998	115
1999	115
2000	95
2001	110
2002	115
2003	141
2004	125
2005	135
2006	141
2007	90
2008	156
2009	135
2010	125
Mean	121

Source: Fieldwork,2013

Table 4: Millet and sorghum yields forecast models

Locations	Millet yield forecast model	R^2 %
Kano	$Y = -0.733\log_{10}AR + 2.483$	19.7
Katsina	$Y = 0.503\log_{10}AR - 1.292$	61.7
Potiskum	$Y = -0.185\log_{10}AR + 0.529$	43.0
	Sorghum yield forecast model	R^2 %
Potiskum	$Y = -0.008\log_{10}M - 0.018$	68.1

Source: Fieldwork, 2013; Y – millet/sorghum yields (ton/ha), AR - $\log_{10}$ total annual rainfall, M - $\log_{10}$ total rainfall in May

total annual rainfall entered into millet yield forecast model. Other Parameters excluded by the model. Similarly, all the correlated rainfall parameters with Sorghum yields in the six locations, only total rainfall in May at Potiskum entered into stepwise multiple regression models. The model excluded the remaining parameters in the five locations.

Results of the analysis produced four yield forecast models; three for millet yields at Kano, Katsina and Potiskun and one for sorghum yield at Potiskum: There is no millet yield forecast model produced at Maiduguri. No rainfall parameter entered into the Stepwise multiple regression models for Sokoto and Gusau. Similarly, there is no sorghum yield forecast model produced for Kano, Katsina, Maiduguri, Sokoto and Gusau. This was because no rainfall parameter that showed, significant relationship with sorghum yield entered into the stepwise multiple regression models in these locations.

The four yields developed forecast models are shown in Table 4. The results show that 19.7% of the variation in millet yield at Kano was accounted for by variations in annual rainfall. About 62% of the variation in millet yield at Katsina was accounted by the variation in annual rainfall. About 43.0% of the variation in millet yield at Potiskum was accounted for by variation in annual rainfall. Similarly, 68.1% of the variation in sorghum yield at Potiskum accounted for by variation in total rainfall in May. These results obtained based on holding the observed rainfall parameters constant. The percentages indicate that other factors beside annual and may rainfall totals, could influence millet and sorghum yield variation. For instance, the unaccounted variations of 80.3% in millet yield forecast model at Katsina, 38.3% in Kano and 57% in Potiskum could be due to other factors. Similarly, the unaccounted variation of 31.9% in sorghum yield forecast model could be attributed to other factors. Models having less unaccounted yield percentage variation, $Y = 0.503\log_{10}AR - 1.292$ for millet at Katsina and $Y = -0.008\log_{10}M - 0.018$ for sorghum at Potiskum assumed the best-fitted yield forecast models in the study area.

Validity of Crop Yield Models

An estimated rainfall and yield records of 2013 for each station was used to check the validity of the developed yield forecast models. Results for validation at Kano presented in Table 5.

Table 5: Validity of millet developed yield forecast model for Kano

Crop	Yield Forecast Model	R^2 (%)	Year	Observed rainfall (mm)	Observed yield (ton/ha)	Forecast yield (ton/ha)	FE (%)
Millet	$Y = -0.733\log_{10} AR + 2.483$	19.7	2013	923.2	1.4	1.2	16.7

Data Source: Field work, 2013; AR - $\log_{10}$ total annual rainfall, FE - forecasting error

Table 6: Validity of developed millet yield forecast model for Katsina

Millet	$Y = 0.503\log_{10}AR - 1.292$	61.7	2013	576.8	1.0	1.1	-9.1

Data Source: Fieldwork, 2013; AR - $\log_{10}$ total annual rainfall, FE - forecasting error

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Table 7: Validity of developed millet and sorghum yields forecast models for Potiskum

Crop	Yield Forecast Model	R^2 (%)	Year	Observed Rainfal1 (mm)	Observed yield (ton/ha)	Forecast yield (ton/ha)	FE (%)
Millet	$Y = -0.185\log_{10}AR + 0.529$	43.0	2013	691.3	0.52	1.1	−54.5
Sorghum	$Y = -0.008\log_{10}M - 0.018$	68.1	2013	36.05	0.71	1.1	−35.5

Data Source: Fieldwork, 2013; AR - Log_{10} total annual rainfall, FE - forecasting error

It observed from Table 5 that the percentage of FE ratio for millet-developed yield forecast model in 2013 is 16.7%. This value is less than 25% and indicates that the model is valid for forecasting the yield of millet base on annual rainfall at Kano.

An estimated rainfall and millet yields records of 2013 at Katsina also used to check the validity of the developed millet yield forecast model. Results of validation presented in Table 6.

Data presented in Table 6 revealed that the value of FE for the developed millet yield forecast model at Katsina is −9.1% in 2013. This value is in the range of FE ≤ 25%. This finding indicating that the developed millet yield forecast model is valid for Katsina. The model can therefore be used in forecasting millet yield in this location. An estimated rainfall, millet and sorghum yields records of 2013 for Potiskum also used to check the goodness fit of the best two developed crop yield forecast models. Results of this validation presented in Table 7.

Data presented in Table 7 showed that the FE percentage value for the developed millet yield forecast model at Potiskum is −54.5% in 2013. It is 35.5% for the developed sorghum yield forecast model in the same period. It seen that the FE percentage value for the observed year is less than 25%. This indicates that the two crops developed yields forecast models $Y = -0.185\log10AR + 0.529$ for millet yield at Katsina and $Y = -0.008\log10M - 0.018$ for sorghum at Potiskum are valid. The former could used to forecast the yield of millet based on total annual rainfall and the later based on total rainfall in May in other locations respectively.

CONCLUSION

The results of this study revealed empirically that rainfall variability parameters could used to develop yield forecast models for millet and sorghum in the Sudan Savanna ecological zone of Nigeria. Furthermore, the distribution of the identified rainfall variables such as monthly rainfall amounts during months of the growing season, total annual rainfall and the length of growing season are important variables and should be considered in planning and managing agricultural activity in this zone. The study, however, held the observed variables constant, means that other factors could influence the yield variability of the two-crops. Further research should attempt to investigate the influence of other factors.

It is recommended that based on holding annual total and may rainfall constant, the two best fitted crop yield models $Y = 0.503\log10AR - 1.292$ for millet yield at Katsina and $Y = -0.008\log10M - 0.018$ for sorghum yield at Potiskum should be used for planning and forecasting the yield of millet and sorghum in the Sudan Savanna Ecological Zone of Nigeria.

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