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Forecast Models for the Yield of Millet and Sorghum in the Semi Arid Region of Northern Nigeria Using Dry Spell Parameters

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Abstract: This study aims at presenting models for the prediction of millet and sorghum yields in the face of occurrence of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days during the growing season. Daily rainfall records and crop yield per hectare for three decades (1976-2005) were used to develop forecast models for the yield of millet and sorghum in the semi arid region of Northern Nigeria on the basis of dry spell parameters. Frequencies of dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days were determined. Bivariate correlation analysis, stepwise regression (forward selection) and double log multiple regression were then used to develop models for the prediction of the yield of the two crops. Results of the analyses show that of the twenty-one (21) dry spell parameters, only one (total dry spells in the growing season) indicated significant correlation with millet at 0.01 levels. Except 7-day dry spells in May and 5-day dry spells in September, sorghum show significant correlation with the remaining nineteen (19) dry spell parameters. Stepwise multiple regression identified total dry spells during the growing season as being critical to millet yield while 5-day dry spells in May and total dry spells in the growing season were picked for sorghum. The model for millet yield is $\log Y = 0.0715 - 0.0817 \log X_2$, implying that if the occurrence of total dry spells during the growing season is unity, the yield of millet would be reduced by about 0.0817 T/ha in the study area. That for sorghum is $\log Y = 0.170 + 0.0629 \log x_1 - 0.141 \log x_2$, meaning that the occurrence of a single 5-day dry spell in May would increase sorghum yield by about 0.0629 T/ha but that of total dry spells would reduce it by 0.141 T/ha. About 54.5% variation in millet yield is accounted for by occurrences of total dry spells during the growing season while 63.2% of the variation in sorghum yield is due jointly to the occurrence of 5-day dry spells in May and total dry spells in the growing season. Both the forecast error and the linear graph of observed and predicted yields suggest that the models are good enough for the forecast of millet and sorghum yield in the area.

Key words: Coefficient of determination, double log function, dry spells, forecast model

INTRODUCTION

It is becoming increasingly necessary to predict the annual yield of the staple crops in the semi arid region of northern Nigeria in the face of eminent climate change and persistent occurrence of dry spells. This will identify years with deficit yields and inform the Government of how much grains to be released from the Strategic Grain Reserves of the country.

The development of a good forecast model, however, requires the use of such variables as agricultural inputs or technological changes and meteorological variables. Among the meteorological variables, rainfall, temperature and soil moisture are some of the important elements, which significantly affect crop yields (Amrender and Lalmohan, 2005). Most of the developed forecasting models for crop yields are weather variable - based with the exception of (2) who included trend variable in the model as a measure of technological change. Quantitative crop yield forecasts are generally carried out by means of multiple regression models. Principal among researchers that developed forecast models for the prediction of crop yield are (Amrender and Lalmohan, 2005; Parasad and Jain, 1995; Agrawal *et al*., 1980; Parasad and Dudhane, 1989; Adebayo and Adebayo, 1997). The objective of this study, therefore, is to develop statistical models that can be used to predict millet and sorghum yields whenever dry spells of 5, 7, 10 and equal to or greater than 15 consecutive days occur during the growing season in the semi arid region of Northern Nigeria.

Study area: The semi arid region of northern Nigeria coincides with the northern part of the Sudan and the entire Sahel savanna bioclimatic zones at the extreme northern fringes of the country, located between latitudes 12º N and 14º N and longitudes 2º44′E and 14º42′E (Fig. 1). This region covers the boarder states of Sokoto, Kebbi, Zamfara, Katsina, Kano, Jigawa and Yobe and parts of northern Borno, Bauchi and Gombe states.

This bioclimatic zone mostly suffers from the effects of droughts in Nigeria. Rainfall here is sporadic and intermittent. The rainy season lasts for between 3 and 4

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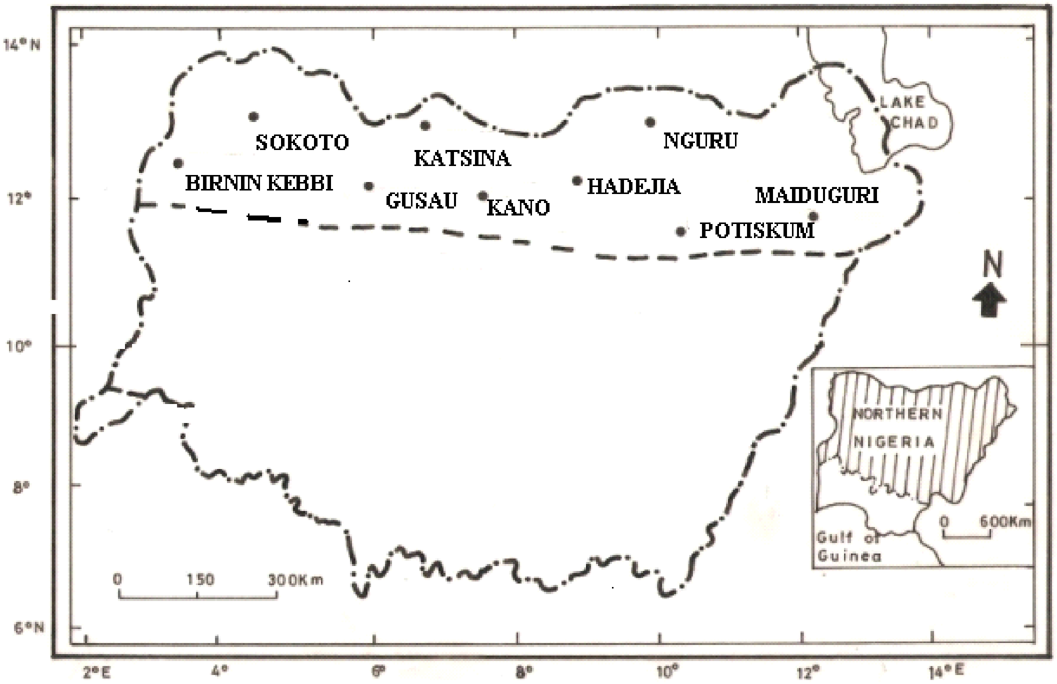

Fig. 1: Study area and selected meteorological stations

months (June - September) and characterized by frequent dry spells. The occurrence and persistence of dry spells significantly influence the yield of grain crops in this region. Therefore modelling the relationship between crop yield and the dry spell parameters will give an insight into yield short falls and it is a step forward towards adapting to the impact of drought through the release of grains to affected areas by the Nigerian Federal Ministry of Agriculture.

MATERIALS AND METHODS

Data types and sources: Two sets of data for three decades (1976 - 2005) for each of the meteorological stations in Fig. 1 (Birnin Kebbi, Sokoto, Gusau, Katsina, Kano, Hadejia, Nguru, Potiskum and Maiduguri) were used in this study. First, daily rainfall records for 30 years (1976 - 2005) for the nine (9) synoptic meteorological stations in the study area, which were obtained from the Nigerian Meteorological Services Agency, Oshodi, Lagos. Secondly, data on crop yield in T/ha for the respective meteorological stations were sourced from their relevant agricultural Departments and Agencies.

Determination of dry spell parameters: A threshold value of rainfall below which a day was considered dry was defined to identify wet and dry days and subsequently dry spells. For this study, therefore, a threshold of 0.25 mm was defined according to the Nigerian Meteorological Service definition. A day with rainfall equal to or greater than 0.25 mm was considered a wet day and one with less than this threshold was regarded as dry.

The daily rainfall observations were then used in determining dry spells of 5, 7, 10 and equal to or longer than 15 days consecutive days after Stern and Dale (1982). Here, the last day of rainfall of 0.25 mm or more in October was coded ¯1 and the following dry days were coded 1, 2, 3 …n into November until the next wet day in the preceding year. Consecutive wet days were coded ¯1, ¯2 …¯n so that the daily observations are recoded as sequences of wet and dry days. The runs of dry spells of lengths 5, 7, 10 and equal to or greater than 15 days were, therefore, computed directly month wise for each of the rainfall stations.

Dry spells are measured in days while crop yield is measured in tons per hectare. Therefore, to harmonize the two sets of data, they were both converted into $Log_{10.}$

Multiple regression models have widely been employed in making quantitative crop yield forecasts (Amrender and Lalmohan, 2005; Agrawal *et al*., 1980; Parasad and Dudhane, 1989). In order to predict the yield of the selected grain crops in the study area, double log multiple regression model was adopted after Adebayo and Adebayo (1997). The general form of the double log regression equation is given as:

$$Y = \partial + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_n \log x_n$$

where,
Y = Log_{10} Predicted crop yield in T/ha
∂ and b = Constants

$X_1, X_2, X_3 \ldots X_n$ = Dry spells of 5, 7, 10, 15 consecutive days respectively

The dry spell parameters and crop yield per hectare values were first subjected to bivariate correlation analysis to determine which dry spells correlate significantly with the yield of millet or sorghum at 5% level. The dry spells that showed significant correlation with the crops were then further subjected to stepwise regression analysis (forward selection) in order to identify which dry spell lengths are critical to the yield of the two selected crops. The predictors in this model are, therefore, those dry spell parameters identified by stepwise regression as being critical to the yield of the crops. The above analysis was conducted by station year record using MINITAB software of the computer. Not all the crop yield data were used in developing the models as the last two years' records (2004 and 2005) were purposefully omitted and were later used to validate the models by obtaining the predicted yield values. To check the appropriateness of the developed models, examination of residuals- that is, differences between the observed and predicted values was carried out. The goodness of fit of the models was judged by the coefficient of determination (R^2) statistic. Accuracy of the forecast models was examined by the forecast error (%) which is computed as follows:

$$FE = \frac{Observed\,Yield - Forecast\,Yield}{Observed\,Yield} \times 100$$

Where FE = Forecast error

For goodness of fit, the percentage errors should not vary significantly one from the other. Line graphs of the predicted and observed crop yield values were drawn to show their pattern of disparities.

RESULTS AND DISCUSSION

The dry spell parameters and crop yield per hectare values were subjected to bivariate correlation analysis. The results are presented in Table 1.

From Table 1, it is seen that millet shows significant correlation with only total dry spells in the growing season at 0.01 level of significance out of the twenty-one (21) dry spell parameters. Sorghum on the other hand is sensitive to nineteen (19) out of the twenty-one dry spell parameters. The exceptions are 7-day dry spells in May and 5-day dry spells in September. The results of the bivariate correlation in Table 1 only depict the isolated relationship between the occurrence of dry spells of 5, 7, 10, and 15 or consecutive dry days and the yield of the two selected crops. They do not indicate the level of importance of each of the dry spells influencing the yield. Therefore, in order to identify clearly those dry spell parameters that are critical to the yield of each of the selected crops in the study area, those dry spells that correlate significantly with the yield of the two crops were further subjected to stepwise multiple regression analysis. The results show that total dry spells during the growing season is critical to millet yield. For sorghum, out of the nineteen (19) significant cases, only two dry spell parameters (5-day dry spell in May and total dry spells in the year) were identified. To be able to predict the yield of each of the crops, double log multiple regression model was adopted using the identified critical dry spell parameters. The results of the model are given in Table 2.

Table 1: Station year correlation matrix of dry spells and crop yield

Dry Spell	Millet	Sorghum
May 5	0.139	- 0.312**
May 7	- 0.127	0.087
May 10	0.014	- 0.280**
May ≥ 15	0.074	- 0.171*
June 5	- 0.021	- 0.153*
June 7	0.017	- 0.175*
June 10	0.057	- 0.280**
June ≥ 15	0.062	- 0.217**
July 5	- 0.004	- 0.231**
July 7	0.096	- 0.216**
July 10	0.065	- 0.264**
July ≥ 15	0.057	- 0.285**
Aug 5	0.035	- 0.196**
Aug 7	0.042	- 0.275**
Aug 10	0.043	- 0.258**
Aug ≥ 15	0.040	- 0.253**
Sept 5	0.023	0.075
Sept 7	- 0.028	- 0.160*
Sept 10	0.040	0.229**
Sept ≥ 15	0.043	0.269**
Total dry	- 0.206**	- 0.157*

**: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed)

From Table 2, the double log function multiple regression equation for millet is given as logY = 0.0715 - 0.0817 $\log X_2$. This implies that given that the occurrence of total dry spells during the growing season is unity, the yield of millet in the study area would be reduced by about 0.0817 T/ha. The coefficients of determination (R^2) given in the second column of Table 2 show that the occurrences of total dry spells during the growing season accounts for 54.5% of the variation in the yield of millet in the study area.

The double log function multiple regression equation for sorghum is logY = 0.170 + 0.0629 $\log x_1$ - 0.141 $\log x_2$. This means that the occurrence of a single 5-day dry spell in May would increase sorghum yield by about 0.0629 T/ha but that of total dry spells would reduce it by 0.141 T/ha. Such that if the occurrence of 5-day dry spell in May and total dry spells during the growing season was

Table 2: Forecast models for yield of millet and sorghum in the study area

Crop	Yield forecast model	R^2	Year	Observed yield (T/ha)	Forecast yield (T/ha)	Forecast error (%)
Millet	$\log Y = 0.0715 - 0.0817 \log X_2$		2004	0.111	0.072	35.1
	T- Ratio = - 2..73			{1.291}	{1.180}	
		54.5	2005	0.097	0.072	25.8
				{1.250}	{1.180}	
Sorghum	$\log Y = 0.170 + 0.0629 \log X_1$		2004	0.255	0.233	8.6
	$- 0.141 \log X_2$			{1.799}	{1.710}	
	T- Ratio = 4.32 and – 2..14	63.2	2005	0.160	0.177	10.6
				{1.445}	{1.503}	

Figures in parenthesis { } are observed yield values
where
logY = Predicted yield of Millet and Sorghum (T/ha)
X_1 = 5-day dry spells in May
X_2 = Total dry spells in the year

unity, the yield of sorghum would be about 0.0919 T/ha. About 63.2% of the variations in sorghum yield is due jointly to the occurrence of 5-day dry spells in May and total dry spells in the growing season. The most important point to note here is that the forecast errors do not vary significantly (10 and 2%) for millet and sorghum respectively. With this knowledge, therefore, it is possible to determine how much of the crops' yield will be obtained during a drought year and how much grains need to be supplemented by releases from the National Strategic Grains Reserve by the Government.

The values of the coefficients of determination (54.5 and 63.2%) exhibited by the dry spell parameters suggest that there are also other factors that contribute to the yield variations of these crops in the study area. These factors are both climatic and agronomic. The climatic factors include wind, radiation, onset and cessation dates of the rains, length of the rainy season, rainfall amounts in the months of the growing season, the total amount of rainfall during the growing season, the spread of the rains, number of rainy days, rainfall intensity etc as observed by Adebayo and Adebayo (1997) and Folorunsho *et al*. (1998). The agronomic factors would include seed varieties, use of fertilizers, differences in soil fertility, weeding practices, occurrence of pests and diseases, and harvesting time as observed by Folorunsho *et al*. (1998), which were not considered in this study. These factors account for 45.5 and 36.8% of the variations in the yield of millet and sorghum respectively in northern Nigeria.

It could be observed from Table 2 that there is an insignificant difference between the observed and predicted values of the crop yields. These together with the insignificant variations in the forecast error given in the last column of Table 2 suggest that these forecast models fit well in the prediction of the yield of the crops in the study area.

The developed models were used to predict the crop yields for each station. Figure 2 and 3 show the line graphs of the observed and predcted yield values for the two crops respectively. The results show that there is an insignificant difference between the predicted and observed yields as the trend lines follow closely similar

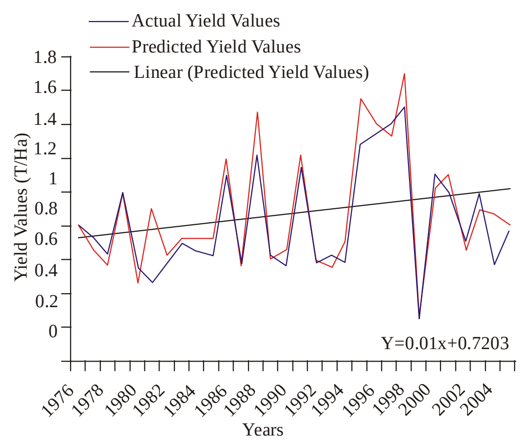

Fig. 2: Actual and predicted yields values of Millet in Northern Nigeria

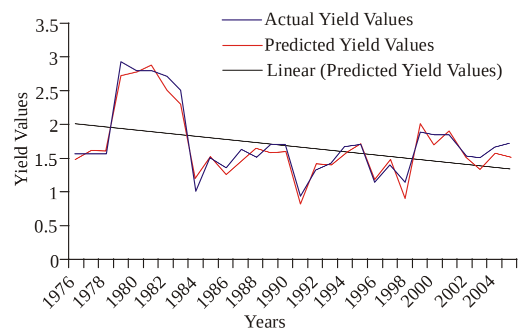

Fig. 3: Actual and predicted yield values of Maize in Northern Nigeria

pattern. This implies that the model is well fitted and can be used to predict the yield of the crops in the area.

A comparison of the observed and predicted yield values of the two crops (Figure 2 and 3) show no significant variations; suggesting further that the model is well fitted and good enough to be used in the forecasting of the yield of these crops. Good as this model may be, it is still advisable to consider the other climatic and agronomic variables.

CONCLUSION

Results of the research have shown that sorghum is more responsive to dry spell occurrence than millet. Occurrence of dry spells at some phenological stages of development of sorghum is beneficial and increases its yield. About 54.5 and 63.2% of the variations in the yield of millet and sorghum respectively are accounted for by the variations in occurrence of dry spells. These suggest that other factors (climatological and agronomic), account for about 45.5 and 36.8% in the yield variations of millet and sorghum respectively. The low range of forecast errors suggest that the developed forecast model fits well in the prediction of the yield of the crops in this region.

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