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ORIGINAL RESEARCH ARTICLE

DEVELOPMENT OF CROP WATER PRODUCTION MODEL IN A RAINFED TROPICAL MAIZE CROP CULTIVATION

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ABSTRACT

Crop production, which is one of the sources of food for human and animal sustenance is a function of the availability of adequate quantity of water. The rainfall being seasonal is the main source of water for agricultural production in Nigeria. Maize production is majorly through rainfed agriculture in Nigeria and the irregularity of which affect the yield. This research work was to develop crop-water production model in tropical rain fed maize crop cultivation using maize yield and rainfall data from Oyo state. One of the major problems of food production in attempting to determine the relative future roles of irrigated and rain-fed agriculture is the lack of sufficient ground and accurate tool on a localized basis. Hence, the essence of this research works. Using correlation and full quadratic regression analysis, the effects of some rainfall indices (monthly and annual rainfall, raindays, and rainfall onset and rainfall cessation) on maize yield in Oyo State were examined. The results of the correlation statistics showed that cessation has the strongest association (r= -0.284) with maize yield. The analysis also showed that early maize and late maize suffer moisture deficiency in March and November respectively while excessive rainfall of June/July and September also have implication for maize yield. It was also observed that the rainfall characteristics jointly contributed 96.7% in explaining the variations in the yield of maize per hectare. Conclusively, a model was development for predicting maize yield in Oyo State. The study also recommends the use of state own yield so as to harmonize with state rainfall data, application of appropriate moisture conservation management practices that ensured efficient use of water and use of drought resistance crop species with shorter growing periods as adaptive measures to the changing rainfall pattern within the study area.

1.0 Introduction

Crop production, which is one of the sources of food for human and animal sustenance is a function of the availability of adequate quantity of water. The water, natural is to be gotten directly from rainfall, but this source of water is also climatic dependent. This water is the main factor for any crop

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production on which other factors may depend. The rainfall being seasonal is the main source of water for agricultural production in Nigeria. This has restricted production of crop to only raining season during which the intensity of the events will still affect yield of crop production to some extent. In an interview with the director general of NIMET, Prof Anthony Anforom held on an NTA program "INSIGHT" in August, 2015, the director made it known that as the date, the production of crop in Nigeria is limited to only rain-fed agriculture. That this has affected the crop production for the year, because of the late onset of rainfall and low rainfall as forecasted in the previous year. This, in general, limits the production of food in some areas that depended on rainfall for production and with limited amount of total rainfall per year.

The vast potential of rain-fed agriculture needs to be unlocked through knowledge-based management of natural resources for increasing productivity and income to achieve food security in the developing world. Soil and water management play a very critical role in increasing agricultural productivity in rain-fed areas in the fragile SAT (Semi-arid Tropics) systems (Wani *et al.,* 2009).

Maize crop is one of the generally grown cereal crop in the world. Maize, the main source of food in the tropical region, is grown in different varieties. The grains are rich in vitamins A, C and E, carbohydrates, and essential minerals, and contain 9% protein. They are also rich in dietary fiber and calories, which is a good source of energy (IITA, 2015). Crop production as stated earlier is limited to rainfall in some developing country and maize production is not an exception. Maize production is majorly through rain-fed agriculture in Nigeria and the irregularity of which affect the yield. International Institute of Tropical Agriculture and other research institute scientists have developed high yielding, drought-resistant and disease-resistant varieties that are adaptable to sub-Saharan Africa's various agro-ecological zones but many of which have not been adopted by the local farmers.

Therefore this research work aimed at developing crop-water production model in tropical rain fed maize crop cultivation, with focus on rainfall dataset for Oyo state between 1990 and 2013 periods and maize yield for the same period to determine rainfall indices for the years. One of the major problems of food production in attempting to determine the relative future roles of irrigated and rain-fed agriculture is the lack of sufficient ground and accurate tool on a localized basis. The variability and uncertainty of the climatic condition have drastic effect (low yield) on the crop production, the study of this variability and effect on the production will help for future planning to avert the effect of climatic change, hence the essence of this research work.

(a) (b)

Fig 1. (a) Photograph of maize plantation, and (b) Harvested maize

2.0 Material and Methods

2.1 The Location of the Study Area

Nigeria is located between latitudes 4° and 14°North of the equator and longitudes 3° and 14° East of Greenwich Meridian, and in West African region. The country is of area of 923768 sq kilometer, with tropical climatic condition and annual precipitation on the average ranging from 1800mm in the west to 4300mm in the east and 1300mm inland. The country experiences double rainfall maxima from March to July and September to October. Ibadan city where Nigeria Meteorological agency (NIMET) resides is located in coordinates of 7°23′47″N and 3°55′0″ E and with mean total rainfall of 1420.06mm, falling in approximately 109 days and mean maximum temperature of 26.46°C (Wikipedia, 2015).

2.2 Sources of Climatic and Crop Yield Data

In order to develop the crop-water production model for productivity of water for rain-fed maize crop, weather data comprising of rainfall indices like dates of onset and end of rainy season, annual amount, temperature, duration and rain days, and crop yield are needed. Data on daily rainfall (from which monthly and annual values were derived) was collected over 24 years (1990- 2013) from the official records of the Meteorological Centre of NIMET, Iseyin. The choice of this length of time is in line with the available data for the study, which is in accordance with numbers years for weather data in characterizing the climate of an area, as adopted by the World Meteorological Organization. The data used for this study were archival data on rainfall (in millimeters) and maize yield (in kilograms/hectare). The data on annual maize yield (kg) was collected from the official FAO database for Nigeria and for the same number of years 24 (1990 - 2013)

2.3 Derivation of Other Parameters

From the rainfall data collected, the following parameters were determined:

Date(s) of onset of the rainy season (in days); Date(s) of end of the rainy season (in days); Duration of the rainy season (in days);Annual number of rain days (in days); and, Annual rainfall amounts (in mm).

There are several methods of computing onset, end and duration of the rains such as used by Ilesanmi (1972) and Benoit (1977). However, Walter's formulation as modified by Olaniran (1983) was adopted in this study because of its high prediction reliability among other methods as used by Ifabiyi and Omoyosoye, (2011); Emmanuel and Fanan, (2013). The method was expressed as:

$$Date\ of\ Onset/End\ = DM\ \frac{51-A}{TM} \quad (1)$$

Where:

DM = the number of days in the month containing the date of Onset/End;
A = the accumulated total rainfall of the previous months;
TM = the total rainfall for the month in which 51 mm or more is reached and
51 mm = the threshold of rainfall for both Onset/End month.

Where such onset date was followed by dry spells of up to 14 days, the next rain day date that is not followed by such dry spells was chosen. For computing Cessation or End dates, the formula was applied in reverse order by cumulating the total rainfall backwards from December. Duration of the rainy season was derived by counting the number of rain days between the onset-date and the end-date of the rains in a given year. A rain day is a period of 24 hours (10:00 am - 10:00 am local time) with at least 0.3 mm of recorded rainfall amount. Annual rainfall total is the amount recorded for an entire year at a particular place (Emmanuel and Fannan, 2013).

2.4 Suitability of study area for maize production

The monthly water consumptive use of maize within its growing season as given by Lema (1978) were compared with average monthly rainfall obtainable in the study area during the growing season to bring out the suitability of the study area for maize production. This is as shown in the Table 1.

Table 1: Monthly water consumptive use of maize within the growing season month

	1st	2nd	3th	4th	5th	Total
Consumptive use (mm)	100	90	96	75	65	426

2.5 Model Formulation

The study employed the mean, standard deviation and coefficient of variability in analyzing the variations in the study variables. Partial correlation and multiple linear regression analysis were the statistical tools used to establish the relationship and effect of rainfall characteristics on maize yield.

The regression model (as used by Emmanuel and Fannan, 2013) for the study was computed as:

$$YIELD(HG/HA) = b0 + b1*X1 + b2*X2 + b3*X3 + b4*X4 + b5*X5 + b6*X1^2 + b7*X1*X2 + b8*X1*X3 + b9*X1*X4 + b10*X1*X5 + b11*X2^2 + b12*X2*X3 + b13*X2*X4 + b14*X2*X5 + b15*X3^2 + b16*X3*X4 + b17*X3*X5 + b18*X4^2 + b19*X4*X5 + b20*X5^2$$

Where:

Y = the value of the dependent variable (maize yield/ ha);

b_0= Y intercept

b_1, b_2, b_3, b_4, ··· b_n= regression coefficients (each b represents the amount of change in Y (Maize yield/ha) for one unit of change in the corresponding x-value when the other x values are held constant;

x_1, x_2, x_3, x_4, ··· x_n= the independent variables (*i.e.* rainfall onset, cessation, duration, annual totals and annual number of rain days respectively); and e = the error of estimate or residuals of the regression.

Apart from the coefficients of the independent variables (rainfall characteristics), coefficient of multiple determinations (R^2) was used to determine the percentage explanation achieved jointly by the rainfall characteristics. This method is preferred since it gives the best linear and unbiased estimates among other estimators. Several authors to effectively study the impact of climate on crop yield (Emmanuel and Fannan, 2013) have used this.

3. Results and Discussion

3.1 Variability in Rainfall Characteristics

The descriptive statistics of the rainfall characteristics are shown in the tables below. Table 2 shows the limit statistics of rainfall indices of the area of study and this indicates earliest onset of rainfall as 27th January 1997, latest onset of rainfall as 11th April 2007. Mean onset of Rainfall as 18th March and earliest cessation of rainfall as 5th October 2001, while latest cessation of rainfall as 25th December 1999 and mean ceasation of rainfall as 28th October 1999. Table 3 shows the limit statistics of other rainfall indices of the study area. Table 3 shows minimum annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 909 mm (in 2001), 78 days (in 2006), 82 days (in 2006) and 11181.31 Hg/ha (in 1992) respectively. From table 3, the maximum annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 1596.4 mm (in 1991), 119 days (in 1993), 122 days (in 1999) and 21961.28 Hg/ha (in 2009) respectively. The mean annual amount of rainfall, number of rain-days, annual duration of rainfall, and maize yield as 1212.72 mm, 94 days, 99 days and 14612.25 Hg/ha respectively.

The result indicated that there was a delay in the dates of onset accompanied by early cessation dates of the rainy season, shortening duration of the growing season and number of rain days, consequently declining maize yield per hectare even though high rainfall amount was received. It was also be observed that the lowest rain-days was 78 days in 2006 and lowest annual rain-days (82 days) in the same year which might due to the late onset (12th march) and earlier cessation (25th October) of rainfall in the year. However, maize was not the lowest due to high rainfall (1169 mm) in the year. It can also be observed that 1992 recorded the lowest yield of maize per hectare (11181.30 Hg/ha), probably due to the latest onset date (12th April), earliest cessation date (30th October), short duration (92 days), low number of rain-days (88 days) and annual rainfall amount (1047.5 mm) that occurred in the same year. The lowest annual amount of rainfall (909 mm) in 2001 and shorter annual duration (91 days) might be due to earliest cessation (5th October) of rainfall in the year. The highest amount of rain-days (119 days) and maximum annual duration (122 days) of rainfall and higher annual amount of rainfall (1447 mm) were recorded in 1993 which might be as result of latest cessation (25th December) in the same year but lower maize yield (11847.81 Hg/ha).

Table 2. Limit statistics of onset and cessation of rainfall at the study area

Indices	Mean	Earliest Day	Year	Latest Day	Year
Onset	79	27	1997	103	2007
Date/Days	18-Mar	27-Jan	_	11-Apr	_
Ceasation	303	280	2001	361	1993
Date/Days	28-Oct	5-Oct	_	25-Dec	_

Table 3. Limit statistics of rainfall indices and maize yield at the study area

Indices	Mean	Minimum	Year	Maximum	Year
Annual Amount	1212.72	909	2001	1596.4	1991
Rain-days	94	78	2006	119	1993
Annual Duration	99	82	2006	122	1993/99
Maize Yield	14612.25	11181.31	1992	21961.28	2009

3.2 The Coefficient of Variability

Table 4 shows the descriptive statistics of rainfall indices and maize yield. The coefficient of variability of the rainfall characteristics shows that cessation dates of the rainy season has the highest coefficient of variability (56.1%), followed by dates of onset (29.11%), annual rainfall amount (13.82%), duration of the rainy season (12.77%) and the least variability of 12.12% was found in annual rain-days of the rainy season.

Table 4. Descriptive statistics of rainfall indices and maize yield at the study area

Indices	Mean	Standard Deviation	Coefficient of variance (%)	Sample Variance
Maize Yield(Hg/Ha)	15825.33	2730.03	17.25	7453088.84
Onset(Days)	79	23	29.11	539
Cessation(Days)	303	17	56.10	290
Annual Amount(Mm)	1212.72	167.69	13.82	28116.81
Rain-days(Days)	94	12	12.77	142
Annual Duration(Days)	99	12	12.12	140

On a general note however, the coefficient of variability of (17.25%) was recorded in maize yield per hectare (Table 4). This result means that the annual rainfall durations were more reliable and predictable whereas the dates of cessation were more unreliable and un- predictable in the study area. The highest coefficient of variability of Maize could be as a result of the joint effect of the variability in all the rainfall characteristics studied and other climatic and non-climatic factors not directly considered in this study.

3.3 Suitability of the study area for maize production

The analysis of maize consumptive water use is also presented in Table 5. The mean rainfall amount obtainable in March according to Table 5 is 52.0mm. This amount fell short of the 100 mm that is required at the first set of planting. Thus, early maize plants in March may experience inadequate watering due to the nature of onset.

Table 5. Mean monthly pattern of rainfall for Oyo State (1990 – 2013)

Months	Rainfall(mm)
Jan	10
Feb	18.2
Mar	52
Apr	106.3
May	150.8
Jun	165.8
Jul	152.8
Aug	147.8
Sep	198.9
Oct	170.2
Nov	21.5
Dec	19.5
Mean(x)	101.2

A critical period during the planting season of maize is the month of November; as the minimum required (65mm) looks almost impossible to be met. In November the obtainable rainfall is only 21.5mm. This indicates a need of irrigation for the period for the purpose of preventing drought to the planted crop. The total consumptive use of 426mm of rainfall for maize production can be met in Oyo state as both rainfall obtainable for early maize and late maize were 627.7 mm and 710.7 mm respectively are more higher than the water consumption of maize production. However, it should be noted that the pattern of rainfall distribution is also relevant to the agronomy of any crop.

Table 6. Monthly water consumptive use of maize within the growing season

Month	1st	2nd	3th	4th	5th	Total
Consumptive use (mm)	100	90	96	75	65	426
Rainfall obtainable for early maize (mm)	52 (March)	106.3 (April)	150.8 (May)	165.8 (June)	152.8 (July)	627.7
Rainfall obtainable for late Maize (mm)	152.8 (July)	147.8 (August)	198.9 (September)	170.2 (October)	21.5 (November)	710.7

3.4 Relationship between Rainfall Characteristics and Maize Yield

The correlations between rainfall characteristics and maize yield shows that dates of onset (0.263) had weak (significant) positive correlation with maize yield; dates of cessation (-0.284), annual rainfall amounts (-0.241),and rain days (-0.174) had weak negative correlations with maize yield; while annual rain days (−0.088) had very weak negative correlations with maize yield (Table 7). The dates of onset have greatest effect on the annual variation in yield. This implies that the area of study is prone to early onset of rainfall that has effect on the yield of early maize. Annual rain-days have the lowest influence on maize yield. This reveals that only the rain days during production season has effect on the yield of maize significantly.

Table 7. Correlation coefficients analysis of rainfall indices and maize yield at the study area

Chracteristics	Yield	Onset	Cessation	Rain-Days	Annual Amount	Annual Rain-Days
	(Hg/Ha)	Date	Date	Day	Mm	Day
Yield (Hg/Ha)	1					
Onset	.263	1				
Cessation	-.284	-.016	1			
Rain-Days	-.174	-.405	.481*	1		
Annual Amount	-.241	-.418	.408	.710**	1	
Annual Rain-Days	-.088	-.287	.415	.975**	.660**	1

*Coefficient is significant at 0.10 confidence level (2-tailed), **Coefficient is significant at 0.05 confidence level (2-tailed).

3.5 Model for Predicting Maize Yield

3.5.1 Coefficient of prediction

The model for predicting maize in relation with rainfall indices is presented in coefficients as shown in table 8.

From the regression coefficients shown in Table 8, the regression equation or predictor model of the study was stated thus:

$$YIELD\left(\frac{HG}{HA}\right) = 656575 - 4309.2 * X1 + 356.20 * X2 + 19851.6 * X3 + 503.65 * X4 - 35940.4 * X5 + 0.469 * X1^2 + 11.99 * X1 * X2 + 167.61 * X1 * X3 + 0.07657 * X1 * X4 - 155.42 * X1 * X5 - 7.256 * X2^2 - 221.88 * X2 * X3 - 1.202 * X2 * X4 + 258.64 * X2 * X5 + 859.51 * X3^2 + 25.49 * X3 * X4 - 1613.6 * X3 * X5 - 0.161 * X4^2 - 22.04 * X4 * X5 + 756.40 * X5^2$$

Where;

Y = Predicted yield of maize in the area.

X_1, X_2, X_3, X_4, and X_5 are Onset date, cessation date, rain-days duration, annual amount and annual rain-days respectively.

From this model, it can be inferred, that, given a unit change in any of the rainfall characteristics while holding others constant, the highest variation in yield of maize in the area will be accounted for, by Rain days (19851.6 kg/ha), followed by interaction of Rain days (859.51 kg/ha), interaction of Annual rain days (756.40 kg/ha), Annual amount (503.65kg/ha), Cessation (356.20 kg/ha), interaction of Cessation and Annual rain days (258.64 kg/ha), interaction Onset and Rain days (167.61 kg/ha) and interaction Annual amount and Annual rain days (25.49kg/ha). Also followed by interaction of Onset and Cessation (11.99 kg/ha), interaction of Onset (0.469 kg/ha), interaction of Onset and Annual amount (0.07657 kg/ha), interaction of Annual amount (-0.161 kg/ha),interaction of Cessation and Annual amount (-1.202 kg/ha), interaction of Cessation (-7.256 kg/ha), interaction of Annual rain days and Annual amount (-22.04 kg/ha), interaction of Onset and Annual rain days (-155.42 kg/ha), interaction of Cessation and Rain days (-221.88 kg/ha), interaction of Rain days and Annual rain days (-1613.6 kg/ha), Onset (-4309.2 kg/ha), and the least change in yield will be from annual Rain days (-35940.4 kg/ha).

Table 8. Coefficient of prediction for full quadratic multiple regressions

	Coefficient	P value	Std Error	-95%	95%	t Stat	VIF
b0	656575	0.308	536247	-1050000.761	2363150.624	1.224	-
b1	-4309.2	0.270	3196.2	-14481.1	5862.6	-1.348	29474.7
b2	356.20	0.918	3167.9	-9725.3	10437.7	0.112	13324.1
b3	19851.6	0.547	29320.2	-73458.5	113162	0.677	629446
b4	503.65	0.177	286.27	-407.38	1414.7	1.759	13607.9
b5	-35940.4	0.290	28040.0	-125176	53295.4	-1.282	558065
b6	0.469	0.933	5.153	-15.93	16.87	0.09104	1440.2
b7	11.99	0.481	14.94	-35.56	59.54	0.802	60003.0
b8	167.61	0.332	145.03	-293.95	629.17	1.156	466521
b9	0.07657	0.888	0.499	-1.511	1.664	0.154	1026.5
b10	-155.42	0.313	128.48	-564.29	253.45	-1.210	445507
b11	-7.256	0.399	7.399	-30.80	16.29	-0.981	29698.7
b12	-221.88	0.316	184.83	-810.09	366.34	-1.200	3888302.362
b13	-1.202	0.302	0.966	-4.277	1.873	-1.244	20737.7
b14	258.64	0.237	175.30	-299.26	816.54	1.475	3405930.095

b15	859.51	0.203	530.27	-828.03	2547.1	1.621	7949715.86
b16	25.49	0.126	12.11	-13.06	64.04	2.105	687535
b17	-1613.6	0.184	937.33	-4596.5	1369.4	-1.721	25375258.58
b18	-0.161	0.188	0.09466	-0.462	0.140	-1.699	9044.2
b19	-22.04	0.127	10.50	-55.45	11.36	-2.100	526325
b20	756.40	0.164	412.74	-557.12	2069.9	1.833	5132571.28

These showed that among the rainfall characteristics, number of Rain days (X_3) is the most valuable variable for the variation in maize yield in the study area indicating that the yield of maize increases as number of rain-days increases. This is followed by interaction of Rain days (X_1^2), meaning that there was higher yield of maize under years with high number of Rain days than those with low rain days. The Rain-days and Annual amount over rainfall period has been the major determinant of maize yield in the area. The contributions of Rain days and Annual amount are followed by those of Annual rain days, dates of cessation and date of onset but with insignificant coefficients.

The coefficient of multiple determinations (R^2) of 0.936 which was computed as 93.6% was observed. This means that 93.6% of the variations in the yield of maize per hectare for the past 25 years in the study area can be explained jointly by the variations in the five identified rainfall characteristics. The remaining 6.4% of the variations in the yield of maize can be attributed to other unexplained factors such as farming practices, soil properties, planting dates, weeds, fertilizer application seed varieties, pest and diseases, harvesting and other rainfall characteristics/climatic factors and technological involvement.

3.6 Validation of the Regression

The Figure 1 shows the scatter diagram of predicted yield and the original yield. The figure shows a good correlation between predicted yield and the yield, hence, the ability of the regression equation to predict yield, when all included rainfall indices are available.

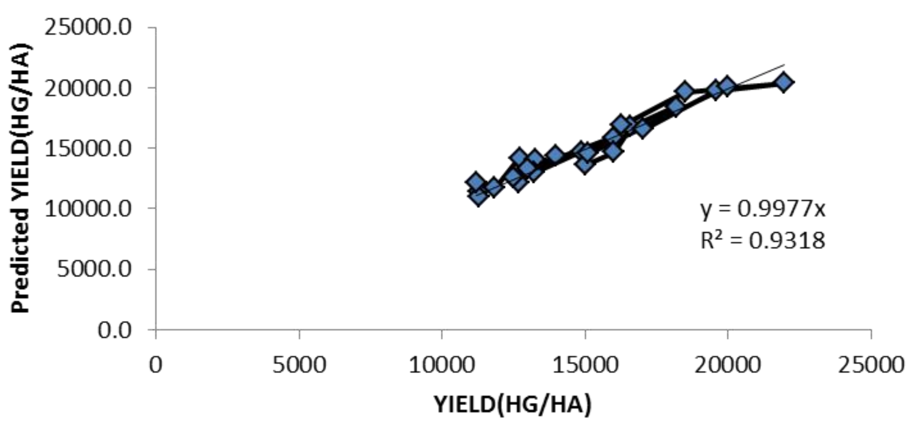

Fig 1. Scatter diagram of predicted yield versus yield

4.0 Conclusions

The study employed the mean, standard deviation and coefficient of variability in analyzing the variations in the study variables. Partial correlation and multiple linear regression analysis were the statistical tools used to establish the relationship and effect of rainfall characteristics on maize yield. This study established high variability in rainfall characteristics, which indicates high variability in

Maize yield per hectare. Additionally, the study showed the suitability of the area for maize production.

The study shows that maize experiences moisture deficiency at the early stages (especially early maize) and at the last month of the growing season (late maize) in the study area. In the months of June, July and September rainfall is in excess of the total amount required and that there is relative response of variability in onset/cessation date to variability in rain days. This results in variability in amount of rainfall per rain period. The results also reveal that number of rain days and annual rainfall amount have the strongest influence on maize yield per hectare in the study area. Conclusively, a predictive model was established for maize yield in the area.

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