EFFECTS OF PENTAD DRY SPELLS ON THE YIELD OF SOME CROPS IN THE SEMI-ARID ECO-CLIMATIC REGION OF NORTHERN NIGERIA

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Abstract

This paper examines the impact of pentad dry spells on the yield of maize, millet, sorghum, groundnuts and cowpea in the semi arid region of northern Nigeria using daily rainfall data from 1960 to 2009 and crop yield per hectare for 4 synoptic stations. Bivariate Correlation Analysis was used to deduce the statistical relationship between occurrence of pentad dry spells and the yield of the crops. Stepwise Multiple Regression was used to isolate dry spell parameters that are critical to crop yield in the region. Results obtained show that occurrence of pentad dry spells in all the months and total dry spells have significant effect on the yield of sorghum and groundnuts. Maize yield showed a significant relationship with 1 and 2 pentads as well as total dry days. While only total dry spells show a significant relationship with the yield of millet. Maize shows more sensitivity to dry spells than the other crops and millet showed more resistance to dry spells than the other crops. Two dry spell parameters (10-day dry spells in August and total dry spells during the growing season) were identified as being critical to the yield of the crops in the area. These two factors jointly accounted for about 74.1%, 21.5%, 52.9%, 51.4% and 40.1% of the variations in the yields of the crops respectively in the region.

Key words: Bivariate Analysis, Coefficient of Determination, Drought, Dry Spells, Pentads, Stepwise Regression,

1. Introduction

One of the impacts of climate change on rain-fed agrture in the arid and semi arid region of northern Nigeria is the increasing frequency and magnitude of occurrence of dry spells. A dry spell is a period of 3 or more days of lack of rainfall during the wet season. A pentad dry spell is a dry spell of five days duration. Dry spells, apart from limiting soil moisture for plant use, pose serious threat to uptake of nutrients thereby affecting crop yield. Occurrence of dry spells during the growing season which cause deficiency of soil moisture therefore, poses the greatest threat to food security in this region. Dry spell occurrence has not only reduced the yield of crops in this region but have in many case lead to complete loss during extended period of occurrence, leading to drought. The 1972/73 and 1984 droughts in Nigeria were a consequence of cumulative effect of dry spells of long duration that led to the droughts in the extreme northern states of Nigeria.

Adejuwon (1962), Oguntoyinbo (1966, 1967), Olaniran and Babatolu (1987a & b) and Adebayo (1997) among others, have researched into crop–climate relationships for a number of places in Nigeria where records of both climatic parameters and agricultural yields exist. Adejuwon (1962) established the relationship between rainfall and cocoa distribution in south-western Nigeria and concluded that the areas favourable for the cultivation of cocoa should have a mean annual rainfall of between 1,270mm and 1,524mm. Oguntoyinbo (1967), related rainfall and computed evapotranspiration to cotton yield at Samaru in north- central Nigeria and recommended that the optimum rainfall for growth of rain-fed cotton is about 762mm during the growing season, concentrated mainly in the first three months; and the mean five-day rainfall should not be less than 5.08mm for the first three months from the month of planting. The rainfall should also extend to October.

Kowal and Kassam (1973) examined the effect of variability in the length of the growing season on yield of groundnuts on the assumption that the groundnut crop can continue pod-filling for about 20 days on residual moisture stored in the soil after the end of the rains. They found that as the growing season reduced by 30 to 50 days, groundnut yield also declined by 28 to 56 per cent respectively. Kowal and Adeoye (1973) illustrated the use of empirical approach in determining the geographical limits of crop production in Nigeria by matching water requirements of millet in terms of water availability and length of the rainy season separately with latitude. They delineated the northern boundary for the successful cultivation of the crop without irrigation as latitude 14.7^0N. Kowal and Kassam (1973) using the same approach presented regression equations derived between total annual rainfall and latitude on the one hand and water use by groundnut crop and latitude on the other and found out that the water requirements of a 120-day crop of groundnut would be met south of latitude 11.8^0N. Eghareva *et al* (1980) and Fakorede (1985) investigated the effects of rainfall and date of planting on millet and maize yields in Nigeria respectively. According to them, when planted at less than 50mm of rainfall or far into the rainy season, less moisture in the soil and decreased heat unit respectively adversely affect the yield of these crops.

Akintola, (1983) analyzed the effects of climate on production of food crops in Ibadan noted that the agro-climatic factors correlate with the yields of rice, maize, yam and cowpea. Fisher (1984) observed that there is a great impact of climate on crop yield stability. While Yayock and Owonubi (1986) reported the influence of weather on groundnut production in Nigeria and stressed that rainfall is a critical factor.

Adebayo and Adebayo (1997) in their study of relationship between rainfall and rice yield in Yola, north-eastern Nigeria noted that four critical climatic factors: hydrologic ratio, onset dates of rains, number of dry spells (in pentads) during the growing season and rainfall in June influence rice yields in Adamawa state. Adebayo (1998) studied the effect of dry spells on rice yield in Yola and noted that the incidence of dry spell was responsible for the variation in rice output in Yola between 1996 and 1997. Abdulhamid and Adebayo (2006) observed that total rainfall, relative humidity and seasonality index together accounted for about 76% of the variation of Sorghum yield at Wailo (Bauchi state). Adebayo *et al* (2006) in their study of the influence of climatic factors on the growth and yield of sugar cane at Numan observed that total rainfall, relative humidity, minimum temperature and evaporation are critical to sugar cane growth and yield at various stages of development.

The statistical relationships between the occurrence of dry spells of 5, 10 and 15 or more days and the yield of five selected staple crops (maize, millet, sorghum, groundnuts and cowpea) in the semi arid region of northern Nigeria is the thrust of this paper.

2. The study area

The study area is the extreme northern part of Nigeria corresponding to the drought prone parts of the country. This is an area that experiences frequent dry spells of different magnitudes. The study covers four stations: Sokoto (13^0 10N – $05^0$11′E), Katsina (13^0 10N – 07^0 – 41′E), Kano (12^0 03N – 08^0 32′E) and Maiduguri (11^0 51N – 13^0 05′E) see Fig 1.

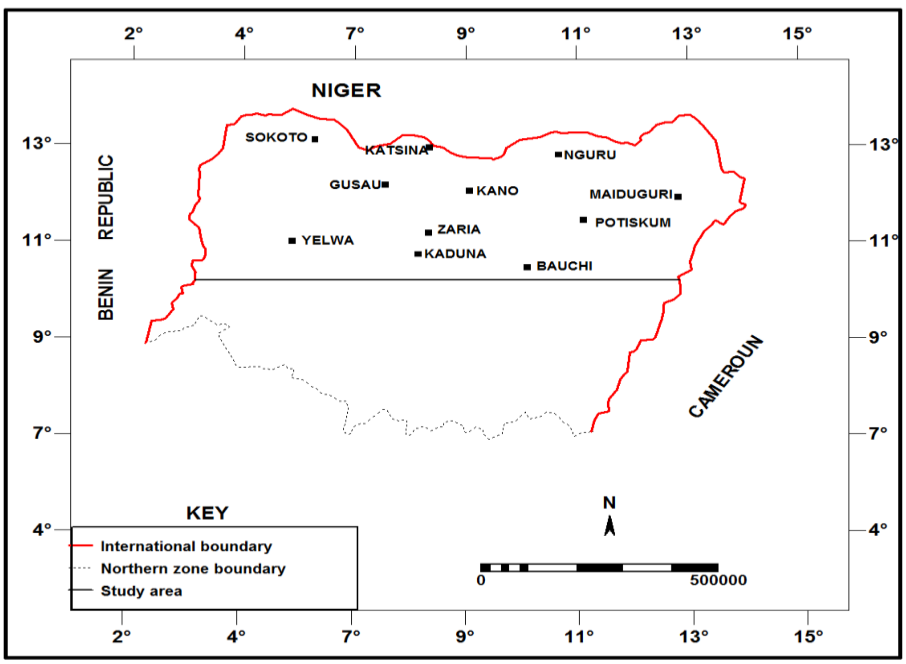

FIG. 1: MAP OF THE STUDY AREA AND SELECTED METEOROLOGICAL STATIONS.

The climate of northern Nigeria north of latitude 11^0N is of tropical continental (AW) type characterized by distinct wet (April – October) and dry (November – March) seasons respectively as dictated by the oscillation of the Inter-tropical Discontinuity (ITD). The study area is characterized by northern Guinea savanna to scrubland in the extreme northern parts. The soils are typical leached tropical furrogenuous soils that are sandy in texture.

The study area is located on the High Plains of northern Nigeria between about 450m and 750m above sea level with granitic inselbergs such as the Kufena hills of Zaria and volcanic plateaux like the Jos Plateau occasionally interrupt the monotonous high plain.

3. Materials and methods

Fifty years' (1960–2009) daily rainfall observations sourced from the Nigerian Meteorological Agency were used to derive dry spells of 5, 10 and equal to or longer than 15 days using Stern and Dale's (1982) method. In their method, the last day of rainfall of 0.25mm or more in October was coded ¯1, 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 were recorded as sequences of wet and dry days. From this, runs of dry spells of 1 pentad (5) days, 2 pentads (10) days and equal to or greater than 3 pentads (15) or more days were computed directly month wise for each of the rainfall stations. Records of crop yield per hectare for the five selected crops (maize, millet, sorghum, cowpea and groundnuts) within the region of the meteorological stations were also sourced from the state Agricultural Development Programme of each state.

The relationship between the occurrence of pentad dry spells and the yield of the selected crops in the study area was tested. Bivariate correlation analysis of the form:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}}$$

where
- r = Correlation coefficient
- x and y = individual observations of dependent and independent variables respectively
- $\bar{x}$ and $\bar{y}$ = Mean of dependent (x) and independent (y) variables respectively

was used to determine this relationship. The crop yield values were taken as the dependent variables Y_1, Y_2, Y_3, Y_4 and Y_5) and dry spells of 5, 10, 15 and greater than 15 days, taken as the independent variable X_1 to X_5 respectively. The dry spell parameters that have shown significant correlation with crop yield were subjected to stepwise multiple regression to determine which ones are more critical to the yield of the crops

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4. Results and discussion

4.1. Relationship between occurrence of pentad dry spells and crop yield at Sokoto

Table 1 gives the correlation matrix between occurrence of pentad dry spells and the yield of the five crops at Sokoto. From Table 1, it is seen that maize yield has a significant negative relationship with occurrence of 1 and 2 pentad dry spells in June and July respectively at 0.05 level of significance. These two months correspond with the planting/germination and vegetative development of maize at Sokoto.

Table 1: Correlation Matrix of Pentad Dry Spells and Crop Yield at Sokoto

Months	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.034	.247	-.168	.307	.064
May 10	-.099	.063	.383	.209	-.100
May ≥ 15	-.001	.141	-.054	.322	-.179
June 5	-.267*	.086	-.031	.161	-.039
June 10	-.153	.562*	.379	.044	-.017
June ≥ 15	.260	-.333	.109	-.441	.328
July 5	.321	-.340	.307	.129	.166
July 10	-.362*	.248	.243	-.017	-.202
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.061	-.131	-.001	-.006	.307
Aug 10	-.088	-.013	-.727**	.135	-.361
Aug ≥ 15	-.437	-.013	-.142	.569*	-.633*
Sept 5	.053	.353	-.450	.785**	-.094
Sept 10	.185	-.100	.535	-.432	.165
Sept ≥ 15	-.088	-.013	-.727**	.135	-.361
Total dry	.015	-.127	-.084	.414	.007

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
a Cannot be computed because at least one of the variables is constant

Source: Authors' computation

These periods depend on high rainfall otherwise if dry spells set in, lack of good germination and stunted growth will be the case and consequently low yield. The yield of millet has a significant positive correlation with occurrence of 10-day dry spells in June at Sokoto. This implies that if dry spells of 2 pentads occur in June at Sokoto, there will be higher yield of millet if all other conditions remain the same.

The occurrence of 2 or more dry pentads in August and September respectively has significant negative relationship with the yield of sorghum at 0.01 level of significance. This is so because August and September correspond with the period when sorghum grains are produced and ripen at Sokoto. This stage requires high rainfall for grains to develop well. Occurrences of dry spells during this stage will therefore, causes less moisture as a result the grains will not develop properly and the yield will be reduced.

The occurrence of 15 and 5-day dry spells in August and September respectively both show significant positive relationship with the yield of groundnuts at Sokoto. This implies that the occurrence of dry spells in these months encourages better groundnuts yield at this place. This is because at Sokoto, groundnut ripens within these two months and during this ripening stage, a short dry spell is needed. Thus the significant positive correlation between yield and dry spells in these two months.

4.2 Relationship between occurrence of pentad dry spells and crop yield at Katsina

The relationship between occurrence of pentad dry spells and the yield of the crops is given in Table 2.

From this table, it is observed that all the significant relationships are negative. A significant negative correlation is indicated at 0.05 level between 15-day dry spells in June and July; 10-day dry spells in September and the yield of maize at Katsina. This implies that the occurrence of these dry spells all cause reduced maize yield in the area. May is the planting period while July corresponds with part of the vegetative growth period of maize in the area.

Table 2 Correlation Matrix of Pentad Dry Spells and Crop Yield at Katsina

Months	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.199	.286	.222	.041	.130
May 10	.237	-.281	.173	-.306	-.228
May ≥ 15	-.255*	-.102	-.193	.113	.168
June 5	.275	.011	.176	.156	.138
June 10	-.017	-.253*	.207	-.690**	-.017
June ≥ 15	-.255*	.026	-.499*	.527	-.253*
July 5	-.036	-.255*	-.314*	-.308	-.082
July 10	.390	.204	.178	.149	.288
July ≥ 15	-.172	-.153	.041	.334	-.111
Aug 5	-.261	.066	-.290	-.269	.148
Aug 10	.319	-.341	.099	.(a)	.169
Aug ≥ 15	-.172	-.153	.041	.334	-.111
Sept 5	.077	.028	.213	-.411	-.295*
Sept 10	-.288*	-.122	-.416*	-.116	-.201
Sept ≥ 15	.175	-.212	.184	-.028	.026
Total dry	-.048	-.289*	-.110	-.611*	.005

* * Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

a Cannot be computed because at least one of the variables is constant.

Source: Authors' computation

These two stages require adequate rainfall therefore, the occurrence of dry spells in May and July means low or no rainfall, implying low soil moisture content during these two periods, as a result, poor germination and vegetative development will follow respectively consequently low yield.

Dry spells of 2 pentads in June, 1 pentad in July and total dry spells in the year all have significant negative correlation with millet yield at 0.05 level of significance. This also implies that their occurrences all have significant negative impact on the yield of millet. At Katsina, millet is planted in June. Its proper germination is based on enough rainfall that will provide enough soil moisture. Proper vegetative growth of millet occurs under high rainfall between June and August. The occurrence of dry spells during these stages leads to reduced rainfall and consequently poor germination, poor vegetative development and diminished yield.

Sorghum yields show significant negative relationship at 0.05 level of significance with occurrence of 15-day dry spells in June, 5-day dry spells in July and 10-day dry spells in September. This is so because the successful planting, germination and vegetative development of sorghum in June and July respectively depend on high rainfall. The occurrence of dry spells in these months certainly reduces rainfall and leads to low yield. Sorghum needs high rainfall for its 'eying' and ripening in October. This moisture is derived from September rainfall, as October is usually a dry month. Occurrence of dry spells in September will lead to lack of moisture for the 'eying' in sorghum and this will reduce its yield.

Groundnuts yield shows a negative significant relationship at 0.05 and 0.01 levels with 2 dry pentads in June and with total dry spells at 0.05 level. The vegetative growth of groundnuts occurs in June and it requires adequate rainfall. Dry spell occurrence during this period is detrimental to the yield of groundnuts.

Cowpea yield shows a negative correlation with the occurrence of 15-day dry spells in June and 5-day dry spells in August. Cowpea is planted in June and needs adequate rainfall for germination. Dry spell occurrence will not only affect the germination but will also reduce the production of cowpea leaves that photosynthesize the food for the plant. This will lead to reduced yield. The rainfall that occurs in September provides the moisture used by cowpea for flowering and pod development in October. If dry spells occur in September, there will be reduced moisture in October and this will adversely affect cowpea yield.

4.3 Relationship between occurrence of pentad dry spells and crop yield at Kano

Table 3 shows the correlation matrix of between occurrence of pentad dry spells and the yield of maize, millet, sorghum, groundnuts and cowpea at Kano.

Table 3 Correlation Matrix of Pentad Dry Spells and Crop Yield at Kano

Months	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	-.342	.090	.422	.145	-.008
May 10	.075	-.049	.042	-.045	-.434
May ≥ 15	-.222	-.059	-.129	-.098	.352
June 5	-.295	-.068	.463	.027	-.647*
June 10	-.613*	-.266	.236	.328	.208
June ≥ 15	.015	-.121	-.549	.092	-.375
July 5	.161	-.179	-.164	.387	.019
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Aug 5	.191	.306	.169	.257	.300
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	.(a)	.(a)	.(a)	.(a)	.(a)
Sept 5	.194	-.317	-.420	-.152	-.195
Sept 10	-.481	-.100	.597*	.060	-.003
Sept ≥ 15	.139	.321	.393	.080	.076
Total dry	-.300	-.079	.405	.538	-.334

*Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.
Source: Authors' computation

From Table 3, it is evident that there is a general negative relationship between occurrence of pentad dry spells and the yield of the five crops. Although millet and groundnuts do not show any significant correlation with any dry spell, maize indicates a negative correlation with the occurrence of dry spells of two pentads in June. This implies that the occurrence of this length of dry spells in June leads to reduced yield of maize at Kano.

Late May to early June, correspond to the sowing period of maize at Kano. This period requires adequate moisture for the proper germination of the planted seeds. The occurrences of dry spells of up to 10 days at this stage will therefore, lead to poor germination and consequently reduced maize yield. Sorghum shows a significant negative relationship with the occurrence of 3 or more dry pentads in June but a significant positive relationship with occurrence of 2 dry pentads in September both at 0.05 level of significance. This implies that while the occurrence of 15-day dry spells in June leads to diminution of sorghum yield, occurrence of 10-day dry spells in September is beneficial and leads to an increase in the yield of sorghum. June to August represent the vegetative growth stage of sorghum when high rainfall (high soil moisture) is needed, hence the negative relationship between sorghum yield and dry spells of 15 or more days in June.

September corresponds with the ripening stage of sorghum at Kano, therefore, dry spell is needed at this stage, hence the positive relationship between sorghum yield and the occurrence of 10-day dry spells in September. Cowpea shows a negative relationship with the occurrence of 5-day dry spells in June. This is the planting period for cowpea at Kano and high rainfall (high soil moisture index) what is needed at this stage. The occurrence of dry spells at this stage therefore, will definitely lead to cowpea yield diminution.

4.4 .Relationship between occurrence of pentad dry spells and crop yield at Maiduguri

The relationship between the occurrence of pentad dry spells and the yield of the five crops at Maiduguri is given in Table 4.

From Table 4, it could be seen that the yields of all the crops show negative relationship with most of the dry spell lengths. Maize yield indicates a significant negative correlation at 0.01 level of significance with the occurrence of 15-day dry spells in September. As already highlighted earlier, 'eyeing' stage (grain development) for maize takes place in September. This stage requires high soil moisture index for successful development of grains.

The occurrence of dry spells of equal to or greater than 15 days at this stage therefore, causes soil moisture diminution leading to shortage of nutrients for the crops consequently low maize yields will be the result. Millet yield has significant positive relationship with the occurrence of 5-day dry spells in September at 0.05 level of significance at Maiduguri. This implies that millet does not need high soil moisture (high rainfall) in September. This could be explained by the fact that the ripening of millet grains at Maiduguri occurs in September. This stage of development in millet requires a short dry condition with high sunlight. The occurrence of high rainfall at this stage will discourage the proper ripening of millet seeds to grains, thus low yield.

Table 4 shows that the yields of sorghum and groundnuts both have significant negative correlation at 0.05 level with the occurrence of 5-day dry spells in July. At Maiduguri, the vegetative growth of sorghum and groundnuts takes place between June and August. This requires a lot of soil moisture (high rainfall). If dry spells occur within these months, particularly in July and August, this stage is disturbed therefore; this will reduce the yield of these two crops.

Table 4 Correlation Matrix of Pentad Dry Spells and Crop Yield at Maiduguri

Months	Maize	Millet	Sorghum	G/nuts	Cowpea
May 5	.198	-.179	-.252	-.383	-.243
May 10	-.112	-.404	-.281	-.171	-.440
May ≥ 15	.005	.188	.047	-.107	.245
June 5	-.378	-.002	.078	.409	-.038
June 10	.019	-.326	-.360	-.356	-.359
June ≥ 15	-.035	-.066	.173	-.079	.001
July 5	.320	-.144	-.645*	-.607*	-.034
July 10	.(a)	.(a)	.(a)	.(a)	.(a)
July ≥ 15	-.485	-.327	.225	.334	-.296
Aug 5	.482	.182	-.308	-.283	.257
Aug 10	.(a)	.(a)	.(a)	.(a)	.(a)
Aug ≥ 15	-.489	-.209	-.071	.482	-.178
Sept 5	.469	.573*	.222	.054	.546*
Sept 10	.353	.318	.192	.266	.297
Sept ≥ 15	-.676**	-.410	.201	.406	-.365
Total dry	.083	.043	.001	.193	.110

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
a Cannot be computed because at least one of the variables is constant.
Source: Authors' computation

There is a significant positive correlation between occurrence of 5-day dry spells in September and the yield of cowpea. As expected, cowpea does not need heavy rainfall in September, as it will only enhance vegetative growth and not seeds. Cold dry condition is what is needed by cowpea in September; otherwise, high rainfall will lead to vegetative development of cowpea. The occurrence of dry spells in September enhances cowpea flowering and pod development.

4.5. Critical pentad dry spell parameters for crop yield

Results of the stepwise multiple regression that identified the critical dry spell parameters to crop yield in the region is given in Table 5. Two-day dry spells in June and August are the most critical dry spell parameters for the yield of the grain crops in the region. The coefficient of determination (R^2) from Table 5 shows that while the three factors are jointly responsible for 74.1% of the variation in maize yield, they account for 21.5% and 52.9% of the variations in the yield of millet and sorghum in the area. 51.4% and 40.1% of the variations in the yield of ground nuts and cowpea respectively are accounted for by these three dry spell parameters.

5. Summary

In summary, results of the correlation between pentad dry spell occurrence and crop yield indicate that maize shows more sensitivity to dry spells than the other crops. Among the five selected crops, Millets is the least sensitive to monthly occurrence of dry spells. This implies that millet is a drought – resistant crop that is not affected by occurrence of mere 1 or 2 pentads. It is only the total dry spells in the growing season that show significant negative relationship with millet yield. While Sorghum and Groundnuts are moderately sensitive to dry spells, Cowpea, which is planted in late August yields better with much dew than rainfall. Its yield is not dependent on occurrence of dry spells in earlier months at most stations.

Table 5: Coefficient of Determination (R^2) Values for Critical Pentad Dry Spell Parameters in the Region

Crop	Critical Dry Spell Parameters	R^2
Maize	2 dry pentads in June and August and Total numbers of dry spells	74.1
Millet		21.5
Sorghum		52.9
G/nuts		51.4
Cowpea		40.1

Source: Authors' computation

6. Conclusion

From the results of this study, it is concluded that not all dry spell occurrences are detrimental to crop yield in the study area. At least a pentad dry spell is needed for most crops during the period of first weeding and application of fertilizer say two weeks after germination. Such is the case with maize, sorghum and ground nuts. During the grain production and development period, occurrence of any length of dry spell affects the yield of these crops negatively. Finally, during the maturing period, dry spell of short duration is important for the proper maturity and drying of the seeds for harvesting.

7. Recommendation

In northern Nigeria, agriculture is a weather-sensitive operation, farmers should therefore, seize the opportunity of occurrence of dry spells at the appropriate periods either for weeding and application of fertilizer or harvesting in order to maximize their yield.

Good viable seeds should be reserved as dry occurrence of dry spells can cause crop wilting and drying up which will call for second planting.

The study region is a drought-prone region, therefore, more drought –resistant early maturing and high-yielding varieties of the grains need to be developed and planted in the area.

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