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RELATIONSHIP BETWEEN RAINFALL AND TEMPERATURE VARIABILITY AND THE YIELDS OF SELECTED GRAIN CROPS IN SOKOTO STATE, NIGERIA

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Abstract

This study assessed the relationship between rainfall and temperature variability and the yield of selected grain crops in Sokoto State, Nigeria. The study design involved the collection and analyses of annual rainfall, temperature and yield data for millet, maize and sorghum for 48 years (1970 – 2017) for Sokoto State. The rainfall and temperature data were used to characterize the climate of the study area and to show the relationship between weather parameters and the yield of millet, maize and sorghum. The data were analysed using trend line equations and correlation (r) analysis. The result in the yield pattern of millet, maize and sorghum showed an increase. The result of the correlation showed that there is an insignificant, negative relationship between total annual rainfall and the yield of millet, sorghum and maize in the study area (r = -0.130, -0.176 and -0.270, respectively). The result further showed a negative relationship between onset dates of rainfall with millet and maize yield (r = -0.187 and -0.112, respectively). Based on the findings of the study, major recommendations made include the adequate provision of improved seed varieties that require less consumptive use of moisture and have a shorter growing season and encouraging grain farmers to adopt viable adaptation strategies in the study area.

Keywords: Farmers, Rainfall, Temperature, Variability, Yield

Introduction

Grain crops are grown in greater quantities and provide more energy worldwide than any other type of crops in Sub-Saharan Africa, they are, therefore, staple food crops (Sarwar, Sarwar, Sarwar, Qadri and Moghal, 2013). Grain crops account for about 50 per cent of the total per capita calories supply and 45 per cent per capita protein supply in diets (Muhammed and Omotesho, 2008). Sorghum, millet and maize are crops that constitute the largest volume of grains produced and consumed in northern Nigeria. These grain crops form the food base of northern Nigeria and are the most available, affordable and important sources of energy (National Agricultural Extension Research and Liaison Services [NAERLS] 1996). Therefore, millet, maize and sorghum crops were selected for this study.

Rainfall variability is a weather condition that directly or indirectly affects agricultural production. Climate determines the choice of what plant to cultivate, how to cultivate it, and the yields of crops (Mijinyawa and Akpenpuun, 2015). The degree to which rainfall amounts vary across an area or through time is an important characteristic of the climate of an area. This subject area in meteorology/climatology is called rainfall variability (Nouaceur and Muraresc u, 2016). Crop production is highly sensitive to weather. Climate change implies a new mean climatic state or climatic normal. The most crucial thing about the concept of climate change is not only the time involved but also the degree of variability that the change is subjected to, as well as the duration and impact of such variability on man and the ecosystem (Ayoade, 2003). Rainfall and temperature are major variables of weather that determine agricultural activities in sub-Saharan Africa.

According to Ajadi (2011) solar radiation, temperature, moisture and other climatic parameters affect the global distribution of crops, livestock as well as crop yield. Ikpe, Ariko and Nnachi (2020) reported that rainfall distribution and the occurrence of moisture stress conditions during the vegetative period are critical for the yield formation of sorghum in northern Nigeria. Given the foregoing, Odjugo (2010a) opined that climate change is unequivocal and its impacts are here with us. Available pieces of evidence show that each day brings fresh proofs of climate change effects and these effects include increasing temperatures, decreasing rainfall in the continental interiors, drought, desert encroachment, extreme weather, floods, water scarcity, health and agricultural problems among others. Excessive increases in temperature result in low agricultural productivity and this may lead to depletion of soil nutrients and destruction of soil structure and organisms which contribute to the fertility of the soil. Ordinarily, rainfall can be considered to have a positive effect on agricultural productivity except where it leads to flooding, erosion and leaching. Rainfall amount and high temperatures are the most important elements of climate change in Nigeria, as a result, the northern region of Nigeria is increasingly becoming an arid environment at a very fast rate occasioned by the fast reduction in the amount of surface water, flora and fauna resources on the land. Consistent reduction in rainfall leads to a reduction in the regeneration rate of land resources. The northern zone, therefore, faces the threat of desert encroachment (FME, 2004).

The specific impacts of changes in precipitation regimes on crops vary significantly. The levels and distribution of precipitation determine whether a crop can be grown without irrigation and/or drainage, or whether investments in this area are necessary (Tubiello, Soussana, Howden and Easterling, 2007). Some crops are more tolerant than others to certain types of stresses, and at each phenological stage, different types of stresses affect each crop species in different ways (Simpson, 2017). Changes in precipitation regimes include changes in seasonal mean, the timing and intensity of individual rainfall events, and the frequency and length of droughts. Each of these factors is critical to crop productivity. The impact of changes in precipitation will be particularly marked when they are combined with temperature alterations that affect the crop's evaporative demands. This may lead to different forms of moisture stress depending on the phenological stage the crop has reached.

Temperature alterations can take many forms: changes in average temperature; changes in daytime high and nighttime low temperatures; and changes in the timing, intensity and duration of extremely hot or cold weather. The increase in average temperature during the growing season typically causes plants to use more energy for respiration for their maintenance and less to support their growth. According to Lobell and Field (2007), with a 1°C increase in average temperatures, yields of the major food and cash crop species can decrease by 5 to 10 per cent. With higher average temperatures plants also complete their growing cycle more rapidly (Hatfield, Boote, Kimball, Ziska, Izurralde, Ort, Thomas and Wolfe, 2011). In general, photosynthesis in C_3 plants is more sensitive to higher temperatures compared with C_4 crops (Lipiec, Doussan, Nosalewicz and Kondracka, 2013). As climate changes, crop production strategies must change too. There will always be some uncertainty associated with modelling the complex relationships between grain yields and future climate scenarios.

Climate change has affected the supply of sufficient food for the increasing population and has already altered the climatic characteristics which have led to a shift in crops cultivated in northern Nigeria (Odjugo, 2010b). As a result, the production of the principal crops like millet, maize, and sorghum in the past few decades have continued to decline while the population increases (Adamgbe and Ujoh, 2013). This scenario increases the risk of hunger and food insecurity thereby placing a heavy reliance on food aid at the national and household levels. Meeting this challenge requires a drastic increase in the productivity of the principal staples crops especially millet, maize and sorghum which are very important staple food crops in Nigeria, and northern Nigeria in particular where these crops constitute the largest volume of grains produced and consumed. However, the yield of millet, maize and sorghum has continued to be very low particularly in Sokoto State which has a lot of potentials for grain production (Iheanacho, 2000). According to Sokoto, Tanko, Abubakar, Dikko, and Abdullahi (2015), climate change has altered the climatic characteristics of Sokoto State which have directly affected grain yield in the state.

The Study Area

Sokoto State is located in the North-West Sudano-Sahelian Savannah ecological belt of Nigeria between Latitudes 11° 03' and 13° 50' N of the Equator and Longitudes 4° 14' and 6° 40' E of the Greenwich Meridian (Abubakar, 2006). Its headquarters is at Sokoto. It has an area of 25,973

Km^2. It is bounded by the Niger Republic to the north, Zamfara State to the east and south and Kebbi State to the west. Presently, the State has twenty-three (23) Local Government Areas (LGAs). The climate of Sokoto is tropical continental and is dominated by two opposing air masses: tropical maritime and tropical continental. The rainy seasons are usually short, which is often within the ranges of four to five months (May/June to September/October). Owing to seasonal fluctuations, it could even drop to less than four months. Hence, evapotranspiration is usually high most especially in the dry season (Desanker and Magardza, 2001). The annual rainfall is between 500mm in the north and 800mm in the south. The showers rarely last long and are far from the regular torrential rain known in wet tropical regions. According to Odjugo (2010a), this short growing season affects crop yield and makes it difficult to cultivate crops that require a longer growing season and high amount of rainfall; but favours grains like millet, sorghum and maize which have a short growing season and require a low amount of rainfall. On the whole, Sokoto is located in the semi-arid zone of Nigeria.

The average temperature during the dry season is about 40.6°C. However, maximum daytime temperatures are for most of the year generally under 40°C. The hottest months are February to April when daytime temperatures can exceed 45°C. Dwyer, Ghannoum, Nicotra and Caemmerer (2006) reported that high temperature affects C4 plants such as maize through its effects on the availability of water which is very important in the process of photosynthesis. From late October to February, during the dry season, the climate is dominated by the Harmattan wind blowing Sahara dust over the land. The dust dims the sunlight thereby lowering temperatures significantly and also leading to the inconvenience of dust everywhere in houses (Abubakar, 2006).The average relative humidity is 55 per cent and wind velocity reaches a speed of about 30km p/h between October and February but decreases to less than 15km/hr. by April. The adequate sunshine and moderate rainfall in Northern Nigeria, favour post-harvest preservation conditions for these cereals (Iken and Amusa, 2004). Sokoto is known to be very prone to some the hazards such as drought, increasing evapotranspiration and an increase in temperature. Other meteorological hazards such as hailstorms, floods have been occurring at more frequent rates than in years and decades have gone by. These meteorological hazards affect crop production (Abubakar, 2006).

The prevailing type of weather existing in Sokoto State can be characterized by low humidity, moderate wind velocity and atmospheric pressure (Sani, 2005). According to Abubakar (2006), farmers in Sokoto State are faced with the challenge of growing food crops as a result of the high temperature, strong solar radiation and increase in evapotranspiration which increases water stress on the plant and reduces maximal photosynthesis.

Methodology

Annual yield data for maize, millet and sorghum for Sokoto State was sourced from the Sokoto Agricultural Development Project (SADP) and NAERLS (1970 – 2017). The yield pattern of millet, maize and sorghum were analysed and discussed

Source: Administrative Map of Sokoto State (2020).

using the trend line equation. Annual rainfall and temperature data for 48years (1970 – 2017) was sourced from the Nigerian Meteorological Agency (NiMET) office and was used to characterise the climate of the study area – Total Annual Rainfall (TAR) Onset dates, Cessation dates, and Length of the rainy season (LRS). The effect of TAR, onset dates, cessation dates, LRS, the minimum and maximum temperature on the yield of millet, maize and sorghum grain crops were also analysed and discussed using correlation (r) analysis.

The trends in the yield pattern of millet, maize and sorghum are presented in Figures 2, 3 and 4 and are succinctly discussed.

Results and Discussion

Yield pattern of grain crops in Sokoto State

Trends in the yield of millet

Figure 2 shows the pattern of millet yield in the study area. Figure 2 indicate that millet yield in the study area is characterized by marked variability, although the trend line equation y = 0.013x + 0.5364 shows an increasing trend in the yield of millet. The highest yield was recorded in 2010 (1.40 tons/ha), the lowest was recorded in 1996 (0.40 tons/ha) and the average yield within the period reviewed was 0.85 tons/ha. The trend line shows a steady increase in the yield of millet from 1970 (0.42 tons/ha) to 1992 (1.11 tons/ha). Between 1993 (0.70 tons/ha) and 2001 (1.30 tons/ha), there were marked variability in the yield of millet which could be attributed to several factors. According to the Kano agricultural and rural development agency (KNARDA, 2008), there has been an appreciable increase in the land area and output of millet in Nigeria which could be attributed to advance in agricultural technology such as the introduction of high yielding varieties, application of fertilizers and provision of services such as seminars and workshop to the rural farmers, provision of agricultural facilities and seeds for the farmers. Today, millet is a staple food for millions of Nigeria. Millet is more drought-tolerant and one of the few crops that thrive well in drier areas where sorghum and maize cannot grow to full maturity without irrigation. That millet yield is increasing disagrees with the findings of Emeghara (2015) which reported a decline in the yield of millet in Sokoto State. The reason for the difference within the space of two years could be attributed to the early onset date of rainfall, increase in TAR, increase in LRS and the use of viable adaptation strategies such as improved seed varieties.

Trends in the yield of maize

The trend in the yield of maize is shown in Figure 3. Figure 3 indicates an increasing trend in maize yield in the study area with the trend line equation y = 0.0147x + 0.7006. The highest yield was recorded in 2012 (1.85 tons/ha), the lowest yield was recorded in 1970 (0.71 tons/ha) and 1.06 tons/ha was the average yield obtained within the period reviewed. According to Adamgbe and Ujoh (2013), most households in Nigeria cultivate maize more than any other grain crop. Maize is an important source of carbohydrates, protein, iron, vitamin B and minerals. It is a staple food for the masses and also provides dry season feed for farm animals. That maize yield is increasing in the study area disagrees with the findings of Adamgbe and Ujoh (2013) who reported low yield of maize crop in Benue State, Nigeria. The result further disagrees with the findings of Emeghara (2015) which reported a negative trend line equation in the yield of maize in Sokoto State.

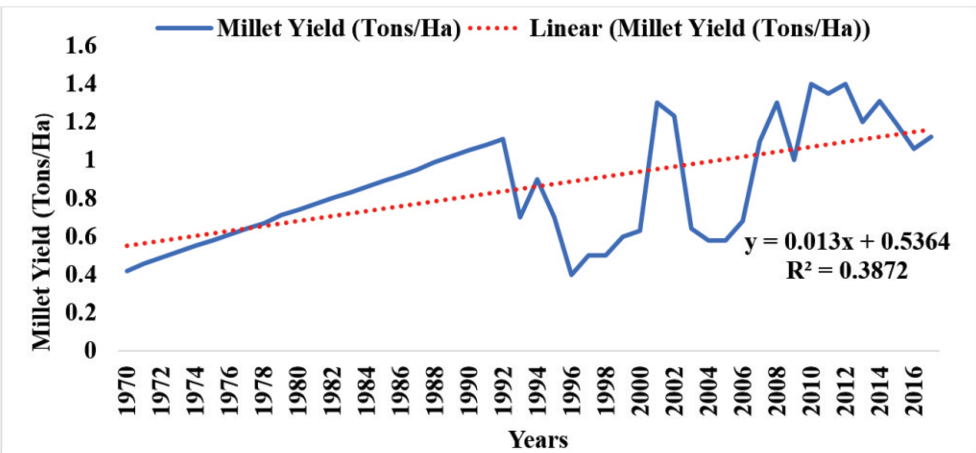

Figure 2: Trends in the Yield of Millet
Source: Fieldwork 2018

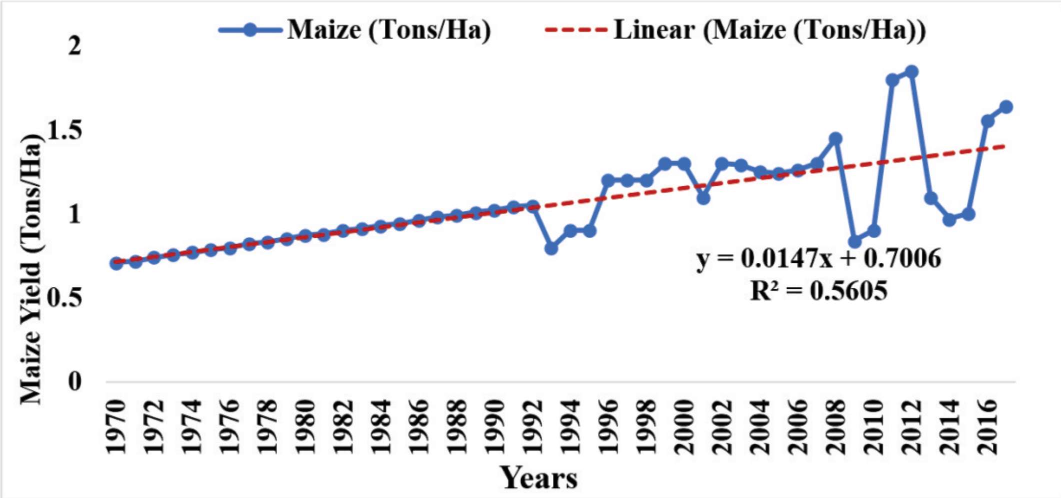

Figure 3: Trends in the Yield of Maize
Source: Fieldwork 2018:

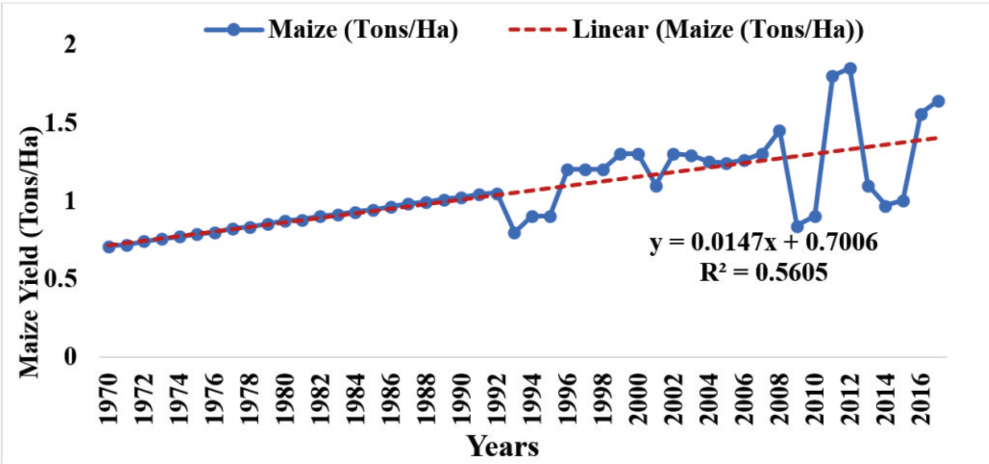

Figure 4: Trends in Sorghum Yield
Source: Fieldwork 2018

The reason for the increase in the yield of maize in Sokoto State could be attributed to the early onset date of rainfall, increase in TAR, increase in LRS and the use of viable adaptation strategies such as improved seed varieties.

Trends in the yield of sorghum

Figure 4 shows the yield pattern of sorghum. Like other crops, the trend line of sorghum yield indicates a positive linear trend equation ($y = 0.009x + 0.5549$) which implies an increase in the yield of sorghum in the study area. The highest yield was recorded in 2008 (1.5 tons/ha); 2012 recorded the lowest yield (0.44 tons/ha) while the average yield for the period reviewed was 0.77 tons/ha.

Relationship between the yield of grains and weather parameters

The level of relationship between grain yield and weather parameters is presented in Table 1. The results show the correlation (r) analysis between TAR, onset date, cessation date, LRS, maximum and minimum temperature with millet, maize and sorghum yield in the study area.

Relationship between millet and weather parameters

Table 1 shows a statistically insignificant, negative correlation between millet yield and TAR with (r) value -0.130. This implies that variations in TAR do not account for the variation in millet yield. According to Ojedran, Adamu and George (2010), millets can survive in areas with as little as 300mm or less of seasonal rainfall compared with sorghum

Table 1: Relationship between Selected Grain Crops and Weather Parameters

Crop	Total Rainfall (p-Value)	Onset Dates (p-Value)	Cessation Dates (p-Value)	LRS (p-Value)	Max. Temp. (p-Value)	Min Temp. (p-Value)
Millet	-0.130	-0.187	0.231	0.367*	0.080	0.003
	(0.379)	(0.204)	(0.115)	(0.010)	(0.589)	(0.984)
Sorghum	-0.176	0.028	-0.102	-0.107	0.341*	0.443**
	(0.232)	(0.852)	(0.491)	(0.471)	(0.018)	(0.002)
Maize	-0.270	-0.112	-0.155	-0.013	0.329*	-0.102
	(0.064)	(0.447)	(0.292)	(0.931)	(0.022)	(0.492)

p-probability, Max.-maximum, Min.-minimum, Temp.-temperature

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

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

whose minimum water requirement is 400mm and maize 500-600mm. Millet is a short season crop that requires only 60-75 days from seedling to maturity. The average TAR of the study area was 625.60mm which is sufficient for millet production in the study area. Ojedran et. al. (2010) further reported that millets are better adapted than most other crops to dry, infertile soils, high temperatures, low and erratic precipitation, short growing seasons and acidic soils with poor water-holding capacity.

This confirms the findings by Emeghara (2015) which stated that there was no significant relationship between millet yield and TAR in Sokoto State. This result disagrees with the findings of Bello (2012) who reported a significant and positive correlation between TAR and millet yield at Kano, Nigeria.

Table 1 further shows that the onset of rainfall has a high negative correlation with millet yield (r = -0.187). This implies that the late onset of rains in the study area could drastically reduce the final yield. Ojedran, Adamu and George (2010) reported that to get proper plant establishment, it is important to plant millet at the beginning of the early rains. According to Bello (2012), late-onset of rainfall usually affects farmers adversely because rainfall received during the pre-sowing period to some extent determines the amount of soil moisture available at germination. That is why farmers have identified the onset dates as the single most desirable piece of forecast information because rainfall will become fairly continuous and sufficient to ensure adequate soil moisture before and after planting. The delayed onset of rains is very critical in rain-fed agriculture as it may lead to crop failure or poor yield. This result confirms the findings of Bello (2012) which reported a high negative correlation between the onset of rainfall with millet yield at Dambatta, Kano State. The result also agrees with Emeghara (2015) who reported that millet is negatively correlated to the onset of rainfall at -0.318.

The correlation between cessation of rainfall and millet yield shows that there is no significant relationship with (r) value 0.231. The correlation results for LRS show a positive relationship between the yield of millet and LRS (r= 0.367) at a significant level of 0.010. The result shows the implication of LRS in the area. Where the LRS is longer it tends to influence the high yield of crops and the reverse is the case in the area. This may be as a result of the early onset and early cessation of rainfall as observed in the study area (Figures 2 and 3). Onset dates of rainfall in the area range from May and July within the period reviewed. This result agrees with the findings of Bello (2012) which reported that LRS has a significant correlation with the yield of millet in Kano (r = 0.734). Table 2 shows that the correlation values for maximum temperature have no significant relationship with the yield of millet ®= 0.080).

Relationship between maize and weather parameters

TAR was found to be insignificantly and negatively correlated with maize yield with (r) value -0.270. According to IITA (2012), maize requires a considerable amount of moisture of about 500-750 mm of well-distributed rainfall conducive for proper growth. The average TAR of the study area was 625.60mm which is sufficient for maize production in the study area. Maize requires more moisture during the reproductive period and less moisture when developing towards maturity. Onset dates were also negatively correlated with maize yield (-0.112) and cessation date (-0.155) had weak negative correlations with maize yield. This implies that variations in onset and cessation dates of rainfall account for some of the variations in maize yield in the study area. Therefore, the earlier the date of onset, the higher the yield of maize. This result confirms the findings by Emeghara (2015) who reported a negative correlation (-0.616) between onset date and maize yield. The maximum temperature has a significant relationship (0.329) with the yield of maize. The positive correlation coefficient between maximum temperature and maize yield shows increases in the yield of maize with a moderate relationship between maize yield and temperature.

Relationship between Sorghum and weather parameters

With regards to the TAR and sorghum yield, the correlation of -0.176 is interpreted as an insignificant and negative relationship between the two variables. As earlier stated, sorghum requires a minimum rainfall amount of 400 - 600mm with a duration of at least five (5) months spread over eighty (80) rainy days (Danbaba, 2007; Odjugo, 2009). That means where rainfall totals fall below 600mm, effective sorghum production may be affected. It also implies that sorghum production may also be affected where the amount of rainfall exceeds the required maximum. The average TAR for the study area for the period reviewed was 625.60mm. In addition, the result of correlation analysis on the yield of sorghum shows a weak correlation of 0.028 for the onset of rainfall and a weak negative correlation of -0.102 for the cessation month. This implies that the onset and cessation of rainfall in Sokoto State were not significant with sorghum yield. LRS and sorghum relationship shows a weak negative relationship with a correlation value of -0.107. This implies that there is no significant relationship between LRS and the yield of sorghum. The LRS is of great agricultural significance to farmers, because it guides the farmers on the type of crops that can be grown and the number of days needed by the crop to grow to the point of harvests.

The result between sorghum yield and temperature shows that maximum temperature has a significant relationship with the yield of sorghum. The positive correlation coefficients between maximum temperature lead to a corresponding increase in the yield. Reduction in temperature at a minimum level significantly affects the yield of sorghum with a positive relationship. This implies that lower temperatures in the study area tend to increase the yield of sorghum. The result agrees with the study of Ajadi (2011) in south-east Nigeria which reported that climatic parameters such as rainfall, LRS and temperature determine crop yield.

Conclusion

This study has examined the effect of rainfall and temperature variability on the yield of maize, millet and sorghum crops. The results indicate an increase in the yield of millet, maize and sorghum. The correlation (r) analysis showed an insignificant negative relationship between TAR and the yield of millet, maize and sorghum. The result also showed a negative relationship between onset dates with millet and maize yield.

Recommendation

Based on the findings of the study, major recommendations made include the provision of improved seed varieties that requires less consumptive use of moisture and have a shorter growing season and encouraging grain farmers to adopt viable adaptation strategies in the study area.

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