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Inter-Annual Variation of Weather Pattern in the Semi Arid Region of Nigeria and Its Implication on Sorghum Production

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Abstract - **Sorghum is a drought resistant crop, able to withstand periods of high temperature and even water logging, thereby making it a good staple food in food –insecure regions in the world. This study assesses the effect of inter-annual variation of climate on sorghum production in the semi-arid region of Nigeria using regression analysis. Sorghum yield data collected from the archives of the Institute of Agricultural Research, Ahmadu Bello University Zaria for the period of 1989 – 2019 was correlated with climate parameters from the same source. The data were analysed to show the weather pattern of each weather parameter viz –a- viz Temperature (maximum and Minimum), Relative humidity (morning and afternoon) and Rainfall to assess their corresponding effects and importance to Sorghum yield in Samaru, Zaria, Nigeria. The result from the regression analysis shows that rainfall is decreasing at the rate of 0.77mm/year in this station and more drought period were observed between 1982 and 2001. The pattern of Rainfall is unimodal, an implication of only one rainfall peak. This is a vantage for the production of Sorghum because of its adaptive nature to both drought and water logging. There is an increasing yield as rainfall decreases. However, between 2010 and 2013, yield increases as rainfall increases. The trend of other climatic parameters was also considered. The results imply that all the parameters under study are very relevant to the yield of sorghum at every stage of growth and hence, should be well studied over other locations for more productivity.**

Keywords: Climate change, annual rainfall, drought, sorghum, mean temperature.

I. INTRODUCTION

Sorghum (*Sorghum bicolor L. Moench*) is an essential diet in the semi-arid tropics where droughts cause frequent failures of other crops. It contributes to the food security of many of the world's poorest countries or food-insecure regions (FAO and ICRISAT, 1996; Msongaleli *et al.*, 2017). Moreover, it is highly valued as a source of feed and fodder for livestock, biofuel (Abdel-Ghani*et al.*, 2015; Druille *et al.*, 2020), and enables small holder farmers to diversify into more lucrative crop/livestock systems. The sale of feed blocks also provides an important source of income for smallholder sorghum farmers. It is uniquely drought-resistant among cereals and can withstand periods of high temperature, and even water-logging (Taylor, 2010; Tack *et al*., 2017). Sorghum grows on naturally in areas where the annual rainfall is in the range of 500-700 mm per year. In the last 35 years, the area allotted to sorghum in Africa has nearly doubled, but yields averaging 800 kg/ha have not increased -as a result of cultivation of inherently low yielding varieties, poor soil fertility, Striga, pests and diseases, drought and climate variability (Atokple, 2006).

There is a growing consensus in the scientific literature that in the coming decades the world will witness higher temperature and changing precipitation levels (Rogelj *et al.*, 2016; IPCC, 2018). The effect of this might put a serious threat on Agricultural productions. Evidence has shown that climate variability is already affecting crop yields in many countries (IPCC, 2007; Deressa *et al*, 2008; BNRCC, 2008). Many African countries whose economies are majorly based on Agricultural productions like Nigeria are vulnerable to this change. This may lead to a reduction in farm income, food scarcity, malnutrition, hunger and increase in poverty (Abdulai, 2018; Lokonon and Mbaye, 2018).

With the present population growth and development in Africa, the agricultural sector is already facing a challenge to produce more food with less water or to produce more crops per drop (Molden *et al.*, 2003). Efforts to address climate change have so far focused on two response strategies: mitigation and adaptation (IPCC, 2001; Liu and Basso, 2020).

The main purpose of this research is to investigate the effect of inter-annual variation of climate on sorghum production in the semi-arid region of Nigeria. The inter-annual variability of rainfall, particularly in the northern parts is large, often results in climate hazards, especially floods and droughts

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with their devastating effects on food production and associated calamities and human sufferings. More often than not, certain parts of Nigeria receive less than 75 percent of their annual rainfall and this is particularly worrisome in the north (Ajetomobi and Abiodun, 2010). The climate of the country strides from a fairly wet coastal area with an annual rainfall greater than 3500 m to the Sahel region in the northwestern and northeastern parts with annual rainfall of less than 600 mm (Adejuwon, 2004).

II. MATERIALS AND METHODS

Study site

The study was undertaken at the Institute of Agricultural Research, Samaru, Zaria, a semi-arid region of Nigeria, one of the major Sorghum production belts of Nigeria. Samaru lies on Latitude 11^0 11'N and Longitude 7^0 38'E in the Northern Guinea Savanna zone of Nigeria. The immediate environments of the experimental site are the two local Governments of Giwa and Zaria.

Samaru experiences a typical tropical continental climate classified by Koppen as Aw [Tropical rainy climates (**A**), winter dry season (**w**)] (Reddy and Reddy, 2007). The climate is characterized by a unimodal rainfall pattern and hence one well-defined wet season which normally begin in April/May and ends in October and a dry season which extends from mid-October to April of the following year (Abaje, 2010).

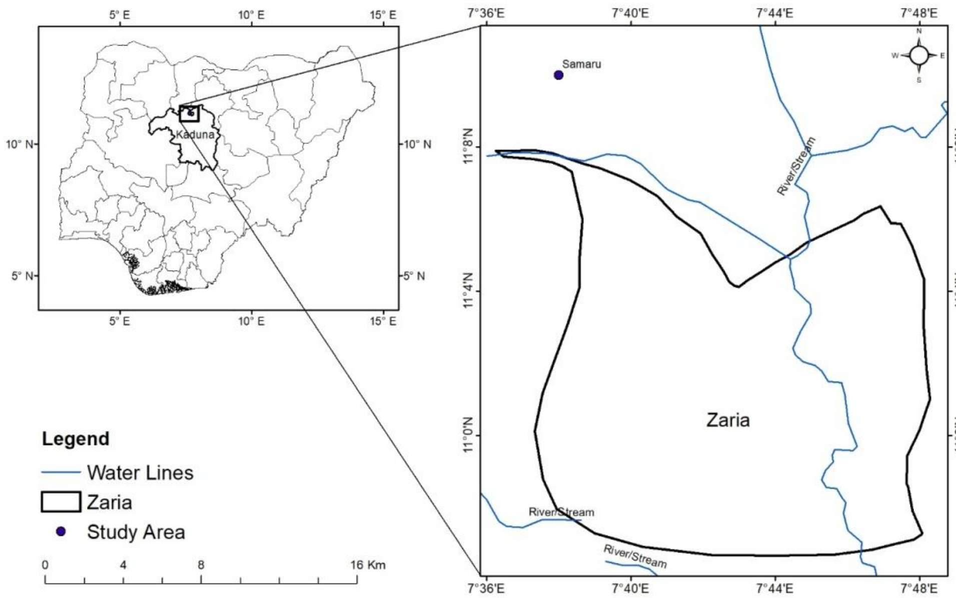

Figure 1: Map of Institute of Agricultural research Samaru Research Farm, Ahmadu Bello University, Zaria

Materials and Method of Analysis

The study area located in the semi arid region of Nigeria is one of the Northern region characterized by unimodal pattern of Rainfall. The annual rainfall in this region varies from 700 to 1000mm and average maximum temperature of between 20 - 23^0C while minimum temperature ranges between 20 – 23^0C(Akinseye et al, 2012). Data used for the study are crop yield data for sorghum variables; Daily historical data consisting of daily rainfall, minimum temperature, maximum temperature, relative humidity from 1989-2019 collected from the Meteorological station of the Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. Sorghum yield (kg/ha) data for corresponding years were obtained from the experimental farm of the Institute of Agricultural Research, Samaru, Zaria, located on Latitude 11^0 11'N and Longitude 7^0 38'E.

The standard precipitation index for the study area was considered putting into consideration the very wet and dry years. The total SPI were split into 10 years interval on a 3 monthly bases.

The statistical significance of Sorghum to climate variability was examined using Pearson's correlation coefficient. This method is based on whether or not there is a linear relationship between 2 or more variables. It is said to have a perfect correlation if the value is near ± 1, that is, as one variable increases, the other variable tends to also increase (if positive) or decrease (if negative). On the other hand if the

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coefficient value lies between ± 0.50 and ± 1, then it is said to be a strong correlation.

III. RESULTS AND DISCUSSION

The trend of annual Rainfall in Samaru, Zaria for the period of 1971 – 2017

Rainfall is very important in the phenological growth and yield of any crop and Sorghum is not an exception even though it is a drought-resistant crop, it still requires about 700 – 1000 mm of rainfall to do well especially at the vegetative stage. The growth of Sorghum is in stages; from the germination to the leafing, tasseling and finally, harvesting. All the stages need a certain amount of water to support yield. Crops are usually planted during the rainy season, implying that crop productivity is largely a function of rainfall. Irregularities in rainfall reliability and spread have therefore contributed significantly to the poor yields and high variability in production from year to year (Mortimore, 1989). To understand the effect of climate on sorghum production, annual analysis of rainfall is highly desirable.

Figure 2 shows the trend of annual rainfall for Samarubetween 1971 to 2017. It was observed that the rainfall is decreasing at the rate of 0.77mm/year in this station. This agrees with Odunze, (1997) who observed a similar trend.The reduction in rainfall was evident in the year 2009, although 2008 was a wet year. This was also observed by earlier study by Yamusa*et al.*, 2015. Lawal and Yamusa, (2020) observed that there was an inverse relationship between the amount of rainfall and the rainy days in Samaru, between 1961 – 2017. At about the same time in some African countries, for example Ethiopia, farmers reported a lack of rain in 2015 and it was described being worse than previous years for sorghum or other crops cultivation (Eggen*et al.*, 2019).

Figure 3a, b, c are the standardized precipitation index plots of the total rainfall for Samarubetween 1989 – 2017. It was deduced from the three plots (3a, 3b and 3c) that out of about 45 plots, more than 25 years experienced moderate-severe droughts. A more drought period is however observed between 1982 and 2001, coinciding with the Sahelian droughts of the early 1980s (Cohns, 1975, Anyamba and Tucker, 2005). However, Rainfall remains significantly below the average for the past century. In the Northern region of Togo, inter-seasonal monthly precipitation was reported to be significantly and negatively related to sorghum yield (Ali, 2018). The unpredictable precipitation frequency imposes water deficiency stress on crop growth, which in turn reduces biomass accumulation and residue return to soils (Basso *et al*., 2018).

Figure 4 implies that Samaru has a unimodal pattern of rainfall which gets to its peak around August and starts decreasing immediately after the peak until it eventually ceases. This makes it difficult to have the production of sorghum more than once a year, except with extensive irrigation, because it requires rainfall at its vegetative stages which might not be available since the pattern only provides once for that. This can account for reduction in the production/yield of sorghum in some climes where irrigation cannot be adopted.

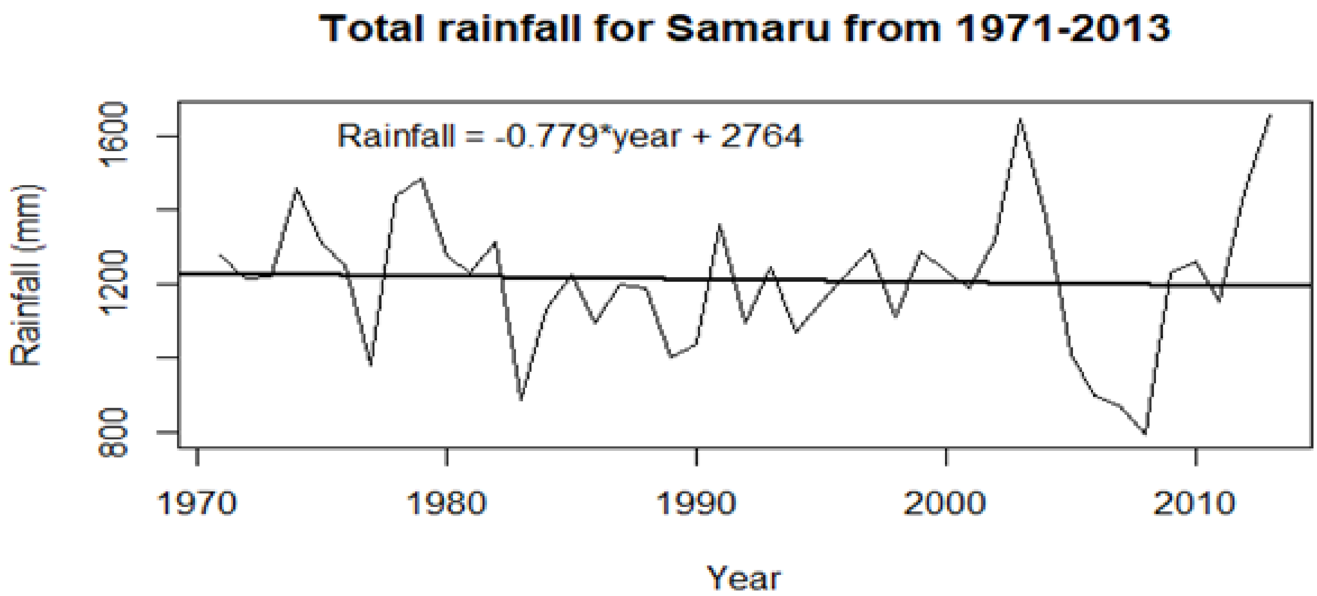

Figure 2: Total Rainfall for Samaru from 1971 – 2013

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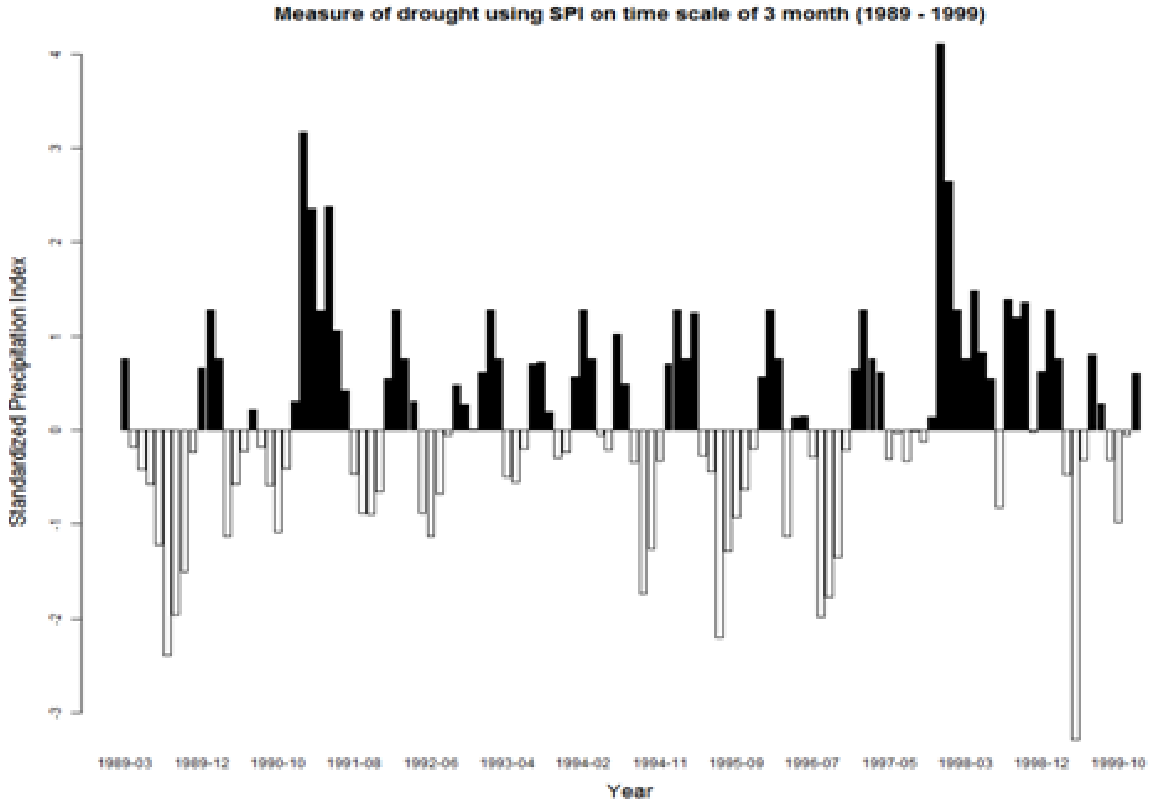

Figure 3a: Standard precipitation index on time scale of 3 months for Samaru (1989 – 1999)

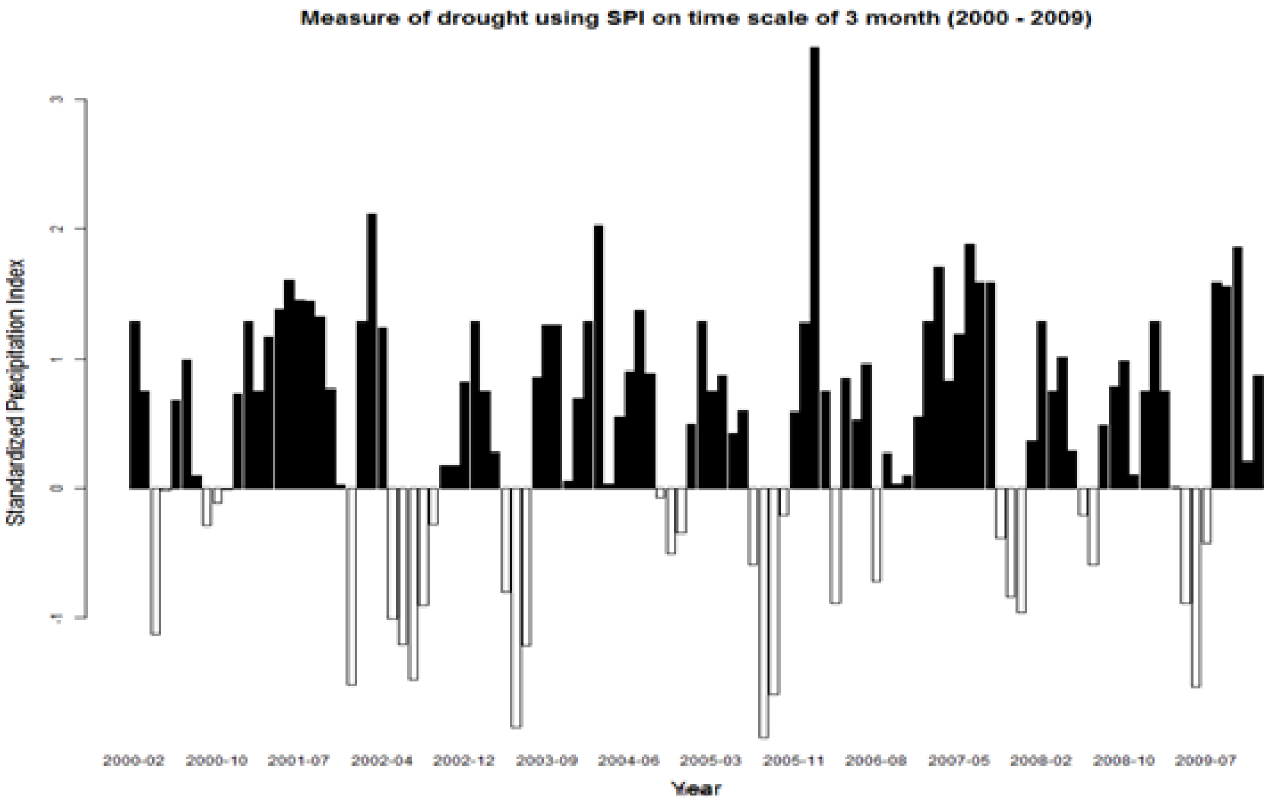

Figure 3b: Standard precipitation index on time scale of 3 months for Samaru (2000 – 2009)

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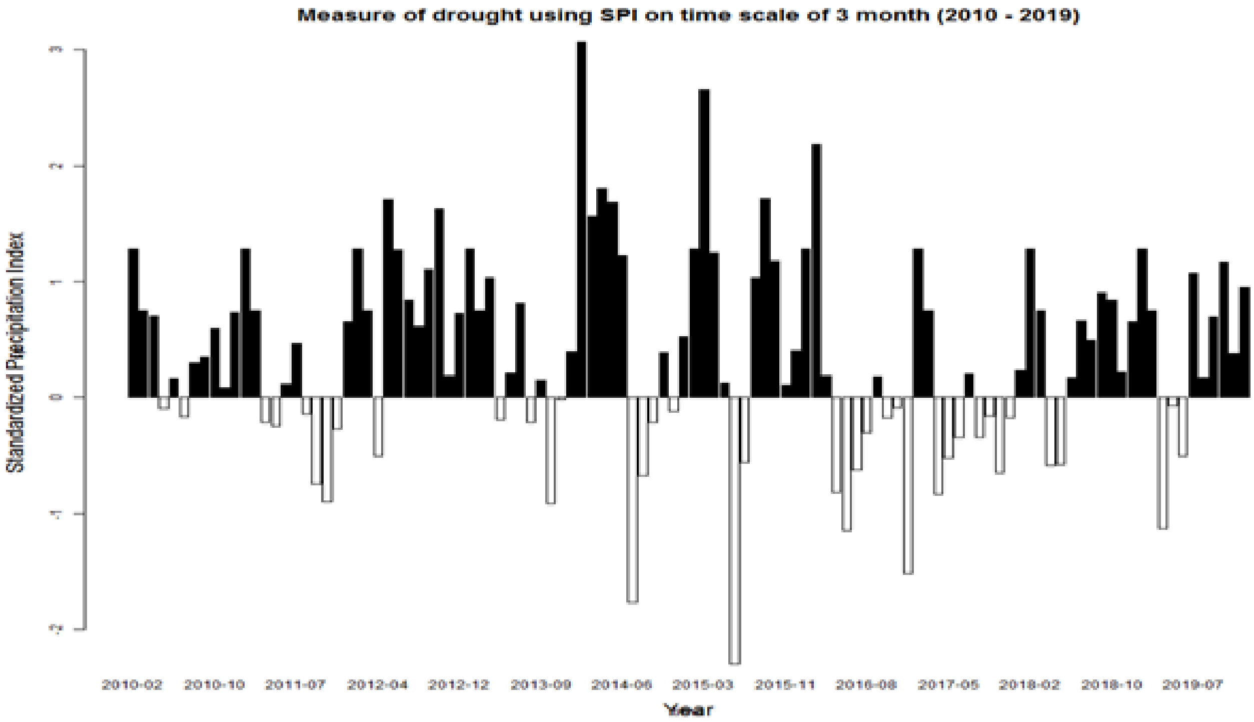

Figure 3c: Standard precipitation index on time scale of 3 months for Samaru (2010 – 2019)

Sorghum Yield Statistical Inference

Table 1: Average statistics for all variables

	Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Min. Temp (℃)	Mean	14	17	20.5	23.2	22.7	21.4	20.9	20.7	21.2	20.0	15.4	14.3
	STD	1.96	1.85	1.65	1.62	1.76	1.47	1.25	1.20	2.0	2.07	2.24	1.87
Max. Temp (℃)	Mean	30.9	33.9	36.7	37.4	34.6	31.7	30.0	29.2	30.8	33.1	32.9	31.7
	STD	2.86	2.75	1.60	1.19	1.57	0.90	0.94	0.91	0.77	3.36	1.72	2.60
Morning Temp 30 cm (℃)	Mean	23.6	25.4	28.4	30.4	29.2	28.8	26.1	25.6	26.4	26.9	25.6	23.8
	STD	1.99	1.25	0.996	1.06	1.13	5.14	0.42	0.46	0.44	1.22	2.04	1.81
	Mean	24.7	26.6	29.9	32.1	30.5	28.5	27.0	26.2	27.1	27.6	26.5	25.0
Afternoon Temp 30 cm (℃)	STD	2.08	1.32	2.24	2.18	1.34	1.78	0.74	0.52	0.54	0.78	0.98	1.27
Morning Relative Humidity (%)	Mean	21.5	18.8	23.2	45.4	67.5	75.7	81.8	83.4	78.8	67.1	30.6	23.6

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	STD	10.1	10.8	11.8	11.1	5.70	5.32	3.43	3.02	3.89	8.41	10.3	9.68
Afternoon R.H (%)	Mean	16.9	14.9	17.2	28.8	48.6	61.6	68.9	74.1	75.7	53.7	26.3	18.6
	STD	7.92	8.08	8.42	10.3	6.97	6.01	5.2	4.89	36.6	11.1	8.98	5.45

n = 372 observations

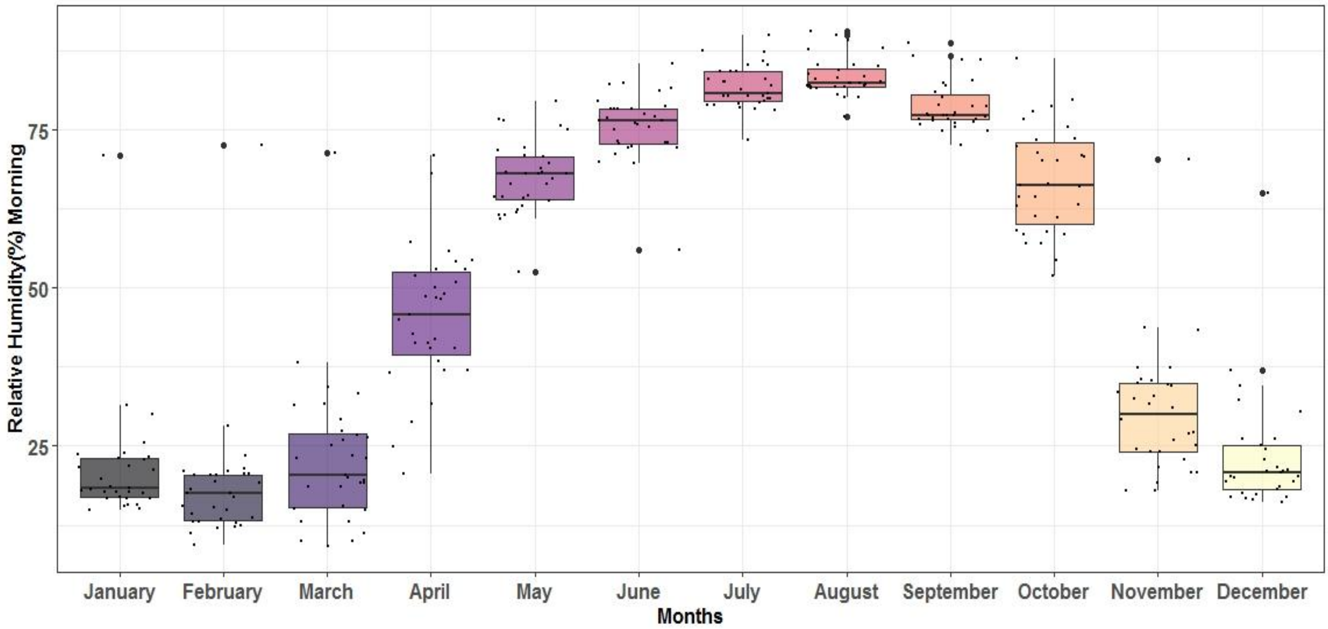

Figure 4: Box Plot showing average morning relative humidity (℃) between 1989 and 2019

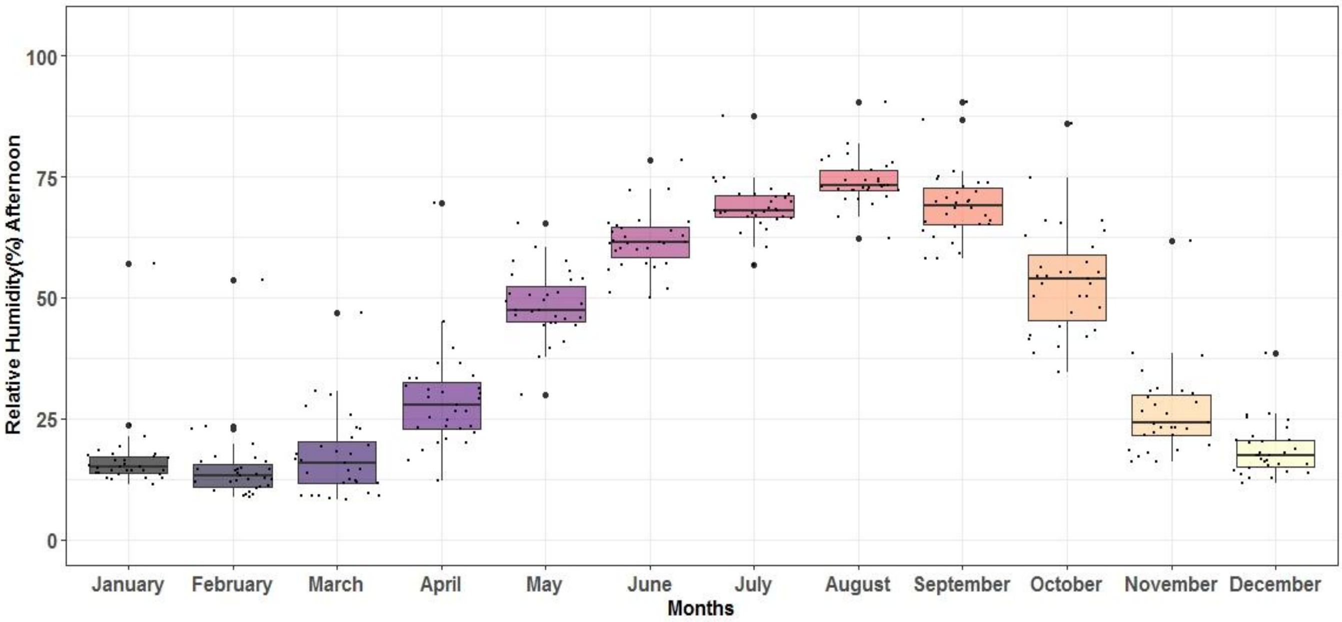

Figure 5: Box Plot showing average afternoon relative humidity (℃) between 1989 and 2019

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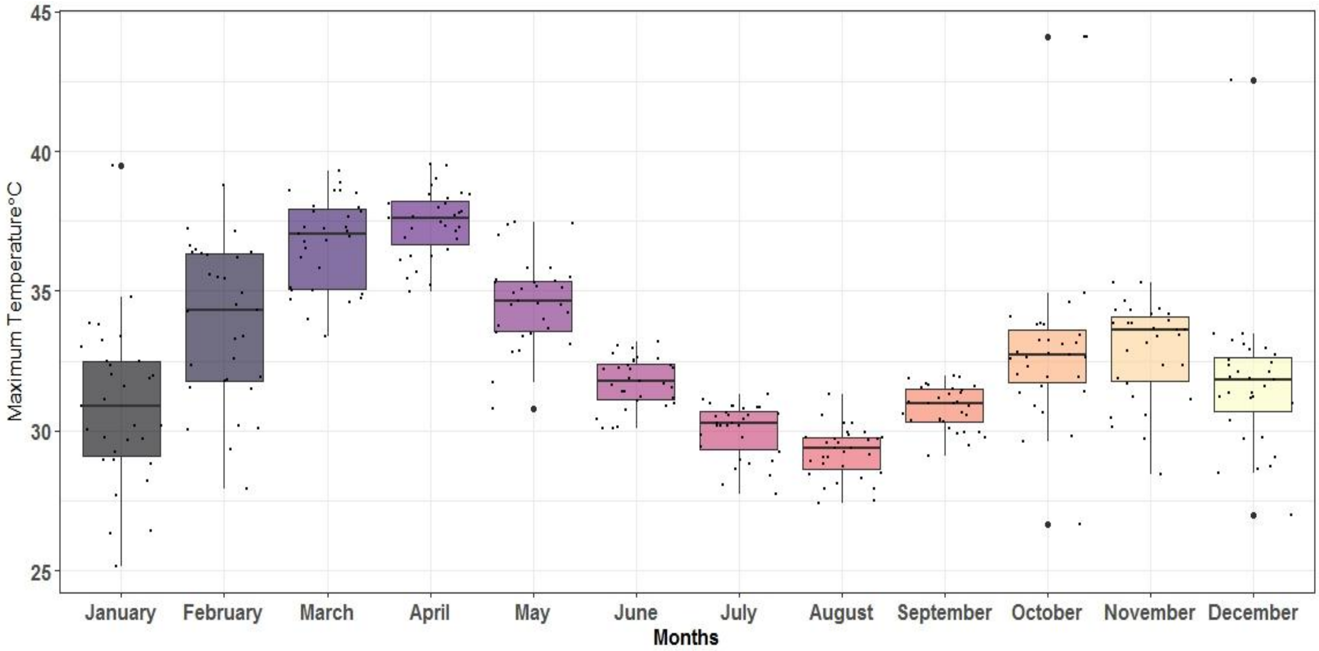

Figure 6: Box Plot showing average monthly maximum temperature (℃) between 1989 and 2019

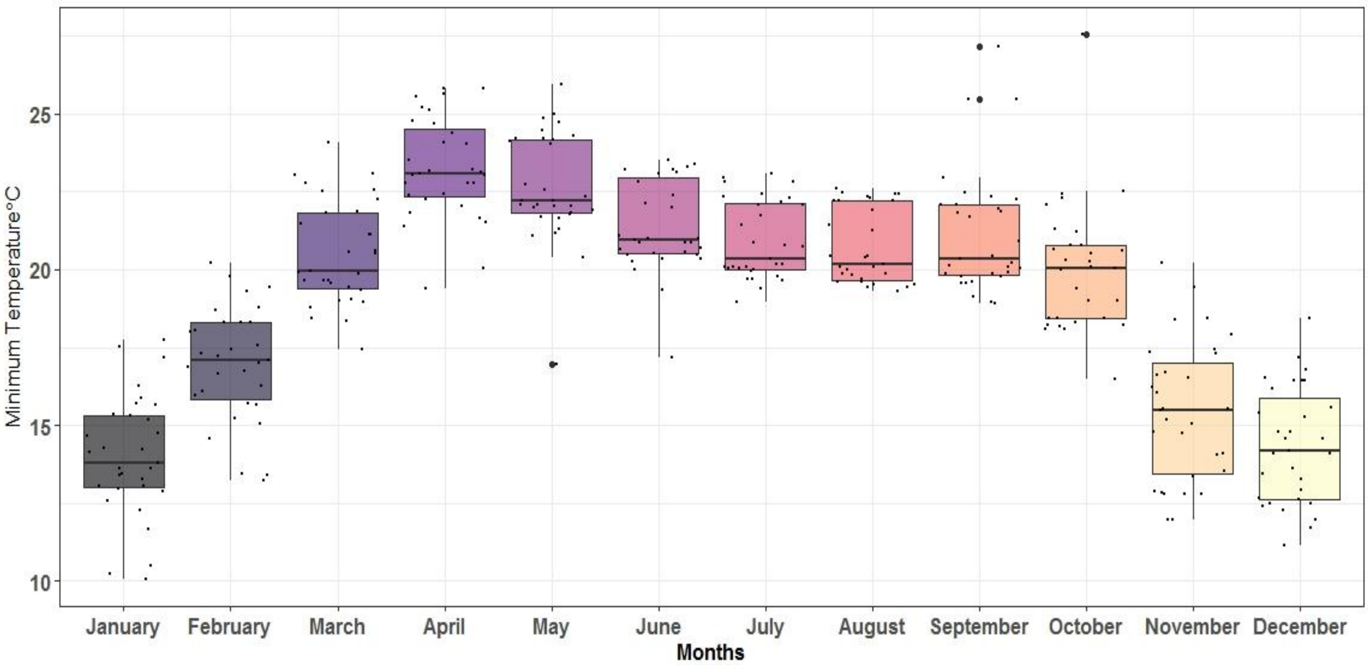

Figure 7: Box Plot showing average monthly minimum temperature (℃) between 1989 and 2019

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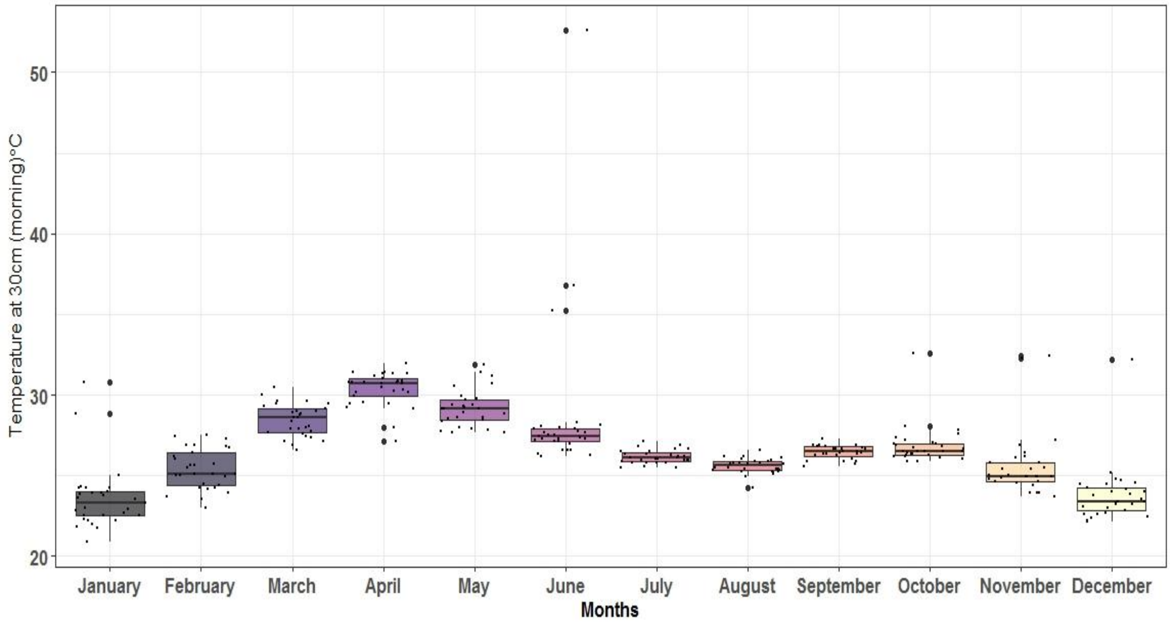

Figure 8: Box Plot showing average morning temperature at 30 cm (°C) between 1989 and 2019

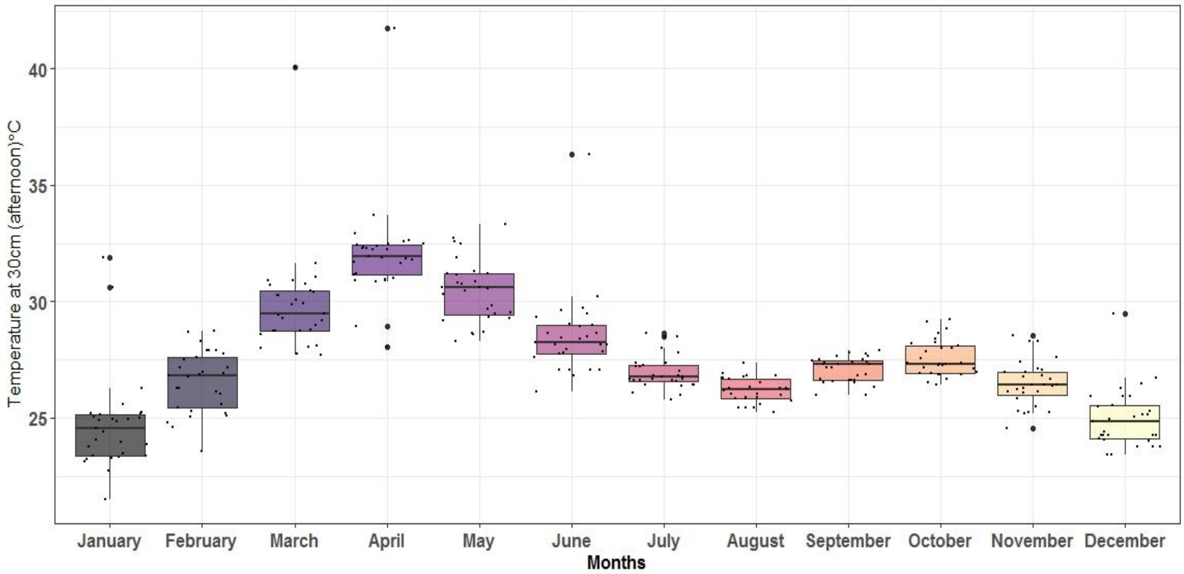

Figure 9: Box Plot showing average afternoon temperature at 30 cm (°C) between 1989 and 2019

Table 1 summarizes the average monthly statistics across all climatic variables between 1989 and 2019. In Figs. 4 & 5, relative humidity variations show similar characteristics in the morning and afternoon hours, maximum in July, August at the peak of the wet season and minimum in the dry winter months (December to February). The mean relative humidity was observed highest at 81.8% and 83.4% in July and August respectively for morning hours, and 68.9% and 74.1% for afternoon in similar months. In the winter months, relative humidity was lower with 23.6%, 21.5% and 18.8% in December, January and February respectively for morning hours and 18.6%, 16.9% and 14.9% in the afternoon. Higher variations were observed in relative humidity during morning hours in winter months as compared to the afternoon hours, while the variations were relatively lower in the summer months for morning hours than in the afternoon.

The maximum temperature as represented in Figure 3 shows a double maxima pattern in April and November, and minimum in August. Higher values were observed in dry months with peak maximum temperature in April at an average of 37.4±1.19°C. Also, maximum temperature was much lower during the raining between June – September (JJAS). In the drier months maximum temperature ranges were higher averaging 33.9°C, 36.7°C, 37.4°C and 34.6°C between February and May. The minimum

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temperature variations showed in Figure 4 shows different variations as compared to the maximum temperature. Lower values were observed herein in the winter months between November to February at 15.4℃, 14.3℃, 14℃ and 17℃ respectively. Peak values of minimum temperature were observed in April and May at 23.2℃ and 22.7℃ respectively.

The average temperature (30 cm) in the morning and afternoon hours showed similar variations (Figs. 8 & 9). Higher temperature values were observed in the dry months between March and May, while lower values were seen in some rainy months and the winter season. However, average temperature in the afternoon hours were significantly higher than morning hours through the months as seen in Table 1. This is expected, as afternoon hours receive more incoming solar radiation and higher daytime heating than the morning hours.

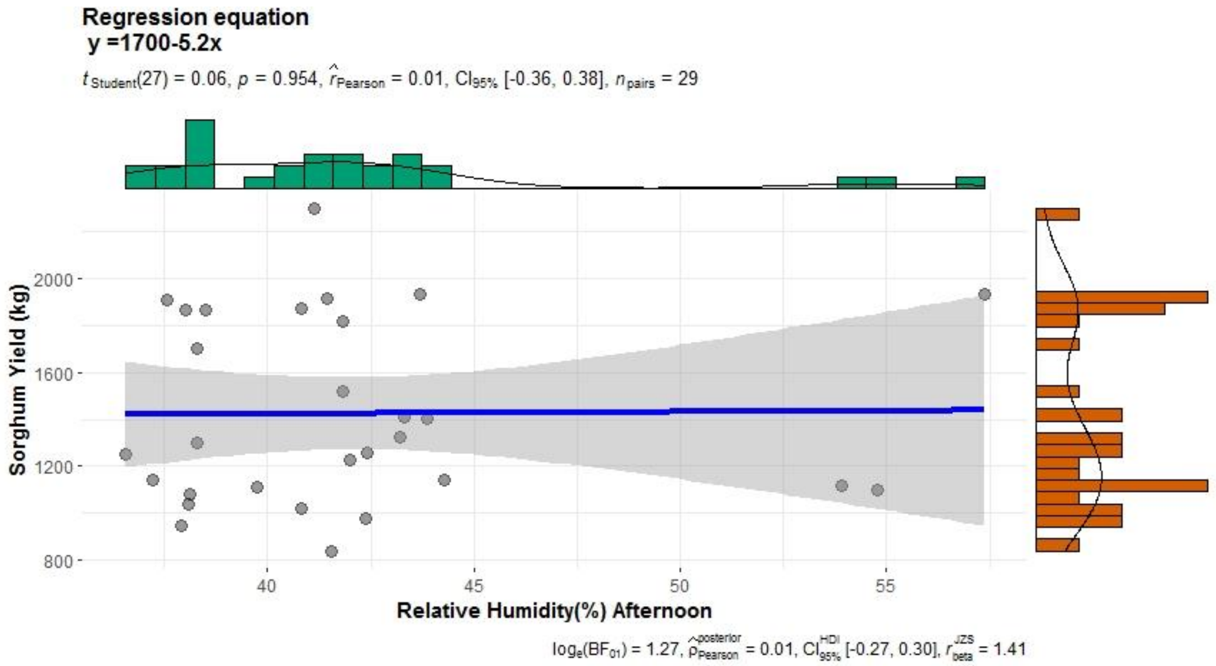

Figure 10: Scatter Plot of Sorghum yield (kg/ha) and relative humidity (%) afternoon

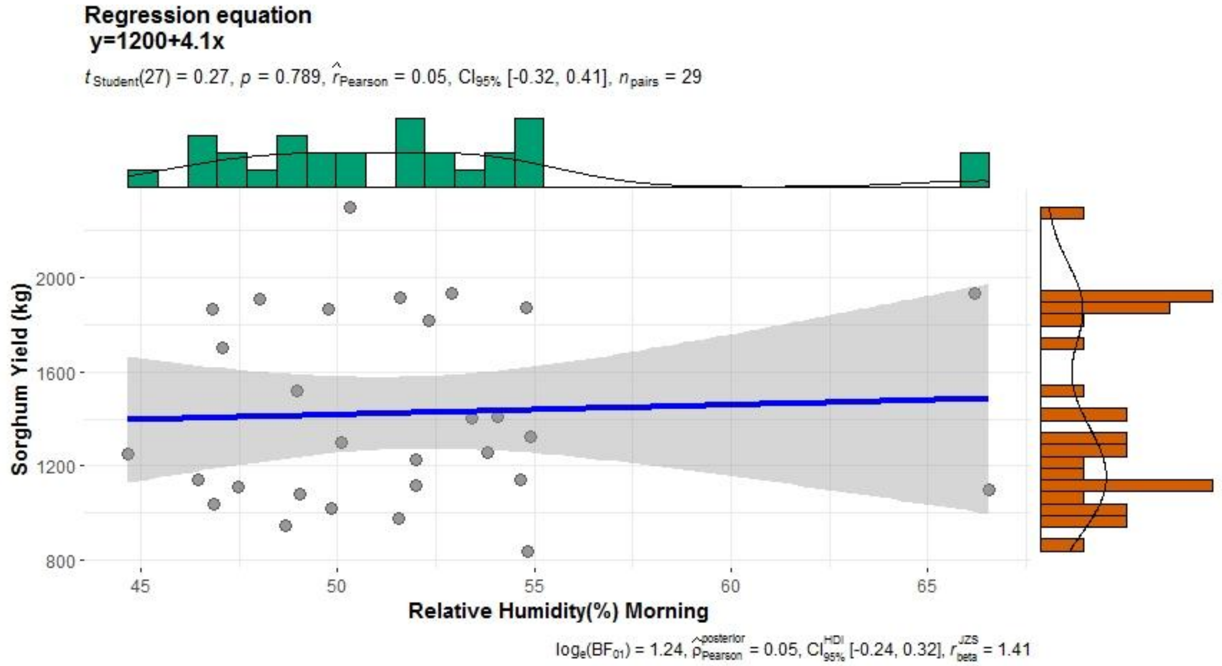

Figure 11: Scatter Plot of Sorghum yield (kg/ha) and relative humidity (%) morning

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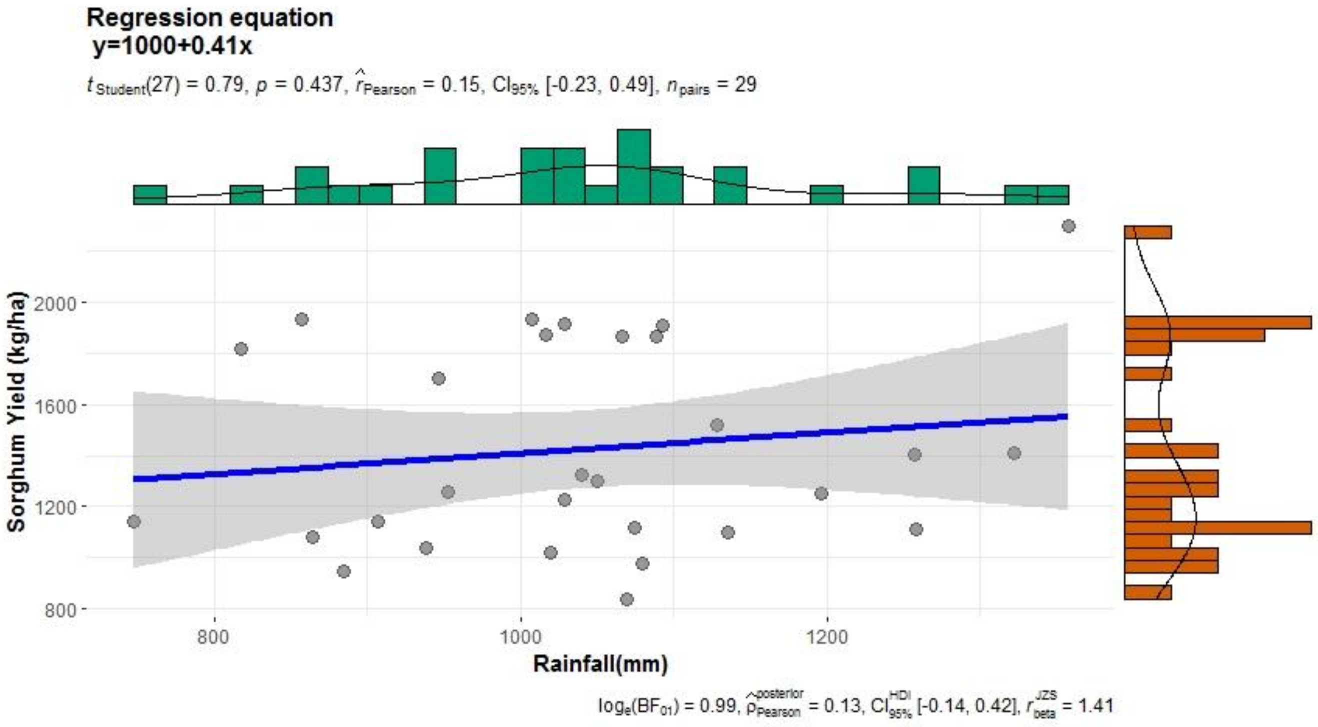

Figure 12: Scatter Plot of Sorghum yield (kg/ha) and rainfall (mm)

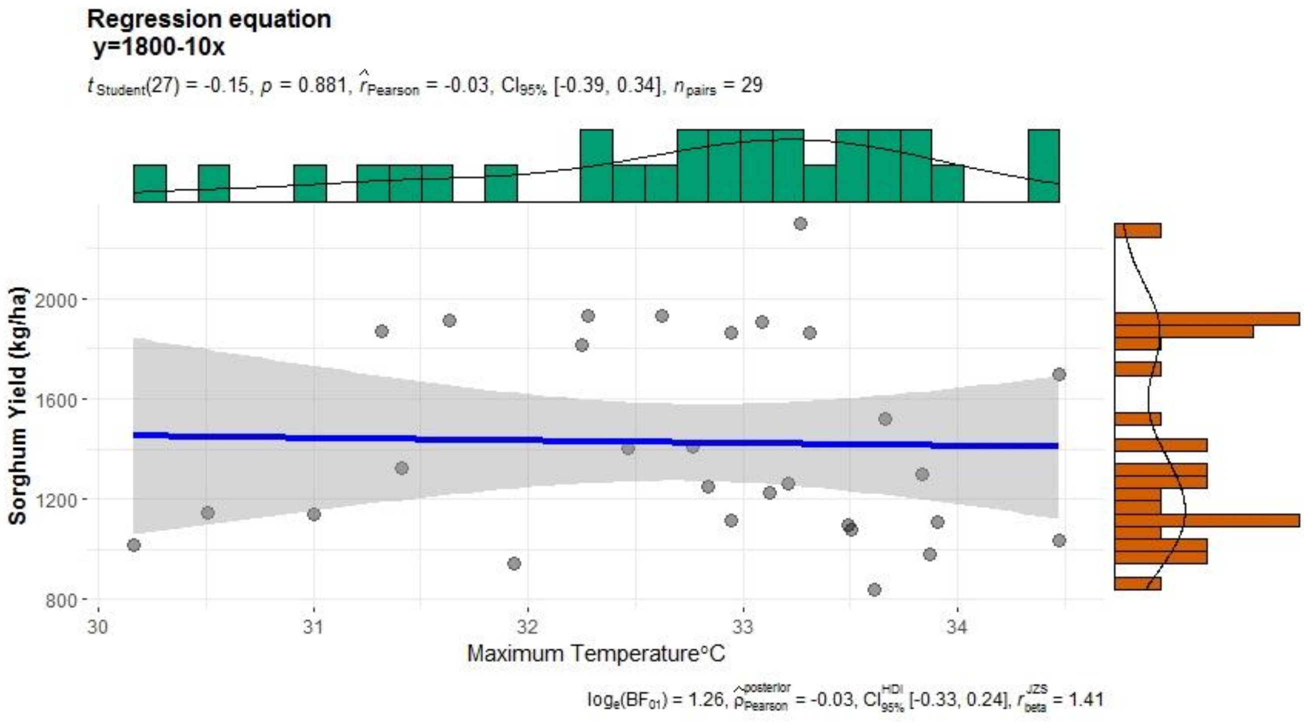

Figure 13: Scatter Plot of Sorghum yield (kg/ha) and maximum temperature (℃)

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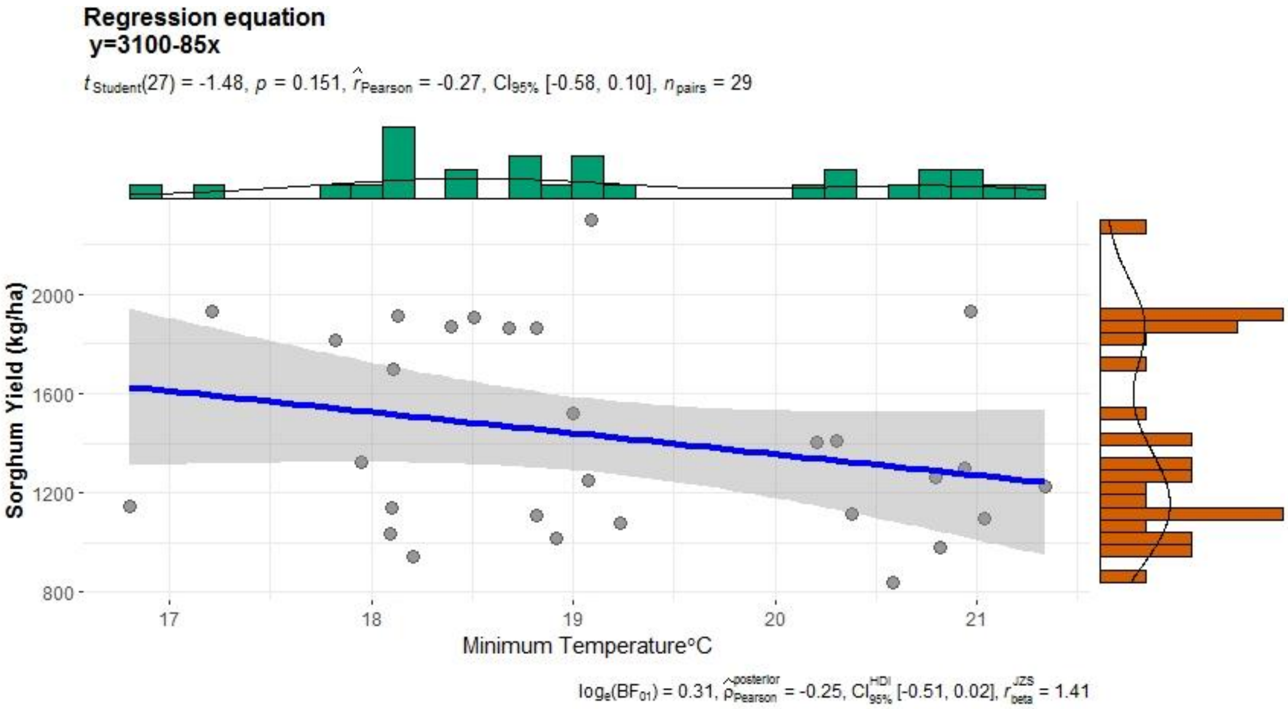

Figure 14: Scatter Plot of Sorghum yield (kg/ha) and minimum temperature (℃)

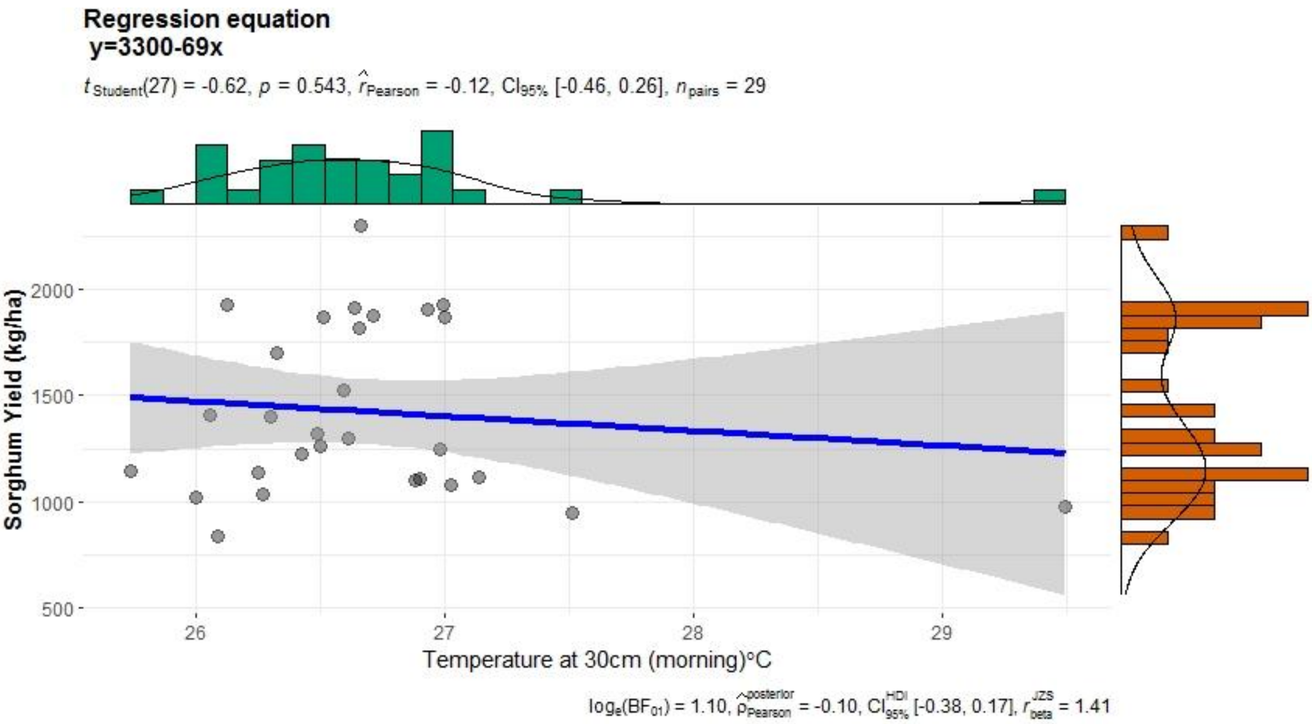

Figure 15: Scatter Plot of Sorghum yield (kg/ha) and temperature (℃) at 30cm (morning)

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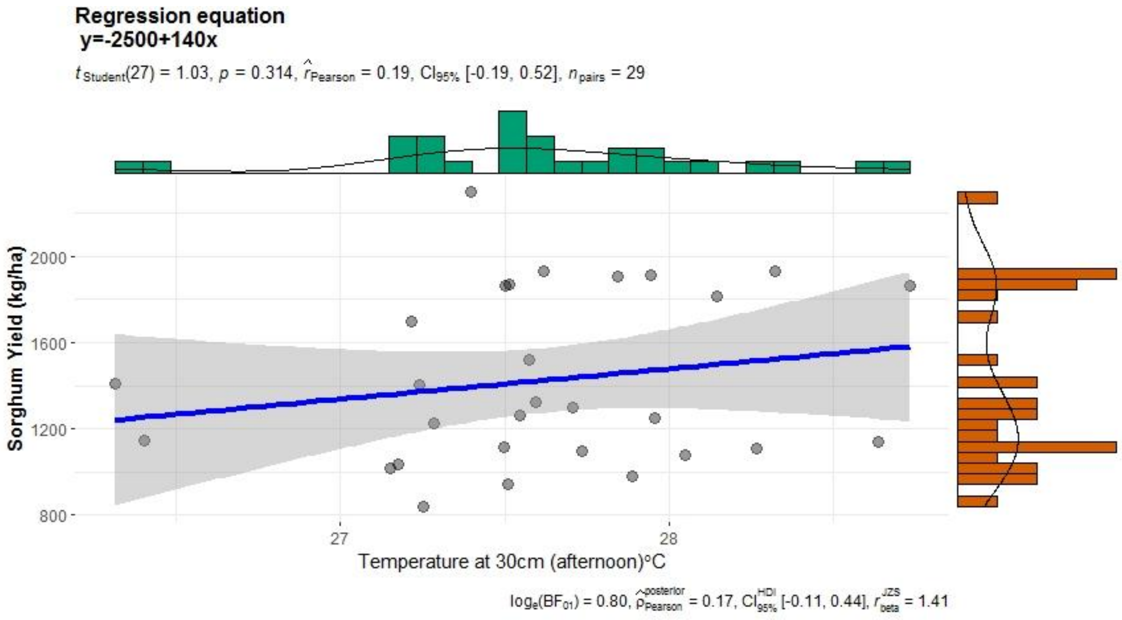

Figure 16: Scatter Plot of Sorghum yield (kg/ha) and temperature (℃) at 30 cm (afternoon)

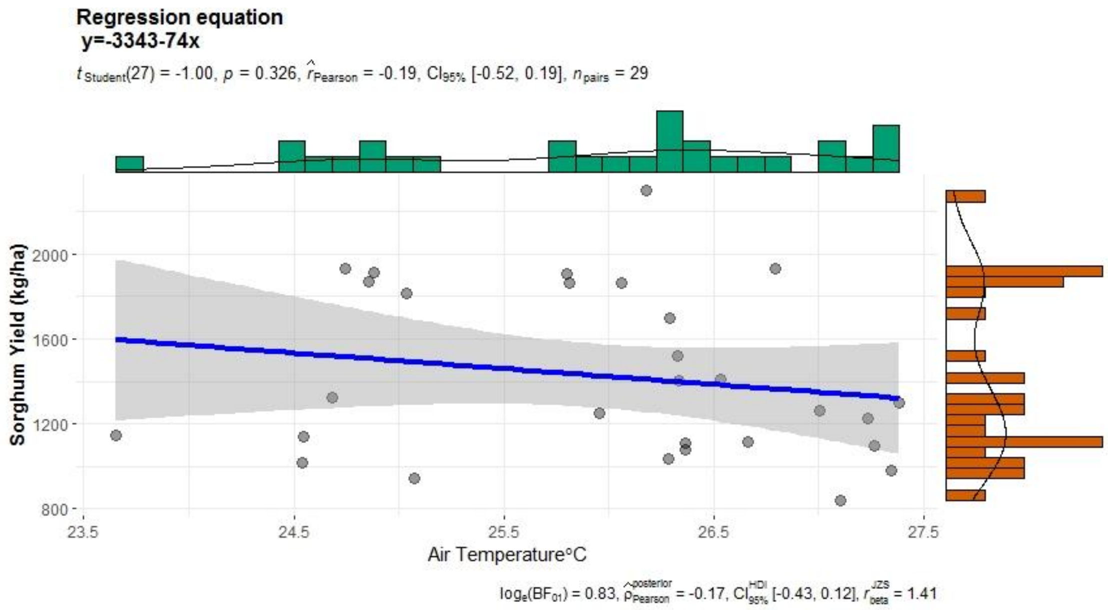

Figure 17: Scatter Plot of Sorghum yield (kg/ha) and air temperature (℃)

The relationship (Statistical effect) of each climatic variable (relative humidity, rainfall, air temperature, minimum and maximum temperature) on sorghum yield (kg) is shown in (Figs. 10 to 17). The statistical effect of relative humidity (afternoon) on sorghum yields as depicted in Figure 10 indicated that sorghum yield was more largely concentrated under a certain climatic condition when relative humidity (morning) falls below 45%, the highest sorghum yield (kg) production also coincide with this range. This was also statically insignificant at p-value of 0.954. On the other hand, average relative humidity in the morning hours (Fig. 11) was also insignificant (p-value = 0.789), though lesser as compared to the afternoon hours. Also, sorghum yields were largely distributed between the range less than 55% relative humidity. Similar range below and above the trend line in both hours of the day (morning and afternoon) shows relative humidity amount may have less effects in estimating the total sorghum yield.

Furthermore, the statistical significance of monthly rainfall is examined with the sorghum yield (Fig. 12). The regression line showed positive correlation between rainfall amount and sorghum yield. However, a lower correlation coefficient (r) value of 0.15 showed rainfall has minimal or insignificant effect on sorghum yields. A p-value of 0.437 also shows less significance of this climatic variable on sorghum production.

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For maximum and minimum temperature, both variables showed negative correlations with sorghum yield at correlation coefficient (r) of -0.03 and -0.27 respectively. The p-value of 0.881 for maximum temperature shows that the variable is statistically insignificant to sorghum yield. For minimum temperature, the p-value of 0.151 means it is more statistically significant to sorghum yield compared to maximum temperature. Higher minimum values of minimum temperature might reduce sorghum yield production.

Finally, the study considers the effects of temperature at 30 cm and air temperature on sorghum yield production (Figs. 15-17). At 30 cm, negative correlation (r = -0.12) was observed for sorghum production in morning hours temperature as compared to positive correlation (r = 0.19) in the afternoon. Negative correlation (r = -0.19) was also observed between sorghum production and average air temperature. The p-value were relatively high for all three variables suggesting they are statistically insignificant to sorghum production over the study region. However, a near-indirect relationship exists between average air temperature and temperature at 30 cm in the afternoon. Also, it is noteworthy that about 90 % of sorghum yield produced were recorded when morning temperature at 30 cm varied between 26 °C – 27 °C.

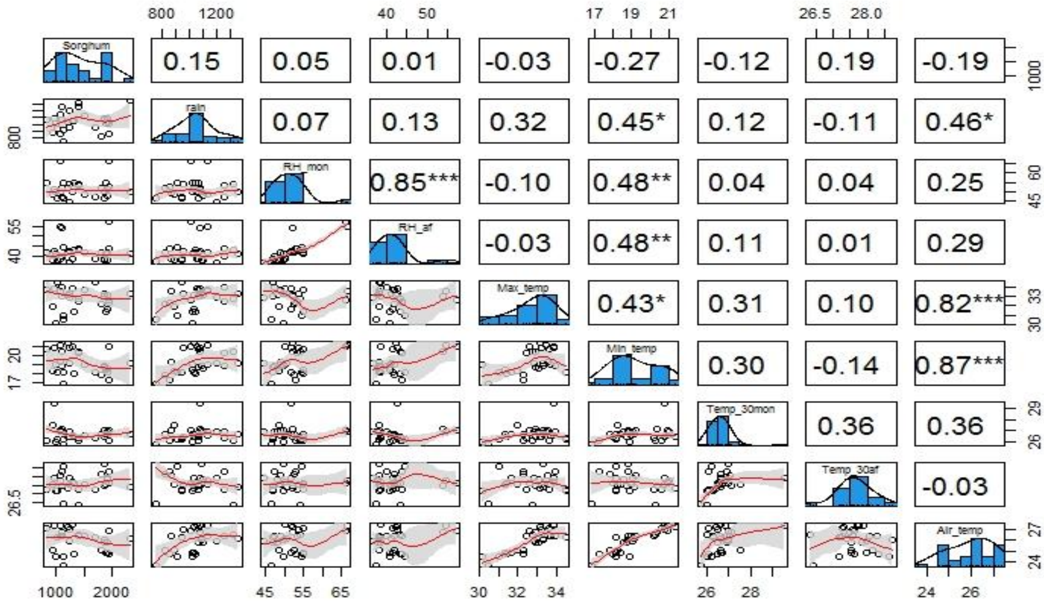

Figure 18: Correlation Matrix of Sorghum yield (kg/ha) and relative humidity (morning and afternoon), rainfall, minimum and maximum temperature, air temperature and temperature at 30 cm (morning and afternoon)

Table 2: Spearman Pearson Correlation for Sorghum Yield (kg/ha)

	Sorghum	*rain*	*RH_mon*	*RH_af*	*Max_temp*	*Min_temp*	*Temp_30mon*	*Temp_30af*	*Air_temp*
Sorghum		0.150	0.052	0.011	-0.029	-0.274	-0.118	0.194	-0.189
rain	0.150		0.067	0.125	0.322	0.449*	0.119	-0.110	0.461*
RH_mon	0.052	0.067		0.854***	-0.098	0.480**	0.036	0.045	0.249
RH_af	0.011	0.125	0.854***		-0.035	0.484**	0.106	0.015	0.286
Max_temp	-0.029	0.322	-0.098	-0.035		0.428*	0.313	0.101	0.821***
Min_temp	-0.274	0.449*	0.480**	0.484**	0.428*		0.301	-0.137	0.867***
Temp_30mon	-0.118	0.119	0.036	0.106	0.313	0.301		0.359	0.363
Temp_30af	0.194	-0.110	0.045	0.015	0.101	-0.137	0.359		-0.031
Air_temp	-0.189	0.461*	0.249	0.286	0.821***	0.867***	0.363	-0.031	

Computed correlation used pearson-method with listwise-deletion.

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IV. CONCLUSION AND RECOMMENDATION

From the study, it was noted that Sorghum requires minimal rainfall to establish its flowering after which it thrives with very little or no rainfall. The result from the study conducted by Akinseye *et al.* (2020) confirmed that temperature and rainfall could be factors limiting sorghum production in a semi-arid area. It is also noteworthy to state that varieties of sorghum that are of medium to late maturity may be favored with the rainfall pattern due to changes in the weather variables as a result of their ability to recover from any moisture stress and also adjust to higher temperatures during the growing season.

Planting of sorghum is majorly done in May except there is a deviation in the onset of rainfall in the study area. At the planting time in May, the maximum temperature is needed for proper exposure and germination of the seeds sown. There is a negative correlation observed for some months of production, and this concurred with the prediction of Rowhani *et al.* (2011) that sorghum is likely reduced in yield by about 8.8% as a result of a 2°C increase in seasonal temperature. The maximum temperature is relevant to Sorghum production at the stage of growth which is called the boot stage. Moreover, an increase in temperatures can contribute to spoilage and contamination. Reduction in yield was reported to be due to the effect of high temperature in shortening the growth cycle, heat stress, reduction in photosynthesis rate during an thesis, increase in evapotranspiration loss, reduction in organic carbon, and unavailability of nutrients (McCarthy and Vlek, 2012; Deryng *et al.*, 2014; Sunoj *et al.*, 2017). The increase or decrease in maximum and minimum temperature invariably determine whether the crop will give a bumper harvest or will be reduced relatively. These and good management practices are the bedrock of profitable sorghum farming.

Furthermore, the minimum temperature is also an essential element for the cultivation of sorghum, so also is the relative humidity. The relative humidity is responsible at the budding, flowering and seeding stage of growth. A very high relative humidity will cause seed moulding.

The effect of rainfall on sorghum yield is very important because rainfall helps in establishing germination at the initial stage of planting (around May) and during the sprouting and budding stages. Although, sorghum is drought resistant crop but it is also sensitive to dryness especially after panicle initiation and post-flowering (Assefa*et al.*, 2010; Rurinda*et al.*, 2013). In the study conducted in the Northern Ghana, it was reported that inter-annual sorghum yield was significantly sensitive to total rainfall in the planting season (Amikuzuno and Donkoh, 2012). Likewise, the study among Ethiopian farmers stated lack of early rainfall as a cause of sorghum yield reduction in 2015 (Eggen*et al.*, 2019).

It is therefore of no doubt that climate variability will affect food security at the global, regional, and local level. Climate change can disrupt food availability, reduce access to food, and affect food quality (USDA, 2015). The projected increase in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability will all result in reduced agricultural productivity. Results from this study have shown that over Samaru, the weather pattern is of utmost significance to sorghum production in that the crop gets essential amount of each wether parameter at every stage of growth.

All the parameters under study are very relevant to the yield of sorghum at every stage of growth and hence, should be well studied over a particular location to know how well they suit the yield. Further study can be done in this regard for other locations, other crop types and more weather parameters. Increase in the frequency and severity of extreme weather events can interrupt food delivery, and resulting in spikes in food prices.

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