

PROCEEDINGS OF THE NIGERIAN METEOROLOGICAL SOCIETY CONFERENCE 2024

25 – 28 November 2024

Olusegun Agagu University of Science and Technology

Okitipupa, Ondo state, Nigeria

EDITORS

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**OLUSEGUN AGAGU UNIVERSITY OF SCIENCE AND TECHNOLOGY
(OAUSTECH) OKITIPUPA NIGERIA**

Theme:

**SUSTAINABLE DEVELOPMENT
IN A CHANGING CLIMATE:
THE ROLE OF METEOROLOGY**

NIGERIAN METEOROLOGICAL SOCIETY (NMetS)
2024 NATIONAL CONFERENCE AND 34TH ANNUAL GENERAL MEETING
HELD AT OLUSEGUN AGAGU UNIVERSITY OF SCIENCE AND TECHNOLOGY,
OKITIPUPA, ONDO STATE, NIGERIA

BOOK OF PROCEEDINGS

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IMPACT OF TEMPERATURE AND RAINFALL FLUCTUATIONS ON THE GROWTH STAGES OF WHEAT (TRITICUM AESTIVUM L.) IN THE SAVANNAH REGION: AN AGRO-METEOROLOGICAL PERSPECTIVE

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ABSTRACT

Agricultural activities most especially crop production is climate determined in all ecological zones of Nigeria. Wheat crop production in the savannah ecological zone of Nigeria faces significant challenges due to climate variability, particularly temperature and rainfall fluctuations. Crop productivity is strongly influenced by these climatic factors, as they affect all stages of crop growth and development and hence yield. This study investigates the impact of temperature and rainfall variability on the growth stages of wheat (*Triticum aestivum* L.) in the savannah region of Nigeria. Ten years climatic data from the Nigerian Meteorological Agency and wheat yield data from the Lake Chad Research Institute were analyzed. Pearson Moment Correlation and Multiple Regression analysis were employed to assess the relationship between wheat yield and selected climatic variables. Results revealed that maximum temperature ($r = 9.8$) was positively correlated with wheat yield, though not statistically significant, while minimum temperature ($r = -25.1$) and rainfall ($r = -45.7$) exhibited negative correlations, with rainfall being statistically significant at $p < 0.05$. The coefficient of determination (R^2) indicated that 78.2% of the variation in wheat yield was explained by these climatic variables. The study concludes that fluctuations in temperature and rainfall significantly impact wheat growth, especially during critical stages such as germination and flowering. To mitigate these effects, the adoption of climate-smart agricultural practices, is recommended.

KEYWORDS: Climate variability, Wheat yield, Temperature fluctuations, Rainfall variability, Agro-meteorology

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple food crop that plays a crucial role in global food security (Maity and Shrivastav, 2024; Abideen et al. 2023; Acevedo et al. 2018), providing a major source of calories and protein for billions of people. According to Ugwuona et al. (2023), in Nigeria, wheat production has become increasingly important due to the growing demand for wheat-based products such as bread, pasta, and noodles. Although traditionally, Nigeria is not a major wheat-producing country, but it has recognized the potential of expanding wheat cultivation to reduce import dependence and ensure food security (Adeleke et al. 2023). Reports indicate that one of the regions where wheat production potential is high is the Savannah ecological zone (Akaangee et al. 2023). The Savannah ecological zone of Nigeria, covering a vast portion of the country's central and northern regions, is characterized by semi-arid conditions with distinct wet and dry seasons. According to Agegnehu et al (2024), this zone offers unique opportunities for wheat cultivation, particularly due to its large land area, suitable soil types, and climate conditions that, when properly managed, can support wheat growth. Nigeria imports a significant proportion of the wheat it consumes, making the country vulnerable to fluctuations in global wheat prices and supply chain disruptions.

Expanding wheat production in the Savannah zone can help reduce the nation's dependency on imports, ensuring a steady supply of this critical staple crop for its growing population (Erenstein et al. 2022).

According to Sadiq et al (2024), wheat farming has the potential to provide significant economic benefits to rural communities in the Savannah region. By increasing wheat production, farmers can generate additional income, create employment opportunities, and stimulate rural economies. Moreover, developing the wheat value chain (processing, storage, and transportation) will also boost local industries and enhance economic activities. Given the challenges posed by climate change and the declining productivity of traditional crops like maize and millet in some parts of Nigeria, wheat offers a viable alternative. Diversifying into wheat production can enhance the resilience of the agricultural sector, allowing farmers to adapt to changing environmental conditions while taking advantage of the high demand for wheat products (Naik et al. 2024; Silva et al. 2023; King et al. 2024; Noort et al. 2022).

Scientists observed that temperature is a critical environmental factor that influences every stage of wheat growth, from germination to maturity (Filip et al. 2023; Sharma et al. 2022; Slafer et al. 2021). Wheat is a temperate crop that thrives in cool to moderate temperatures, making the timing of planting and the management of temperature fluctuations essential for

optimal growth in Nigeria's Savannah region. Wheat seeds require a soil temperature of approximately 10–15°C for successful germination (Faisal et al. 2023). Temperatures that are too high can inhibit germination, while excessively low temperatures may delay the process. In the Savannah zone, the planting of wheat is typically done during the cooler dry season to ensure that the early growth stages occur under favorable temperature conditions (Verma et al. 2024; Peery et al. 2023).

According to Lin et al. (2023), during the vegetative phase, moderate temperatures (15–25°C) are ideal for wheat development. However, high temperatures, particularly during this phase, can negatively affect photosynthesis and biomass accumulation, leading to stunted growth and reduced yields. Sall et al. (2024), posited that in the Savannah zone, wheat is vulnerable to heat stress if temperature spikes occur during critical stages of vegetative growth, making temperature monitoring essential. The reproductive stage, including flowering and grain filling, is highly sensitive to temperature. Optimal temperatures for this stage range from 20–25°C. Exposure to high temperatures during flowering can result in pollen sterility, while elevated temperatures during grain filling can lead to poor grain development, reduced grain weight, and lower overall yield. This is especially important in the Savannah region, where late-season heat waves can compromise grain quality and quantity (Pandey et al. 2023).

Durowoju et al (2023), explained that rainfall is another crucial factor that affects wheat production, particularly in the rain-fed agricultural systems common in Nigeria's Savannah ecological zone. The region experiences distinct wet and dry seasons, with most of the annual rainfall occurring between May and October. For successful wheat cultivation, managing water availability is essential. Adequate soil moisture is necessary for seed germination and early seedling development. In the Savannah zone, wheat is typically planted after the rainy season when the soil retains moisture, ensuring that the seeds can germinate and establish a strong root system before the dry season sets in (Si et al. 2023; Singh et al. 2023; Zeng et al. 2023).

Batool et al. (2023), observed that wheat requires a consistent supply of water throughout its growth stages, particularly during tillering, flowering, and grain filling. However, excessive rainfall during the growing period can lead to waterlogging, which negatively affects root respiration and nutrient uptake. In contrast, drought conditions during critical stages, especially during grain filling, can result in yield losses. Thus, farmers in the Savannah region must carefully manage irrigation and water conservation practices to ensure that wheat receives adequate moisture (Brempong et al. 2023; Yadav et al. 2022).

Study Area

The study area is the savannah ecological zone of Nigeria. Savannah zone is located within latitudes 6° 58' and 13° N of the equator and between longitudes 3° and 14° E of the Greenwich Meridian (Idowu et al. 2011). The area covers approximately 730,885 km². The Savannah ecological zone of Nigeria is an extensive area covering nineteen northern states and extending into the northern fringes of Ondo, Osun, Edo, Anambra, Enugu, Ebonyi and Cross River State as indicated in Figure 1.

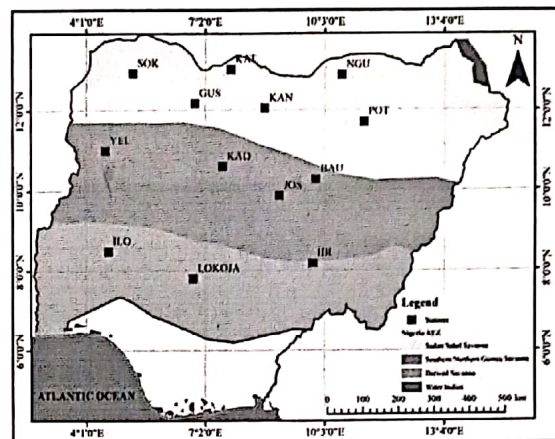


Figure 1: Study Area

Source: Office of the Surveyor General of the Federation, Abuja; Google Map (2024)

The landscape of the Nigerian savannah environment is typified by vast, level plains that are sporadically broken up by granite mountains. However, the African Shield's old crystalline rocks make up the majority of the surface of the Nigerian savannah. There are significant areas with little portions of younger granites in the Jos Plateau. Photius (2004) posited that sedimentary strata dating back from various eras cover the parent and older rocks in different places within the savannah region. Wide plains with few notable rocky outcrops and characteristic table-topped ridges are typical features of sedimentary rock formations. The Niger and Benue River basins are frequently home to this type of ecosystem. The deep ravines of the Chad and Sokoto rivers, located in the extreme northeast and northwest, respectively, were a part of the Sudan/Sahel Savannah. Southeast Nigeria, where enormous sedimentary layers from the Abakiliki Uplift to the Anambra Basin have been slanted and eroded, is home to some of the most stunning and dramatic sedimentary landscapes.

Strong latitudinal zones define the savannah climate in Nigeria, which is progressively dryer as one advances away from the derived guinea savannah towards the Sudan and Sahel. According to Tarfa et al. (2019), the two main seasons are the rainy season, which persists from April to October, and the dry season, which continues from November to March. Two air masses — dry continental air moving south from the Sahara Desert and air from the ocean that is humid moving north from the Atlantic Ocean — influence rainfall. The eastern border highlands and the Jos Plateau region are the only places where topographic relief can significantly affect local climate.

Southern Nigeria has a tropical monsoon climate classified as "Am" by the Koppen climate classification system. Monsoon wind, which originates in the South Atlantic Ocean and is transported by maritime tropical air mass which include moist, warm, seasonal wind from sea to land has an impact on the climate. As a result of water vapor condensation in the quickly ascending air mass, its high humidity and warmth characteristics enhance its strength to move upward creating copious and abundant rainfall. Furthermore, Sudan/Sahel ecological zone has a mostly Sahel climate, sometimes known as a tropical dry climate. In contrast to the

southern and central parts of Nigeria, this climatic type has low yearly rainfall. For instance, the rainy season only lasts from June to September in the northern section of Nigeria. Temperatures can reach as high as 40°C over the remaining part of the year, which is hot and dry (Akinbile et al. 2019).

When air from the Atlantic covers the whole country in August, the vast majority of northern Nigeria experiences the wettest month. In southern locations, this period corresponds to the August break. This interval allows for a short dry season, which is primarily an opportunity for grain harvesting. It is very noticeable in the southwest but is rarely completely dry.

The northeast trade winds often promote sunny sky with comfortable temperatures, and lower humidity from September through November. However, the northeast trade wind blows fiercely from December through February and frequently carries a load of Saharan fine dust with it, locally called harmattan. This wind carrying dust frequently resembles a thick fog and blankets everything in a thin layer of dust. Except for a small area near the southwest coast. The harmattan impacts the entire nation but is more pronounced in the north (Danlami et al. 2018; David, 2009). Moving from south to north, rainy seasons get shorter and shorter, with Kano's average rainy season being 120 to 130 days long and Katsina and Sokoto's being 10 to 20 days shorter. According to Peter et al. (2018), the northern hemisphere receives 500 to 750 millimeters of rainfall on average every year. In recent years, one of the most prominent features of the climate in Nigeria has been the frequency of dry spells, especially in the drier parts of the country's savannah belt. The severe effects of climate variability are typically felt near the drier edges of agricultural zones or in the savannah ecological zone, which are evidenced by these drought episodes.

MATERIALS AND METHODS

Meteorological data and wheat yield data were utilized in this study. The meteorological data used are rainfall (mm) and temperature (minimum and maximum) for Derived Guinea savannah, Southern/Northern Guinea savannah and Sudan/Sahel savannah (Figure 1). Rainfall and temperature data were obtained from the Nigeria Meteorological Agency Operation headquarters, Abuja. Wheat crop yield data was collected mainly from Lake Chad Research Institute (LCRI), Maiduguri, Borno state, and Agricultural Development Project's office, under the Federal Ministry of Agriculture, located in the state capital (Kwara) within the ecological zones of the study area. The data were collected for ten (10) years spanning from 2011 – 2020. Inferential statistics were used to analyze the data collected for the study. Trend analysis was used to examine the trends of climatic elements and wheat yield in different savannah ecological zone. Pearson Moment Correlation and Multiple Regression analysis were used to assess the relationship between agro-climatic variables and wheat yield in the study area.

RESULTS AND DISCUSSION

Trends of Climatic Variables and Wheat Yield in the Study Area

Rainfall trend was analyzed using bar chart and time series in the study area. The results show that there were fluctuations in annual rainfall. The highest rainfall amount was recorded in year 2020 in Sudan/Sahel, year 2017 in Guinea and year 2019 in Derived Guinea savannah ecological zone respectively (Figure 2).

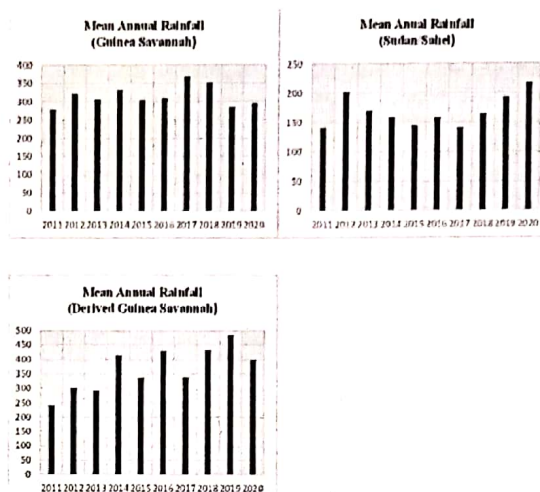


Figure 2: Mean Annual Rainfall Amount in Savannah Ecological zone of Nigeria
Source: Researcher's Fieldwork, 2024

Throughout the study period, Derived Guinea savannah had the highest total mean rainfall (3675.58 mm), followed by guinea savannah (3149.06 mm), and Sudan/Sahel savannah (1689.87 mm). Corresponding to this, Derived Guinea, Guinea, and Sudan/Sahel Savannah ecological zones experienced their highest mean annual rainfall amounts in 2019, 2017, and 2020, at 485.37mm, 278.53mm, and 217mm, respectively. Also, the Derived Guinea, Guinea, and Sudan/Sahel savannah each had the lowest mean annual rainfall amounts of 242.83mm, 278.52mm, and 140.37mm in 2011, respectively (Figure 2).

From the observation, the Sudan/Sahel savannah ecological zone and Guinea got less rainfall throughout the study period than the derived guinea savannah. This finding is consistent with Akintola and Sowunmi (2010) observations about the patterns of rainfall in different ecological zones of Nigeria. The observed rainfall pattern is more likely to have a significant impact on wheat yield. Similar results for rainfall from trend analysis reveal a rising trend line with a mild slope in Sudan/Sahel and Guinea savannah, but steeper slope is observed in Derived Guinea savannah zone (Figure 3).

Once again, this outcome supported Umar's (2012) investigation into meteorological indicators of climate change. According to the results, there is a high amount of rainfall variability in Nigeria's northern regions (Guinea, Sudan, and the Sahel savannah).

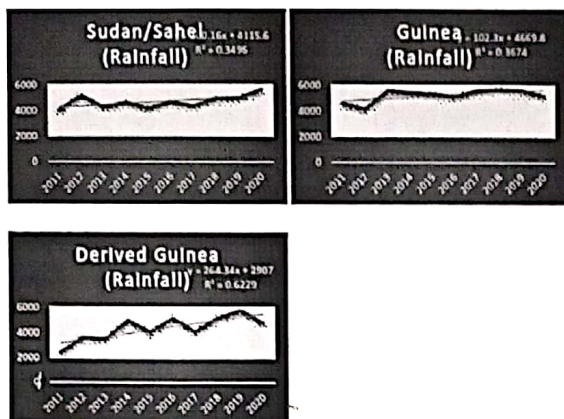


Figure 3: Rainfall in the Savannah Ecological zone
Source: Researcher's Fieldwork, 2024

According to the trend line equation in Figure 3, the result shows steady but gradual increase in rainfall which was statistically significant at $p = 0.05$ in Sudan/Sahel, Guinea, and Derived Guinea savannah at 34%, 36%, and 62% variance annually over a ten-year period, respectively.

Mean Annual Maximum Temperature Trend

In Figure 4, the mean annual maximum temperature was plotted against time. The three ecological zones showed significant variation. The findings indicate that although the Sudan/Sahel ($R^2 = 0.02$) and Guinea savannah ($R^2 = 0.26$) observed a slight drop in maximum temperatures, Derived savannah ($R^2 = 0.03$) witnessed a considerable increase in maximum temperatures with significant volatility at $p = 0.05$. The trend line equation also showed a downward trend in the Sudan/Sahel and Guinea Savannah. This suggests that the maximum temperature in Sudan/Sahel and the Guinea savannah decreases with time at the rates of 2.91% and 26% variance respectively, particularly during the harmattan cold, which occurred during these regions' wheat-growing seasons.

Wheat yield is greatly impacted by this rapid interannual variation in maximum temperature. This is due to the fact that wheat is extremely sensitive to temperature; for instance, Jaiswal (2009) suggested that the maximum temperature for wheat throughout the growth season should be lower than 32.5°C. The bread wheat undoubtedly did well during the chilly harmattan period. Also, the trend line in the Derived Guinea savannah demonstrates that during the study period, temperature is rising at the rate of 3.33% each year (Figure 4). According to Kehinde et al (2020), the derived guinea savannah ecological zone of Nigeria has experienced temperature increase majorly due to decreasing rainfall scenario over time. This is essentially due to the impact of climate change and variability in the region.

Mean Annual Minimum Temperature Trend

The result of the minimum temperature trend in the three ecological zone as shown in Figure 5 is that minimum temperature decreases at 48% and 0.95% variance which is statistically significant at $p = 0.05$ in the Sudan/Sahel and not statistically significant in Derived Guinea savannah respectively with negative trend equation.

The implication of this trend is that minimum temperature decreased significantly in Sudan/Sahel savannah during the period under study. Generally, there is variability in minimum temperature in the three ecological zones. It was also observed that minimum temperature increased slightly in the Guinea savannah ecological zone. The trend equation shows an increase of 22% variance in minimum temperature in the zone (Figure 5).

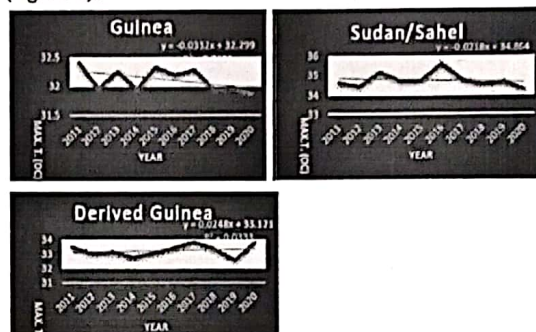


Figure 4: Mean Annual Maximum Temperature in Savannah Ecological zone
Source: Researcher's Fieldwork, 2024

The outcome makes it clear that a drop in minimum temperature is anticipated in the Sudan/Sahel ecological zones. This is because, in comparison to other zones, the area receives more dust particles. Hence, there is more room for back-to-space winter radiation, less energy can reach the surface, resulting in an estimated minimum temperature.

This result is in agreement with the findings of Usuru et al (2011) in their study on evidence of climate change in derived savannah niche, Nsukka, South-Eastern Nigeria. The increase in minimum temperature in Guinea savannah ecological zone is very important in the growth of wheat. This is due to the fact that wheat growth and development is enhanced by relatively low temperature (Ubi and Onyibe, 2004).

Wheat Yield Trend in Savannah Ecological Zone

From Figure 6, wheat yield was plotted against years(time) in the study area. A graph with negative trend line was obtained in the study area for the 10-year period under review. This implies that wheat yield is decreasing with time in the study area. Wheat yield shows gradual decrease at 1.8%, 1.1% (statistically insignificant), and 53.4% variance (statistically significant) at $p = 0.05$ in the Sudan/Sahel, Guinea, and Derived Guinea savannah ecological zones respectively.

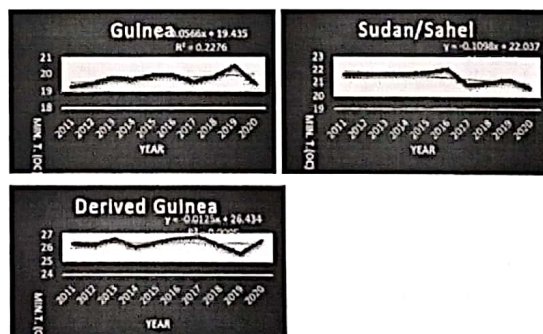


Figure 5: Mean Annual Minimum Temperature in the Savannah Ecological zone



Figure 6: Wheat Yield in Savannah Ecological Zone of Nigeria
Source: Researcher's Fieldwork, 2024

In addition, during the study period, a significant decrease in temperature especially during harmattan period in Sudan/Sahel and Guinea Savannah, with exception of Derived Guinea Savannah, may favor high yield of wheat. However, other environmental parameters, such as soil type, slope, planting season, etc., may affect wheat production, but they cannot account for high wheat yield by themselves because they are largely impacted by local climate. This observation agrees with the findings of Okoro (2018).

Correlation Between Wheat Yield and Climatic variables in the study Area.

Correlation analysis was deployed to examine the level of association between wheat yield and agro-climatic variables in the study area. The correlation as shown in Table 1 revealed that there is relationship between wheat yield and the climatic variables. However, the correlation coefficient (r) with p -value < 0.01 confidence level shows that only maximum temperature showed weak positive relationship.

Table 1: Correlation Matrix for Climatic Variables and wheat Yield

	Wheat Yield	Rainfall	Temp _{max}	Temp _{min}
Wheat Yield	1			
Rainfall	-.503	1		
Temp _{max}	.080		1	
Temp _{min}	.102	-.503		1
	.739	.080		
	-.280	.092	.377	
	.353	.765	.204	

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

Source: Researcher Computation (2024)

In addition, it was statistically non-significant ($r = 10.2$, $P < 0.01$) and this indicates low wheat yield in the study area (Table 2). The results also showed a slight negative association between wheat yield and minimum temperature ($r = -28.0$, $P < 0.01$) and a moderately negative relationship between wheat yield and rainfall ($r = -50.3$, $P < 0.01$).

Rainfall was correlated with wheat yield. Indeed, it was noted that rainfall has a moderate negative relationship with wheat yield and is statistically not significant (Table 1). This is an indication that rainfall though not statistically significant, has detrimental effect on wheat yield in the study area.

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Rainfall was correlated with wheat yield. Indeed, it was noted that rainfall has a moderate negative relationship with wheat yield and is statistically not significant (Table 1). This is an indication that rainfall though not statistically significant, has detrimental effect on wheat yield in the study area. This result confirmed the finding of Singh, Hundal, and Kaur (2008) that rainfall was negatively correlated to wheat yield in their study on the impact of temperature and precipitation (rainfall) on wheat yield in Punjab's South Western region. Another study conducted by Weiwei et al (2022), on the topic that discussed the main meteorological constraint on winter wheat yield in the middle and lower parts of the Yangtze River is heavy rainfall, confirmed that increase rainfall reduces wheat yield. Generally, the result revealed that bread wheat requires warm weather, cooled night temperature, and little rainfall or irrigation system for its optimum yield.

Predicting Wheat Yield from Explanatory Variables

In order to predict the impact of agrometeorological variables on wheat yield, multiple regression analysis was used; unstandardized coefficients were taken into account. Unstandardized coefficients reveal how much the dependent variable varies with an independent variable when all other independent variables are held constant.

Table 1: Correlation Matrix for Climatic Variables and wheat Yield

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
1 (Constant)	9.078	4.189		2.167	.032
Maximum Temperature	.225	.134	.199	1.687	.094
Minimum Temperature	-.300	.114	-.309	-2.640	.009
Rainfall	.002	.005	.029	.303	.762

Therefore, the model coefficient in predicting the wheat yield is revealed in (Equation i)

Wheat yield = $9.078 + 0.225\text{Maxt} - 0.3\text{Mint} + 0.002\text{Rainf} \pm e$ equation (i).

The results from Table 2 explain that 1 % increase in maximum temperature would produce an increase of 0.225 gm of wheat. Moreover, an increase in a percentage of minimum temperature will bring a decrease of 0.3gm of wheat. While an increase in 1 % of rainfall will give an increase of 0.002gm of wheat. This result indicates that there is significant impact of agrometeorological variables on wheat yield in the study area.

CONCLUSION AND RECOMMENDATIONS

Climate has been identified as the primary determinant of agricultural productivity especially in the tropical countries including Nigeria.

The study therefore concludes that climate variability, particularly fluctuations in temperature and rainfall, significantly affects wheat yield in the savannah ecological zone of Nigeria. While maximum temperature showed a positive correlation with wheat yield, the effects were not statistically significant. However, minimum temperature and rainfall had negative correlations with wheat yield, with rainfall showing a statistically significant impact. These findings suggest that climate variability poses a critical challenge to wheat cultivation in the region. Therefore, adopting climate-resilient agricultural strategies is essential for sustainable wheat production in the face of changing climatic conditions. In view of the above, the following recommendations were made:

Continued research and development efforts should be undertaken to understand the specific challenges affecting wheat growth in the savannah ecological zone of Nigeria. This includes studying the fluctuating patterns of climatic variables and their impact on wheat yield. Investments in research will aid in developing targeted solutions and adaptation strategies. Adoption of climate-smart agricultural practices is very crucial. Farmers should adopt climate-smart strategies, including efficient water management systems, to address rainfall variability and enhance wheat yield under fluctuating climatic conditions. Development and use of heat-tolerant wheat varieties is very important. Research institutions and agricultural bodies should promote the cultivation of heat-tolerant wheat varieties to cope with the increasing maximum temperature and mitigate yield losses. Furthermore, strengthening agrometeorological Services to improve access to accurate weather forecasts and agrometeorological information will enable farmers to make informed decisions on planting schedules and water usage. This will help minimize the negative effects of temperature and rainfall variability on wheat production in savannah ecological zone of Nigeria.

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