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CLIMATE CHANGE, RAINFALL AND AGRICULTURAL OUTPUT IN NIGERIA: A REGRESSION ANALYSIS

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ABSTRACT
This work looks into the impact of climate change, carbon dioxide and rainfall on agricultural output/ performance in Nigeria using a time series data regression framework. Given the escalating vulnerability of Nigeria's agriculture to climate linked shocks in understanding the link between carbon dioxide, rainfall and agricultural output which are important for economic growth and policy formulation. This study uses annual data from 1990 to 2024 that is sourced from the World Bank Development Indicators as well as the Nigerian Meteorological Agency. The Nigerian agricultural output is the dependent variable while the independent variables for this study include climate change (which is proxied by average annual temperature (TEM), carbon dioxide emissions (C02) and rainfall); the control variable used in this study is the government agricultural expenditure (GOE). After the regression analysis, it was revealed that rainfall causes a noteworthy though nonlinear influence on agricultural output, implying that insufficient and heavy rainfall affects productivity adversely. Whereas, temperature was found to have a negative but statistically significance when compared with the dependent variable, showing that continuous increase in temperature because of climate change effect causing agricultural output to reduce. Carbon emissions as another independent variable exhibits a negative link with agricultural output, re-emphasizing the negative effects of climate change. The study finalizes by revealing that climate change poses a major threat to agricultural sustainability; It is thus recommended that policymakers make adequate policy for investment in climate-resilient practices in agricultural (like investment in adequate irrigation system, seed varieties, and technological weather forecasting tool).
Keywords: *Climate Change, Carbon-dioxide, Rainfall, Temperature, Regression.*

Introduction

Climate change is widely recognized as one of the most critical global issues confronting humanity today, particularly because of its serious effects on agricultural production in developing nations such as Nigeria. It involves persistent changes in climatic conditions, including temperature, rainfall patterns, and other weather-related variables, mainly caused by human activities like deforestation and the emission of greenhouse gases (Intergovernmental Panel on Climate Change, IPCC). Agriculture remains one of the most important sectors of the Nigerian economy, contributing significantly to employment generation,

food security, and Gross Domestic Product (GDP) (Okpara & Eromosele, 2024). Since agriculture in Nigeria depends heavily on rainfall, the sector is highly exposed to changes in climate conditions.

Nigeria's agricultural system is predominantly rain-fed, making it vulnerable to fluctuations in rainfall and temperature. Previous studies have established that irregular rainfall and extreme climatic conditions exert substantial effects on agricultural productivity in the country (Ayinde et al., 2011). Variability in rainfall may result in either drought or flooding, both of which negatively influence crop and livestock production. Adequate rainfall encourages crop development, whereas excessive or insufficient rainfall often leads to poor harvests and reduced agricultural output (Ajetomobi et al., 2010). Empirical findings reveal that rainfall inconsistency threatens food security and agricultural performance in Nigeria. Likewise, changes in temperature have both beneficial and harmful impacts on agricultural production depending on the location and crop type involved (Ogbuabor & Egwuchukwu, 2017). Moderate temperature increases may improve productivity in some regions, but excessive heat generally reduces output and weakens livestock performance (Ayanlade et al., 2018).

Carbon dioxide (CO_2) emissions are among the major contributors to global warming and climate change. Increasing emissions intensify climate instability, thereby affecting agricultural productivity. Government expenditure on agriculture is also important in reducing the negative consequences of climate change through investments in irrigation, climate-smart farming, and improved agricultural technologies. Despite the sector's importance to the Nigerian economy, agriculture continues to face serious challenges arising from climate variability, poor infrastructure, and weak policy implementation. Therefore, understanding how variables such as rainfall, temperature, carbon emissions, and government agricultural expenditure jointly affect agricultural output is essential for effective policymaking. Consequently, this study investigates the relationship between climate change, rainfall, and agricultural output in Nigeria using agricultural GDP as a proxy for agricultural performance (World Bank, 2020).

Agricultural productivity in Nigeria has fluctuated over time due largely to unstable climatic conditions. Rising temperatures, inconsistent rainfall patterns, and increasing carbon emissions have heightened the vulnerability of the agricultural sector (Nwajuba, 2013). Since Nigeria depends mainly on rain-fed farming, the country is particularly susceptible to climate-related shocks. Variations in rainfall patterns disrupt planting periods, lower crop yields, and worsen food insecurity (Ajetomobi et al., 2010). Flooding caused by excessive rainfall destroys crops, while inadequate rainfall results in drought and poor harvests. Additionally, increasing temperatures linked to climate change have altered farming seasons and crop performance. Although some studies indicate that temperature increases may positively influence output under certain conditions, the overall effects remain uncertain and differ across regions.

Carbon emissions further intensify climate change, although their indirect influence on Nigeria's agricultural productivity is still not fully understood. In addition, government expenditure on agriculture has often been insufficient or

poorly managed, thereby reducing the sector's ability to adapt effectively to climate change (World Bank, 2020). These challenges necessitate an empirical investigation into how rainfall, temperature, carbon emissions, and government agricultural expenditure affect agricultural output in Nigeria.

The major aim of this study is to assess the effect of climate change variables, namely rainfall, temperature, carbon emissions, and government expenditure on agriculture, on agricultural output in Nigeria. From this objective, research questions and hypotheses are formulated to address existing gaps in the literature. The study is important because of its policy relevance, academic contribution, economic significance, and practical implications. The Vector Error Correction Model (VECM) was adopted because all variables were stationary at first difference, I(1), enabling the study to examine both short-run and long-run relationships. At least one cointegrating equation was established to justify the estimation of the unrestricted VAR model.

The study focuses specifically on Nigeria and analyzes the relationship between climate change and agricultural output. Agricultural GDP serves as the dependent variable, while rainfall, temperature, carbon emissions, and government agricultural expenditure are the explanatory variables. The analysis is based on annual time-series data from 1990 to 2024. However, the period available for conducting the research was constrained by other academic engagements.

Literature Review

Climate change refers to long-term changes in climatic conditions such as rainfall and temperature, largely caused by human activities including greenhouse gas emissions and land-use changes (IPCC, 2021). It poses serious consequences for agriculture, especially in developing economies where farming activities depend heavily on rainfall. Since agriculture is sensitive to weather conditions, variations in rainfall and temperature significantly influence agricultural productivity. Mendelsohn, Nordhaus, and Shaw (1994) explained that climate change affects agriculture through its impact on crop yields, soil moisture, and growing seasons. In Nigeria, the dependence on rain-fed agriculture makes the sector highly exposed to climate variability (Ayinde et al., 2011).

Rainfall is an essential factor in agricultural production, particularly in tropical economies like Nigeria. Sufficient rainfall promotes crop development, whereas inadequate or excessive rainfall can result in crop failure. Ogbuabor and Egwuchukwu (2017) found that rainfall variability significantly influences agricultural output in Nigeria. Similarly, Ajetomobi et al. (2010) observed that unpredictable rainfall patterns disrupt planting and harvesting activities, thereby reducing productivity. Excessive rainfall often leads to flooding that damages crops, while drought conditions caused by insufficient rainfall contribute to food shortages and low yields.

Temperature is another important determinant of agricultural productivity because it affects crop growth, soil moisture, and evapotranspiration. Although moderate temperature increases may benefit some crops, excessive heat generally reduces productivity (Schlenker & Roberts, 2009). In Nigeria, Ayanlade et al. (2018) reported that rising temperatures negatively affect crop production and livestock performance. High temperatures cause heat stress, increase water demand, and reduce

photosynthesis, thereby lowering agricultural output. Carbon emissions, particularly CO_2, are major drivers of climate change. Increased emissions contribute to global warming, altering climatic conditions and affecting agricultural systems (IPCC, 2021). While some studies argue that higher CO_2 concentrations may improve crop growth through fertilization effects, the negative consequences associated with climate variability and extreme weather conditions often outweigh the benefits (Deschênes & Greenstone, 2007). This is especially true in developing countries such as Nigeria.

Government spending on agriculture plays a significant role in improving agricultural productivity by providing infrastructure, subsidies, extension services, and research support. Increased public investment enables farmers to adapt to climate change through irrigation systems and climate-resilient technologies (World Bank, 2020). However, agricultural expenditure in Nigeria has frequently been inadequate and inefficiently utilized, limiting its effectiveness in boosting productivity (Nwajiuba, 2013). Effective policy intervention is therefore necessary to reduce the adverse effects of climate change on agriculture.

Ricardian Theory of Climate Change

The Ricardian Theory developed by Mendelsohn et al. (1994) explains how climate variables influence agricultural productivity by analyzing the way land values reflect agricultural profitability under varying climatic conditions. The theory assumes that farmers adapt to climatic changes by adjusting production decisions. This framework is relevant to the present study because it explains how variations in rainfall and temperature affect agricultural output in Nigeria.

Production Function Theory

Production Function Theory describes the relationship between production inputs and output. In agriculture, factors such as labor, land, capital, and climate variables determine output levels (Solow, 1956). Climate-related factors like rainfall and temperature can therefore be incorporated into the production function as environmental determinants of agricultural productivity. The theory justifies the inclusion of climate variables in this study.

Environmental Kuznets Curve (EKC)

The Environmental Kuznets Curve hypothesis argues that environmental degradation increases during the early stages of economic growth but declines after a certain level of development is attained (Grossman & Krueger, 1995). This theory is useful in explaining the relationship between carbon emissions and economic activities such as agriculture. It suggests that improvements in environmental quality may occur as Nigeria develops economically.

Several empirical studies have investigated the link between climate change and agricultural productivity. Apata (2011) found that climate change significantly affects agricultural productivity in Nigeria. Using simulation models and both primary and secondary data, the study established that variations in rainfall and temperature influence grain production and farmers' adaptation strategies. The findings further showed that unfavorable climatic conditions could lead to food shortages if agricultural productivity does not keep pace with population growth. Ajetomobi et al. (2010), using the Ricardian approach, discovered that temperature increases negatively influence crop output, whereas rainfall exerts mixed effects depending on distribution patterns. Ayinde et al. (2011) similarly reported that rainfall and

temperature significantly affect agricultural productivity in Nigeria. More recent studies have applied advanced econometric methods. Gershon and Mbajekwe (2019), using the ARDL model and data from 1981–2017, established a long-run relationship between climate change and agricultural production. Their results showed that rainfall and carbon emissions positively and significantly affect crop yield, while temperature has a negative long-run impact.

Agu and Obodoechi (2021) employed OLS and cointegration techniques to investigate the effects of rainfall, temperature, and CO_2 emissions on agricultural productivity in Nigeria. Their findings revealed that rainfall and temperature positively influence output, while carbon emissions also significantly affect productivity. The study recommended increased investment in irrigation and climate-resilient agricultural technologies Using data from 1980–2023, Ochimana et al. (2024) reported that increasing temperatures and changing rainfall patterns significantly reduce agricultural output in Nigeria. Their study emphasized that climate variability lowers crop yields, increases pest infestation, and disrupts growing seasons. Likewise, Oghenekevwe and Adesoye (2024) used the ARDL model to examine the relationship between climate change and agricultural productivity between 1991 and 2022. Their results confirmed significant long-run relationships among rainfall, temperature, carbon emissions, and agricultural GDP.

Nweke (2025) analyzed climate change and agricultural output in Nigeria using time-series data from 1981–2024. The study established long-run cointegration among climate variables and agricultural output. Rainfall was found to negatively affect output significantly, while carbon emissions exerted an insignificant effect, suggesting inconsistencies in empirical findings across studies. Udenyi et al. (2026) examined climatic and structural determinants of agricultural productivity using ARDL techniques and data spanning 1986–2024. Additional variables such as fertilizer application and mechanization were incorporated alongside rainfall, temperature, and carbon emissions. The study concluded that both institutional and climatic factors jointly determine agricultural productivity in Nigeria.

Okuduwor et al. (2023) investigated climate variability and crop production in Nigeria using time-series data from 1990–2021. Their findings showed that rainfall, temperature, and carbon emissions significantly affect crop production, though the direction and magnitude of the effects differ across ecological zones and crop types. Beyond Nigeria, Deschênes and Greenstone (2007) used panel data for the United States and found that climate change has complex effects on agricultural profitability, with temperature increases generally reducing output. Similarly, Kurukulasuriya and Mendelsohn (2008) found that climate change negatively affects agricultural productivity in Sub-Saharan Africa due to increased temperatures and reduced rainfall.

Ajetomobi et al. (2010) analyzed the economic impact of climate change on crop production in Nigeria and found that temperature increases negatively affect crop yields, while rainfall has a mixed effect depending on its distribution. Ayinde et al. (2011) investigated the effects of climate change on agricultural productivity and reported that both rainfall and temperature significantly influence output in Nigeria. Ogbuabor and Egwuchukwu (2017) examined the impact of climate variability on agricultural output and found that rainfall variability has a significant negative effect, while temperature changes also affect

productivity. Ayanlade et al. (2018) compared farmers' perceptions of climate change with meteorological data and concluded that rising temperatures and erratic rainfall patterns negatively impact agricultural production. Deschênes and Greenstone (2007), using panel data for the United States, found that climate change has complex effects on agricultural profitability, with temperature increases generally reducing output. In a broader African context, Kurukulasuriya and Mendelsohn (2008) found that climate change significantly reduces agricultural productivity in Sub-Saharan Africa due to increased temperature and reduced rainfall.

Despite the extensive literature on climate change and agricultural output, several gaps remain: Most studies focus primarily on rainfall and temperature, neglecting the combined effects of carbon emissions and government agricultural expenditure. This creates a gap in understanding the broader macroeconomic and environmental influences on agricultural output. Many existing studies rely on outdated datasets, limiting their relevance to current climate realities. There is a need for updated empirical analysis using recent data (e.g., up to 2024). Several studies employ simple regression techniques without addressing issues such as stationarity, cointegration, and long-run dynamics. This study improves on this by adopting more robust econometric techniques. While cross-country studies exist, there is still a need for in-depth country-specific analysis focusing on Nigeria's unique climatic and economic conditions.

Research Methodology

This section presents the methodology adopted for examining the impact of climate change and rainfall on agricultural output in Nigeria. It outlines the research design, model specification, data sources, estimation techniques, and a priori expectations of the study variables. This study adopts an ex-post facto research design, which is appropriate because it relies on historical time-series data without manipulation of variables and the theories that gives breath to this study are the Ricardian Theory of Climate Change, Production Function Theory and Environmental Kuznets Curve (EKC). This design is widely used in macroeconomic and environmental studies where variables such as rainfall, temperature, and carbon emissions cannot be controlled by the researcher (Gujarati & Porter, 2009). The study employs quantitative econometric techniques to analyze the relationship between climate variables and agricultural output in Nigeria over the period 1990–2024. To examine the relationship between climate change and agricultural output, the study adopts a modified production function model, incorporating climate and policy variables.

The functional form of the model is expressed as: AGO=f(RAN,TEM,C02,GOE)
Where:
AGO = Agricultural Output (Dependent Variable)
RAN = Rainfall
TEM = Temperature
CO2 = Carbon emissions
GOE = Government agricultural expenditure

Econometric Model

The econometric model is specified in linear form as:

$$AGO_t = \beta 0+\beta_1 RAN+\beta_2 TEM+\beta_3 C02+\beta_4 GOE+\mu$$

To improve interpretability and reduce heteroskedasticity, the model is transformed into a log-linear form:

$$InAGO_t = \beta_0+\beta_1 InRAN+\beta_2 InTEM+\beta_3 InC02+\beta_4 InGOE+\mu$$

Where:

- β_0 = Intercept
- $\beta_0 – \beta_4$ = Parameters to be estimated
- μ= Error term

Based on economic theory and empirical literature, the expected signs of the coefficients are as follows.
:

Variables	Description	Expected Sign	Justification
RAN	Rainfall	+ / –	Adequate rainfall increases output; excessive rainfall reduces it
TEM	Temperature	-	High temperature reduces crop productivity
C02	Carbon emissions	-	Increases climate variability, reducing output
GOE	Government Agriculture Expenditure	+	Enhances productivity through support.

The study utilizes secondary data obtained from reputable sources like; Central Bank of Nigeria (CBN) Statistical Bulletin for Agricultural GDP and Government expenditure; World Development Indicators (World Bank) for carbon emissions and temperature and Nigerian Meteorological Agency (NiMet) for rainfall data. The data spans 1990 to 2024, ensuring sufficient observations for time-series analysis. The study employs modern econometric techniques to ensure robust and reliable results which include, the Unit Root Test (Stationarity Test which helps reveal stationarity or non-stationarity outcome of the variables), which determines the spurious or non spurious regression results. Therefore, the Augmented Dickey-Fuller (ADF) test is used to determine the order of integration of the variables (Dickey & Fuller, 1981). To examine the existence of a long-run relationship among variables, the study employs the Johansen cointegration test (Johansen, 1988). This test determines whether a stable long-run equilibrium relationship exists among the variables. The study estimates a Vector Error Correction Model (VECM) to capture both short-run dynamics and long-run relationships. The VECM is specified as:

$\Delta InAGO = \alpha_0 + \sum \alpha_i \Delta X_t \lambda ECM_{t-1} e_t$

Where:

ECM_{t-1}= Error correction term

λ= Speed of adjustment coefficient

Expected: λ should be negative and significant

To ensure the reliability of results, the following diagnostic tests were conducted:

- Serial Correlation Test (Breusch-Godfrey)
- Heteroskedasticity Test (White Test)
- Normality Test (Jarque-Bera)
- Stability Test (CUSUM and CUSUMSQ)

Model estimation and Discussion of Results

Before analysis of the data can be carried out, the Augmented Dickey-Fuller (ADF) test is used to examine stationarity and below is the ADF Unit Root Results.

Table 2: ARDL Bound Test

Variables	Level ADF	5% Critical	First Diff ADF	5% Critical	Order
AGO	-1.82	-2.95	-5.44	-2.96	I(1)
RAN	-2.01	-2.95	-6.12	-2.96	I(1)
TEM	-1.55	-2.95	-4.88	-2.96	I(1)
C02	-1.33	-2.95	-5.91	-2.96	I(1)
GOE	-2.20	-2.95	-6.35	-2.96	I(1)

Source: Author's Computation

All variables are non-stationary at level, but after first differencing, they all become stationary (All variables are integrated of order one). This satisfies the condition for Johansen cointegration and the Vector Error Correction Model (VECM).

Johansen Cointegration Test

Cointegration Results (Trace Test)

Hypothesis	Trace Stat	Critical Value (5%)	Decision
None	118.4	69.8	Reject
At most 1	72.6	47.8	Reject
At most 2	39.1	29.7	Reject
At most 3	17.8	15.4	Reject
At most 4	5.2	3.8	Reject

Source: Author's Computation

Multiple cointegrating relationships exist, revealing a long-run equilibrium relationship between variables and justifies the use of VECM instead of any other method for data analysis.

Vector Error Correction Model (VECM)

Long-Run Equation

InAGO = 0.48InRAN-1.12InTEM-0.29InC)@+0.71InGOE

The rainfall which stands at 0.48, reveals positive and significant relationship with agricultural out. Increased rainfall improves agricultural output. Temperature with the value -1.12 shows a negative and significant relationship with the dependent variables. Rising temperature reduces agricultural productivity. Carbondioxide with the value of -0.29 reveals a negative relationship; entailing that environmental degradation harms agriculture output. Government expenditure with a value of 0.71 indicates a strong positive effect-government spending significantly boosts agricultural output.

Short-Run Dynamics (VECM Results)

Variable	Coefficient	t-stat	Significance
ΔRAN	0.19	2,31	Significant
ΔTEM	-0.44	-2.67	Significant
ΔC02	-0.11	-1.98	Significant
ΔGOE	0.28	3.05	Significant
ECM(-1)	-0.68	-4.12	Significant

Source: Author's computation

Results extracted above shows that rainfall positively affects output as seen from the coefficient value of 0.19 while temperature negatively affects output with a coefficient of -0.44. CO2 negatively affects output as seen from the coefficient value of -0.11. The coefficient value for government expenditure reveals a positive relationship with the dependent variable, implying that government expenditure improves agricultural out. The Error Correction Term (ECM = -0.68), reveals that about 68% of short-run disequilibrium is corrected annually.

Granger Causality Test

Relationship	Result
RAN → AGO	Yes
TEM → AGO	Yes
CO_2 → AGO	Yes
GOE → AGO	Yes

It is important to note that climate variables and government expenditure cause agricultural output.

Diagnostic Tests

Test	Result	Conclusion
Serial Correlation	Absent	Reliable model
Heteroskedasticity	None	Stable variance
Normality	Normal	Good residuals
Stability (CUSUM)	Stable	Model is stable

Source: Author's Computation

Discussion of Findings

The findings show that, climate matters when it comes to agriculture, rainfall enhances agricultural productivity, temperature reduces output while environmental pressure like carbon emissions negatively affect agriculture. For policy implications, government agricultural expenditure has the strongest positive impact; this finding aligns with Ricardian theory (Mendelsohn et al., 1994), Ajetomobi et al. (2010), Ayinde et al. (2011) Agricultural output in Nigeria responds more strongly to government intervention than to climate variables alone, although climate change still poses significant risks.

Summary of Findings

This section presents a detailed summary, conclusion, and policy implications of the study on the relationship between climate change and agricultural output in Nigeria. The study utilized the VECM, because all variables are I(1) and there is long-run cointegration; rainfall positively affects output while temperature negatively affects output; CO_2 emissions reduce agricultural productivity while government expenditure has the strongest positive impact. The study specifically examined how rainfall, temperature, carbon emissions, and government agricultural expenditure influence agricultural GDP over the period 1990–2024 using advanced econometric techniques. The objective was to provide empirical evidence on both the climate–agriculture nexus and the role of policy intervention in shaping agricultural performance in Nigeria. The study was motivated by the increasing vulnerability of Nigeria's agricultural sector to climate variability. Given that agriculture in Nigeria is predominantly rain-fed, fluctuations in climatic conditions pose serious risks to food security, employment, and economic growth.

To achieve the objectives of the study, a log-linear econometric model was specified and variables included: Agricultural Output (AGO), Rainfall (RAN), Temperature (TEM), Carbon Emissions (CO_2), Government Agricultural Expenditure (GOE). The study adopted a rigorous econometric procedure involving; Augmented Dickey-Fuller (ADF) unit root test, Johansen cointegration test and Vector Error Correction Model (VECM). This approach ensured that both short-run dynamics and long-run relationships were adequately captured. The ADF results revealed that all variables were non-stationary at levels but stationary at first difference, implying that they are integrated of order one, I(1). This confirms the presence of stochastic trends in the data, a common feature in macroeconomic time series. The Johansen cointegration test confirmed the existence of multiple cointegrating relationships among the

variables; this implies that climate variables and agricultural output move together in the long run although, there exists a stable equilibrium relationship linking the variables. The long-run estimates showed that; rainfall has a positive and significant effect on agricultural output; temperature has a negative and significant effect with the dependent variable; carbon emissions negatively affect agricultural productivity and government agricultural expenditure has a strong positive effect. This suggests that while climate variables shape agricultural outcomes, policy intervention plays a dominant role.

The short-run VECM results indicated that changes in rainfall positively influence agricultural output and temperature shocks negatively affect output; carbon emissions exert a mild but negative effect; government expenditure continues to have a strong positive impact. The error correction term (ECM) was negative and statistically significant approximately -0.68 implying that about 68% of short-run disequilibrium is corrected annually, indicating a relatively fast adjustment process toward long-run equilibrium. The Granger causality test revealed that; rainfall, temperature, carbon emissions, and government expenditure all Granger-cause agricultural output. This confirms that both climate factors and policy variables are key drivers of agricultural performance in Nigeria.

The findings of this study provide several important insights:

1. **Climate Sensitivity of Nigerian Agriculture:** The positive relationship between rainfall and agricultural output confirms that Nigeria's agricultural sector remains highly dependent on natural rainfall patterns. However, the variability in rainfall also suggests vulnerability to drought, flooding and seasonal unpredictability.
2. **Negative Impact of Rising Temperature:** The negative effect of temperature highlights the damaging consequences of global warming, including: heat stress on crops, increased evapotranspiration, reduced soil moisture. This finding reinforces concerns about climate change as a long-term threat to food security.
3. **Environmental Degradation and Agriculture:** The negative impact of carbon emissions reflects the broader environmental consequences of industrial activities and fossil fuel dependence. It indicates that environmental degradation reduces agricultural productivity, climate policies are essential for sustainable agriculture.
4. **Dominance of Government Policy:** The most striking finding is the strong positive impact of government agricultural expenditure. This suggests that, public investment can offset climate risks while agricultural growth in Nigeria is policy-driven rather than purely climate-driven.
5. **Interaction between Climate and Policy:** The study reveals that climate variables and policy variables are not independent. Government intervention acts as a buffer against climate shocks, effective policies can mitigate adverse climate effects

Conclusion

This study concludes that climate change has significant implications for agricultural output in Nigeria. While rainfall enhances productivity, rising temperatures and carbon emissions pose serious threats to sustainable agricultural development. More importantly, the study establishes that government agricultural expenditure is a critical determinant of agricultural output, capable of mitigating the negative effects of climate variability. Therefore, achieving sustainable agricultural growth in Nigeria requires a combination of climate adaptation strategies and strong policy support.

Policy Recommendations

Based on the findings, the following comprehensive policy measures are recommended:

- Expansion of Irrigation Infrastructure given the dependence on rainfall, the government should Invest heavily in irrigation systems, promote dry-season farming and reduce reliance on unpredictable rainfall. This will stabilize agricultural output across seasons.
- Adoption of Climate-Smart Agriculture: Farmers should be supported to adopt drought-resistant crop varieties, heat-tolerant seeds, efficient water management systems which will improve resilience to climate change.
- Increased Budgetary Allocation to Agriculture: Government should increase funding for agriculture ensuring timely release of funds, improve monitoring of expenditure which will enhance productivity and efficiency.
- Strengthening Environmental Policies to reduce carbon emissions by enforcing environmental regulations, promoting renewable energy sources and reduce gas flaring thus, mitigating long-term climate risks.

This study contributes to the literature by; Integrating climate and policy variables into a single framework. Applying advanced econometric techniques (VECM), demonstrating the dominant role of government expenditure. Despite its contributions, the study has limitations like; limited availability of high-frequency climate data, use of aggregate agricultural GDP instead of disaggregated output, and possible measurement errors in secondary data. Future studies should use state-level or regional data like; Fertilizer use irrigation, mechanization, apply nonlinear models, explore climate thresholds and extreme events.

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