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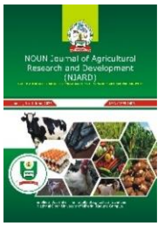

Original Article

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Climate change and Groundnut productivity in Nigeria: A Macro-Economic Investigation

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ABSTRACT

This study analyzed the effects of climate change on groundnut productivity in Nigeria from 1991 to 2022. It assessed how climate variables such as rainfall, temperature, sunshine duration, carbon dioxide emissions, and relative humidity influenced cassava productivity. The research utilized secondary data analyzed through econometric models, including the Autoregressive Distributed Lag (ARDL) model, and the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The findings revealed among the climate variables, Average Annual Rainfall (LNARF), a lagged value of Average Annual Temperature (LNATEMP(-1)), a lagged value of Average Annual Relative Humidity (LNARELH(-1)), a lagged value of Average Annual Sunshine Duration (LNASUN(-1)), and the current value of Average Annual Sunshine Duration (LNASUN) exhibit significant impacts on groundnut productivity. Macroeconomic variables such as the previous year's area of land under groundnut cultivation (LNALUC_GROUNDNUT(-1)), current and previous year's value of Agricultural Foreign Direct Investment (LNAFDI & LNAFDI(-1)), current and a lagged value of Private Domestic Investment in Agriculture (LNDIA & LNDIA(-1)), current previous year's value of Government Capital Expenditure in Agriculture (LNGCEA & LNGCEA(-1)), previous year's average annual inflation rate LN(INFR(-1)), and the current and previous year's Real Exchange Rate (LNRER & LNRER(-1)) also exhibit notable effects. Improving groundnut productivity requires targeted investments in climate-resilient agricultural practices and infrastructure.

Keywords: *Climate change, Groundnut, Productivity, Nigeria.*

1.0 INTRODUCTION

Understanding the impact of climate change on agricultural productivity is critical in tackling climate change effects (Oyeranti, 2024). Agricultural Productivity refers to the efficiency with which agricultural inputs-such as land, labour, capital, and materials are converted into outputs, including crops, livestock, and other agricultural products. It is a critical indicator of a nation's agricultural efficiency and economic viability, reflecting the capacity to produce sufficient food and raw materials for both domestic consumption and export, climate variability, further has implications for maize prices and national food security. (Ogbo *et al*, 2019). Agricultural productivity is commonly measured using several metrics, including yield per hectare (the amount of crop produced per unit area of land), total factor productivity (TFP), which assesses the overall efficiency of all inputs used in production, and output per labour unit, which examines the amount of agricultural produce generated per worker. These metrics provide insights into the sustainability and growth potential of the agricultural sector, highlighting areas where improvements can be made through technological advancement, better resource management, and policy interventions. It is a critical determinant of a nation's food supply and economic stability, and is highly sensitive to climatic conditions (FAO, 2019). Climate variability is one of the predominant themes in agricultural research Anarah *et al*, (2019) and can seriously affect agricultural production. In Africa as a whole and Nigeria in particular, the pattern of rainfall has already altered, affecting the commencement of the planting season and resulting in poor harvest yields (Elijah *et al*, 2018).

The specific objective is to analyzed the effects of climate change on groundnut productivity in Nigeria from 1991 to 2022 with some selected macroeconomic variable.

2.0 MATERIALS AND METHODS

2.1 The Study Area

This study was carried out in Nigeria, the population of Nigeria in 2023 was approximately 223,804,633, based on World meter's elaboration of the latest United Nations data, with a population density of 226 per km² and a total land area of 909,890 square kilometers (FAO, 2018).

Model Specification

According to Pesaran *et al*. (2001), the dependent variable must be I(1), while the exogenous variables can be either I(1) or I(0). Based on empirical literature, theories of interest, and diagnostic tests, the long run relationship between climate change and cassava productivity is given as:

$$InAPR_t = \lambda_0 + \lambda_1 InARF_t + \lambda_2 InATEMP_t + \lambda_3 InARELH_t + \lambda_4 InACDE_t + \lambda_5 InASUN_t + \lambda_7 InAFDI_{t-1} + \lambda_8 InDIA_t + \lambda_9 InGCEA_t + \lambda_{10} InINFR_t + \lambda_{11} InRER_t + \varepsilon_t \quad \ldots (1)$$

Where,

λ's = Long run coefficients

In= Stands for Natural Logarithm,

APR_{it} = Value of Groundnut productivity in period t

ARF_t = Average annual rainfall (millimetres) in period t

$ATEMP_t$= Average annual temperature (°C) in period t

$ARELH_t$ = Average annual relative humidity (%) in period t

$ACDE_t$ = Average annual carbon dioxide (CO_2) emissions (Metric tons per year) in period t

$ASUN_t$= Average annual sunshine (hours) in period t

$AFDI_t$ = Agricultural foreign direct investment in period t

DIA_t = Total domestic private investment in agriculture (₦'Billion) in period t,

$GCEA_t$ = Government capital expenditure on agriculture (₦' Billion) in period t,

$INFR_t$ = Inflation rate (%) in period t,

RER_t = Real exchange rate (₦/$) in period t,

ε_t = Stochastic disturbance term.

3. RESULTS AND DISCUSSION

3.1 Diagnostic Tests: Stationary Properties of the Variable used in the Analysis

Estimation of the various economic models used in this study was preceded by an examination of the statistical properties of the series, specifically the stationarity of the individual variables. Table 4.6 presents the results of the stationarity tests conducted using the Augmented Dickey–Fuller (ADF) test (1979) and the Phillips–Perron (PP) test (1988). The results indicate that some variables were stationary at level I(0), while others became stationary after first differencing, I(1). This differentiation in stationarity is crucial for selecting appropriate econometric techniques.

Gujarati (2003) emphasized the importance of using the ARDL (Auto-Regressive Distributed Lag) approach to co-integration, particularly in cases where the data exhibit mixed integration orders (I(0) and I(1)). The ARDL approach, developed by Pesaran and Shin (1999), has significant advantages over the Johansen co-integration method. It is versatile, allowing for the analysis of data that is purely I(0), purely I(1), or a mix of both. This flexibility is particularly beneficial in the context of this study, where the stationarity tests reveal a mix of I(0) and I(1) variables. The variables were first logged to their natural logarithms before subsequent unit root test.

The analysis of climate change's effect on groundnut productivity in Nigeria from 1991 to 2022 provides a nuanced understanding of both long-run and short-run effects. This study delves into how climate variables have influenced groundnut production over the years, incorporating selected macroeconomic variables as controls to refine the model's accuracy. The inclusion of a bounds test to investigate the presence of a co-integration relationship further strengthens the analysis, ensuring that the dynamic interactions between these variables are thoroughly captured across varying time frames. This approach enables a more comprehensive assessment of the factors driving groundnut productivity, offering insights into the sustained effect of climate and economic conditions on agricultural outcomes.

Table 1: Result of unit root test of logged variables used in the analysis

Variable	Augmented Dickey-Fuller Test			Phillips-Perron Test		
	Level	1st Difference	IO	Level	1st Difference	IO
Average annual CO_2 emission ($ACDE_t$)	-1.599	-4.349 **	I(1)	-1.348	-4.431**	I(1)
Agricultural foreign direct investment ($AFDI_t$)	-1.516	-6.197**	I(1)	-1.339	-6.835**	I(1)
Area of land harvested of groundnut ($ALUCG_t$)	-2.429	-5.813**	I(1)	-2.574	-5.808**	I(1)
Value of groundnut productivity ($APFCG_t$)	-2.967	-7.400**	I(1)	-2.736	-13.378**	I(1)
Average annual relative humidity ($ARELH_t$)	-2.770	-6.373**	I(1)	-2.667	-8.511**	I(1)
Average annual rainfall (ARF_t)	-10.122**	-	I(0)	-6.228**	-	I(0)
Average annual sunshine hours ($ASUN_t$)	-5.042**	-	I(0)	-8.195**	-	I(0)
Average annual temperature ($ATEMP_t$)	-4.331*	-	I(0)	-1.909	-4.411**	I(1)
Total domestic investment in agriculture (DIA_t)	-4.588**	-	I(0)	-4.526**	-	I(0)
Food security index (FSI_t)	-2.847	-7.439**	I(1)	-2.847	-10.953**	I(1)
Govt. capital expenditure on agric. ($GCEA_t$)	-2.130	-6.816**	I(1)	-1.893	-9.373**	I(1)
Average annual real exchange rate (RER_t)	-0.308	-4.251*	I(1)	-0.444	-4.131*	I(1)

*Note: For ADF test at level, critical value at 1% = - -4.297, and at 5% = -3.568; at first difference, critical value at 1% = -4.297, and at 5% = -3.568. For PP test at level, critical value at 1% = -4.285, and at 5% = -3.563; at first difference, critical value at 1% = -4.297, and at 5% = -3.568. Asterisks * and ** represent 5% and 1% significance levels, respectively. These tests were performed by including a constant and trend in the regressions. IO = integration order.*

Table 2: Bounds test result of the presence of a co-integration relationship between climate change indicators, as well as macroeconomic indicators and groundnut productivity in Nigeria

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	7.316173	10%	2.07	3.16
k	11	5%	2.33	3.46
		2.5%	2.56	3.76
		1%	2.84	4.1

Source(s): Author Construction from EViews 13 computation, 2024

Bounds Test

The result of the bounds test performed to investigate the presence of a co-integration relationship between climate change indicators and groundnut productivity in Nigeria is presented in Table 2.

The bounds test results presented in Table 4.10 reveal that the F-statistic of 7.316173 substantially exceeds the upper bounds critical values across all significance levels, including the 1% level (4.1) and the 5% level (3.46). This clearly indicates that the test statistic surpasses the critical values at each of these significance levels, thereby allowing us to reject the null hypothesis of no co-integration at the 1% level. Such compelling evidence strongly suggests the existence of a long-run co-integration relationship among the variables under consideration.

This result confirms the presence of a stable long-term equilibrium relationship between the climate change indicators, macroeconomic factors, and groundnut productivity in Nigeria. The co-integration relationship implies that although the variables may exhibit short-term fluctuations, they are likely to move together in the long run, reflecting a synchronized dynamic over time. This finding significantly bolsters the robustness of the model in capturing the intricate dynamics that influence groundnut productivity in Nigeria.

Moreover, the results underscore the critical interplay between climate change indicators and macroeconomic factors, establishing that their long-term impacts on groundnut productivity are underpinned by a statistically significant equilibrium. This discovery lays the foundation for a deeper exploration of the specific effects of these variables on groundnut productivity, which will be rigorously examined through the long-run estimation tests presented in the subsequent analysis.

ARDL Long-run Coefficients

Table 4.11 presents the ARDL long-run coefficients, which detail the effect of climate change and selected macroeconomic variables on groundnut productivity in Nigeria from 1991 to 2022. The model exhibits a high explanatory power, as evidenced by the R-squared value of 0.991743 and an adjusted R-squared of 0.960091. These values indicate that the independent variables collectively explain 99.1% of the variation in groundnut productivity during the study period, affirming the model's robustness in capturing the dynamics of groundnut productivity in Nigeria. Additionally, the significant F-statistic of 31.33236 (p = 0.000171) confirms the overall significance of the model. The Durbin-Watson statistic of 2.001380 suggests that the model is free from serial autocorrelation, further validating its reliability.

Model selection for estimating the effect of climate change, along with selected macroeconomic variables, on groundnut productivity in Nigeria was guided by the Akaike Information Criterion (AIC). The AIC indicated that the ARDL(1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 1) model was optimal for this analysis. This model configuration best captures the dynamics between the independent variables and groundnut productivity over the study period.

To refine the model, dynamic regressors were incorporated with a one-period lag, ensuring that the model automatically adjusted to include only relevant variables. The selection process adhered to the guidelines suggested by the Phillips-Perron unit root test, which was employed to verify the stationarity of the variables, thereby ensuring robust and reliable estimation.

The lag value of groundnut productivity is integrated into the model to capture the effects from previous years. The lagged value of groundnut productivity (LN(APFC_GROUNDNUT(-1))) is significant at the 10% level with a coefficient of 0.380597, indicating that a 1% increase in the previous year's groundnut productivity results in a 38.1% increase in the current year's productivity, which is in tandem with (Ayinde et al., 2020).

Table 3: Results of the ARDL Long-Run Coefficients for the Effect of Climate Change on Groundnut Productivity in Nigeria (1991–2022), with Control for selected Macroeconomic Variables

Dependent Variable: LN(APFC_GROUNDNUT)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (1 lag, automatic): LN(ARF) LN(ATEMP(-1)) LN(ACDE(-1)) LN(ARELH(-1)) LN(ASUN) LN(ALUC_GROUNDNUT(-1)) LN(AFDI(-1)) LN(DIA) LN(GCEA(-1)) LN(INFR(-1)) LN(RER(-1))
Fixed regressors: C @TREND
Selected Model: ARDL(1, 0, 1, 1, 1, 0, 1, 1, 0, 1, 1, 1)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LN(APFC_GROUNDNUT(-1))	0.380597	0.180501	2.108556*	0.0795
LN(ARF)	2.405512	0.799235	3.009768**	0.0237
LN(ATEMP)	-3.411512	5.926565	-0.575631	0.5858
LN(ATEMP(-1))	-20.29637	6.792120	-2.988224**	0.0244
LN(ACDE)	0.203086	0.758480	0.267754	0.7979
LN(ACDE(-1))	0.560777	0.704667	0.795804	0.4565
LN(ARELH)	0.845463	0.333144	2.537834**	0.0442
LN(ARELH(-1))	-0.414605	0.491380	-0.843755	0.4312
LN(ASUN)	-1.421483	0.540711	-2.628917**	0.0391
LN(ASUN(-1))	1.100264	0.371473	2.961893**	0.0252
LN(ALUC_GROUNDNUT)	1.399995	0.281572	4.972065***	0.0025
LN(ALUC_GROUNDNUT(-1))	0.791833	0.223736	3.539148**	0.0122
LN(AFDI)	0.066906	0.027450	2.437383**	0.0507
LN(AFDI(-1))	0.081288	0.024086	3.374954**	0.0150
LN(DIA)	0.739884	0.175556	4.214521***	0.0056
LN(DIA(-1))	-0.448641	0.155605	-2.883201**	0.0279
LN(GCEA)	-0.497166	0.140751	-3.532235**	0.0123
LN(GCEA(-1))	0.089024	0.037379	2.381647*	0.0546
LN(INFR)	-0.063629	0.057742	-1.101961	0.3127
LN(INFR(-1))	-0.251660	0.047365	-5.313170***	0.0018
LN(RER)	0.344767	0.126440	2.726722**	0.0343
LN(RER(-1))	0.762352	0.171759	4.438495***	0.0044
C	-16.85567	5.241476	-3.215824**	0.0182
@TREND	-0.001279	0.005199	-0.245960	0.8139
R-squared	0.991743	Mean dependent var		4.396525
Adjusted R-squared	0.960091	S.D. dependent var		0.320426
S.E. of regression	0.064013	Akaike info criterion		-2.668912
Sum squared resid	0.024586	Schwarz criterion		-1.547954
Log likelihood	64.03368	Hannan-Quinn criter.		-2.310308
F-statistic	31.33236***	Durbin-Watson stat		2.001380
Prob(F-statistic)	0.000171			

Source(s): Author Construction from EViews 13 computation, 2024. (***), (**) and (*) denote 1%, 5% and 10% significance level

This positive relationship suggests strong persistence in groundnut productivity over time, where the output of one period significantly influences the subsequent period. Such persistence could be due to the accumulation of effective agronomic practices, farmer experience, and sustained soil fertility, which contribute to continued high yields.

From the table, among the climate variables, Average Annual Rainfall (LNARF), a lagged value of Average Annual Temperature (LNATEMP(-1)), a lagged value of Average Annual Relative Humidity (LNARELH(-1)), a lagged value of Average Annual Sunshine Duration (LNASUN(-1)), and the current value of Average Annual Sunshine Duration (LNASUN) exhibit significant impacts on groundnut productivity.

Average annual rainfall (LN(ARF)) significantly impacts groundnut productivity at the 5% level, with a coefficient of 2.405512. This positive relationship underscores the importance of adequate rainfall for groundnut cultivation, particularly in Nigeria's rain-fed agricultural systems. Groundnuts require sufficient water supply for optimal growth, and adequate rainfall helps maintain the necessary soil moisture levels throughout the growing season. However, while rainfall is generally beneficial, its distribution must be optimal to prevent the adverse effects of drought or excessive moisture, which can hinder groundnut productivity, this finding is in agreement with (Anarah *et al*, 2021).

The lagged value of average annual temperature (LN(ATEMP(-1))) shows a significant negative effect on groundnut productivity at the 5% level, with a coefficient of -20.29637. This suggests that higher temperatures in the previous year are detrimental to groundnut productivity in Nigeria. Groundnut crops thrive within a specific temperature range, and temperatures exceeding this range can cause heat stress, disrupting vital physiological processes such as photosynthesis and leading to reduced yields. The negative effect of high temperatures highlights the vulnerability of groundnut crops to climate change, particularly in regions where temperatures are increasing due to global warming.

Average annual relative humidity (LN(ARELH)) and its lagged value are also significant, though they exhibit contrasting effects. The current value of relative humidity (LN(ARELH)) has a positive and significant effect on groundnut productivity at the 5% level, with a coefficient of 0.845463. This suggests that higher humidity levels are generally favorable for groundnut cultivation, as they help maintain soil moisture and reduce the rate of evapotranspiration, thus supporting the plant's water needs. However, the lagged value (LN(ARELH(-1))) is not significant, which implies that the effect of relative humidity on groundnut productivity is more immediate rather than prolonged.

The average annual sunshine duration (LN(ASUN)) and its lagged value significantly affect groundnut productivity, though their impacts are opposite in direction. The current value of sunshine duration negatively influences productivity with a coefficient of -1.421483, significant at the 5% level, indicating that excessive sunlight might be detrimental in the short run, possibly due to increased evaporation rates leading to water stress. However, the lagged value of sunshine duration (LN(ASUN(-1))) positively impacts productivity with a coefficient of 1.100264, also significant at the 5% level. This suggests that while too much sun can be harmful in the immediate term, sufficient sunlight in the previous year benefits groundnut productivity in the long term, possibly by ensuring proper maturation and increased photosynthesis over time (Ayinde et al., 2020).

Macroeconomic variables such as the previous year's area of land under groundnut cultivation (LNALUC_GROUNDNUT(-1)), current and previous year's value of Agricultural Foreign Direct Investment (LNAFDI & LNAFDI(-1)), current and a lagged value of Private Domestic Investment in Agriculture (LNDIA & LNDIA(-1)), current previous year's value of Government Capital Expenditure in Agriculture (LNGCEA & LNGCEA(-1)), previous year's average annual inflation rate LN(INFR(-1)), and the current and previous year's Real Exchange Rate (LNRER & LNRER(-1)) also exhibit notable effects.

The area of land under groundnut cultivation (LN(ALUC_GROUNDNUT(-1))) in the previous year exhibits a strong positive effect on current productivity, with a coefficient of 1.399995, significant at the 1% level. This relationship suggests that expanding the area dedicated to groundnut cultivation leads to higher productivity, likely due to better resource allocation, economies of scale, and the potential for adopting improved agricultural practices on a larger scale. The persistence of this positive effect in subsequent periods, as shown by the significance of the lagged value, emphasizes the long-term benefits of increased land allocation for groundnut farming in Nigeria.

In the context of Foreign Direct Investment (FDI) in agriculture, both the current and previous year's FDI in agriculture are significant and positively affect groundnut productivity. The coefficient for the current year's FDI (LNDAFDI) is 0.066906, with a p-value of 0.0507, indicating that a 1% increase in FDI in the current year results in a 0.067% increase in groundnut productivity. The previous year's FDI (LNDAFDI(-1)) also shows a positive relationship, with a coefficient of 0.081288 and a p-value of 0.0150, demonstrating that past FDI continues to influence productivity positively. This positive effect suggests that FDI injects necessary capital, advanced technologies, and expertise into the agricultural sector, facilitating improvements in productivity. FDI can lead to the introduction of modern farming techniques, improved seed varieties, and better infrastructure, all of which contribute to enhanced groundnut yields. The sustained effect from the previous year's FDI underscores the lasting benefits of such investments, as they help build a stronger, more resilient agricultural sector capable of maintaining higher productivity levels over time (Ayinde et al., 2020).

Conversely, the results for domestic private investment in agriculture (LNDIA) reveal a complex relationship with groundnut productivity. The current year's domestic private investment (LNDIA) shows a significant positive effect with a coefficient of 0.739884 and a p-value of 0.0056, indicating that an increase in domestic investment enhances productivity. However, the previous year's investment (LNDIA(-1)) presents a significant negative effect, with a coefficient of -0.448641 and a p-value of 0.0279. This suggests that while immediate investments can boost productivity, there might be diminishing returns or inefficiencies over time, possibly due to misallocation of resources or shifts in investment focus away from agriculture. The dual effect could reflect the challenges in sustaining effective private investment without supportive policies and consistent public investment, as private capital alone may not fully address the sector's needs for long-term growth.

The current and previous year's Government Capital Expenditure on Agriculture (GCEA) exhibit a nuanced relationship with groundnut productivity in Nigeria, reflecting the critical role of public investment in the agricultural sector. The current year's government capital expenditure (LN(GCEA)) has a significant negative effect on groundnut productivity, with a coefficient of -0.497166 and a p-value of 0.0123. This suggests that an increase in government capital expenditure in the current year is associated with a reduction in groundnut productivity. This negative relationship might seem counterintuitive, as one would expect government spending to enhance agricultural productivity. However, this could be indicative of inefficiencies or delays in the implementation of government projects. For instance, funds allocated for agricultural infrastructure, research, or extension services might not yield immediate results, or the benefits might be offset by bureaucratic inefficiencies, corruption, or misallocation of resources. The negative effect could also reflect a lag between expenditure and actual outcomes, where the benefits of current investments are not realized within the same year. In contrast, the previous year's government capital expenditure (LN(GCEA(-1))) shows a significant positive effect on groundnut productivity, with a coefficient of 0.089024 and a p-value of 0.0546. This positive relationship indicates that the benefits of government investment in agriculture become apparent over time, contributing to increased productivity in subsequent years. This lagged effect suggests that while current investments might initially disrupt productivity due to implementation challenges, their positive impacts materialize as the infrastructure, technologies, and programs funded by these expenditures begin to take effect. This underscores the importance of sustained and well-planned public investment in agriculture, as the benefits of such expenditures may take time to fully manifest but are crucial for long-term agricultural development. The contrasting effects of current and previous year's government capital expenditure highlight the importance of effective planning, timely execution, and sustained investment in the agricultural sector. While immediate results might not always be positive, the long-term benefits of well-targeted government spending can significantly enhance groundnut productivity, supporting broader agricultural growth and economic development in Nigeria.

The previous year's average annual inflation rate (LNINFR(-1)) is also significant and negatively impacts groundnut productivity, with a coefficient of -0.251660 and a p-value of 0.0018. This finding indicates that inflationary pressures from the previous year have a detrimental effect on current productivity levels. High inflation erodes the purchasing power of farmers, increasing the costs of essential inputs such as seeds, fertilizers, and machinery. As these costs rise, farmers may reduce their investment in productivity-enhancing practices, leading to lower yields. Additionally, inflation can create economic uncertainty, making it more challenging for farmers to plan and invest in their operations effectively. The negative effect of inflation on groundnut productivity highlights the importance of macroeconomic stability in supporting agricultural productivity.

The real exchange rate (RER) in both the current and previous years significantly affects groundnut productivity. The coefficient for the current year's real exchange rate (RER) is 0.344767, with a p-value of 0.0343, while the previous year's real exchange rate (RER(-1)) has a coefficient of 0.762352 and a p-value of 0.0044. These positive relationships suggest that a higher real exchange rate, which indicates a weaker domestic currency relative to foreign currencies, benefits groundnut productivity. A weaker domestic currency can make Nigerian groundnuts more competitive in international markets, potentially increasing demand and encouraging farmers to invest more in production. The sustained effect from the previous year further emphasizes the importance of exchange rate stability in fostering a conducive environment for agricultural growth. However, it also suggests that excessive volatility in exchange rates could pose challenges for long-term planning and investment in the sector.

3.2 ARDL Error Correction Regression Estimated Short-run Coefficients

Table 4. presents the result of the ARDL error correction regression estimated short-run coefficients for effect of climate change on groundnut

productivity within the study period, with selected macroeconomic controls.

The ECM results of the short run indicate that not all climate change indicators and macroeconomic determinants have a significant effect on groundnut productivity in the short run. In the short run, the immediate effects of certain climatic variables, such as average annual temperature (DLN(ATEMP, 2)) exhibits a deflationary effect on groundnut productivity at a 5% significance level. This indicates that an increase in temperature negatively affects groundnut productivity in the short run.

Table 4: Results of the ARDL Error Correction Regression Estimated Short-run Coefficients for the Effect of Climate Change on Groundnut Productivity in Nigeria (1991–2022), with Control for selected Macroeconomic Variables

ARDL Error Correction Regression
Dependent Variable: DLN(APFC_GROUNDNUT)
Selected Model: ARDL (1, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1)
Case 5: Unrestricted Constant and Unrestricted Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-16.85567	1.073498	-15.70163***	0.0000
@TREND	-0.001279	0.000865	-1.478598	0.1897
DLN(ATEMP, 2)	-3.411512	1.284207	-2.656513**	0.0377
DLN(ACDE, 2)	0.203086	0.237826	0.853927	0.4259
DLN(ARELH, 2)	0.845463	0.108801	7.770763***	0.0002
DLN(ASUN)	-1.421483	0.130690	-10.87678***	0.0000
DLN(ALUC_GROUNDNUT, 2)	1.399995	0.093398	14.98955***	0.0000
DLN(AFDI, 2)	0.066906	0.006567	10.18875***	0.0001
DLN(DIA)	0.739884	0.046763	15.82199***	0.0000
DLN(GCEA, 2)	-0.497166	0.029575	-16.81059***	0.0000
DLN(INFR, 2)	-0.063629	0.014536	-4.377300***	0.0047
DLN(RER, 2)	0.344767	0.041332	8.341395***	0.0002
ECM(-1)	-0.619403	0.039273	-15.77181***	0.0000
R-squared	0.961050	Mean dependent var		0.039803
Adjusted R-squared	0.933555	S.D. dependent var		0.147532
F-statistic	34.95439***	Durbin-Watson stat		2.001380
Prob(F-statistic)	0.000000			

Diagnostic test

Test statistics	*F-statistic*	*P-value*	*Interpretation*
Heteroskedasticity test: Breusch-Pagan-Godfrey	0.705768	0.7492^{ns}	No heteroskedasticity
Breusch-Godfrey Serial Correlation LM Test	0.099502	0.9075^{ns}	No Serial Correlation
Ramsey RESET stability	0.006373	0.9390^{ns}	Model correctly specified
Jacque-Bera test	0.449352	0.7988^{ns}	Normal distribution

Source(s): Author Construction from EViews 13 computation, 2024. (***), and (**) denote 1%, and 5% significance level. (^{ns}) denote not significant.

This result highlights the sensitivity of groundnut crops to temperature fluctuations, which could potentially reduce yields if not managed properly. Conversely, relative humidity (DLN(ARELH, 2)) at a 1% significance level shows a positive and significant influence on groundnut productivity, indicating that higher humidity levels are beneficial in the short run. This is likely due to its role in maintaining soil moisture. However, sunshine duration (DLN(ASUN)) exhibits a negative and significant effect on productivity at a 1% significance level, suggesting that excessive sunshine may harm productivity, possibly due to increased evapotranspiration and heat stress on crops. This further suggests that while sunlight is essential for photosynthesis, excessive exposure can lead to adverse effects on productivity, possibly necessitating better water management practices. The ARDL results for groundnut productivity in Nigeria during the study period suggest that, in the short term, achieving positive and meaningful groundnut productivity requires strategic mitigation efforts to control temperature fluctuations and manage sunshine exposure. To this end, it is imperative that the Nigerian government implements robust climate change policies that address the effects of these climatic variables on groundnut production. Extreme weather events such as floods, landslides and drought are caused by climate variation (Anarah *et al*, 2021).

Additionally, the ARDL error correction regression's estimated short-run coefficients for the effect of climate change on groundnut productivity indicate that the area of land under groundnut cultivation (DLN(ALUC_GROUNDNUT, 2)) at a 1% significance level has a positive and significant effect on groundnut productivity in the short run. This finding suggests that an increase in the land area under groundnut cultivation leads to an increase in productivity, which aligns with theoretical expectations. This could be attributed to the fact that expanding land under cultivation allows for greater output, assuming other inputs are effectively managed. However, this result contrasts with some previous studies like (Ayinde et al., 2020). indicating that the specific context of Nigeria's agricultural practices may play a role in this positive outcome.

Moreover, the ARDL error correction regression's estimated short-run coefficients for the effect of climate change on groundnut productivity indicate that macroeconomic indicators such as foreign direct investment in agriculture (DLN(AFDI, 2)), private domestic investment in agriculture (DLN(DIA)) and the real exchange rate (DLN(RER, 2)), all at a 1% significance level, have a positive and significant effect on groundnut productivity. However, some macroeconomic determinants, such as government capital expenditure on agriculture (DLN(GCEA, 2)) and inflation rate (DLN(INFR, 2)), have negative and significant impacts on groundnut productivity. The negative effect of government capital expenditure could indicate inefficiencies or misallocation of resources, while the negative effect of inflation reflects the eroding purchasing power, which could increase production costs and reduce profitability. These results suggest that, in the short term, improvements in government capital expenditure in agriculture for groundnut production and effective management of inflation are crucial for achieving positive and meaningful groundnut productivity. To support this, the Nigerian government should implement strong economic policies that address these areas proactively.
The awareness of farmers to adopting improved seed varieties as a panacea for climate change adaptation, has been relatively widely studied in Nigeria (Ogbodo *et al*, 2018).

The adjustment speed to equilibrium, as indicated by the Error Correction Model (ECM), is negative and significant at the 1% level, confirming the model's long-term stability. With an ECM coefficient of -0.619403, which is negative and lies between zero and one, the speed of adjustment to long-run equilibrium is approximately 61.9% annually. Chikezie et al. (2017) indicated that an ECM that is negative and significantly different from zero justifies long-run adjustment with a speed of less than 100%. The results, therefore, indicate that the stochastic error (residuals) processes generated and their movements over time in the model can be corrected, with the speed of adjustment back to equilibrium in the long run being 61.9%. Consequently, the short-run analysis suggests that while relative humidity, land under cultivation of groundnut, foreign direct investment in agriculture, private domestic investment in agriculture, and real exchange rate positively and significantly influence groundnut productivity, annual temperature, sunshine duration, government capital expenditure on agriculture and inflation rate contribute to a slowdown in groundnut productivity with the period under study.

Diagnostic tests for serial autocorrelation, heteroskedasticity, and model stability were conducted to assess the model's robustness. The Breusch-Pagan-Godfrey correlation and heteroskedasticity tests, along with the Breusch-Godfrey serial correlation LM test, the Ramsey RESET stability test, and the Jacque-Bera test, confirm the absence of serial autocorrelation, homoscedasticity, model instability, and distributional issues. The Breusch-Pagan-Godfrey test for heteroskedasticity yields an F-statistic of 0.705768 with a p-value of 0.7492, indicating that there is no evidence of heteroskedasticity in the model's residuals, meaning the variance of the errors is constant. The Breusch-Godfrey Serial Correlation LM Test shows an F-statistic of 0.099502 and a p-value of 0.9075, suggesting that there is no serial correlation in the residuals, implying that the errors are independent over time. The Ramsey RESET test for model specification returns an F-statistic of 0.006373 with a p-value of 0.9390, confirming that the model is correctly specified without any omitted variables. The Jarque-Bera test is a rigorous statistical measure used to evaluate the normality of the residuals in a regression model, a critical assumption underlying the validity of many econometric models. In the context of this study, the Jarque-Bera test statistic is 0.449352, with a p-value of 0.7988, far exceeding conventional thresholds for significance (typically 1%, 5%, or 10%). This result implies that the null hypothesis of normality in the residuals cannot be rejected, signifying that the residuals of the ARDL error correction model are normally distributed. The normal distribution of residuals is a cornerstone for ensuring the reliability and robustness of the model’s estimates, as it underpins key assumptions such as homoscedasticity, unbiasedness, and efficiency of the estimators. Consequently, the normality confirmed by the Jarque-Bera test reinforces the statistical soundness of the model, lending further credibility to the interpretations and inferences drawn from the regression analysis in this study. The p-values for these diagnostic tests exceed the 5% significance level, indicating that the relationship between the dependent and independent variables is accurately defined. Overall, these diagnostic tests validate the robustness and adequacy of the model.

4.0 CONCLUSION AND RECOMMENDATIONS

Average annual rainfall, a lagged value of average annual temperature, a lagged value of average annual relative humidity, a lagged value of average annual sunshine duration, the current value of average annual sunshine duration, the previous year’s area of land under groundnut cultivation, the current and previous year’s value of agricultural foreign direct investment, the current and lagged value of private domestic investment in agriculture, the current and previous year's value of government capital expenditure in agriculture, the previous year's average annual inflation rate, and the current and previous year's real exchange rate significantly influenced groundnut productivity in the long-run. In the short-run, the second lag of average annual temperature, the second lag of average annual relative humidity, the current value of average annual sunshine duration, the second lag of the area of land under groundnut cultivation, the current values of foreign direct investment in agriculture, domestic investment in agriculture, government capital expenditure in agriculture, the inflation rate, and the second lag of the real exchange rate significantly influenced groundnut productivity in Nigeria.

Improving groundnut productivity requires targeted investments in climate-resilient agricultural practices and infrastructure. Policymakers should prioritize the expansion of irrigation systems and the adoption of drought-resistant groundnut varieties, particularly in the Sahel region where temperature increases are most pronounced. Additionally, enhancing private domestic and foreign investment in agriculture, coupled with increased government capital expenditure, will be crucial in providing the necessary resources for farmers to adopt these innovations. Moreover, effective management of macroeconomic variables, such as inflation and exchange rates, should be pursued to stabilize the economic environment for groundnut production.

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