CLIMATE VARIABILITY, FARMERS' PERCEPTION, ADAPTATION AND AGRICULTURAL OUTPUT IN BORNO STATE, NIGERIA.

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Abstract
Climate variability poses significant risks to smallholder agriculture in sub-Saharan Africa, where dependence on rainfall and limited adaptive capacity heighten vulnerability. Despite growing literature on climate perception, few studies in conflict-affected northeastern Nigeria jointly examine how farmers' perception and adaptation strategies influence agricultural output while accounting for institutional support. This study examines farmers' perceptions of climate variability and its effects on agricultural output in Maiduguri, Biu, and Bayo Local Government Areas of Borno State, Nigeria. Using a cross-sectional survey design, primary data were collected from 600 farmers through structured questionnaires and analyzed using descriptive statistics, chi-square tests, and multiple regression techniques. Results reveal that over 80% of farmers perceive declining rainfall and rising temperatures, and 72% report yield reductions, particularly for maize, millet, and sorghum. Education and farming experience significantly enhance perception accuracy ($p < 0.05$). Both perception ($\beta = 0.284$) and adaptation strategy indices ($\beta = 0.352$) significantly improve agricultural output, while institutional support also exerts a positive direct effect on productivity ($p = 0.022$). The study concludes that accurate perception and proactive adaptation, strengthened by education and institutional access, are crucial for building resilience in semi-arid farming systems.

Keywords: Adaptation, agricultural output, borno state, climate variability, institutional support, Nigeria, perception.

1.0 Introduction

Agricultural systems in sub-Saharan Africa face mounting pressure from climate variability and long-term climatic change. Increased rainfall variability, delayed rainy-season onset, earlier cessation, and rising temperatures are already eroding yield stability across staple crops, including cereals and legumes, and are projected to intensify with continued warming (IPCC, 2014; Niang et al., 2014). In much of sub-Saharan Africa, over 95% of cropland remains rain-fed (FAO, 2022), leaving smallholders acutely vulnerable to fluctuations in rainfall and temperature. These stressors

interact with socioeconomic challengessuch as land fragmentation, low input use, and limited access to technologycompounding farmers' exposure to risk (Lobell et al., 2008; Sultan et al., 2019).

Across the Sudano Sahelian band, empirical and model-based assessments show that heat stress and water deficits are the dominant pathways through which climatic changes depress crop productivity. A modest 1 °C rise in average temperature can shorten crop maturation, reduce photosynthetic efficiency, and lower maize and sorghum yields by up to 10% (Lobell et al., 2008; Sultan et al., 2019). Erratic rainfall and dry spells further increase interannual yield volatility, amplifying risk for smallholders reliant on rainfed production (Mertz et al., 2009; Waha et al., 2013). Localized studies indicate that smallholder farmers actively interpret and respond to climatic shifts, modifying planting dates, diversifying crops, and adopting new cultivars based on experience (Mertz et al., 2009; Limantol et al., 2016; Amadou et al., 2022).

Nigeria exemplifies this vulnerability. Agriculture provides livelihoods for over 70% of rural households (FAO, 2022), yet the northern and northeastern zones particularly Borno, Yobe, and Adamawa States experience high temperature increases and rainfall inconsistency (NIMET, 2021). Declining rainfall trends of 10–15% and temperature rises of 1.5 °C have been recorded in the Sudano–Sahelian belt (Usmail et al., 2023; Mohammed et al., 2022). Socio-political instability, including the prolonged insurgency in Borno, further disrupts markets, displaces populations, and limits extension services, constraining adaptive capacity (FAO, 2022; NPC, 2021).

Understanding how smallholders perceive climatic changes and translate perceptions into adaptive behavior is critical for designing relevant interventions. Perception is the first cognitive step in adaptation: if farmers notice meaningful shifts in rainfall or temperature, they are more likely to adjust practices; misperception can lead to maladaptation or inertia (Deressa et al., 2008; Limantol et al., 2016). Studies in Ghana, Ethiopia, and Niger show that perception accuracy is linked to education, experience, and access to information (Legesse et al., 2013; Amadou et al., 2022; Mairura et al., 2021). For example, Ethiopian farmers with extension contact were twice as likely to adopt climate-smart practices (Deressa et al., 2008).

Adaptation outcomes also depend on structural enablers that provide information, resources, and risk-sharing mechanisms. Weak institutions foster low-return coping strategies rather than productive adaptation (Ampaire et al., 202O; Madaki et al., 2025). Evidence from northeastern Nigeria remains sparse, with studies largely descriptive, focusing on awareness rather than quantifying how perception and adaptation jointly affect agricultural productivity (Agwu et al., 2018; Usmail et al., 2023). Few have examined how institutional support through extension services, farmer associations, and rural credit programs affects adaptation effectiveness.

This study investigates farmers' perceptions of climate variability and its effects on agricultural output in Maiduguri, Biu, and Bayo LGAs of Borno State. It focuses on the "perception, action, output" nexus, viewing perception as both a precursor and determinant of adaptation (Sahu & Mishra, 2013; Nhemachena & Hassan, 2007), testing three hypotheses:

H_{01}: Farmers' accurate perception of climate variability positively affects agricultural output.
H_{02}: Adoption of adaptation strategies positively impacts agricultural output.
H_{03}: Access to institutional support enhances agricultural output.

By combining behavioral and institutional analyses in a conflict-affected, semi-arid setting, the study contributes threefold: it provides extensive empirical data on climate perceptions and adaptive behavior in northeastern Nigeria, links perception and adaptation to agricultural output, and tests the moderating effect of institutional support, offering insights for targeted policy interventions. Findings aim to inform the Federal Ministry of Agriculture, NIMET, and international partners in mainstreaming climate resilience into agricultural policy.

2.0 Literature Review

Climate Variability-Productivity Nexus

Climate variability and long-term climate change are already affecting agricultural productivity worldwide, especially in sub-Saharan Africa, where most farmers rely on rain-fed farming and have limited resources to respond to shocks (IPCC, 2014; Niang et al., 2014; Sultan et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) warns that rising temperatures of 1.5-2 °C, together with erratic rainfall, will reduce yields of staples such as maize, millet, and sorghum by mid-century unless adaptation is scaled up.

The Sudano-Sahelian region has been identified as a global "hotspot" of agricultural vulnerability, where even small temperature or rainfall changes could reduce food production by 10-20 % (Lobell et al., 2008). Later studies show that not only average climate shifts but also increased interannual rainfall variability, shorter rainy seasons, delayed onset, and intense dry spells reduce yields and increase risks for smallholder farmers (Waha et al., 2013; Sultan et al., 2019).

Farmers in sub-Saharan Africa face reduced soil moisture, shorter crop cycles, pest outbreaks, and loss of arable land (Omotoso et al., 2023). Poverty, poor infrastructure, and weak institutions worsen vulnerability (Ampaireet al., 2020; FAO, 2022). Without adaptive management, West Africa's cereal yields could fall by 15-25 % by 2050 (Faye & Ducoin, 2020).

Perception Theory and Behavioral Adaptation

Farmers' perceptions of climate change are important triggers for adaptation. Many smallholders in West Africa and the Sahel notice later rainy season onsets, shorter growing periods, more droughts, and higher temperatures (Mertz et al., 2009; Limantol et al., 2016; Amadou et al., 2022). These perceptions often match meteorological data, suggesting that experience and environmental signs provide useful information for decision-making (Waha et al., 2013; Legesse et al., 2013).

However, perception accuracy depends on socioeconomic factors. Farmers with more education, longer experience, or access to extension or climate information services are better able to interpret climate trends (Sahu & Mishra, 2013; Mairura et al., 2021). Gender and age also matter, men and household heads often report stronger awareness due to more involvement in training and decision-making, while women perceive climate effects mainly through household food security (Moser & Satterthwaite, 2010; Adisa et al., 2024).

Behavioral models suggest that farmer's act based on perceived climate changes, not necessarily observed changes (Grothmann & Patt, 2005). Studies in Ghana, Ethiopia, and India show that farmers who perceive declining rainfall or increasing temperatures are more likely to adopt adaptive practices, though the strength of this link depends on resources and institutions (Limantol et al., 2016; Legesse et al., 2013; Sahu & Mishra, 2013; Deressa et al., 2008; Nhemachena & Hassan, 2007).

Adaptation Strategies

Smallholder farmers employ a variety of strategies to cope with the impacts of climate change. These strategies aim to reduce risks from rainfall variability, higher temperatures, and other environmental stressors. Common adaptation measures include adjusting planting dates to align with rainfall patterns, adopting drought-tolerant crop varieties, diversifying both crops and income sources, applying organic manure, and implementing soil and water conservation practices (Deressa et al., 2008; Mairura et al., 2021; Ampaire et al., 2020).

In West Africa, adaptation practices are often knowledge-based and low-cost because smallholders typically have limited financial resources. For instance, in Ghana, a large majority of farmers around 80 % reported adjusting their planting dates and diversifying crops in response to changing climatic conditions, yet only 12 % had access to irrigation facilities (Limantol et al., 2016). Similarly, in Mali, nearly all farmers were aware of climate change, but adoption of advanced technologies remained limited due to both financial and informational constraints (Amadou et al., 2022).

The effectiveness and choice of adaptation strategies are also shaped by land tenure, risk perception, and market access. Farmers who have larger or secure landholdings are more likely to invest in long-term soil management and other sustainable practices, whereas tenants or smallholders with limited tenure security tend to favor short-term coping measures (Bryan et al., 2009). In Nigeria, for example, rice farmers in Niger State widely employed planting-date adjustments and early maturing varieties, yet many cited lack of credit, high input costs, and limited extension services as significant barriers to adopting broader or more advanced adaptation strategies (Adisa et al., 2024).

Overall, these findings suggest that while smallholders are proactive in adopting adaptation measures, the scope and intensity of their strategies are constrained by financial, informational, and institutional limitations. Addressing these barriers is therefore essential for enhancing the resilience of smallholder agriculture under changing climatic conditions.

Institutional Theory

Institutions both formal (extension, credit, cooperatives) and informal (social networks, community norms) shape farmers' ability to adapt (Deressa et al., 2008; Nhemachena & Hassan, 2007). Strong institutions reduce transaction costs, spread information, and support collective action, increasing the benefits of adaptation (Agrawal, 2010). Farmers with access to extension are 2–3 times more likely to adopt water-harvesting or improved seed technologies (Legesse et al., 2013; Mairura et al., 2021).

In many fragile regions, institutional weakness is common. Local governments often lack resources, have overlapping mandates, or face political instability (Madaki et al., 2025). In conflict-affected areas like Borno State, institutional erosion limits farmers' access to extension and credit. Combining indigenous knowledge with formal institutions is essential for inclusive and sustainable adaptation (Chambon et al., 2024).

In Nigeria, fewer than 30 % of smallholders have regular extension contact, and less than 15 % have access to credit (FAO, 2022). Seasonal forecasts exist (NIMET, 2021) but have limited reach and reliability at the local level. These gaps highlight the importance of institutional support in enabling effective adaptation.

Empirical Gaps and Study Focus

Existing Nigerian and Sahel studies often use small samples, descriptive statistics, and focus on awareness rather than productivity outcomes (Agwu et al., 2018; Usmail et al., 2023). Few studies test whether perception accuracy and adaptation intensity improve yields or whether institutions enhance these effects. Research has also focused on southern and central Nigeria, leaving the semi-arid northeast underrepresented (Mohammed et al., 2022).

This study surveys 600 farmers across Maiduguri, Biu, and Bayo in Borno State. It constructs perception and adaptation indices and examines the interaction between adaptation intensity and institutional support. Using frameworks from Deressa et al. (2008) and Nhemachena and Hassan (2007), the study models how education, experience, and institutional access influence the perception–adaptation–productivity link. The findings provide micro-level evidence from a conflict-affected setting and inform climate-resilient agricultural policies.

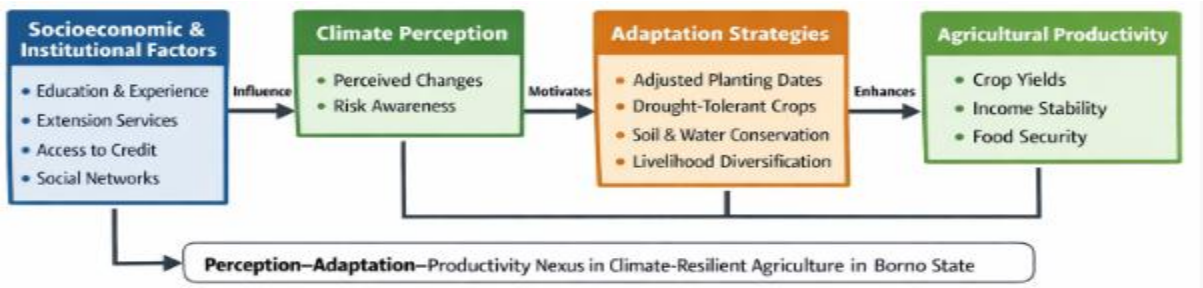


Figure 1: Conceptual framework showing the perception adaptation productivity nexus in climate-resilient agriculture in Borno State, Nigeria.

3.0 Methodology

Study Area

This study was conducted in three Local Government Areas (LGAs) of Borno State, Maiduguri, Biu, and Bayo representing the semi-arid and Sudan Sahel ecological zones of northeastern Nigeria. The region is geographically located between latitudes 10°-13° N and longitudes 11°-14° E and has an estimated population exceeding 3 million people (NPC, 2021). Annual rainfall ranges from 500 mm to 850 mm, largely concentrated between June and September, while the dry season extends from October to May, with mean monthly temperatures between 26 °C and 38 °C (NIMET, 2021).



Figure 2: Map of Borno State.

Agriculture is the primary source of livelihood, employing over 70% of the labor force, with staple crops including sorghum, millet, maize, rice, and groundnut. The area's agro-climatic conditions characterized by recurrent droughts, erratic rainfall, and rising temperatures create significant variability in crop yields, contributing to food insecurity (Deressa et al., 2008; Agwu et al., 2018). These climatic and environmental constraints provide a relevant context for econometric analyses of agricultural output, as variations in rainfall, temperature, and other local factors can be quantitatively linked to household-level productivity, input use, and adaptation strategies.

Research Design

The study adopted a cross-sectional quantitative explanatory research design, using structured questionnaires to obtain data from crop farmers. This design captures farmers' perceptions and behavioral responses to long-term climatic trends within a single survey period, making it suitable for establishing associations and exploring potential causal relationships between variables (Mertz et al., 2009). Fieldwork was conducted between October and December 2025.

Population, Sampling and Sample Size

The population comprised small- and medium-scale arable farmers actively cultivating crops in the three LGAs. A multi-stage sampling technique was used:

i. Stage 1: Purposeful selection of the three LGAs based on high agricultural intensity.
ii. Stage 2: Random selection of two communities per LGA, yielding six communities.
iii. Stage 3: Simple random sampling of 100 farmers per community, giving a total of 600 respondents.

The sampling frame was obtained from the agricultural extension offices in each LGA, which maintain updated lists of registered crop farmers. Of the 600 questionnaires administered, 582 were returned and found complete, representing a response rate of 97%, which is adequate for statistical reliability.

The sample size satisfies f's (1977) formula for large populations at a 95 % confidence level and ± 4 % margin of error. This size ensures representativeness for inferential analysis such as regression and chi-square tests.

Instrumentation

Data for the study were collected using a structured questionnaire designed to capture information relevant to climate variability and agricultural outcomes. The questionnaire was developed based on validated instruments previously used in similar climate-perception studies in Africa, ensuring both reliability and contextual relevance (Deressa et al., 2008; Agwu et al., 2018).

It consisted of five sections:

A: Socio-demographics (age, gender, education, household size, farm size, farming experience) to explain differences in perceptions and adaptive capacity.

B: Perceptions of climate variability, including rainfall, temperature, drought, and floods.

C: Effects of climate variability on crop yields and farm performance.

D: Adaptation strategies, such as changes in planting dates, drought-resistant seeds, irrigation, crop diversification, fertilizer use, and off-farm activities.

E: Institutional and government support, including sources of information and constraints to adaptation.

The questionnaire was translated into Hausa to enhance comprehension. Enumerators were trained on ethics, interviewing techniques, and data quality to ensure accurate and reliable responses.

Validity and Reliability

The questionnaire was reviewed by agricultural-climate experts from the University of Maiduguri to ensure content validity. A pilot test with 30 farmers in Konduga LGA produced a Cronbach's α of 0.83, indicating high internal consistency, above the commonly accepted threshold of ≥ 0.70 (Hair et al., 2019).

Data Coding and Management

After data collection, questionnaire responses were coded using a standardized guide, with open-ended answers grouped into categories through content analysis (Krippendorff, 2018). The coded data were entered into SPSS, with double-entry verification and consistency checks to ensure accuracy and reliability for statistical analysis (Field, 2018; Pallant, 2020).

Analytical Techniques

Data analysis was conducted in three stages. First, descriptive statistics (frequencies, percentages, means, standard deviations) summarized respondents' socio-economic characteristics and perceptions of climate variability (Field, 2018). Second, chi-square (χ^2) tests examined associations between socio-demographic factors and climate-perception differences (Deressa et al., 2008; Onyeneke et al., 2018).

Third, the effects of climate-perception and adaptation strategies on agricultural output were assessed using ordinary least squares (OLS) regression. Agricultural output (Yi), measured as crop yield in kg/ha, was regressed on the Climate-Variability Perception Index (Pi), the Adaptation Strategy Index (Ai), access to institutional support (Si), their interaction ($Ai{\times}Si$), and control variables (age, education, farming experience, farm size), as specified in the equation:

$$Y_i = \beta_0 + \beta_1 P_i + \beta_2 A_i + \beta_3 S_i + \beta_4 (A_i \times S_i) + \beta_5 X_i + \epsilon_i$$

In the regression model, agricultural output (Y_i) was measured in kilograms per hectare, serving as the dependent variable. The main explanatory variables included the climate-variability perception index (P_i), which ranged from 0 to 5 and captured farmers' observations of changes in rainfall, temperature, drought, and flood frequency, and the adaptation strategy index (A_i), representing the total number of measures adopted by each farmer, such as adjusting planting dates, using drought-resistant seeds, and diversifying crops. Access to institutional support (S_i) was included as a dummy variable, coded 1 for farmers with support and 0 otherwise, while a vector of socio-economic characteristics (X_i) including age, education, farming experience, and farm size was incorporated as control variables. The error term (ϵ_i) captured unobserved factors affecting output.

To ensure the reliability and validity of the OLS estimates, several diagnostic tests were conducted. Multicollinearity among independent variables was assessed using variance inflation factors (VIF), heteroskedasticity was evaluated with the Breusch Pagan test, and the normality of residuals was examined. Additionally, robust standard errors were applied to account for potential violations of classical OLS assumptions. All analyses were performed using SPSS, and statistical significance was evaluated at the 5% level (Pallant, 2020; Nhemachena & Hassan, 2007).

Ethical Consideration

To ensure the study met ethical standards, several steps were taken during fieldwork. Informed consent was obtained from all 600 participants after explaining the purpose of the study and confirming that participation was voluntary. Respondents' anonymity and confidentiality were protected by removing names and personal identifiers, and all data were used only for academic

purposes. The research was also conducted with respect for the local cultures and traditions of communities in Maiduguri, Biu, and Bayo..

4.0 Results and Discussion

Socio-Demographic Characteristics

Table 1 presents the demographic profile of respondents. Of the 600 farmers, 67.5 % were male and 32.5 % female, confirming male predominance in agriculture. Mean age was 42.7 years, and mean farming experience 17.8 years. Approximately 45 % had secondary education, 30 % primary, and 12 % tertiary, while 13 % had no formal education. The average farm size was 2.6 ha, and mean household size 7 persons.

Table 1:
Socio-Demographic Profile of Respondents (n = 600)

Variable	Category	Frequency	%
Gender	Male	405	67.5
	Female	195	32.5
Age (yrs)	<30	72	12.0
	30-49	338	56.3
	≥50	190	31.7
Education	None	78	13.0
	Primary	180	30.0
	Secondary	270	45.0
	Tertiary	72	12.0
Mean farming experience		17.8 yrs	
Mean farm size		2.6 ha	

Source: Authors'Compilation, 2026.

The dominance of middle-aged male farmers suggests that production and adaptation decisions are concentrated within economically active household heads. The relatively moderate education level implies basic literacy capacity, which may facilitate access to climate information and adoption of innovations. Farm size remains small on average, indicating limited capital endowment and potential vulnerability to climatic shocks. These patterns are consistent with findings from northern Nigeria (Agwu et al., 2018; Sofoluwe et al., 2011).

Farmers' Perception of Climate Variability

A striking 89 % of respondents perceived that rainfall timing has changed, while 82 % believed rainfall amounts had decreased. Likewise, 86 % observed higher temperatures and 74 % reported more frequent droughts and floods. Chi-square analysis (Table 2) showed significant associations between perception of climate variability and education level ($\chi^2 = 21.42$, $p < 0.01$) as well as years of farming experience ($\chi^2 = 16.37$, $p < 0.05$). This implies that more educated and experienced farmers have higher awareness of climatic trends, corroborating Deressa et al. (2008) and Kapoury et al. (2016).

Table 2:
Chi-Square Tests of Farmers' Perception of Climate Variability

Variable	χ^2	df	p-value	Decision
Gender × Perception	2.84	1	0.09	Not significant
Age × Perception	9.61	2	0.008	Significant
Education × Perception	21.42	3	0.000	Significant
Experience × Perception	16.37	2	0.015	Significant

Source: Authors' Computation, 2026.*Note: Significance level at $p < 0.05$.*

The statistically significant associations indicate that education and experience meaningfully increase climate awareness. The effect sizes (Cramér's V, moderate range) suggest non-trivial differences across groups. More educated and experienced farmer's likely process climatic signals more accurately, consistent with Deressa et al. (2008) and Kapoury et al. (2016). However, only 43% linked climate change to human activities, indicating limited understanding of anthropogenic drivers.

Farmers mainly attributed these changes to "less predictable rainfall" and "increasing heat," consistent with findings from the Sahel (Mertz et al., 2009; Ayanwuyi et al., 2010). Although most recognized variability, only 43 % associated it with human activities such as deforestation or burning, revealing limited understanding of anthropogenic drivers (Ogalleh et al., 2012).improving climate literacy through extension and media could strengthen adaptive responses.

Effects of Climate Variability on Agricultural Output

Roughly 72 % of respondents experienced declining crop yields over the last decade, while 18 % reported stability and 10 % an increase. Yields of maize, millet, and sorghum were most affected. The key perceived causes were poor rainfall (47 %), heat stress (25 %), and pest/disease outbreaks (15 %).

Table 3:
Reported Changes in Crop Yield and Major Causes

Crop	% Reporting Yield Decline	Main Cause Decline
Maize	78	Reduced rainfall
Millet	70	Heat stress
Sorghum	66	Irregular rainfall
Groundnut	54	Pest/ poor soil
Rice	48	Flooding

Source: Authors' Compilation, 2026.

The high prevalence of yield decline aligns with projections for semi-arid regions (IPCC, 2014). Given that over two-thirds report productivity losses, climate variability represents a systemic production risk rather than isolated shocks. The concentration of decline in cereals underscores vulnerability of staple crops critical to food security.The finding aligns with IPCC (2014)

projections and Lobell et al. (2008), who noted that temperature increases of > 1 °C in semi-arid zones could reduce cereal yields by up to 10 %.

Adaptation Strategies

Nearly all respondents (93 %) practiced at least one adaptation measure. The most common were changing planting dates (65 %), using drought-resistant varieties (54 %), crop diversification (50 %), and fertilizer/manure use (46 %). Only 28 % had access to irrigation. Farmers adopting multiple strategies reported relatively stable yields, suggesting adaptive benefits.

Table 4:

Adoption Rate of Adaptation Strategies

Adaptation Measure	Adoption (%)
Early/Late Planting	65
Drought- Resistant Seeds	54
Crop Diversification	50
Fertilizer/Manure Use	46
Irrigation/Water Harvesting	28
Off-Farm Income	22

Source: Authors' Compilation, 2026.

Farmers who received climate information through extension or radio were significantly more likely to adopt adaptation measures ($p < 0.05$). This finding reinforces Nhemachena & Hassan (2007) and Habiba et al. (2012) that access to information and institutional support enhance resilience.The high adoption rate suggests widespread behavioral response. However, adaptation remains largely low-cost, and rain-fed based, with limited irrigation investment. This reflects financial and infrastructural constraints. The strong link between information access and adoption reinforces the role of extension services in strengthening resilience (Nhemachena & Hassan, 2007). Scaling irrigation access and information dissemination could yield substantial productivity gains.

Institutional Support and Barriers to Adaptation

Only 35 % of farmers reported receiving any form of external support for climate adaptation. Among them, seed distribution (42 %), fertilizer provision (28 %), and training (18 %) were the main interventions. Sources of information included radio/TV (44 %), extension agents (33 %), fellow farmers (29 %), and NGOs (17 %).Key constraints identified were lack of finance (46 %), poor access to inputs (25 %), and inadequate extension support (18 %)patterns consistent with Deressa et al. (2008) and Agwu et al. (2018).Limited institutional reach constrains adaptive capacity. Financial barriers dominate, suggesting credit market imperfections. Strengthening rural finance and input delivery systems would likely enhance climate resilience.

Regression Analysis

To assess how farmers' perception of climate variability and adaptation strategies affect agricultural output, a multiple linear regression model was estimated. The results are summarized in Table 5. The model explains a substantial share of the variation in output ($R^2 = 0.47$; Adj. $R^2 = 0.45$; $F(6, 593) = 41.27$, $p < 0.001$), indicating good explanatory power for a cross-sectional study of smallholder farmers.

Table 5:
Regression Results-Determinants of Agricultural Output

Variable	Coefficient (β)	Std. Error	t-value	p-value
(Constant)	2.103	0.211	9.96	0
Perception Index (P)	0.284	0.072	3.94	0.000 ***
Adaptation Index (A)	0.352	0.061	5.77	0.000 ***
Adaptation × Support (A×S)	0.129	0.058	2.22	0.027 **
Education (yrs)	0.118	0.046	2.57	0.011 **
Farm Size (ha)	0.097	0.033	2.94	0.004 **
Experience (yrs)	0.056	0.028	2	0.046 *
Access to Support (dummy)	0.163	0.071	2.29	0.022 **

$R^2 = 0.47$ Adj. $R^2 = 0.45$ F (6, 593) = 41.27, $p < 0.001$

Source: Authors' Compilation, 2026.

Farmers' perception of climate variability has a positive and statistically significant effect on output (β = 0.284, p < 0.001). Standardized beta comparison shows that its effect (β_std = 0.271) is slightly smaller than that of the adaptation index (β_std = 0.338), suggesting that while awareness of climate change is important, actual implementation of adaptation strategies contributes more strongly to productivity gains. This supports behavioral adaptation theory, which posits that perception is a critical first step in climate-related decision-making (Grothmann & Patt, 2005; Deressa et al., 2008).

The adaptation strategy index is strongly positive (β = 0.352, p < 0.001), confirming that farmers who adopt more measuressuch as adjusting planting dates, using drought-tolerant varieties, and crop diversificationachieve higher yields. Institutional support also shows a positive and significant association (β = 0.163, p = 0.022), highlighting the role of extension services, input provision, and climate-related information in improving farm performance (Deressa et al., 2008;Ampaire et al., 2020).Importantly, the interaction term between adaptation and institutional support (A × S) is positive and statistically significant (β = 0.129, p = 0.027). This indicates that institutional support strengthens the productivity effect of adaptation strategies. In practical terms, farmers who both adopt adaptation measures and receive institutional assistance experience higher marginal returns to adaptation compared to farmers who adopt similar measures without institutional backing.

Among control variables, education (β = 0.118, p = 0.011), farm size (β = 0.097, p = 0.004), and farming experience (β = 0.056, p = 0.046) all positively affect output, demonstrating that human capital and resource endowment enhance adaptive capacity and productivity.Variance Inflation Factors (VIFs) were all below 5, indicating no multicollinearity. The Breusch–Pagan test detected mild heteroskedasticity, so robust standard errors were applied. Residuals approximated normality, and alternative model specifications, including exclusion of interaction terms, yielded consistent coefficient signs and significance levels, confirming robustness.A potential limitation is reverse causality, as higher-output farmers may have better access to climate information, improving perception. Inclusion of education, experience, and institutional-support variables mitigates some omitted-variable bias, but future studies using panel data or instrumental-variable techniques are recommended to strengthen causal inference.

Overall, the results confirm that accurate perception, active adaptation, human capital, and institutional support jointly drive higher agricultural output in climate-vulnerable regions. These findings reinforce evidence that climate resilience in smallholder agriculture depends not only on awareness but also on effective adaptive action supported by strong institutions (Sahu & Mishra, 2013; Lobell et al., 2008; Nhemachena & Hassan, 2007; Legesse et al., 2013; Mairura et al., 2021).

Discussion

Results collectively reveal that farmers in northeastern Nigeria have a strong perception of climate variability, shaped primarily by direct environmental experiences such as delayed rainfall onset, shorter rainy seasons, and recurrent droughts. Over 80% of respondents reported noticing these shifts, consistent with earlier Sahelian studies showing that farmers' experiential knowledge is a reliable indicator of climatic trends (Mertz et al., 2009; Limantol et al., 2016). The magnitude of awareness observed in this study is comparable to findings from Burkina Faso and Niger, where 75–85% of smallholders reported observable changes in rainfall patterns (Deressa et al., 2008).Despite high awareness, knowledge gaps persist regarding the scientific causes of climate change and the range of available adaptation options. Many farmers attribute observed changes to divine or natural cycles rather than anthropogenic drivers, reflecting the continued disconnect between local perceptions and scientific understanding (Sahu & Mishra, 2013). This limitation may reduce the effectiveness of some adaptation decisions, particularly for strategies requiring understanding of long-term climate trends.

The observed decline in agricultural output over the past decade highlights the vulnerability of rain-fed systems in semi-arid environments. In line with Lobell et al. (2008) and Sultan et al. (2019), even small increases in temperature and rainfall variability can substantially reduce yields of maize, sorghum, and millet, the region's staple crops. The positive and statistically significant association between adaptation and output found here aligns with IPCC (2014) recommendations, demonstrating that localized adaptive measures such as adjusted planting calendars, drought-tolerant cultivars, and water-conservation techniques can partially offset yield losses. However, adoption remains constrained by institutional limitations, including limited access to credit, weak extension coverage, high input costs, and delays in input delivery. Similar institutional barriers have been documented in the Sahel and South Asia, highlighting a widespread impediment to adaptive capacity (Habiba et al., 2012; Ampaire et al., 2020).

Enhancing resilience therefore requires integrating indigenous coping mechanisms timely planting, crop-mix diversification, and community seed exchange with modern climate-smart technologies. Gender-responsive extension services are also critical, as women remain underrepresented in training and input programs despite their substantial role in post-harvest activities and marketing (FAO, 2022). Acknowledging these limitations, strengthening inclusive institutional frameworks can transform awareness into effective, sustainable adaptation, improving both productivity and long-term climate resilience.

5.0 Conclusion and Policy Implications

This study explored how farmers in Borno State, Nigeria, perceive climate variability and how it affects their crop production. The survey of 600 farmers showed that most have noticed changes in rainfall patterns, higher temperatures, and more frequent droughts, which agrees with observed climatic trends in the Sahel (Mertz et al., 2009; Usmail et al., 2023). More than two-thirds of respondents reported declining crop yields, mainly due to irregular rainfall and heat stress.

Although farmers are aware of these changes, their understanding of the causes of climate change and the full range of adaptation strategies is limited. Education and farming experience were found to improve farmers' perception accuracy and the likelihood of adopting adaptive practices, a finding similar to studies in Ethiopia and Mali (Deressa et al., 2008; Amadou et al., 2022). Farmers actively use coping strategies such as adjusting planting dates, adopting drought-tolerant seeds, and diversifying crops. However, use of resource-intensive measures like irrigation is low because of poor access to credit, agricultural inputs, and extension services (Ojo & Baiyegunhi, 2020). Regression analysis confirmed that both perception and adaptation have a positive effect on agricultural output, highlighting the importance of building farmers' capacity to respond to climate risks.

The study suggests that policy efforts should focus on improving farmer education, providing timely climate information, increasing access to affordable credit, and strengthening extension services. Institutional support and better rural infrastructure are also essential to improve resilience and food security in semi-arid regions.

Limitations of this study include its reliance on cross-sectional survey data, which limits the ability to establish causality. Self-reported perceptions may introduce bias, and focusing on three LGAs may reduce generalizability to other areas. Future studies could use panel data, incorporate remote-sensing climate information, and examine gender-specific adaptation practices to address these gaps.

Overall, the findings show that farmers are not passive victims of climate change but active decision-makers. Providing them with knowledge, resources, and institutional support is key to achieving climate-resilient agriculture and sustainable livelihoods under changing environmental conditions (Lobell et al., 2008; IPCC, 2014).

Policy Recommendations

i. Strengthen climate-information services: Develop localized agro-meteorological advisories via radio, SMS, and community platforms to improve farmers' decision-making.
ii. Enhance extension capacity: Recruit and train more extension officers in climate-smart agriculture, emphasizing women's inclusion.
iii. Facilitate access to credit and inputs: Create micro-credit windows and timely fertilizer/seed distribution through public–private partnerships.
iv. Promote irrigation and soil-water management: Encourage affordable small-scale irrigation, water harvesting, and conservation farming.
v. Integrate indigenous and scientific knowledge: Build participatory adaptation frameworks incorporating traditional wisdom with modern techniques.

Future Research

Future studies could use panel or longitudinal data and remote-sensing climate information to validate farmers' perceptions, while exploring gender, socio-cultural differences, and adaptation practices to improve generalizability and causal insights.

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