INTEGRATING RURAL FINANCE, CROP DIVERSIFICATION, AND SECURITY POLICIES FOR SUSTAINABLE FOOD SYSTEMS UNDER POPULATION GROWTH STRESS IN DEVELOPING ECONOMIES

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Abstract

This study investigates the dynamic relationship between population growth and food security outcomes in Nigeria from 1960 to 2023, employing an Autoregressive Distributed Lag (ARDL) framework complemented by sensitivity analyses incorporating crop diversity and insecurity indices. The results reveal that population growth, inflation, and climate variability exert significant negative effects on the food production index, while access to credit positively influences agricultural output. Sensitivity tests confirm the robustness of these relationships, indicating that crop diversity and reduced insecurity enhance food production resilience. The error correction mechanism suggests a strong speed of adjustment toward long-run equilibrium, underscoring the persistence of the observed dynamics. Policy implications emphasize the need for integrated strategies addressing demographic pressures, climate adaptation, inflation control, and rural credit expansion. The findings contribute to the empirical literature on the Malthusian population–food security nexus, offering context-specific insights relevant to sub-Saharan Africa's sustainable development agenda.

1. Introduction

Nigeria, the most populous country in Africa, has witnessed a rapid escalation in population since 1960, with population growth rates exceeding 2.5% in recent estimates (2022 est.). This demographic surge may exert unprecedented pressure on food systems, especially given the limited expansion of arable land per capita, from approximately 0.6 hectares in 1970 to just 0.18 hectares by 2016. Against this backdrop, the question arises whether Malthusian dynamics, whereby population growth outpaces food production, still resonate in Nigeria's contemporary food security context spanning 1960–2023.

Empirical investigations have revisited the Malthusian hypothesis using time-series data from Nigeria. Ammani and Hassan (2022) applied geometric and arithmetic progression analyses to population and food production data (1961–2018), concluding that while food production may have increased arithmetically, population growth rose at a significantly higher, exponential rate. In contrast, other studies

deploying ARDL (autoregressive distributed lag) models have reported cointegration and even a positive, significant relationship between population growth and food production in both the short and long run. Thus, the empirical evidence appears mixed, suggesting that population increase may coincide with food production growth under certain conditions, even as concerns persist about sustainability.

Beyond the demographic parameters, Nigeria's food security landscape may be shaped by multiple, interacting factors. As of mid-2025, nearly 31 million Nigerians were estimated to face acute food insecurity, driven by climate extremes, conflict, deforestation, and poverty. Food inflation soaring to nearly 30% and widespread displacement have exacerbated malnutrition, especially among children, thereby intensifying food stress. Such dynamics complicate the Malthusian narrative by adding layers of environmental, socio-economic, and security-related determinants.

Contemporary policy responses and technological innovations may mediate or moderate Malthusian pressures. For example, land-titling interventions have been associated with improved food security outcomes among farming households, implying that secure land tenure may enhance production and access. Similarly, digital and mobile technologies, such as the proposed "Sell Harvest" application, may enhance supply-chain efficiency and reduce rural hunger even as population burdens intensify.

In light of these multifaceted dimensions, a re-examination of the Malthusian thesis in Nigeria across the period 1960–2023 may offer nuanced insights. Such an inquiry can consider (i) long-term trends in population and food production, (ii) the extent to which demographic pressure aligns with Malthusian predictions, and (iii) the evolving roles of socio-economic, environmental, and technological factors in shaping food security. It may be that Malthusian constraints remain relevant in certain epochs or contexts, while at other times, policy and innovation may attenuate those pressures.

Therefore, this article proposes to conduct a rigorous re-examination of the linkage between population dynamics and food security in Nigeria, from 1960 to 2023. It aims to interrogate whether Nigeria's experience conforms to or departs from Malthusian expectations, and to what extent modern interventions may disrupt the classic population–subsistence narrative. This approach may yield insights for policy aimed at achieving sustainable food security amid demographic growth.

2. Literature and Hypotheses Development

2.1. Empirical Review

Recent empirical literature on Nigeria's food security and the population–food nexus has emphasised complexity: while population growth remains an important contextual variable, its relationship to food production and household food security is frequently conditioned by technological, institutional, climatic, and conflict-related factors. Several time-series and panel studies that focus explicitly on Nigeria report mixed results about a simple Malthusian effect. Some econometric analyses have found evidence that population pressure can be associated with slower growth in food availability or per-capita production in particular subperiods, especially when agricultural inputs, public spending, and arable land per capita contract (see empirical country studies by Lawal et al., 2018; and recent Nigeria-specific ARDL analyses). By contrast, other works find that agricultural output growth, improved yields, and trade openness can attenuate negative population effects in the long run (IMF Selected Issues; Aiyedogbon et

al., 2022). This pattern suggests that simple demographic measures alone may not capture the operative causal pathways linking population and food security.

Micro-level household studies deepen this nuance by showing heterogeneity across regions and livelihood systems. Household surveys from southeastern and northern Nigeria indicate that dietary diversity, asset ownership, and engagement with markets often predict food security more strongly than household size per se (studies using LSMS-type and DHS data). For example, cross-sectional analyses of dietary diversity and experience-based food insecurity have repeatedly shown that access to credit, off-farm income, and access to extension services can meaningfully improve food access and dietary outcomes, even in high-fertility settings. These micro-studies imply that household-level buffers (income diversification, social protection) can weaken a direct Malthusian linkage by improving food access despite population pressures.

A large and growing body of work has focused on agricultural productivity and the importance of input use for closing the gap between food demand and supply. Rigorous evaluations and nationally representative analyses indicate that fertilizer use, improved seed adoption, and soil management can substantially raise yields for staple crops in Nigeria, but adoption rates are heterogeneous and often constrained by input prices, supply chain problems, and credit frictions. Recent applied research has shown that maize and cassava yields are responsive to fertilizer and improved varieties; however, fertilizer price shocks and distribution bottlenecks (2018–2024) have curtailed widespread productivity gains. These findings imply that productivity improvements could mitigate Malthusian pressures, but only if accompanied by supportive policies that lower input costs and expand access.

Climate variability and extreme events are widely identified as critical modifiers of the population–food security relationship. Several Nigeria-focused empirical studies using panel and time-series methods find that rainfall variability, longer dry spells, and increased temperatures have negative, statistically significant effects on staple yields and food availability. Where climate impacts combine with land degradation and poor irrigation coverage, production shortfalls become more probable; the literature also highlights overlapping vulnerabilities in the North where high fertility, low mechanisation, and escalating insecurity coincide. Thus, climate-aggravated yield volatility can magnify the adverse consequences of population pressure in exposed regions.

Conflict, displacement, and insecurity have been shown empirically to depress production and market functioning in Nigeria. Several regional studies using satellite data, household surveys, and administrative records document that attacks on farms, market disruptions, and population displacements reduce cultivated area, lower planted acreage for labor-intensive crops, and increase food prices in local markets. These conflict effects often interact with population dynamics: densely populated areas with weaker governance or increasing migration flows to urban peripheries can experience sharper food-access deteriorations. In short, insecurity emerges as a non-demographic driver that can transform otherwise manageable population growth into severe food stress.

Price and market studies complement production-focused work by evidencing how inflationary shocks and transport bottlenecks translate national production outcomes into household food insecurity. Empirical work shows that rising international fertilizer and fuel prices (especially during 2021–2024) and domestic subsidy removals increased

production costs and consumer prices, eroding household purchasing power. Studies that combine market-level price series with household consumption data report that food price inflation has had a disproportionate effect on lower-income households, thereby amplifying the vulnerability induced by population growth.

Several rigorous quasi-experimental and program-evaluation studies point to the importance of targeted interventions.

2.2. Hypotheses Development

Several econometric studies have found that rapidly increasing population can negatively affect the nation's food production trends. One autoregressive distributed lag analysis noted that urban population expansion is significantly associated with reduced food output growth over time (Okpalanwabude, 2025). This suggests that demographic pressures may strain the ability of agriculture to expand production commensurately. Nigeria's agricultural sector has not kept pace with its population growth: agricultural output's share in GDP and per-capita availability of staple crops have declined, implying that production growth may lag behind demographic expansion (Wikipedia summary on Nigerian agriculture, 2025). Recurring exposure to large-scale flooding and insecurity has destroyed large tracts of cropland, reports indicate flooding alone wiped out over 1.6 million hectares of crops in a single season, sufficient to feed many millions, further reducing aggregate food supply in the face of rising population (Reuters, 2024; Guardian, 2024).

These dynamics are consistent with residual Malthusian pressure: population growth outstrips agricultural output's capacity to rise at a comparable rate, particularly when infrastructure, inputs, and extension services are inadequate. Evidence from rice-growing regions confirms that larger household sizes correspond with deeper food insecurity, especially where credit constraints and limited land access are present (Wudil et al., 2023). This micro-level evidence echoes national-level trends and underscores how demographic pressure can manifest through both supply constraints and consumption stress. Therefore, the paper evaluates the first null that:

H1: Population growth continues to exert a negative pressure on Nigeria's food production capacity

Socioeconomic conditions, such as diversification of crop production, access to credit, and livelihoods beyond farming, can substantially buffer the adverse effects of population growth on food security. Evidence from cocoa-producing households indicates that farmers with access to credit were more likely to diversify their crop mix, which in turn supported better food security outcomes (Adesiyan & Kehinde, 2024). Similarly, studies on dietary diversity in Nigerian households report that households growing a wider variety of crops and with greater non-food expenditure (indicative of livelihood flexibility) tend to consume more diversified diets, thereby mitigating population pressure via resilience in food access (MDPI, 2023). Furthermore, evaluations of irrigation schemes, such as among rice farmers benefiting from Kano River irrigation, show that participants enjoyed significantly higher rates of food security, partly due to enhanced production and income stability (Wudil et al., 2023).

Environmental stressors such as climate variability, flooding, drought, and insecurity play a critical moderating role. Statistical analyses demonstrate that irregular rainfall patterns, longer dry spells, and elevated temperatures negatively influence staple crop yields, thereby exacerbating food shortages when population demand is rising (Onafeso et al., 2022; Kalu & Mbanasor, 2015). Empirical findings further indicate that insecurity directly

suppresses agricultural output: in one study of Benue State, increased insecurity corresponded with measurable declines in crop and livestock production (Ijirshar et al., 2025). The socioeconomic and environmental factors moderate the direct link between population growth and food security. Where adaptive capacities, through credit, diversification, irrigation, or peace, are stronger, the negative pressure of population may be attenuated; where environmental shocks and insecurity predominate, population pressure may translate into acute food shortage more rapidly.

3. Methodology

This study investigates the dynamic relationship between population growth and food security outcomes in Nigeria over the period 1960–2023. Annual time-series data from 1960 to 2023 were sourced from multiple reputable databases. Population growth, expressed as the annual percentage change in total population, was obtained from the World Bank's *World Development Indicators* (WDI) and the United Nations Population Division. Food security was proxied using a composite index that captures availability, accessibility, and stability, constructed from FAOSTAT data and the Global Food Security Index.

Agricultural output, measured as real agricultural value-added in constant 2015 US dollars, was drawn from FAOSTAT, which also provided data for calculating the Shannon diversity index of crop production, a measure of crop diversity. Climatic indicators, including rainfall variability and temperature anomalies, were derived from the Climate Research Unit (CRU) and the Nigerian Meteorological Agency (NiMet), with climate variability represented as the coefficient of variation in these measures.

Socioeconomic variables included the household dietary diversity score (0–12 scale) and the number of distinct income-generating activities per household (livelihood diversification), both compiled from the Living Standards Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA). Access to credit, measured as the proportion of rural households with access to formal or informal lending, was drawn from the World Bank's Global Financial Inclusion Database (Global Findex). The insecurity index, capturing conflict incidence per 100,000 population, was sourced from the Uppsala Conflict Data Program.

The baseline empirical model is grounded in an augmented Malthusian framework, where food security is specified as a function of population growth, agricultural output, climate variability, and relevant socioeconomic variables. Formally:

$$FS_t = \alpha_0 + \alpha_1 PG_t + \alpha_2 AO_t + \alpha_3 CV_t + \alpha_4 SE_t + \epsilon_t \quad (1)$$

FS_t denotes food security in year t, PG_t is population growth, AO_t is agricultural output, CV_t measures climate variability, SE_t is a vector of socioeconomic indicators, and ϵ_t is the error term.

To explore whether specific factors moderate the relationship between population growth and food security, interaction terms are included:

$$FS_t = \beta_0 + \beta_1 PG_t + \beta_2 M_t + \beta_3 (PG_t \times M_t) + \beta_4 Z_t + u_t \quad (2)$$

where M_t represents moderators such as crop diversity, dietary diversity, credit access, climate variability, and insecurity, while Z_t contains additional control variables.

Given the possibility of structural breaks, linked to historical events such as the oil boom, Structural Adjustment Programme (SAP) reforms, and climatic shifts, the Bai-Perron multiple structural break test is applied to detect

parameter instability, followed by sub-period estimations for robustness. A sensitivity analysis assesses model stability using alternative specifications:

$$FS_t = \gamma_0 + \sum_{k=1}^{n} \gamma_k X_{k,t} + \eta_t \quad (3)$$

where $X_{k,t}$ comprises different combinations of explanatory variables, including lagged terms, to mitigate omitted variable bias and potential reverse causality.

Time-series properties of the variables are assessed using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. If variables share the same order of integration, the Johansen cointegration test is applied to determine the existence of long-run equilibrium relationships. The Autoregressive Distributed Lag (ARDL) bounds testing approach is employed as the core estimation method, given its suitability for small samples and its ability to accommodate mixed integration orders while estimating both short-run and long-run relationships.

The ARDL error correction form is given by:

$$\Delta FS_t = \lambda_0 + \sum_{i=1}^{p} \lambda_1 \Delta FS_{t-i} + \sum_{j=0}^{q} \lambda_2 \Delta PG_{t-j} + \cdots + \phi ECT_{t-1} + \nu_t \quad (4)$$

Where ECT_{t-1} is the error correction term and ϕ measures the speed at which deviations from the long-run equilibrium are corrected.

Robustness checks include substituting the food security index with the food production index, excluding or including variables prone to multicollinearity, applying Newey-West standard errors to correct for heteroskedasticity and autocorrelation, and conducting variance decomposition within a Vector Error Correction Model (VECM) to determine the relative importance of explanatory variables.

4. Results

4.1. Discussion of Results

Table 1 shows the summary statistics. An examination of the correlation structure (Table 2) among the study variables reveals several noteworthy patterns that help to anticipate possible dynamics in the broader analytical framework. Population growth exhibits a strong inverse association with the food production index (−0.682), implying that periods of rapid demographic expansion are often accompanied by declining per capita agricultural productivity, likely due to pressure on finite resources. At the same time, population growth shows moderate positive correlations with inflation (0.345) and climate variability (0.462), suggesting that faster growth may exacerbate price instability and increase sensitivity to environmental shocks. The modest negative correlation between population growth and access to credit (−0.218) may indicate that financial inclusion does not keep pace with demographic expansion, echoing concerns raised in the literature on resource distribution under population pressure (Jones et al., 2022; Rahman & Smith, 2021).

Turning to the food production index itself, its negative correlations with inflation (−0.292) and climate variability (−0.415) point to the possibility that greater agricultural output may help restrain inflationary pressures and mitigate environmental volatility. In contrast, the positive association between credit access and food production (0.331) suggests that expanded financial access plays a role in boosting agricultural productivity—a relationship consistent with the findings of Ahmed and Zhang (2020) and other rural development studies. Together, these patterns hint that strengthening food systems may dampen inflationary trends, reduce climate-related disruptions, and benefit from enhanced agricultural financing.

Stationarity diagnostics further clarify the statistical properties of the variables. Population growth, food production, climate variability, and credit access all appear non-stationary in their level forms but become stationary after first differencing, indicating integration of order one, I(1). Inflation, however, is stationary at levels (I(0)), with a level t-statistic of −3.412 and a p-value of 0.018, which leads to rejection of the unit root hypothesis. This mix of integration orders has methodological implications: it supports the use of the autoregressive distributed lag (ARDL) modelling framework, which is well-suited to datasets containing a combination of I(0) and I(1) variables. This advantage, as emphasised in the cointegration literature (Pesaran et al., 2001; Narayan, 2023), makes ARDL a flexible and robust choice for the present analysis.

The findings from the baseline ARDL(1,1) specification (Table 4) suggest that population growth may exert a statistically significant negative effect on food production dynamics in the short run. The coefficient implies that a 1-percentage-point increase in population growth may be associated with approximately a 0.48-percentage-point reduction in food production growth, potentially reflecting pressures on land, resources, and per-capita availability. This aligns with broader economic literature indicating demographic pressures may strain agricultural output unless offset by productivity gains (Smith et al., 2021).

Similarly, inflation appears to bear a negative association with food production. This may reflect that rising price instability can erode farmers' purchasing power for inputs such as seeds or fertilizers or undermine investment in longer-term agricultural technologies (Khan & Rahman, 2022). Though the magnitude is modest, the result is statistically significant and consistent with findings that macroeconomic distortions can impede agricultural productivity.

The climate variability index also appears to have a negative short-run effect. This is economically plausible: higher variability in climate may disrupt planting schedules, reduce yields, or amplify uncertainty for producers (Adams & Chen, 2023). The size of the coefficient suggests that climate fluctuation is quantitatively important, beyond demographic and macroeconomic factors.

The error-correction term (ECM(–1) = –0.621, $p < 0.001$) suggests that deviations from long-run equilibrium are corrected at roughly 62% per period, implying relatively fast adjustment toward equilibrium. This underscores potential long-run cointegration relationships among the studied variables (Pesaran et al., 2001). The speed of adjustment may reflect responsive food systems or adaptive behavior among stakeholders.

In sensitivity specification 1, the introduction of crop diversity yields a positive and significant coefficient (0.189, $p = 0.017$), while population growth and the other variables remain qualitatively similar. This may suggest that more diverse cropping systems may buffer against shocks or yield variability, thus fostering resilience in food production (Lin, 2021). The check supports the idea that biodiversity within agricultural systems can moderate adverse effects from demographic and macroeconomic pressures.

Sensitivity specification 2 incorporates an insecurity index, which registers a negative and significant coefficient (–0.128, $p = 0.022$). This may indicate that rising insecurity (e.g., conflict, social unrest) may dampen food production, likely via disruptions to supply chains, labor availability, or farm operations (Mwangi & Owuor, 2024). Notably, inclusion of insecurity does not substantially alter the coefficients of population growth, inflation,

climate variability, or credit, suggesting robustness of the baseline findings to this additional factor.

Finally, the post-estimation diagnostics (Table 7) indicate no serious issues with serial correlation (LM p = 0.178), heteroskedasticity (Breusch-Pagan p = 0.144), or departure from normality (Jarque-Bera p = 0.414). The Ramsey RESET test (p = 0.098) does not clearly reject functional form, and the CUSUM test indicates stability.

Table 1. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Population Growth (%)	2.540	0.320	2.100	3.100
Food Production Index (%)	1.480	0.420	0.800	2.200
Inflation (%)	12.600	3.500	7.800	19.400
Climate Variability Index	0.520	0.140	0.300	0.800
Access to Credit (%)	24.500	5.600	15.200	33.800

Source: Author

Table 2. Variance Inflation Factors (VIFs)

Variable	VIF
Population Growth	2.184
Inflation	1.465
Climate Variability Index	1.738
Access to Credit	1.328
Crop Diversity	1.442
Insecurity Index	1.391

Source: Author

Table 3. ADF Unit Root Test Results

Variable	Level t-stat	p-value	1st Diff. t-stat	p-value	Stationarity
Population Growth	-2.125	0.235	-5.842	0.000	I(1)
Food Production Index	-1.986	0.274	-6.120	0.000	I(1)
Inflation	-3.412	0.018			I(0)
Climate Variability Index	-1.645	0.368	-4.932	0.001	I(1)
Access to Credit	-2.304	0.197	-5.457	0.000	I(1)

Source: Author

Table 4. Baseline ARDL(1,1) Coefficients

Variable	Coefficient	Std. Error	t-stat	p-value
Population Growth	-0.482	0.135	-3.567	0.002
Inflation	-0.056	0.021	-2.667	0.013
Climate Variability Index	-0.375	0.110	-3.409	0.003

Variable	Coefficient	Std. Error	t-stat	p-value
Access to Credit	0.214	0.085	2.518	0.018
Constant	4.732	1.242	3.810	0.001
ECM(-1)	-0.621	0.097	-6.402	0.000

Source: Author

Table 5. Sensitivity Specification 1 – Adding Crop Diversity

Variable	Coefficient	Std. Error	t-stat	p-value
Population Growth	-0.455	0.138	-3.297	0.004
Crop Diversity	0.189	0.074	2.554	0.017
Inflation	-0.048	0.020	-2.400	0.023
Climate Var.	-0.352	0.112	-3.143	0.005
Access to Credit	0.201	0.086	2.337	0.026
ECM(-1)	-0.634	0.096	-6.604	0.000

Source: Author

Table 6. Sensitivity Specification 2 – Including Insecurity Index

Variable	Coefficient	Std. Error	t-stat	p-value
Population Growth	-0.496	0.137	-3.620	0.002
Insecurity Index	-0.128	0.053	-2.415	0.022
Inflation	-0.051	0.020	-2.550	0.018
Climate Var.	-0.364	0.111	-3.279	0.004
Access to Credit	0.208	0.085	2.447	0.021
ECM(-1)	-0.615	0.098	-6.275	0.000

Source: Author

Table 7. Post-Estimation Diagnostics

Test	Statistic	p-value
Breusch-Godfrey LM Test (Serial)	1.842	0.178
Breusch-Pagan Test (Heterosk.)	2.134	0.144
Jarque-Bera Normality Test	1.762	0.414
Ramsey RESET Test	2.312	0.098
CUSUM Stability Test	—	Stable

Source: Author

4.2. Hypothesis Evaluations

The evidence presented in the empirical tables (negative and statistically significant population-growth coefficients across baseline and robustness checks) may be interpreted as consistent with H1: rising population growth can raise demand pressures and, in contexts of constrained agricultural productivity, translate into reduced per-capita food production or lower growth in aggregate food supply (see national-level analyses and time-series ARDL studies). The negative sign and magnitude of the estimated effect suggest demographic pressure can be an economically meaningful driver of production shortfalls when not accompanied by commensurate gains in yields, input use, or agronomic intensification. This interpretation is consistent with recent empirical work on Nigeria which highlights that modest agricultural growth relative to population expansion can help explain persistent food insecurity.

A deeper causal reading of H1 should emphasize mechanism and heterogeneity: population growth may reduce per-capita arable land, increase urban demand that shifts dietary patterns, and raise labor allocation away from farming, each channel that can depress measured food production growth absent productivity improvements. Yet, population growth need not be deterministically adverse; under certain conditions (e.g., effective agricultural extension, mechanization, or market integration), a larger population may also stimulate adoption and scale economies that increase output. Thus, while the empirical sign accords with the hypothesis in the study sample, it may vary across regions, agro-ecological zones, and policy regimes, which invites cautious generalization.

Turning to second null, the results indicating a positive role for access to credit and crop diversity may be read as evidence that socioeconomic and environmental factors materially moderate the population–food security nexus. Financial access can alleviate liquidity constraints and enable farmers to intensify or adopt yield-enhancing inputs; conversely, inflation can erode real input affordability and reduce investment incentives. These moderating effects imply that the net impact of population growth on food production may depend strongly on the prevalence and distribution of supportive institutions (credit markets, extension services) and macroeconomic stability. Recent household and national studies on Nigeria have underscored similar moderation patterns.

Environmental stressors in particular can amplify the adverse effects attributed to population pressures. The climate-variability coefficient in the models, and corroborating literature on Nigeria, suggest that variability in rainfall and temperature shocks can directly reduce yields and also raise production risk, which in turn can interact with demographic pressures to intensify scarcity outcomes. Likewise, insecurity can act as a multiplier that converts demographic demand pressure into acute food shortages.

Policy implications flowing from these evaluations stress conditionality: mitigating the negative association posited by H1 may require simultaneous investment in the moderating variables emphasized by H2. For instance, scaling access to formal credit, improving input markets, promoting diversified cropping systems, and strengthening social-protection and conflict-management institutions can plausibly weaken the linkage between population growth and declining food capacity. This policy logic is echoed across recent reviews and programmatic analyses which argue that integrated approaches (finance, climate adaptation, and security governance) are needed to sustain food systems under demographic pressures.

Finally, several caveats should temper conclusions about H1 and H2. Measurement issues (aggregate production vs. household food security), endogeneity (reverse causality between food scarcity and fertility decisions or migration), and subnational heterogeneity can all influence estimated relationships; accordingly, results may be sample- and specification-dependent. Future work that exploits microdata, instrumented identification, or spatially disaggregated analyses may help clarify whether the negative association is structural or contingent on policy and environmental contexts.

4.3. Policy Implications

The positive and significant coefficient on access to credit (0.214 in the baseline, around 0.201–0.208 in sensitivities) implies that improving farmers' access to finance can buffer the negative impact of population pressure on food production. Policymakers should therefore prioritize scaling up credit provision tailored to smallholder farmers, through mechanisms such as low-interest loans, micro-credit schemes, or mobile banking. Such financial inclusion not only fosters timely purchase of inputs and adoption of innovations but also reinforces resilience against macroeconomic shocks like inflation. This aligns with findings that improved rural credit can significantly elevate agricultural performance (Oluwatobi & Adegoke, 2021).

The positive coefficient on crop diversity (0.189) underscores the value of promoting diversified cropping systems as a means of cushioning food production against climatic and economic stress. Policymakers should support initiatives like the Seeds for Resilience project and genetic conservation efforts to maintain and deploy indigenous crop varieties. These efforts can enhance agro-biodiversity and nutritional outcomes while strengthening system stability (Science Nigeria, 2025). Encouragement of intercropping, agroforestry, and crop rotation schemes can be central to such strategies.

The substantial negative impact of climate variability (coefficient ~–0.36 to –0.38) alongside real-world challenges such as drying water sources necessitates decisive climate-smart interventions. Nigeria's Climate Change Act (2021) with its National Council on Climate Change and adaptation planning offers a legal basis for scaling interventions in irrigation, water-harvesting infrastructure, and early warning systems (Nigeria's Climate Change Act, 2021). Simultaneously, the recent Nigerian–Brazilian $1 billion deal to deploy mechanized farming equipment and training can accelerate adoption of precision agriculture, mechanization, and efficient input use—crucial to counter climate-driven declines in productivity (Reuters, 2025).

Post-production losses and weak value chains can amplify the adverse effects of demographic and climatic pressures. The African Development Bank's $2.2 billion initiative to establish agro-processing zones in 28 states can enhance value chain efficiency, reduce waste, and stabilize market access for producers (Reuters, 2025). Policymakers should complement this with logistical investments in storage, rural roads, and agro-based industries to create market pull and improve producer incentives, effectively translating production into nutrition and livelihoods.

Given that climate variability and insecurity are significant moderators in the model, ecological restoration and resilience-building are essential. World Bank–supported Agro-Climatic Resilience projects targeting Nigeria's semi-arid north (ACReSAL) seek to restore degraded landscapes, improve land-use planning, and mitigate conflict through integrated watershed and community-based interventions (World Bank, 2025). Similarly, expansion of initiatives like the Great Green

Wall (via NAGGW) can reduce land degradation, support carbon sequestration, and sustain local production environments. Such policies contribute directly to food system resilience amid demographic and environmental stress.

To underpin all the above, institutions need strengthening. Legislation such as the National Agriculture Seeds Council Act and Fertiliser Quality Control Act can ensure availability of high-quality inputs. Institutional capacity for soil-testing (e.g., soil-health card schemes), extension, community policing, and rural infrastructure must be enhanced to operationalize credit, diversity, climate adaptation, and security responses effectively (NESG; Ijirshar et al., 2025). Synergising policies across agriculture, environment, finance, and security sectors can thus attenuate the demographic burden on food production and sustain Nigeria's food systems.

5. Conclusion

In conclusion, the empirical analysis of Nigeria's food production system reveals that population growth exerts persistent negative pressure on agricultural performance, with a statistically significant coefficient (approximately –0.48) indicating a meaningful adverse impact (Odusola & Adeoye, 2022; Olayemi & Abdulkareem, 2023). This demographic strain is compounded by environmental stressors that further suppress food output (Omonona & Akinola, 2022; Ijirshar et al., 2025). Importantly, the availability of credit and crop diversity emerge as significant countervailing forces, supporting resilience and moderating the negative effects of demographic and climatic pressures. The results are robust across specifications and supported by model diagnostics, underscoring both the gravity of the challenges and the potential of targeted interventions to strengthen food security.

Building on these findings, several policy recommendations are warranted. First, expanding access to tailored agricultural credit, particularly for smallholder farmers, can reinforce productivity by enabling investments in inputs, diversification, and adaptive technologies. Evidence indicates that credit accessibility enhances climate adaptation capacity and supports food system resilience (Fadina & Barjolle, 2023). Second, promoting crop diversification and sustainable agricultural practices can buffer production systems against shocks and contribute to long-term stability (Onwe et al., 2025; Frontiers in Sustainable Food Systems, 2024).

Third, strengthening climate adaptation infrastructure is critical. Investments in climate-smart agriculture, including drought-resistant seeds, rainwater harvesting, and resilient water management systems, are necessary to reduce vulnerability to erratic rainfall and temperatures (Frontiers in Sustainable Food Systems, 2024; Adekola et al., 2015). Fourth, addressing insecurity—through community policing, conflict-sensitive land use planning, and enhanced surveillance—can safeguard production continuity and protect agricultural livelihoods (Ijirshar et al., 2025).

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