

EFFECTIVENESS OF CLIMATE CHANGE ADAPTATION STRATEGIES IN DRYLAND AGRICULTURAL SYSTEMS OF NORTHERN NIGERIA: A SYSTEMATIC REVIEW

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ABSTRACT

Climate change threatens the sustainability of dryland agriculture in Northern Nigeria through rising temperatures, erratic rainfall, recurrent droughts, and land degradation, with severe consequences for productivity, food security, and rural livelihoods. Although smallholder adaptation strategies are well documented, evidence on their effectiveness remains fragmented. This study uses a systematic narrative review approach to synthesize recent empirical evidence on the effectiveness of climate change adaptation strategies in dryland agricultural systems of Northern Nigeria. A systematic search of scientific databases identified peer-reviewed articles published between 2020 and 2026, which were then synthesized through qualitative thematic analysis. The review finds that crop diversification, drought-tolerant varieties, supplementary irrigation, agroforestry, soil conservation, climate-smart agriculture, and livelihood diversification are the predominant strategies employed across the region, generally improving crop productivity, household income, food security, and resilience when supported by favorable institutional and socioeconomic conditions. However, outcomes vary considerably due to differences in agroecology, access to finance and extension services, and methodological approaches. The review identifies critical gaps, including limited longitudinal evaluation, inconsistent effectiveness indicators, weak attention to maladaptation, and insufficient evidence from highly vulnerable communities. By synthesizing evidence and explaining variation in outcomes, this review provides a foundation for strengthening adaptation policy, guiding future research, and promoting climate-resilient agricultural development in Northern Nigeria.

Keywords: Climate change adaptation; dryland agriculture; Northern Nigeria; climate resilience; narrative review

INTRODUCTION

Climate change is among the greatest threats to agricultural sustainability in the twenty-first century, with dryland regions bearing the greatest exposure and vulnerability (Intergovernmental Panel on Climate Change [IPCC], 2022). Adaptation is strongly shaped by socioeconomic, institutional, and environmental conditions (Ford et al., 2021), and depends on integrating technological innovation with indigenous knowledge (Jellason et al., 2022). In Nigeria specifically, climate-induced droughts and floods increasingly threaten food security (World Bank, 2022), and although farmers have adopted numerous adaptation measures, evidence on their long-term effectiveness remains limited (Onyeneke et al., 2020). Northern Nigeria, spanning the Sahel, Sudan Savanna, and

Northern Guinea Savanna zones, is among the most climate-vulnerable regions in Sub-Saharan Africa because agriculture, the principal livelihood for millions, depends largely on rainfall. Climate change has compounded existing constraints, limited input access, weak extension services, and declining soil fertility (Jellason et al., 2021a). Participatory climate-smart agriculture (CSA) interventions have improved farmers' understanding of adaptation practices, financial limitations and poor access to climate information remain major barriers to sustained adoption (Jellason et al., 2021b). Research attention on Northern Nigeria also remains geographically uneven, with the semiarid northern states receiving comparatively limited long-term assessment despite high climate risk (World Bank, 2022).

Over the past decade, research has shifted from documenting farmers' responses toward evaluating the effectiveness of adaptation interventions. Climate-smart agriculture, agroforestry, improved varieties, supplemental irrigation, and livelihood diversification are among the most widely promoted strategies in dryland regions (Jellason et al., 2022; Reed et al., 2023), yet reported effectiveness is inconsistent: while integrated approaches generally enhance resilience (BerrangFord et al., 2021), outcomes depend heavily on institutional support, extension access, and finance (Jellason et al., 2022). Most Northern Nigerian studies have focused on farmers' perceptions or determinants of adoption within specific states, with comparatively few syntheses evaluating which strategies consistently succeed and why (Jellason et al., 2022; Reed et al., 2023). Methodological inconsistencies and limited attention to effectiveness rather than adoption further limit generalizability (Jellason et al., 2022), while risks of maladaptation remain underexamined (Schipper, 2020).

Against this background, this review critically synthesizes recent empirical evidence on the effectiveness of adaptation in Northern Nigeria's dryland agriculture. Unlike prior reviews that primarily describe adaptation options or adoption determinants, this study compares reported outcomes across studies, identifies areas of agreement and disagreement, examines methodological and policy gaps, and proposes a future research agenda. Specifically, it addresses which strategies have been implemented, the extent to which they have improved productivity, food security, and resilience, why reported outcomes differ, what gaps remain, and what future research priorities would strengthen climate-resilient agricultural development in the region.

MATERIALS AND METHODS

This review adopts a systematic narrative approach, combining a structured search and eligibility process with a thematic, interpretive synthesis of empirical studies on the effectiveness of

climate change adaptation in dryland agricultural systems in Northern Nigeria. This approach was considered appropriate given the heterogeneous study designs, outcome indicators, and methodological approaches used across the evidence base, which are not readily amenable to the standardized, protocol-driven procedures of a full systematic review or meta-analysis. English-language articles published between 2019 and 2026 were considered. Studies were selected for relevance if they reported empirical evidence on adaptation practices, effectiveness, determinants, or resilience outcomes in Northern Nigeria's dryland systems; editorials, conference abstracts, theses, book chapters, opinion papers, and studies lacking methodological detail were excluded. After removing duplicates and reviewing titles, abstracts, and full texts for relevance, the selected studies were organized and synthesized narratively to compare adaptation strategies, outcomes, methodological characteristics, and knowledge gaps across the literature.

RESULTS

Adaptation Strategies Employed in Dryland Agriculture

Farmers in Northern Nigeria employ a diverse portfolio of agronomic, ecological, water management, and livelihood-based strategies rather than relying on single interventions. Improved soil and land management, crop-specific innovations, water management, climate information services, and livelihood diversification represent the dominant pathways (Onyeneke et al., 2020), while effective adaptation is more strongly associated with integrated strategies supported by enabling institutions than with isolated technologies (Jellason et al., 2022). Farmers frequently combine indigenous knowledge with CSA practices to respond to unpredictable rainfall (Jellason et al., 2021b), and widespread adoption of at least one CSA practice has been observed across North Central and North West Nigeria; adoption intensity varies with resource access (Gabriel et al., 2023).

Crop diversification combining cereals such as millet and sorghum with legumes like cowpea and groundnut is the most consistently reported response to climatic uncertainty, reducing the risk of complete crop failure and enhancing food security (Onyeneke et al., 2020; Jellason et al., 2021b), though its benefits depend on seed availability, market access, and extension support (Jellason et al., 2022). Drought-tolerant and early-maturing crop varieties are also promoted to sustain yields under water stress (Jellason et al., 2021b; Gabriel et al., 2023), though high seed costs and weak distribution systems constrain uptake (Onyeneke et al., 2020). Supplementary irrigation reduces dependence on unreliable rainfall (Onyeneke et al., 2020) and supports agricultural production (Gabriel et al., 2023), its effectiveness is constrained by water availability, financial capacity, governance, and inadequate groundwater and infrastructure (Jellason et al., 2021a, 2022).

Agroforestry and soil conservation improve soil moisture retention and reduce land degradation (Jellason et al., 2022), addressing the interaction among climate change, desertification, and declining soil fertility (Jellason et al., 2021a), adoption remains slow due to labor demands, delayed returns, and insecure land tenure. Livelihood diversification into livestock, petty trading, seasonal migration, and nonfarm employment helps households spread climatic and economic risk (Onyeneke et al., 2020; Jellason et al., 2022; Gabriel et al., 2023), though access to these opportunities depends on education, finance, and infrastructure (Jellason et al., 2021a, 2022).

Table 1. Major Climate Change Adaptation Strategies Reported in Northern Nigeria

Strategy	Purpose	Reported Benefits	Common Constraints
Crop diversification	Reduce production risk	Yield stability, food security	Limited seed access, market constraints
Drought-resistant varieties	Improve drought/heat tolerance	Reduced crop failure, higher productivity	High seed cost, weak extension
Irrigation	Supplement rainfall	Increased yields, income	Water scarcity, infrastructure, cost
Agroforestry	Improve ecosystem resilience	Soil fertility, reduced erosion	Slow returns, land tenure issues
Soil conservation	Maintain soil productivity	Reduced degradation, water retention	Labor-intensive, low awareness
Livelihood diversification	Reduce climate-sensitive dependence	Higher income, resilience	Limited finance, skills, employment

Evidence of Effectiveness

Crop productivity. Crop diversification, drought-tolerant varieties, CSA, irrigation, and soil fertility management are generally associated with improved crop performance, although the magnitude varies by location (Jellason et al., 2021b; Gabriel et al., 2023). Integrated strategies combining improved seed, soil conservation, and climate information consistently outperform isolated interventions (Jellason et al., 2022), with access to technology, extension, and institutional support as key determinants of success (Ford et al., 2021; Onyeneke et al., 2020; World Bank, 2022).

Household income. Farmers adopting integrated adaptation practices generally achieve higher, more stable incomes through improved production efficiency and reduced vulnerability (Onyeneke et al., 2020), particularly where livelihood diversification and market access are strengthened (Jellason et al., 2022). Gains, however, are often moderated by access to credit, education, and land ownership (Ford et al., 2021), and persistent inequalities constrain farmers' ability to invest in adaptation technologies (BerrangFord et al., 2021).

Food security. Improved crop management, water conservation, and livelihood diversification are important pathways through which adaptation strengthens food security in Nigeria (Onyeneke et al., 2020), particularly when indigenous knowledge is integrated with scientific innovation (Jellason et al., 2022) and production losses during climatic stress are reduced (Gabriel et al., 2023). Institutional capacity and access to extension and technology remain critical enabling conditions (Ford et al., 2021; World Bank, 2022).

Resilience. Resilience is strongest when farmers combine multiple complementary strategies rather than isolated interventions, with knowledge integration and institutional support (Jellason et al., 2022). Participatory adaptation programs strengthen farmers' confidence and adaptive decision-making (Jellason et al., 2021b), and adaptive capacity increases with education, access to extension services, and climate information (Ford et al., 2021; IPCC, 2022; Reed et al., 2023).

Environmental sustainability. Agroforestry, conservation agriculture, and sustainable land management improve soil quality, reduce erosion, and enhance biodiversity (Onyeneke et al., 2020; Jellason et al., 2022), with land restoration and soil conservation indispensable for sustaining productivity in the Sudan Sahelian drylands (Jellason et al., 2021a). Adaptation policies should therefore promote long-term ecosystem health rather than short-term production gains alone (World Bank, 2022; Reed et al., 2023).

Table 2. Comparative Evidence on the Effectiveness of Climate Change Adaptation Strategies

Outcome	Principal Strategies	Overall Evidence	Key Limiting Factors
Crop productivity	Diversification, drought-tolerant varieties, CSA, irrigation	Generally positive, varies by agroecology	Rainfall variability, input access, extension
Household income	CSA, livelihood diversification, irrigation	Moderate to strong positive	Credit constraints, market access, farm size
Food security	Diversified cropping, soil/water conservation	Positive improvements	Poverty, climate extremes, institutional capacity
Resilience	Integrated adaptation packages	Strongest when combined	Weak governance, limited finance
Environmental sustainability	Agroforestry, conservation agriculture	Positive long-term benefits	Labour demands, insecure tenure

Variation in Adaptation Outcomes

Adaptation outcomes are shaped less by the technologies themselves than by environmental conditions, socioeconomic characteristics, institutional capacity, and methodology (Jellason et al., 2022). Environmental heterogeneity across the Sahel, Sudan Savanna, and Northern Guinea Savanna zones means that a strategy effective in one location may perform poorly elsewhere; supplementary irrigation, for instance, is far less effective where groundwater and infrastructure are limited (Jellason et al., 2021a), and agroforestry benefits are strongest in moderately, rather than severely, degraded environments (Jellason et al., 2022). Socioeconomic characteristics also explain much of the variation: households with more education, larger landholdings, stronger

social networks, and better input access consistently achieve better outcomes (Ford et al., 2021; Onyeneke et al., 2020), while financial and informational constraints limit the effectiveness of CSA programs even where uptake is high (Jellason et al., 2021b; Gabriel et al., 2023). Institutional factors extension services, research, climate information, and coherent policy are similarly decisive: adaptation is markedly more effective where farmers receive continuous technical support and locally relevant information (Jellason et al., 2021b, 2022), whereas weak institutional coordination remains a major barrier (Onyeneke et al., 2020; World Bank, 2022).

Finally, methodological variation contributes to inconsistent findings, as most studies rely on cross-sectional surveys with few longitudinal or experimental designs capable of establishing causal effects (Rosenstock et al., 2022). In addition, inconsistent indicators, including yield, income, food security, resilience, and perceptions, make direct comparison difficult (Jellason et al., 2022). Standardized, transparent evidence synthesis, including greater use of longitudinal and experimental designs and consistent effectiveness indicators, is needed going forward.

Table 3. Factors Explaining Variation in Adaptation Effectiveness

Factor	Evidence	Implication
Environmental conditions	Performance differs across Sahel, Sudan Savanna, and Northern Guinea Savanna zones.	Tailor strategies to local agroecology
Socioeconomic characteristics	Education, income, tenure, and farm size shape adaptive capacity	Integrate poverty reduction and capacity building
Institutional support	Extension, climate information, and policy enhance effectiveness	Strengthen agricultural institutions
Adaptation design	Integrated packages outperform single interventions	Promote combined CSA, ecosystem, and livelihood measures
Methodological differences	Inconsistent indicators and designs limit comparability	Standardize indicators; use longitudinal data

Knowledge Gaps and Future Research Directions

Despite rapid growth in adaptation research, significant gaps remain regarding long-term effectiveness. Global evidence shows that although adaptation initiatives have increased substantially, robust evidence of their effectiveness remains limited because many studies emphasize implementation rather than measurable outcomes, and monitoring and evaluation frameworks remain underdeveloped (BerrangFord et al., 2021), with insufficient attention to long-term transformation (Ford et al., 2021). Research also remains concentrated in more accessible northwestern states, with limited evidence from the Northeast, where climate change interacts with desertification and conflict; strategies effective in one dryland system cannot automatically be generalized to others (Thornton et al., 2022), and most studies still rely on cross-sectional rather than longitudinal designs (Rosenstock et al., 2022). Maladaptation also receives limited attention despite concern that poorly designed interventions may

deepen inequality or shift climate risk between groups (Schipper, 2020); adaptation should be evaluated for social equity and sustainability, not effectiveness alone (Barnett & O'Neill, 2021). Future research should adopt interdisciplinary approaches that integrate climate science, agricultural economics, and social sciences, while employing standardized resilience indicators and participatory, coproduced evaluation frameworks (IPCC, 2022; Reed et al., 2023).

Table 4. Major Knowledge Gaps Identified in the Literature

Knowledge Gap	Evidence	Priority for Future Research
Limited long-term impact evaluation	Most studies assess short-term outcomes only	Establish longitudinal monitoring and panel datasets
Uneven geographical coverage	Research concentrated in a few northern states.	Expand studies across all dryland zones, including conflict-affected areas.
Weak methodological consistency	Diverse indicators limit comparison	Develop standardized evaluation frameworks
Limited assessment of maladaptation	Few studies evaluate unintended consequences	Integrate maladaptation and sustainability assessments
Limited interdisciplinary integration	Research often isolates agriculture from governance/ecosystems	Promote systems-based, interdisciplinary research

Policy and Practical Implications

Strengthening climate adaptation in Northern Nigeria requires coordinated policy efforts rather than promoting individual technologies. Adaptation policies succeed most when they combine technological innovation with investment in institutions, infrastructure, and farmer capacity, embedding CSA within broader rural development strategies that jointly address productivity, resilience, and sustainability (Lipper et al., 2021). Strengthening agricultural extension and climate information services is a recurring priority: timely forecasts and continuous technical support improve farmers' planting, crop selection, and risk management decisions (Cammarano et al., 2023), while extension systems play a critical role in knowledge exchange and adaptive capacity across Africa (Partey et al., 2022). Investment in digital advisory platforms and localized climate information could substantially improve outcomes where access to extension services remains uneven. Financial and infrastructural constraints remain principal barriers to adopting improved seed, irrigation, and conservation technologies; expanding access to affordable credit, weather index insurance, and risk-sharing instruments is essential (World Bank, 2022), alongside investment in rural roads, irrigation infrastructure, and market systems to reduce production risk and

improve returns on adaptation investment (World Bank, 2023). Ecosystem-based adaptation is equally important: restoration, watershed protection, and agroforestry deliver benefits for biodiversity, soil fertility, and risk reduction in a region where desertification continues to threaten productivity (Reed et al., 2023). Because effectiveness varies across agroecological zones, policy should encourage decentralized planning that allows state and local governments to design context-specific interventions incorporating continuous monitoring and adaptive learning (IPCC, 2022; World Bank, 2023). Strengthening collaboration among governments, research institutions, extension agencies, and farming communities will be essential for building resilient dryland agricultural systems.

Table 5. Policy Priorities for Strengthening Climate Change Adaptation in Northern Nigeria

Policy Area	Key Actions	Expected Outcomes
Agricultural extension	Expand workforce, digital advisory services, localized climate information.	Improved technology adoption and decision-making
Agricultural finance	Increase access to credit, insurance, input subsidies	Greater investment in resilient technologies
Climate-smart agriculture	Scale integrated CSA through participatory approaches	Increased productivity, resilience, food security
Water resources management	Invest in irrigation, water harvesting, watershed management	Reduced vulnerability to drought
Ecosystem restoration	Promote agroforestry, reforestation, soil conservation	Improved sustainability and ecosystem resilience
Research and innovation Governance	Support long-term monitoring, interdisciplinary research Improve coordination across government levels and partners	Stronger evidence base for policy More effective, context-specific implementation

Conclusion

This systematic narrative review synthesized recent evidence on the effectiveness of climate change adaptation strategies in the dryland agricultural systems of Northern Nigeria. Farmers have adopted a broad range of strategies, including crop diversification, drought-tolerant varieties, supplementary irrigation, agroforestry, soil conservation, CSA, and livelihood diversification, which generally improve productivity, income, food security, and adaptive capacity when implemented under supportive environmental, socioeconomic, and institutional conditions. However, effectiveness is highly context-specific and varies across agroecological zones and household characteristics, underscoring that no single strategy offers a universal solution. A key contribution of this review is its comparative synthesis of outcomes rather than mere description of practices: differences in reported effectiveness are largely explained by environmental conditions, socioeconomic characteristics, institutional capacity,

and methodological approach, and integrated strategies consistently outperform isolated interventions, although limited finance, weak extension, poor infrastructure, insecure tenure, and fragmented policy continue to constrain resilience. The review also identifies gaps, including limited longitudinal research, a lack of standardized effectiveness indicators, inadequate attention to maladaptation, and insufficient evidence from highly vulnerable areas. Addressing these gaps through integrated, locally appropriate interventions that combine technological innovation with institutional strengthening, ecosystem restoration, and financial inclusion will be essential for advancing climate-resilient agricultural development in Northern Nigeria.

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