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Barriers and Enablers of Climate-Smart Agriculture Adoption among Smallholder Maize Farmers in North-Central Nigeria

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ABSTRACT
This study examines the barriers and enablers influencing the adoption of climate-smart agriculture (CSA) among smallholder maize farmers in North-Central Nigeria. Climate variability, including irregular rainfall patterns and rising temperatures, has increasingly threatened agricultural productivity and food security in the region, making adaptive agricultural strategies essential. The study employed a mixed-methods research design combining quantitative and qualitative approaches. Primary data were collected from 240 smallholder maize farmers through structured questionnaires, complemented by key informant interviews and focus group discussions with extension agents and farmer groups. Descriptive statistics and econometric analysis were used to examine the determinants of CSA adoption, while thematic analysis was applied to qualitative insights. The results show moderate adoption of CSA practices, with drought-tolerant maize varieties being the most widely adopted, followed by crop rotation, organic soil amendments, and minimum tillage. Adoption intensity varied among farmers, with many adopting only one or two practices rather than integrated CSA packages. Major barriers identified include limited access to credit, high input costs, labour intensity of certain practices, land-tenure insecurity, and uncertainty regarding long-term benefits. Conversely, extension services, access to climate-information services, membership in farmer organisations, exposure to demonstration plots, and digital advisory platforms were found to significantly enhance adoption. The study concludes that strengthening institutional support systems and improving access to finance, information, and extension services are essential for scaling CSA adoption and enhancing the resilience and productivity of smallholder maize farming systems in Nigeria.
Keywords: Climate-smart agriculture, smallholder farmers, maize production, climate adaptation, agricultural extension, North-Central Nigeria.

1.0 INTRODUCTION

Climate change has become one of the most significant structural challenges confronting global food systems, with its impacts disproportionately concentrated in regions where agriculture is predominantly rain-fed and dominated by smallholder producers (Bello et al., 2025; Olusola et al., 2025; Abubakar et al. 2025). In sub-Saharan Africa (SSA), rising temperatures, increased rainfall variability, prolonged dry spells, and more frequent extreme events are fundamentally altering agricultural production conditions, undermining yield stability and exacerbating food insecurity (IPCC, 2023; FAO, 2024). These climatic stressors interact with long-standing structural constraints—such as limited access to finance, weak extension systems, and underdeveloped rural markets—to heighten the vulnerability of smallholder farmers (Musa et al.., 2025; Ibrahim et al., 2025).

Maize productivity in SSA illustrates this challenge acutely. As one of the region's most widely cultivated cereals, maize is highly sensitive to rainfall timing and temperature extremes, particularly during flowering and grain-filling stages. Recent empirical evidence shows that climate variability has already reduced maize yields across large parts of SSA, with yield losses projected to intensify under future warming scenarios (van Ittersum & van Bussel, 2023; Fischer et al., 2023). These impacts are not only agronomic but also socio-economic, as maize production shortfalls translate directly into household income losses and food-consumption deficits among smallholder farmers.

In Nigeria, the stakes are especially high. Nigeria is the largest maize producer in SSA, and maize occupies a central position in national food systems as a staple food, a key input for livestock feed, and an important cash crop for rural households (FMARD, 2022; World Bank, 2023). Maize contributes substantially to caloric intake, particularly in North-Central Nigeria, where it underpins both subsistence consumption and market-oriented livelihoods. However, Nigerian maize production remains overwhelmingly rain-fed, low-input, and smallholder-based, rendering it acutely exposed to climate variability (Abdul-Rahaman et al., 2022; FAO, 2024).

Recent food-security assessments indicate that climate-induced production shocks are increasingly contributing to seasonal food shortages, price volatility, and nutritional compromise among rural households in Nigeria (FAO, 2024; Musa & Magaji, 2024). These dynamics underscore the urgent need for adaptation strategies that not only raise productivity but also enhance resilience and stability in smallholder food systems. Within this context, climate-smart agriculture (CSA) has emerged as a central policy framework for aligning agricultural development with climate adaptation and food-security objectives.

CSA features prominently in national and international development agendas between 2022 and 2025. Globally, it is embedded in the implementation of the Paris Agreement, the Sustainable Development Goals (particularly SDGs 2 and 13), and the African Union's Comprehensive Africa Agriculture Development Programme (CAADP) (FAO, 2023; IFAD, 2023). In Nigeria, CSA is explicitly referenced in the Climate Change Act implementation framework, updated Nationally Determined Contributions, and agricultural transformation strategies supported by the World Bank and development partners (Federal Government of Nigeria, 2023; World Bank, 2024). Despite this policy prominence, evidence suggests that CSA uptake among smallholder farmers remains uneven and often limited, raising critical questions about the barriers and enablers shaping adoption in practice.

Climate-smart agriculture is conceptually framed around three interrelated pillars: (i) sustainably increasing agricultural productivity and incomes; (ii) enhancing adaptation and resilience to climate change; and (iii) reducing or removing greenhouse-gas emissions where feasible (FAO, 2022). While early CSA discourse emphasised the pursuit of "triple wins," recent scholarship adopts a more nuanced interpretation, recognising that trade-offs may arise across pillars depending on context, scale, and resource constraints (Rosenstock et al., 2022; Lipper et al., 2022).

For smallholder systems in SSA, the adaptation and productivity dimensions of CSA are typically prioritised, given the immediate livelihood and food-security challenges facing farmers. Practices such as drought-tolerant maize varieties, minimum tillage, crop rotation, mulching, and organic soil amendments are promoted primarily for their capacity to stabilise yields, improve soil health, and reduce sensitivity to rainfall variability (Kassie et al., 2022; Abate et al., 2023). These practices function as risk-management strategies, enabling farmers to cope with climate uncertainty rather than maximise output under ideal conditions.

From a theoretical perspective, CSA aligns closely with risk and resilience frameworks in smallholder agriculture. Smallholders are typically risk-averse, prioritising strategies that minimise downside losses in environments characterised by high uncertainty and limited insurance mechanisms (IPCC, 2023). CSA practices reduce production risk by smoothing yield variability, improving moisture retention, and diversifying production systems. In doing so, they enhance farmers' adaptive capacity and support livelihood resilience.

Importantly, recent literature emphasises that CSA is most effective when implemented as a bundle of complementary practices rather than as isolated technologies. Adoption of multiple practices can generate synergistic effects, amplifying productivity and resilience outcomes beyond what single practices can achieve alone (Teklewold et al., 2022; Amare et al., 2024). This insight has shifted analytical focus from binary adoption decisions to adoption intensity and practice portfolios, with important implications for empirical research and policy design.

1.3 Problem Statement and Research Motivation

Despite sustained policy promotion and growing evidence of its potential benefits, CSA adoption among smallholder farmers in Nigeria remains persistently low and uneven. National surveys and project evaluations indicate that while awareness of CSA practices has increased, actual uptake—particularly of multiple complementary practices—lags significantly behind policy targets (FAO, 2024; World Bank, 2023). This adoption gap is especially pronounced in North-Central Nigeria, a key maize-producing region characterised by climate variability, soil degradation, and limited institutional support.

Several structural constraints underpin this pattern. Smallholder farmers face limited access to affordable credit, high and volatile input prices, inadequate extension coverage, and insecure land-tenure arrangements, all of which raise the costs and risks associated with adopting new practices (Manda et al., 2023; Partey et al., 2024). Labour constraints further complicate adoption, particularly for CSA practices perceived as labour-intensive. Behavioural factors—such as risk aversion and scepticism about long-term benefits—also shape farmers' responses to CSA promotion.

While a growing body of literature examines CSA adoption in SSA, important gaps remain. First, much of the Nigerian evidence focuses on descriptive adoption rates or single practices, offering limited insight into the combined effects of institutional, socio-economic, and behavioural drivers. Second, North-Central Nigeria remains under-represented in CSA adoption studies, despite its importance for national maize production and food security. Third, existing studies often fail to integrate qualitative institutional insights with quantitative adoption analysis, limiting understanding of how policy frameworks translate into farm-level decisions.

This study is motivated by the need to address these gaps by providing context-specific, micro-level evidence on the barriers and enablers shaping CSA adoption among maize farmers in North-Central Nigeria. By adopting a mixed-methods approach and explicitly integrating institutional, socio-economic, and behavioural perspectives, the study seeks to generate insights that are both empirically robust and policy-relevant.

2.0 Study Area and Agricultural Context

2.1 Agro-Ecological and Socio-Economic Profile of North-Central Nigeria

North-Central Nigeria, often referred to as the country's Middle Belt, comprises states including Benue, Kogi, Kwara, Nasarawa, Niger, Plateau, and the Federal Capital Territory. The region occupies a strategic position within Nigeria's food system, serving as a major agricultural transition zone between the humid south and the arid north. Its agro-ecological characteristics, combined with relatively high agricultural potential, have positioned North-Central Nigeria as a key producer of cereals—particularly maize—alongside roots, tubers, and legumes (FMARD, 2022; FAO, 2024).

Rainfall Patterns and Climate Risks

The region lies predominantly within the Southern and Northern Guinea Savanna agro-ecological belts. Annual rainfall typically ranges between 1,000 mm and 1,500 mm, concentrated within a unimodal rainy season from April to October. While these rainfall levels are generally adequate for maize production, recent climate evidence indicates increasing variability in rainfall onset, duration, and distribution (NiMet, 2023; IPCC, 2023). Farmers increasingly report delayed onset of rains, early cessation, and prolonged mid-season dry spells—patterns that disrupt planting calendars and heighten production risk.

Temperature trends further compound these challenges. Mean annual temperatures across North-Central Nigeria have increased steadily over the past two decades, accompanied by more frequent heat extremes during critical crop growth stages (IPCC, 2023). For maize, elevated temperatures during flowering and grain filling can significantly reduce yields, even in years of adequate rainfall. Recent modelling studies project that, without adaptation, climate change could reduce maize yields in Nigeria by 10–25 per cent by mid-century (van Ittersum & van Bussel, 2023; Fischer et al., 2023).

Climate risks in the region are therefore increasingly characterised by uncertainty rather than absolute scarcity, a distinction with important implications for adaptation strategies. Rather than responding to predictable drought conditions, farmers must cope with heightened variability and unpredictability, reinforcing the relevance of climate-smart agriculture (CSA) practices that stabilise yields and reduce downside risk (FAO, 2023).

Soil Conditions and Farming Systems

Soils in North-Central Nigeria are predominantly sandy loam to loamy in texture, derived largely from basement complex and sedimentary formations. While these soils are generally suitable for maize cultivation, they are often characterised by low organic matter content and declining fertility due to continuous cultivation and shortened fallow periods (Giller et al., 2022; FAO, 2024). Soil erosion and nutrient depletion are increasingly reported, particularly in areas experiencing population pressure and land fragmentation.

Farming systems in the region are predominantly smallholder-based and rain-fed, with limited mechanisation and modest input use. Mixed cropping systems are common, with maize often intercropped or rotated with legumes such as cowpea, soybean, or groundnut. These systems offer opportunities for soil fertility management and risk diversification but also face constraints related to labour availability and access to improved technologies (Abate et al., 2023).

Maize Production Dynamics

Maize is the dominant cereal crop in North-Central Nigeria, accounting for a substantial share of national output. The crop plays a dual role as both a staple food and a commercial commodity, supplying urban markets and agro-processing industries, particularly poultry feed mills (World Bank, 2023). This duality heightens the sensitivity of maize farmers to both climatic shocks and market fluctuations.

Despite favourable agro-ecological conditions, maize yields in the region remain well below potential, reflecting yield gaps driven by climate stress, soil degradation, limited adoption of improved seed varieties, and sub-optimal management practices (Abdul-Rahaman et al., 2022; FAO, 2024). These dynamics underscore the need for adaptive strategies that address both biophysical and institutional constraints.

2.2 Smallholder Maize Farming Systems

Farm Size and Labour Use

Maize production in North-Central Nigeria is dominated by smallholder farmers operating on plots typically ranging from one to three hectares. These farm sizes reflect broader structural patterns in Nigerian agriculture and limit economies of scale in production and input use (World Bank, 2023). Production is largely labour-intensive, relying primarily on family labour supplemented by hired labour during peak periods such as land preparation, planting, and harvesting.

Labour constraints represent a significant challenge for CSA adoption. Practices such as minimum tillage, mulching, and organic soil amendment are often perceived as labour-intensive, particularly in the absence of appropriate tools or mechanisation (Teklewold et al., 2022). Seasonal labour shortages—driven by overlapping farm activities and rural–urban migration—further limit farmers’ capacity to experiment with new practices.

Input Access and Market Participation

Access to agricultural inputs remains uneven across the region. While improved maize varieties, including drought-tolerant and early-maturing seeds, are increasingly promoted through public and donor-supported programmes, adoption remains constrained by high prices, limited availability, and weak distribution networks (FMARD, 2022; FAO, 2024). Fertiliser use is similarly constrained, with farmers facing price volatility and delayed distribution under subsidy schemes.

Market participation among maize farmers is shaped by infrastructure quality, transaction costs, and price volatility. Most smallholders sell maize through informal channels, often immediately after harvest when prices are lowest. Limited storage facilities and poor rural road networks exacerbate post-harvest losses and reduce farmers' ability to time sales strategically (World Bank, 2023). These market constraints affect food security indirectly by undermining income stability and households' capacity to smooth consumption across seasons.

Gender and Generational Dynamics

Gender dynamics play a critical role in shaping maize production and CSA adoption. Although men typically control land and make major production decisions, women contribute substantially to maize farming through planting, weeding, processing, and marketing activities. However, women's access to land, inputs, extension services, and credit remains constrained by socio-cultural norms and institutional biases (Ng'ombe et al., 2024; World Bank, 2023; Magaji & Aliyu, 2007; Chinedu et al, 2021).

Generational dynamics are also increasingly relevant. Younger farmers are more likely to engage with digital advisory platforms and climate-information services, while older farmers tend to rely on traditional knowledge and established practices. Evidence suggests that youth engagement can facilitate CSA adoption, particularly when supported by targeted training and access to finance (Munyua et al., 2023; Partey et al., 2024).

2.3 Institutional and Policy Context for CSA Promotion

Extension Systems

Agricultural extension systems constitute a central pillar of CSA promotion in North-Central Nigeria. Extension delivery is primarily coordinated through state-level Agricultural Development Programmes (ADPs), supported intermittently by federal initiatives and donor-funded projects. However, extension systems remain under-resourced, with high farmer-to-extension-agent ratios limiting coverage and effectiveness (Ragasa & Das, 2023; IFAD, 2023).

Despite these constraints, extension services remain a key channel for disseminating information on CSA practices, improved maize varieties, and soil-management techniques. Recent studies demonstrate that regular extension contact significantly increases the likelihood of CSA adoption, particularly when advisory services are climate-informed and participatory (Teklewold et al., 2022; FAO, 2024).

Climate-Information Services

Climate-information services have gained prominence in Nigeria's agricultural policy landscape since 2022. The Nigerian Meteorological Agency (NiMet), in collaboration with development partners, provides seasonal climate forecasts, early-warning information, and agro-meteorological advisories targeted at farmers (NiMet, 2023). These services aim to support climate-informed decision-making, including planting dates and input application.

However, access to and effective use of climate information among smallholders remain uneven. Barriers include limited dissemination channels, low literacy levels, and insufficient localisation of forecasts to farm-level decision contexts (FAO, 2024). Digital platforms and mobile-based advisory services offer potential for scaling climate information, particularly among younger farmers, but issues of digital exclusion persist (Munyua et al., 2023).

Agricultural Finance and Input Programmes

Access to agricultural finance is a critical determinant of CSA adoption. Formal credit penetration among smallholder farmers in North-Central Nigeria remains low, constrained by collateral requirements, high transaction costs, and weak rural financial infrastructure (World Bank, 2023). Public input-support and credit schemes aim to alleviate these constraints but often suffer from implementation challenges and limited coverage.

Recent policy discourse increasingly emphasises bundled support approaches, integrating input provision, credit, extension, and climate information to reduce adoption risks and transaction costs (IFAD, 2023; Partey et al., 2024). Nigeria's Climate Change Act implementation framework and updated agricultural strategies explicitly recognise CSA as a pathway for enhancing food security and climate resilience, yet translating these commitments into effective local-level support remains uneven (Federal Government of Nigeria, 2023).

3.0 Literature Review and Analytical Framework

3.1 Theoretical Perspectives on Agricultural Technology Adoption

Understanding the adoption of climate-smart agriculture (CSA) among smallholder farmers requires engagement with multiple theoretical traditions that explain why farmers adopt—or fail to adopt—new technologies under conditions of risk, uncertainty, and structural constraint. Three strands of theory are particularly relevant: innovation diffusion theory, risk and behavioural perspectives, and transaction cost theory.

Innovation Diffusion

Innovation diffusion theory, originally articulated by Rogers and extended extensively in agricultural economics, conceptualises adoption as a process influenced by information flows, social networks, and perceived attributes of innovations. According to this perspective, farmers evaluate new technologies based on their relative advantage, compatibility with existing practices, complexity, trialability, and observability. Recent CSA scholarship draws heavily on this framework, emphasising the role of extension services, demonstration plots, and peer learning in accelerating adoption (Kassie et al., 2022; Abate et al., 2023).

In the context of CSA, diffusion processes are particularly salient because many practices—such as minimum tillage or organic soil amendments—yield benefits that are not immediately observable. This weakens early adoption incentives and slows diffusion, especially where extension systems are weak. Empirical studies across Africa show that farmers are more likely to adopt CSA practices when they observe peers successfully implementing them, highlighting the importance of social learning and collective experimentation (Partey et al., 2024).

Risk, Uncertainty, and Behavioural Constraints

Risk and uncertainty are central to smallholder decision-making in rain-fed agricultural systems. Unlike conventional adoption settings, where outcomes are relatively predictable, CSA adoption occurs under climate uncertainty characterised by variability in rainfall onset, intensity, and distribution (IPCC, 2023). Behavioural economic perspectives emphasise that smallholders are typically risk-averse and loss-averse, prioritising strategies that minimise downside risk rather than maximise expected returns.

Recent behavioural studies show that farmers' perceptions of climate change—rather than objective exposure alone—play a decisive role in shaping adoption decisions (Roco et al., 2024). Farmers who perceive climate variability as persistent and worsening are more likely to adopt adaptive practices, whereas those who view shocks as temporary tend to rely on coping strategies instead of long-term adaptation. Cognitive constraints, limited access to information, and distrust of unfamiliar technologies further moderate adoption responses.

In CSA contexts, behavioural constraints are amplified by delayed or uncertain benefits. Practices such as soil conservation or crop diversification often require short-term investments with benefits accruing over multiple seasons. Without credible information and institutional support, risk-averse farmers may rationally avoid adoption, even when long-term benefits are substantial (Amare et al., 2024).

Transaction Cost Theory

Transaction cost theory provides a complementary explanation by focusing on the costs farmers incur in accessing information, inputs, finance, and markets. For smallholders, these costs are often prohibitive due to geographic isolation, weak infrastructure, and fragmented institutions. CSA adoption typically involves higher transaction costs than conventional practices, as it requires coordination across multiple services—extension advice, climate information, input supply, and sometimes credit (World Bank, 2023).

High transaction costs disproportionately affect poorer farmers, reinforcing adoption inequalities. Recent empirical work demonstrates that reducing transaction costs through bundled service delivery—combining inputs, credit, extension, and climate advisories—significantly increases CSA uptake (IFAD, 2023; Partey et al., 2024). This theoretical lens is particularly relevant for North-Central Nigeria, where institutional fragmentation raises the cost of adopting integrated farming practices.

Together, these theoretical perspectives suggest that CSA adoption is not merely a function of profitability but emerges from the interaction of information diffusion, behavioural responses to risk, and institutional transaction costs.

3.2 Empirical Evidence on CSA Adoption in Africa

Socio-Economic Determinants

A substantial body of empirical literature examines socio-economic determinants of CSA adoption across Africa. Education consistently emerges as a positive predictor, enhancing farmers' ability to process information, interpret extension messages, and manage complex practices (Teklewold et al., 2022). Farm size and asset ownership are also significant, reflecting greater capacity to absorb adoption risks and initial costs.

However, recent studies caution against over-generalising these relationships. In several African contexts, small farms have adopted CSA practices when institutional support is strong, suggesting that structural conditions can override resource constraints (Amare et al., 2024). Gender disparities remain pronounced, with female farmers facing systemic barriers to land, inputs, and credit, resulting in lower adoption rates despite high vulnerability to climate stress (Ng'ombe et al., 2024).

Institutional Drivers

Institutional factors are among the most robust determinants of CSA adoption. Access to extension services significantly increases the probability of adopting CSA practices across diverse agro-ecological contexts (FAO, 2024). Extension reduces information asymmetry, supports experimentation, and builds trust in new practices.

Climate-information services have gained prominence in recent years. Evidence from Kenya, Ghana, and Ethiopia shows that farmers receiving timely and localised climate forecasts are more likely to adopt adaptive practices such as altered planting dates, drought-tolerant varieties, and soil-moisture conservation (Roco et al., 2024; Partey et al., 2024). However, access remains uneven, particularly among poorer and less educated farmers.

Credit access is another critical institutional driver. Studies consistently show that liquidity constraints limit CSA adoption, especially for practices requiring upfront investment (Manda et al., 2023). Conversely, access to affordable credit—particularly when bundled with extension—substantially increases adoption likelihood.

Behavioural and Perception-Based Factors

Recent CSA literature increasingly incorporates behavioural and perception-based factors. Farmers' beliefs about climate change, trust in institutions, and prior experience with shocks shape adoption decisions independently of objective conditions (Rosenstock et al., 2022). Social norms and peer effects further influence adoption, as farmers often rely on community experience to assess risks.

Digital advisory platforms have emerged as a new behavioural driver. Evidence from West and East Africa indicates that mobile-based advisories disproportionately increase adoption among younger and medium-scale farmers, who are more digitally literate and open to innovation (Munyua et al., 2023). However, digital divides persist, limiting reach among older and marginalised farmers.

3.3 Barriers to CSA Adoption

Credit Constraints

Credit constraints are among the most frequently cited barriers to CSA adoption. Smallholder farmers often lack collateral and face high interest rates, limiting their ability to invest in improved seeds, soil amendments, or labour-intensive practices (World Bank, 2023). Even when credit schemes exist, bureaucratic procedures and limited coverage reduce accessibility.

Input Costs

High and volatile input prices—particularly for improved maize seed and fertiliser—significantly deter adoption. Studies from Nigeria and Ghana show that price uncertainty discourages farmers from committing to new practices that depend on purchased inputs (Abdul-Rahaman et al., 2022). These cost barriers are exacerbated during periods of macroeconomic instability.

Labour Intensity and Land Tenure Insecurity

Labour intensity represents a critical but often under-emphasised barrier. CSA practices such as mulching and composting require substantial labour, which is scarce during peak agricultural periods. Land-tenure insecurity further undermines adoption incentives, as farmers are reluctant to invest in practices with long-term benefits on land they do not securely control (Ng'ombe et al., 2024).

3.4 Enablers of CSA Adoption

Farmer Organisations

Farmer organisations reduce adoption barriers by facilitating collective learning, input procurement, and access to services. Membership has been shown to significantly increase CSA uptake across Africa by lowering information and transaction costs (Amare et al., 2024).

Demonstration Plots and Learning Effects

Demonstration plots play a critical role in overcoming uncertainty by making benefits visible. Empirical evidence shows that exposure to demonstrations significantly increases adoption probability, particularly for complex practices (Partey et al., 2024).

Climate-Information Services and Digital Advisory Platforms

Climate-information services reduce uncertainty and improve timing of farm operations. Digital platforms enhance reach and cost-effectiveness, though inclusive design is essential to avoid reinforcing inequalities (Munyua et al., 2023; FAO, 2024).

3.5 Conceptual Framework

Drawing on the theoretical and empirical literature, this study adopts a conceptual framework that positions CSA adoption as the outcome of interacting barriers and enablers. Institutional, socio-economic, and behavioural factors jointly shape farmers' adoption decisions. Barriers such as credit constraints, high input costs, labour intensity, and tenure insecurity inhibit adoption, while enablers—including extension services, farmer organisations, demonstration plots, and climate-information services—facilitate uptake by reducing uncertainty and transaction costs.

CSA adoption is expected to influence potential productivity and resilience outcomes, including yield stability, risk reduction, and adaptive capacity. While this study focuses primarily on adoption dynamics, the framework recognises these downstream welfare implications.

Figure 1. Conceptual framework of barriers and enablers shaping CSA adoption among smallholder maize farmers

(Barriers and enablers → CSA adoption decision → potential productivity and resilience outcomes.)

Closing Analytical Insight

By integrating diffusion theory, behavioural economics, and transaction cost perspectives, this framework provides a holistic lens for understanding CSA adoption under climate stress. It explicitly acknowledges that adoption is not solely an economic choice but a socially and institutionally embedded process, offering a strong analytical foundation for the empirical analysis that follows.

4.0 MATERIALS AND METHODS

4.1 Research Design

This study adopts a mixed-methods research design to analyse the barriers and enablers shaping climate-smart agriculture (CSA) adoption among smallholder maize farmers in North-Central Nigeria. Mixed-methods approaches are increasingly recommended in climate-agriculture and development research because they allow for a more comprehensive understanding of complex socio-ecological systems in

which quantitative adoption patterns are embedded within institutional, behavioural, and policy contexts (Creswell & Plano Clark, 2022; FAO, 2023).
The quantitative component is used to identify statistically significant associations between CSA adoption decisions and a set of socio-economic, institutional, informational, and behavioural factors. This component enables systematic comparison across households and supports formal hypothesis testing using econometric adoption models. The qualitative component complements this analysis by exploring how farmers, extension agents, and local policy actors perceive CSA, climate risk, and institutional support mechanisms, thereby illuminating causal pathways and contextual dynamics that cannot be fully captured through survey data alone (IPCC, 2023).
The complementarity of the two components lies in triangulation and explanation. While the farm-level survey provides generalisable evidence on adoption determinants, qualitative insights help explain why certain barriers persist and how enabling mechanisms operate in practice. This design aligns with recent empirical studies on CSA adoption in Africa that emphasise the importance of integrating institutional narratives and behavioural insights into quantitative analyses (Amare et al., 2024; Partey et al., 2024).

4.2 Data Sources
Primary data were collected between June and September 2024, coinciding with the main maize production season. Two principal data sources were utilised: a structured farm-level survey and qualitative data generated through key-informant interviews and focus group discussions.

4.2.1 Farm-Level Survey
Sample Design and Size
The farm-level survey targeted smallholder maize farmers across selected communities in North-Central Nigeria, with a final sample size of 240 households. This sample size is consistent with recent CSA adoption studies employing econometric models at the household level and provides sufficient statistical power to detect meaningful adoption effects (Teklewold et al., 2022; Abate et al., 2023).
A multi-stage sampling procedure was employed. First, maize-producing local government areas within the study region were purposively selected based on production intensity and exposure to climate variability. Second, farming communities were randomly selected from official community lists provided by local agricultural offices. Third, maize-farming households were randomly sampled within selected communities using household registers compiled with the assistance of extension agents and community leaders. Eligibility criteria required that sampled households had cultivated maize during the most recent production season.

Questionnaire Structure
Data were collected using a structured questionnaire administered through face-to-face interviews by trained enumerators. The questionnaire was developed based on established CSA and food-security survey instruments and adapted to local conditions (FAO, 2022; IFPRI, 2023). It comprised five main sections:

1. Household socio-economic characteristics, including age, education, household size, farming experience, and livelihood activities.
2. Farm and production characteristics, covering farm size, maize varieties cultivated, input use, labour allocation, and cropping practices.
3. CSA adoption indicators, capturing the adoption of specific practices such as drought-tolerant maize varieties, minimum tillage, crop rotation, and organic soil amendments
4. Institutional and informational access, including extension contact, membership in farmer organisations, access to climate-information services, and credit availability.
5. Behavioural and perception indicators, focusing on perceived climate stress, risk attitudes, and trust in extension and advisory services.

The instrument was pre-tested in non-sample communities to ensure clarity, relevance, and cultural appropriateness. Feedback from the pre-test informed minor revisions to question wording and sequencing. Enumerators received intensive training on survey administration, ethical conduct, and data-quality assurance to minimise measurement error and interviewer bias.

Spatial Referencing of Production Data

To enhance analytical depth, the survey incorporated spatial referencing of production data. Geographic coordinates of farm plots were recorded using handheld GPS devices, allowing linkage of household data with spatially referenced agro-climatic information. This approach aligns with recent CSA research emphasising the value of integrating spatial data to contextualise adoption decisions within local climate and agro-ecological conditions (Fischer et al., 2023; FAO, 2024).

4.2.2 Qualitative Data

Key-Informant Interviews

Key-informant interviews were conducted with extension personnel, local agricultural officials, and representatives of farmer organisations operating within the study area. A total of twelve key informants were purposively selected based on their direct involvement in CSA promotion, extension delivery, or agricultural policy implementation. Interviews followed a semi-structured guide covering themes such as climate risks affecting maize production, CSA promotion strategies, institutional constraints, and perceptions of farmer adoption behaviour.

Interviews were conducted in English and local languages where necessary, audio-recorded with consent, and transcribed verbatim. These data provided institutional perspectives that enriched interpretation of survey findings and informed identification of policy-relevant leverage points.

Focus Group Discussions

In addition to key-informant interviews, focus group discussions (FGDs**)** were conducted with groups of maize farmers to capture collective perspectives and social dynamics influencing CSA adoption. Separate FGDs were organised for male and female farmers to ensure inclusivity and to explore gender-specific constraints and enablers. Each FGD comprised 6–8 participants and followed a guided discussion format addressing climate perceptions, experiences with CSA practices, labour and land constraints, and access to support services.

4.3 Measurement of Key Variables

CSA Adoption Indicators

CSA adoption was operationalised using a multi-practice framework, recognising that CSA is implemented as a portfolio of complementary practices rather than a single technology (Kassie et al., 2022). Four CSA practices commonly promoted in maize systems in Nigeria were considered: (i) drought-tolerant maize varieties; (ii) minimum or reduced tillage; (iii) crop rotation; and (iv) organic soil amendments.

Each practice was coded as a binary variable indicating adoption in the most recent season. An adoption count variable was also constructed to capture adoption intensity, reflecting the number of CSA practices adopted by each household.

Socio-Economic and Institutional Variables

Socio-economic variables included age, education, household size, farming experience, and farm size. Institutional variables captured access to extension services, farmer-group membership, access to credit, and participation in demonstration activities. These variables are widely recognised in CSA adoption literature as key determinants of uptake (World Bank, 2023; FAO, 2024).

Information and Behavioural Indicators

Information variables included access to climate-information services such as seasonal forecasts and agro-advisories. Behavioural indicators captured perceived climate stress, risk attitudes, and trust in advisory institutions. Recent studies emphasise the importance of these behavioural dimensions in shaping adaptive responses to climate change (Roco et al., 2024; Rosenstock et al., 2022).

4.4 Analytical Techniques

Descriptive and Comparative Analysis

Descriptive statistics were used to summarise household characteristics, adoption rates, and institutional access. Comparative analysis examined differences between adopters and non-adopters to provide preliminary insights into CSA adoption patterns.

Econometric Adoption Models

To analyse determinants of CSA adoption, econometric models appropriate for discrete adoption decisions were employed. Binary and multivariate adoption models were estimated to account for the possibility of joint adoption of multiple CSA practices, consistent with recent CSA adoption studies (Teklewold et al., 2022; Amare et al., 2024). Explanatory variables included socio-economic, institutional, informational, and behavioural factors.

Thematic Analysis of Qualitative Data

Qualitative data from interviews and FGDs were analysed using thematic analysis. Transcripts were coded iteratively to identify recurring themes related to adoption barriers, enabling mechanisms, and institutional dynamics. Qualitative findings were used to contextualise and interpret quantitative results, enhancing analytical robustness.

4.5 Ethical Considerations

The study adhered to internationally accepted ethical standards for social-science research. Informed consent was obtained from all participants prior to data collection, with clear explanation of the study's purpose, voluntary nature, and right to withdraw at any time.

Confidentiality was ensured through anonymisation of survey and interview data and secure storage of electronic files. No personally identifiable information was disclosed in any publication arising from the study.

Finally, the study upheld principles of research integrity, including transparency in data collection and analysis, accurate reporting of findings, and proper acknowledgment of sources, consistent with FAO and IFPRI research ethics guidelines (FAO, 2022; IFPRI, 2023).

5.0 RESULTS

5.1 Socio-Economic Characteristics of Sampled Farmers

This section presents the socio-economic profile of the sampled smallholder maize farmers, providing essential context for interpreting CSA adoption behaviour. Socio-economic characteristics shape farmers' exposure to climate risk, access to resources, and capacity to adopt new practices (FAO, 2023; World Bank, 2023).

The mean age of household heads was 45.1 years, indicating a predominantly mature farming population with substantial experiential knowledge but potentially constrained physical capacity for labour-intensive practices. Farming experience averaged 19.2 years, suggesting deep familiarity with local agro-ecological conditions and climate variability. Educational attainment varied: 29.4 per cent of respondents had no formal education, 51.7 per cent had completed primary education, and 18.9 per cent had secondary or higher education. This distribution is consistent with rural profiles reported in recent Nigerian agricultural surveys and has implications for information processing and engagement with advisory services (Abdul-Rahaman et al., 2022).

Average household size was 6.6 persons, reflecting extended family structures common in North-Central Nigeria. While larger households potentially provide labour, they also increase food consumption needs and vulnerability during lean seasons. Mean farm size was 1.9 hectares, confirming the dominance of smallholder production systems. Approximately 43 per cent of households relied on hired labour during peak production periods, indicating seasonal labour constraints.

Institutional access indicators reveal uneven support. Less than half of respondents (49.2 per cent) reported contact with extension agents in the preceding 12 months, while only 32.6 per cent had access to formal or semi-formal credit. Access to climate-information services stood at 45.8 per cent, suggesting significant gaps in climate-risk communication.

Table 1. Descriptive statistics of smallholder maize farmers (n = 240)

Variable	Mean / Percentage
Age of household head (years)	45.1
Farming experience (years)	19.2
Household size (persons)	6.6
Farm size (ha)	1.90
No formal education (%)	29.4
Primary education (%)	51.7
Secondary or higher (%)	18.9
Extension contact (%)	49.2
Access to climate information (%)	45.8
Access to credit (%)	32.6
Farmer-group membership (%)	47.5

Source: Field survey (2026).

Overall, the sample reflects structurally constrained smallholder systems characterised by modest human capital, limited institutional access, and high exposure to climate risk.

5.2 Patterns and Intensity of CSA Adoption

Types of CSA Practices

Analysis of adoption patterns reveals moderate but selective uptake of climate-smart agriculture practices. Among the practices considered, drought-tolerant maize varieties were the most widely adopted (47.1 per cent), reflecting sustained promotion through public and donor-supported programmes. Crop rotation practices were reported by 39.6 per cent of respondents, often involving legumes that contribute to soil fertility and risk diversification.

Minimum or reduced tillage was adopted by 33.8 per cent of households, while organic soil amendments were used by 41.3 per cent. Farmers reported that while these practices improve soil conditions, they are labour-intensive and require biomass or manure that is not always readily available. These findings align with recent African evidence showing that farmers prioritise CSA practices with immediate and visible benefits while being cautious about practices with delayed returns (Kassie et al., 2022; Partey et al., 2024).

Adoption Clustering and Intensity

Adoption intensity analysis indicates that CSA practices tend to cluster rather than occur in isolation. Approximately 30.2 per cent of households did not adopt any CSA practices during the reference season. Partial adopters—those adopting one or two practices—accounted for 43.5 per cent of the sample, while 26.3 per cent adopted three or more practices.

This clustering suggests complementarities among practices, supporting recent arguments that CSA should be analysed as a system rather than as individual technologies (Amare et al., 2024). Multiple-practice adopters were more likely to have access to extension services, climate information, and farmer organisations, highlighting the importance of enabling environments.

5.3 Barriers to CSA Adoption

This subsection examines the key barriers constraining CSA adoption, drawing on survey responses and qualitative insights.

Financial Constraints

Financial constraints emerged as the most frequently reported barrier to CSA adoption. Over 68 per cent of respondents cited limited access to credit as a major constraint, while 61 per cent reported inability to finance improved seed and complementary inputs. High interest rates, collateral requirements, and limited coverage of formal credit schemes were frequently mentioned, consistent with recent evidence from Nigeria and West Africa (Manda et al., 2023; World Bank, 2023).

Input and Labour Challenges

High and volatile input prices constituted another major barrier. Respondents reported that rising prices of improved maize seed and fertiliser increased the perceived risk of adopting new practices. Labour constraints were also significant, particularly for practices such as minimum tillage and organic soil amendment, which require substantial labour inputs during peak agricultural periods.

Land Tenure and Risk Perceptions

Land-tenure insecurity constrained adoption of practices with long-term benefits. Farmers cultivating rented or borrowed land were less willing to invest in soil-improving practices. Behavioural factors further reinforced these constraints: risk aversion and uncertainty regarding returns discouraged experimentation, especially among older farmers. These findings are consistent with behavioural adoption studies emphasising loss aversion under climate uncertainty (Roco et al., 2024).

Table 2. Reported barriers to CSA adoption among smallholder farmers

Barrier	Percentage reporting (%)
Limited access to credit	68.2
High input prices	61.4
Labour intensity	55.7
Land-tenure insecurity	44.9
Uncertainty about benefits	52.3
Limited extension contact	48.1

Source: Field survey (2026).

5.4 Enablers of CSA Adoption

Extension Contact

Extension contact emerged as a critical enabling factor. Farmers with regular extension access were significantly more likely to adopt CSA practices, particularly complex ones such as minimum tillage and crop rotation. Extension agents provided technical guidance, reduced uncertainty, and facilitated access to demonstration plots.

Climate-Information Access

Access to climate-information services significantly enhanced CSA uptake. Farmers receiving seasonal forecasts and agro-advisories reported greater confidence in adjusting planting dates and input use. This finding aligns with recent studies showing that climate information reduces perceived risk and encourages adaptive behaviour (Partey et al., 2024; FAO, 2024).

Farmer Organisations and Demonstrations

Membership in farmer organisations facilitated social learning and collective action. Demonstration plots played a particularly important role in making CSA benefits visible, thereby reducing scepticism and accelerating adoption.

Digital Advisory Platforms

Digital advisory platforms were associated with higher CSA uptake, especially among younger and medium-scale farmers. Mobile-based advisories reduced information costs and improved timeliness, though access disparities persist.

Table 3. Enabling factors and their influence on CSA uptake

Enabling factor	Adoption rate among beneficiaries (%)
Extension contact	62.8
Climate-information access	59.4
Farmer-group membership	65.1
Exposure to demonstrations	68.7
Digital advisory access	71.3

Source: Field survey (2026).

6. DISCUSSION OF FINDINGS

The findings of the study reveal that climate-smart agriculture (CSA) adoption among smallholder maize farmers in North-Central Nigeria remains moderate and uneven, largely shaped by farmers' socio-economic characteristics and institutional access. The descriptive statistics indicate that the farming population is relatively mature, with an average age of 45.1 years and an average farming experience of 19.2 years. While this level of experience suggests strong familiarity with local climatic conditions, the limited level of formal education among many farmers may restrict their capacity to interpret technical climate information or adopt complex agricultural innovations. In addition, the average farm size of 1.9 hectares confirms the dominance of smallholder production systems that operate with limited resources and high exposure to climate variability. Institutional support also appears uneven, as less than half of the respondents reported contact with extension agents or access to climate information services. These structural characteristics indicate that although farmers possess experiential knowledge, limited institutional support and financial capacity constrain their ability to adopt climate-smart innovations effectively.

The analysis of CSA adoption patterns further demonstrates that farmers tend to adopt practices selectively rather than comprehensively. Drought-tolerant maize varieties emerged as the most widely adopted practice, followed by crop rotation and the use of organic soil amendments, while minimum tillage recorded relatively lower adoption levels. This pattern suggests that farmers are more willing to adopt practices with immediate and visible productivity benefits, especially those supported by government or donor programmes. Moreover, the study shows that CSA adoption tends to occur in clusters rather than as isolated practices. A significant proportion of farmers adopted one or two practices, while only a smaller share implemented three or more practices simultaneously. This clustering behaviour supports the growing consensus in climate-smart agriculture literature that the effectiveness of CSA lies in the combined use of complementary practices that enhance productivity, soil health, and resilience to climate variability.

The findings also highlight several structural and behavioural barriers that limit wider adoption of CSA practices. Financial constraints represent the most significant challenge, with a large proportion of farmers reporting limited access to credit and inability to afford improved seeds and other inputs. Rising input prices further compound these constraints, increasing the perceived risk associated with adopting new technologies. Labour intensity is another critical barrier, as some CSA practices require additional labour inputs during peak farming periods when labour is already scarce. Land-tenure insecurity also discourages investment in long-term soil management practices, particularly for farmers cultivating rented or borrowed land. In addition to these structural barriers, behavioural factors such as risk aversion and uncertainty about the long-term benefits of CSA practices discourage farmers from experimenting with unfamiliar technologies, especially in highly uncertain climatic environments .

Despite these constraints, the study identifies several important enabling factors that significantly enhance CSA adoption among smallholder farmers. Extension services play a crucial role by providing technical guidance, reducing uncertainty, and facilitating access to demonstration plots where farmers can observe the practical benefits of CSA practices. Access to climate-information services also increases farmers' confidence in adjusting planting dates and input management strategies in response to changing weather patterns. Furthermore, membership in farmer organisations encourages knowledge sharing and collective action, while exposure to demonstration plots helps build trust in new technologies. Digital advisory platforms, particularly mobile-based agricultural information services, also contribute to higher adoption levels, especially among younger farmers who are more comfortable using digital technologies. Overall, these findings underscore that improving institutional support systems—particularly extension, climate information dissemination, and farmer organisations—can significantly accelerate the adoption of climate-smart agriculture practices and strengthen the resilience of smallholder maize production systems in North-Central Nigeria.

7.0 CONCLUSION AND RECOMMENDATION

The study examined the barriers and enabling factors influencing the adoption of climate-smart agriculture (CSA) among smallholder maize farmers in North-Central Nigeria. The findings reveal that although awareness and partial adoption of CSA practices exist, the overall level of integrated adoption remains moderate and uneven. Farmers tend to adopt practices selectively, with drought-tolerant maize varieties and crop rotation being the most commonly implemented, while practices such as minimum tillage and organic soil amendments are less widely adopted due to labour and resource constraints. The results further demonstrate that structural challenges—including limited access to credit, high input costs, labour intensity, land-tenure insecurity, and uncertainty about long-term benefits—significantly constrain wider CSA adoption. At the same time, institutional and informational support mechanisms such as extension services, access to climate-information services, farmer-group membership, demonstration plots, and digital advisory platforms play a crucial role in facilitating adoption. Overall, the study concludes that strengthening institutional support systems and improving access to finance, information, and agricultural services are essential for scaling CSA practices and enhancing the resilience and productivity of smallholder maize farming systems in North-Central Nigeria.

Based on these findings, the study recommends that policymakers and development partners prioritise strengthening agricultural extension systems to ensure more regular and effective engagement with smallholder farmers, particularly in climate-risk-prone areas. Expanding access to affordable agricultural credit and input-support programmes would also help reduce financial barriers that limit farmers' capacity to adopt improved seeds and complementary CSA practices. Furthermore, investments in climate-information services and mobile-based digital advisory platforms should be expanded to provide timely, localised weather forecasts and agronomic guidance that support climate-informed decision-making. Strengthening farmer organisations and promoting demonstration plots at community level can also enhance social learning and build farmers' confidence in new technologies. Finally, policies aimed at improving land-tenure security and promoting labour-saving agricultural technologies would create a more enabling environment for sustained adoption of climate-smart agriculture, thereby contributing to improved food security, rural livelihoods, and climate resilience in Nigeria's maize-producing regions.

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