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Effectiveness of Climate-Smart Agriculture Practices in Improving Productivity, Resilience, and Livelihood Outcomes Among Smallholder Farmers in the Upper West Region of Ghana

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Abstract
Climate change poses a severe threat to rain-fed smallholder agriculture in Sub-Saharan Africa, undermining food security and livelihoods. Climate-Smart Agriculture (CSA) has been promoted as an integrated solution to enhance productivity, resilience, and mitigation, but empirical evidence on its effectiveness at the household level remains limited, particularly in northern Ghana (FAO, 2013; IPCC, 2022). This study assessed the effectiveness of CSA practices in improving agricultural productivity, household resilience, and livelihood outcomes among smallholder farmers in the Upper West Region of Ghana. A mixed-methods design was employed, combining a cross-sectional survey of 360 farming households with focus group discussions and key informant interviews. A CSA adoption index was used to capture adoption intensity. Household resilience was measured using a Principal Component Analysis (PCA)-based index. Econometric analyses, including Ordinary Least Squares (OLS), Propensity Score Matching (PSM), and ordered logit models, were used to estimate the effects of CSA adoption. CSA adoption was moderate and selective, with higher uptake of low-cost practices like crop diversification (62%) and improved seeds (58%). Econometric results indicate that increased CSA adoption intensity significantly improved crop productivity ($\beta=0.182$, $p<0.05$), household resilience (Coeff.=1.312, $p<0.05$), farm income, and food security. CSA adopters recorded 420 kg/ha higher yields than matched non-adopters. Qualitative findings corroborated these results, highlighting improved soil fertility and risk reduction, alongside constraints of credit access and labour demands. CSA practices are effective in enhancing smallholder welfare in climate-vulnerable regions. Scaling up requires supportive policies that improve access to extension services, credit, and integrated CSA packages tailored to local contexts.

Keywords: *Climate-Smart Agriculture, smallholder farmers, productivity, resilience, livelihood outcomes, Ghana*

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1.0 INTRODUCTION

1.1 Research Problem

Climate change, manifested by erratic rainfall and rising temperatures, critically threatens rain-fed agriculture in northern Ghana, where most smallholders operate (Antwi-Agyei et al., 2012). Climate-Smart Agriculture (CSA) is widely promoted to address these challenges. However, there is a scarcity of comprehensive, household-level evidence on its effectiveness in

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improving productivity, resilience, and livelihoods in the Upper West Region. Most studies focus on adoption drivers, leaving a gap in rigorous impact evaluation that integrates econometric analysis with resilience measurement (Martey et al., 2021; Yaro, 2013).

1.2 Background

Agriculture is the mainstay of Ghana's economy, especially in the north, but its productivity is highly climate-sensitive. The Upper West Region is particularly vulnerable, characterised by a unimodal rainfall pattern, land degradation, and high poverty incidence. CSA, as defined by the FAO (2013), aims to simultaneously achieve three objectives: sustainably increase productivity and incomes, enhance adaptation and resilience, and reduce greenhouse gas emissions. Although promoted through various projects, the actual multidimensional impacts of CSA practices on smallholder households require localised empirical assessment to inform effective policy.

1.3 Objectives

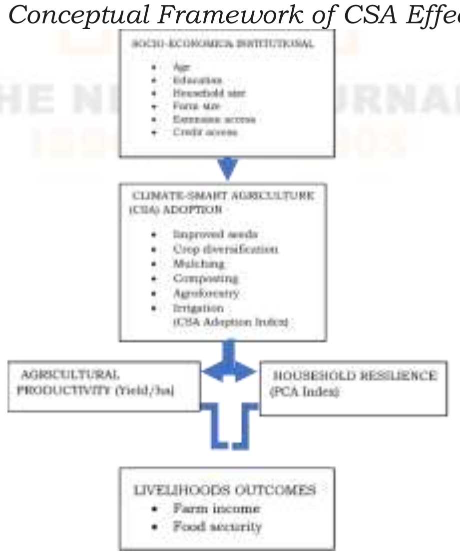
The primary aim was to assess the effectiveness of CSA practices among smallholder farmers in the Upper West Region. Specific objectives were to:

1. Examine the adoption patterns and intensity of CSA practices.
2. Analyse the effect of CSA adoption on agricultural productivity.
3. Assess the impact of CSA adoption on household resilience to climate shocks.
4. Evaluate the influence of CSA adoption on livelihood outcomes (income and food security).

1.4 Conceptual Framework

This study is guided by a conceptual framework integrating the Sustainable Livelihoods Approach and Resilience Theory. The framework posits that CSA adoption, influenced by socio-economic and institutional factors, directly affects agricultural productivity and household resilience. These two outcomes, in turn, mediate the final livelihood outcomes of farm income and food security. Control variables such as farm size, education, and access to extension services moderate these relationships.

Figure 1: Conceptual Framework of CSA Effectiveness



1.5 Significance of the Study

This study provides robust, multidimensional evidence on the impacts of CSA, addressing a critical knowledge gap in the Upper West Region. It offers actionable insights for policymakers and practitioners to design more effective, context-specific CSA interventions. Methodologically, it contributes by employing a composite adoption index and a PCA-based resilience measure within a mixed-methods framework.

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1.6 Research Gap

Existing literature on CSA in Ghana lacks comprehensive studies that quantitatively measure resilience impacts and use adoption intensity indices alongside robust causal inference methods like PSM. This study fills this gap by providing an integrated assessment of productivity, resilience, and livelihood outcomes.

2.0 LITERATURE REVIEW

2.1 Conceptual Foundations and Critiques of CSA

CSA emerged as an integrative "triple-win" framework linking productivity, adaptation, and mitigation (FAO, 2013). While praised for its flexibility, it is criticised for potential conceptual ambiguity and for overlooking socio-structural barriers such as land tenure and gender inequality (Giller et al., 2021; Taylor, 2018). Nonetheless, its context-specific nature makes it a relevant approach for vulnerable agroecologies, such as those in northern Ghana.

2.2 Theoretical Underpinnings

The study draws on three key theories:

1. Agricultural Technology Adoption Theory: Posits that adoption is a function of perceived benefits, costs, and resource constraints (Feder et al., 1985).

2. Sustainable Livelihoods Framework (SLF): Provides a holistic view of how households utilise five capital assets (human, social, natural, physical, financial) to build livelihoods under stress (DFID, 1999). CSA practices are seen as strategies to enhance these assets.

3. Resilience Theory: Focuses on the capacity of systems to absorb shocks, adapt, and transform. CSA practices, such as diversification, theoretically enhance this capacity (Béné et al., 2016).

2.3 Empirical Evidence on CSA Impacts

Evidence from Sub-Saharan Africa generally indicates positive but variable impacts. Studies in Ethiopia and East Africa show CSA adoption boosts yields and income (Kassie et al., 2015; Asfaw et al., 2016). In northern Ghana, research highlights the importance of access to extension services and credit as drivers of adoption, but also notes constraints such as labour shortages and gender disparities (Issahaku & Abdulai, 2020; Nyantakyi-Frimpong & Bezner Kerr, 2015). A critical gap remains in the empirical measurement of resilience outcomes and the synergistic effects of adopting multiple practices.

3.0 METHODOLOGY

3.1 Study Design and Setting

A mixed-methods, cross-sectional design was used, combining quantitative household surveys with qualitative Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs). The study was conducted in the Upper West Region of Ghana, a Guinea Savannah zone marked by high climate vulnerability and subsistence farming.

3.2 Setting

A multistage sampling technique was used to select 360 smallholder farming households. Quantitative data were collected using a structured questionnaire on socioeconomic characteristics, farm characteristics, CSA adoption, yields, income, food security, and exposure to shocks. Qualitative data from 6 FGDs and 10 KIIs provided contextual depth.

3.3 Variable Measurement and Construction

- Dependent Variables: Productivity (crop yield kg/ha); Resilience (PCA-based index from indicators like savings access & diversification); Livelihood Outcomes (Farm income, Food security status).

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- Key Independent Variable: CSA Adoption Index (ranging 0-1), calculated as the mean score of adoption across multiple practices (e.g., improved seeds, diversification, composting, agroforestry).
- Control Variables: Age, education, household size, farm size, access to extension and credit.

3.4 Data Collection and Quantitative Metric

Quantitative data were coded, cleaned, and analysed using Stata Statistical Software, Version 17.0 (StataCorp LLC, College Station, Texas, USA). Data cleaning involved checking for missing values, outliers, and inconsistencies. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were computed to summarise household characteristics and CSA adoption patterns. Graphical tools, including histograms, bar charts, and box plots, were used to visualise key variables.

3.5 Ethical Considerations

Ethical standards were strictly adhered to. Participation was voluntary; informed consent was obtained; and respondents' confidentiality was ensured.

4.0 DATA ANALYSIS

4.1 Descriptive Statistics and Adoption Patterns

The average household head was 42 years old, had 2.1 hectares of land, and had low formal education (5.4 years). Adoption was highest for low-cost, low-risk practices: crop diversification (62%), improved seeds (58%), and composting (46%). Capital-intensive practices such as irrigation (18%) and agroforestry (21%) had low adoption. The CSA adoption index showed 41% of farmers were medium adopters.

Table 1: Socio-Economic Characteristics of Respondents (n = 360)

Variable	Mean	Std. Dev.	Minimum	Maximum
Age (years)	42.3	11.4	21	75
Household size (persons)	6.1	2.3	1	14
Farm size (ha)	2.1	1.2	0.4	6.8
Years of education	5.4	4.1	0	16

Source: Field survey, 2025

The socio-economic profile of respondents presented in Table 1 is consistent with existing studies on smallholder farming systems in northern Ghana and Sub-Saharan Africa. The average age of 42.3 years aligns with findings by Arslan et al. (2015) and Abdul-Razak and Kruse (2017), who reported that economically active age groups dominate agricultural production and are more inclined to adopt climate-responsive practices. This suggests a favourable demographic structure for CSA adoption in the study area.

The mean household size of 6.1 persons corroborates studies by Asfaw et al. (2016) and Issahaku and Abdulai (2020), who argue that larger households can provide labour for labour-intensive CSA practices such as composting and mulching. However, increased consumption needs may offset productivity gains. The small average farm size (2.1 ha) is typical of Ghana's smallholder sector and supports FAO's (2018) argument that land constraints limit investment in long-term CSA practices, such as agroforestry. Low educational attainment further reinforces the importance of extension services, as emphasised by Deressa et al. (2009).

Table 2: Adoption Rates of Key CSA Practices (n=360)

CSA Practice	Adoption (%)
Crop diversification	62
Improved seed use	58
Composting	46
Mulching	39

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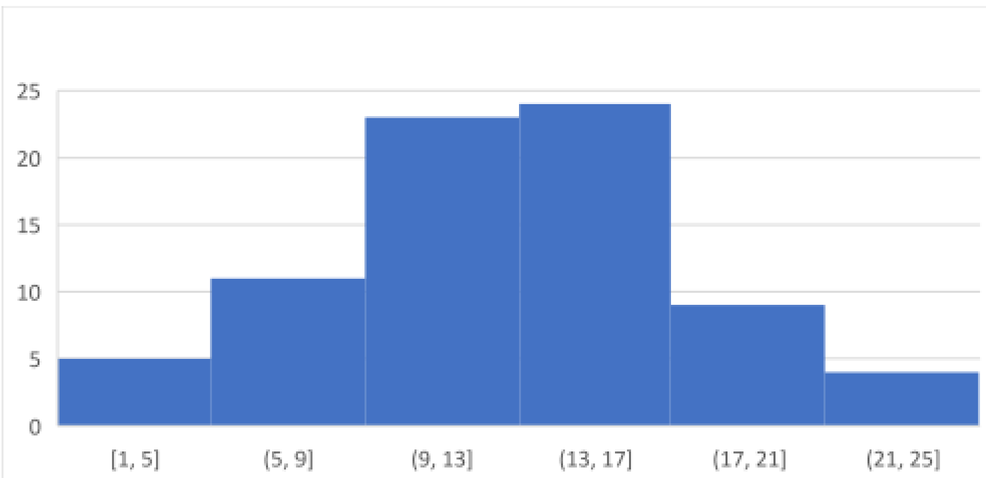
Agroforestry	21
Irrigation	18

Source: Field survey, 2025

The adoption pattern observed in Table 2 is consistent with the literature on CSA uptake in resource-constrained environments. High adoption rates of crop diversification and improved seed use mirror findings by Kpadonou et al. (2017) and Nyantakyi-Frimpong and Bezner Kerr (2015), who observed that farmers prefer practices that are affordable, familiar, and yield short-term benefits. The low adoption of agroforestry and irrigation supports the assertions of Lipper et al. (2014) that capital intensity, land tenure insecurity, and delayed returns discourage investment in such practices.

Table 3: Distribution of CSA Adoption Index illustrates the distribution of the CSA adoption index, showing moderate variability across households.



Source: Field Survey, 2025

4.2 Effect on Agricultural Productivity

CSA adopters had significantly higher average yields than non-adopters. The OLS regression confirmed that a unit increase in the CSA adoption index raised crop yield by 0.182 units ($p<0.05$). PSM analysis reinforced this, showing adopters gained an average of 420 kg/ha more than matched non-adopters (ATT = 420, $p<0.05$).

4.3 Effect on Household Resilience

PCA constructed a resilience index from variables like livelihood diversification and savings access. Ordered logit results showed CSA adoption significantly increased the probability of being in a higher resilience category (Coeff. = 1.312, $p<0.05$). Access to extension and education was also a significant positive contributor.

4.4 Effect on Livelihood Outcomes

CSA adoption had a positive, significant effect on annual farm income (Coeff. = 0.224, $p<0.05$). Food security also improved markedly with adoption intensity: high adopters experienced substantially lower levels of food insecurity compared to low adopters.

4.5 Qualitative Insights

Farmers reported that practices such as composting and diversification improved soil health and reduced the risk of crop failure. Key constraints identified were high labour demand in some practices, limited access to investment credit, and unreliable climate information. Extension officers emphasised the role of demonstrations in fostering adoption.

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4.6 Discussion

The findings demonstrate that CSA adoption can be an effective strategy for enhancing smallholder welfare in climate-vulnerable regions. The selective adoption pattern aligns with adoption theory, in which farmers prioritise affordable, familiar practices with immediate perceived benefits (Feder et al., 1985).

The significant positive impact on productivity corroborates findings from similar contexts (Kassie et al., 2015). The synergy from adopting multiple practices, as captured by the adoption index, appears crucial. The improvement in the empirically measured resilience index is a key contribution, providing tangible evidence for an often theorised benefit of CSA (Béné et al., 2016). The translation of productivity gains into improved income and food security underscores the potential livelihood benefits, though these are moderated by market access and equity.

The qualitative findings highlight the critical role of institutional support, particularly extension and credit, in overcoming adoption barriers, a challenge observed in other LMIC settings (Giller et al., 2021).

5.0 CONCLUSION

This study concludes that Climate-Smart Agriculture practices are effective in improving agricultural productivity, building household resilience, and enhancing livelihood outcomes for smallholder farmers in the Upper West Region. However, effectiveness is constrained by socio-economic and institutional barriers, indicating that CSA is not a standalone solution but must be embedded within supportive rural development systems.

Recommendations

- Policy Integration: Mainstream CSA into regional and district development plans with dedicated budgetary support.
- Strengthen Extension Systems: Enhance the capacity and reach of extension services to provide continuous, hands-on training on integrated CSA packages.
- Improve Financial Access: Develop and promote affordable credit products tailored for smallholders to invest in capital-intensive CSA practices.
- Promote Bundled Practices: Design and demonstrate integrated CSA packages that show the synergistic benefits of combined practices, rather than promoting single technologies.
- Address Equity: Ensure CSA programmes are gender-sensitive and target resource-poor farmers to avoid exacerbating existing inequalities.

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Conflict of Interest Statement

The author declares no conflict of interest.

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