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Research Article

Engendering Climate-Smart Agriculture in Mt. Kenya East: How Farmer Demographics Shape Smallholder Adoption

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Abstract

Climate-smart agriculture (CSA) has emerged as a promising strategy for tackling the challenges of agricultural productivity, resilience, and climate change mitigation. However, its adoption among smallholder farmers in the Mt. Kenya East region has remained low and uneven due to socio-economic barriers. This study examined demographic predictors influencing CSA adoption in Mukothima Ward, Tharaka Nithi County, Kenya, focusing on household characteristics, farmland attributes, and economic and social capital. A mixed-methods design was used, integrating quantitative and qualitative data from a household survey of 418 respondents and six focus group discussions, respectively. The findings revealed that land size, group membership, access to credit, and being a lead farmer were significant predictors of CSA adoption. Male-headed households were more likely to adopt capital-intensive CSA practices, while female-headed households, youth, and farmers with disabilities faced adoption barriers. Social capital, particularly community self-help groups, emerged as a crucial enabler of CSA adoption, mitigating systemic barriers such as limited credit and access to extension services. The study emphasizes the need for targeted interventions to promote CSA adoption in climate-vulnerable areas. Recommendations include land tenure reforms, financial inclusion, gender-sensitive strategies, and strengthening institutional support to improve access to credit for women, youth, and farmers with disabilities.

Keywords

Climate-smart Agriculture, Food Security, Smallholder Farmers, Climate Change, Gender, Extension

1. Introduction

Climate-smart agriculture (CSA) has emerged as a critical climate change adaptation and mitigation strategy, enhancing agricultural productivity while reducing greenhouse gas emissions and strengthening resilience [1, 2]. Smallholder farmers, who produce a significant share of the world's food, are particularly vulnerable to climate-related disruptions, exacerbating food insecurity and threatening livelihoods [3]. Rising temperatures, unpredictable rainfall patterns, and more frequent extreme weather events disrupt agricultural production, worsening these challenges [4, 5].

In Africa, where smallholder farmers cultivate nearly 80% of the farmland, the impacts of climate change are particularly severe. Limited access to modern agricultural technologies, sustainable farming practices, and reliable markets—alongside

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water scarcity and environmental stressors—further undermine food security and economic stability [6, 5]. This is particularly evident in Mt. Kenya East region, where smallholder farmers, the backbone of food production, face recurring droughts, floods, and erratic rainfall [7, 8]. These climate shocks and persistent socioeconomic constraints make targeted adaptation strategies essential for ensuring agricultural sustainability and rural resilience [9].

Despite its advantages in cushioning smallholder farmers against climate shocks, CSA adoption among smallholder farmers in Kenya has been low or varied [10-12]. CSA adoption is influenced by a complex interplay of socio-economic [12], institutional [13, 14], cultural [15], and psychological factors [16, 17] among smallholder farming communities. Many studies have focused on identifying the factors that influence adoption, but few have specifically examined the role of demographic factors in remote and marginalized areas like Mt. Kenya East. Research by Waaswa et al. (2021) [12] has highlighted that socio-economic status, access to credit, land tenure [42, 43], and extension services [34, 36] are significant determinants of CSA adoption. However, these studies often fail to account for the intersectionality of these factors or the role of gender and disability, which have been identified as critical in shaping farmers' capacity and willingness to adopt CSA practices. Understanding the demographic factors influencing the adoption is essential for designing context-specific interventions that enhance resilience and productivity in the face of climate change. Socioeconomic conditions and environmental constraints influence farmers' decisions, resource access, and sustainable agriculture capabilities. [18].

Studies have generated key evidence on farmer attitudes and behaviors toward CSA but are limited by reliance on self-reported information, which may introduce response biases and restrict contextual accuracy [18]. Moreover, existing literature pays insufficient attention to socio-cultural and institutional structures mediating CSA adoption. Studies by Gudina et al. (2023) [13] and Gichuki et al. (2023) [14] highlight institutional support and market accessibility, while critical dimensions like land tenure arrangements and group-based social dynamics within rural settings remain underexplored. This gap limits current research and underscores the need for integrated, context-aware frameworks to understand smallholder decision-making in relation to CSA better.

Given these limitations, there is a clear need for more in-depth studies that address the demographic, cultural, and institutional dimensions of CSA adoption. This study seeks to fill this gap by examining the demographic predictors influencing CSA adoption in Mukothima Ward, Tharaka Nithi County, a critical agricultural zone [7] in Mt. Kenya East and vital water tower experiencing climate variability. [19] This study aims to identify the key factors that shape CSA adoption patterns in this region by focusing on engendered household characteristics, farmland attributes, and economic and social capital. Additionally, the research evaluates how social capital, particularly group membership and access to credit, can enhance or hinder CSA adoption, focusing on the role of gender, youth, and disability in shaping these dynamics.

Ultimately, this study aims to provide insights into the design of targeted interventions that address the specific vulnerabilities of smallholder farmers in Mt. Kenya East, facilitating more effective CSA adoption and improving climate resilience. It seeks to inform policy and practice by strengthening financial inclusion, improving resource access, and enhancing institutional support for marginalized farmers, particularly women, youth, and farmers with disabilities. By providing data-driven recommendations, this study contributes to the broader effort to equip smallholder farmers with the tools and knowledge to mitigate climate risks while sustaining productivity and food security.

2. Materials and Methods

2.1. Study Location

This study focuses on Mukothima Ward in Tharaka Nithi County, Kenya, located on the eastern slopes of Mount Kenya, as illustrated in Figure 1. The county covers about 2,564.4 km^2 and lies between latitudes 0°07' and 0°26' South and longitudes 37°19' and 37°46' East. It is approximately 200 kilometers north of Nairobi and borders Embu, Meru, Kirinyaga, Nyeri, and Kitui counties. Tharaka Nithi features highland and semi-arid regions, forming a distinct ecological transition zone that is highly vulnerable to climate shocks. This makes it ideal for studying the impact of climate change on agricultural productivity among smallholder farmers. [7].

The region has a bimodal rainfall pattern, with long rains from April to June and more reliable short rains from October to December [19]. Rainfall varies from about 500 mm in the lowlands to 2,200 mm in high-altitude areas (Andati et al., 2022). Temperatures range from 14°C to 30°C in highlands and 22°C to 36°C in lowlands, exceeding 40°C during peak dry seasons. These climatic factors significantly affect land use, water availability, and agricultural productivity [20].

Agriculture is key in Tharaka Nithi, with around 80% of the population dependent on farming [21]. The agricultural sector mainly involves mixed farming with cash crops like coffee and tea in the highlands and staple crops like maize and beans in both highland and midland zone. The lowland regions focus on agro-pastoralism, relying on cereals and livestock [8].

Ecologically, the county has varying agroecological zones, from Upper Midland (UM2, UM3, UM4) to Intermediate Lowland Zones (IL5 and IL6). The hydrological system consists of rivers and streams feeding into the Tana River, essential for small-scale irrigation. Mukothima Ward was selected due to its agroecological diversity, climate variability, and agriculture's importance to local livelihoods. The area reflects broader semi-arid challenges like erratic, precipitation, droughts, and soil degradation.

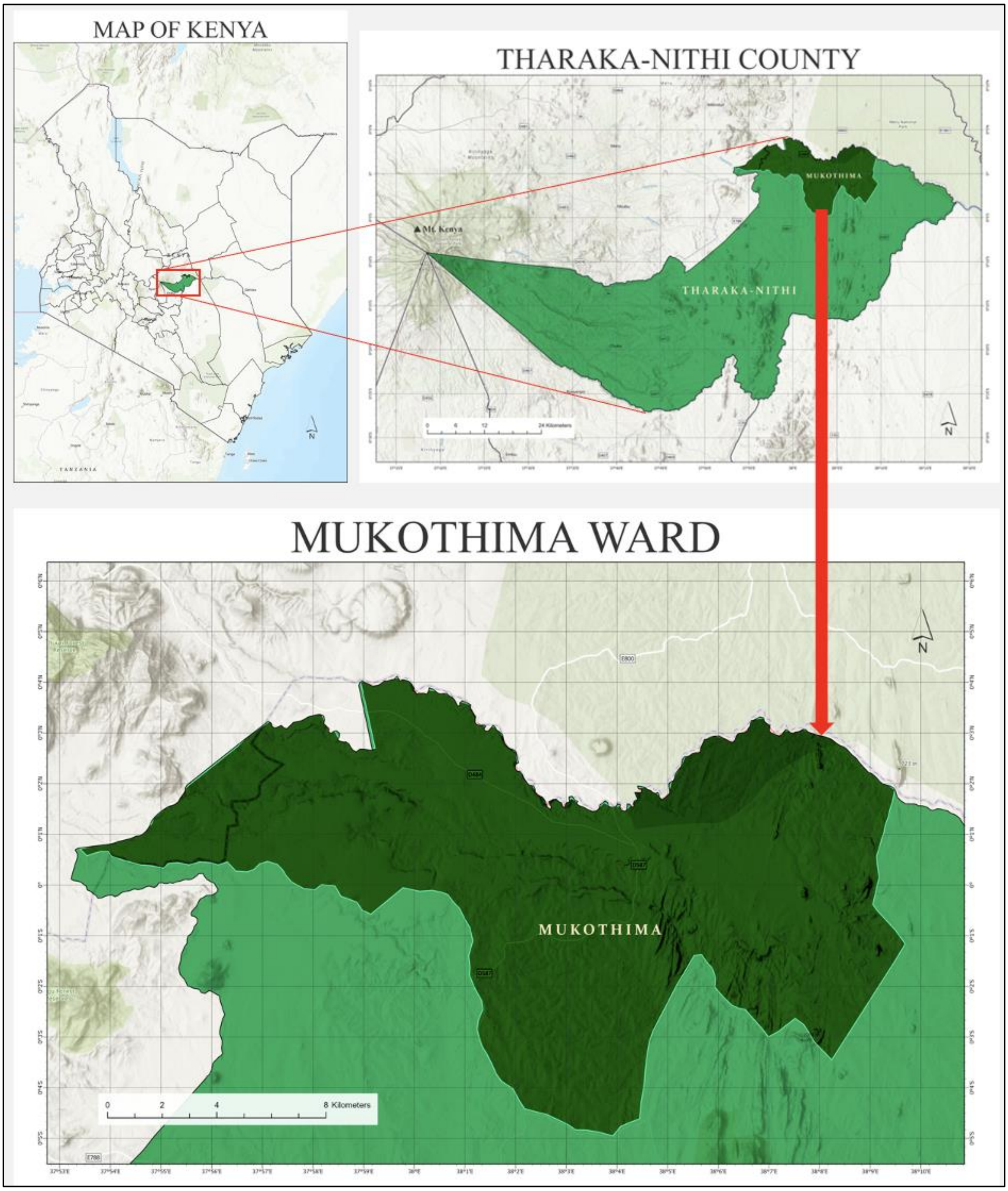

Figure 1. Study Location.

2.2. Research Design and Methods

A partially mixed sequential equal status design (Leech & Onwuegbuzie, 2009) was employed in this study. This design was chosen to integrate both quantitative and qualitative data components with equal weighting, ensuring that both strands equally contribute to answering the research questions. The integration of these data strands was delayed until the interpretation stage, in line with Leech and Onwuegbuzie's (2009) framework [22], which enhances the study's analytical rigor and thematic coherence, as illustrated in Figure 2.

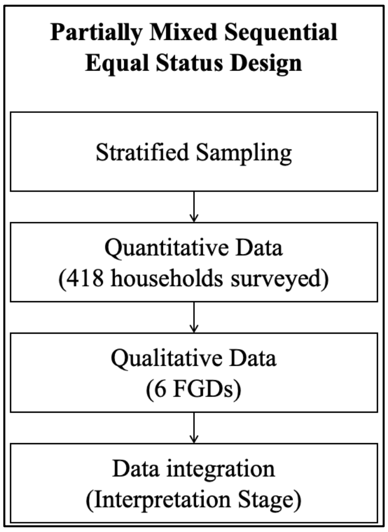

Figure 2. *Research Design.*

To ensure the sample was representative, stratified random sampling was employed. The Ward was systematically divided into distinct strata based on administrative subunits and agroecological variations. This stratification enabled a nuanced understanding of farming practices and household characteristics across different ecological zones. The data collection period was scheduled for February 2025. For quantitative data**,** KoBo Collect, a mobile-based data collection tool, was used to enhance efficiency and accuracy. A total of 418 household survey responses were recorded, yielding a response rate of 109% relative to the target sample of 384 households. The target sample size was determined using Cochran's (1963) formula for sample size estimation:

$$n_0 = \frac{Z^2 p(1-p)}{e^2} \tag{1}$$

Where:

n_0 = required sample size (384.16, rounded to 384)

$Z =$ confidence level (1.96 for 95%)

p = estimated proportion of smallholder farmer households (1,486 smallholder farmer households)

e = margin of error (0.05)

Qualitative data were collected through six focus group discussions (FGDs) to ensure a diverse representation of farmer demographics. These included adult female farmers (n = 6), adult male farmers (n = 6), widowed farmers (n = 6), male youth farmers (n = 6), female youth farmers (n = 6), and farmers with disabilities (n = 6). Each FGD was facilitated by a trained moderator, with a research assistant responsible for note-taking. In adherence to ethical research protocols, informed consent was obtained from all participants prior to their involvement in the study. The research objectives were explicitly communicated to each participant before the commencement of discussions. To ensure data integrity and facilitate accurate transcription and subsequent thematic analysis, all sessions were audio-recorded with the explicit consent of the participants. This study received approval from the Institutional and Scientific Ethics Review Committee of St Paul's University (SPU-ISERC) and the National Commission for Science, Technology, and Innovation (NACOSTI).

This mixed-methods approach, part of a larger PhD research project, provided a strong framework for triangulating findings, capturing both statistical trends and the lived experiences of farmers, thus enhancing the study's validity and depth of insight into smallholder agriculture practices.

2.3. Econometric Model

The analysis employed an ordinal probit regression model to examine the socio-demographic determinants influencing the adoption of multiple CSA practices. This method was chosen to account for the ordered nature of CSA adoption levels while controlling for various household, farm-land, and economic characteristics. The model estimated the probability of farmers adopting multiple CSA practices based on key determinants such as household head gender, literacy levels, farming experience, land tenure, group membership, and access to credit. Coefficient estimates and significance levels provided insights into the relative influence of these factors, allowing for a nuanced understanding of the barriers and enablers shaping CSA adoption among smallholder farmers.

Econometric Model Equation:

$$\Pr(Y_I = j) = \Phi\left(\frac{\beta_0 + \Sigma_{K=1}^{K} \beta_K \; X_{ik} - \gamma_j}{\sigma}\right) \tag{2}$$

Where

Y_I is the ordinal dependent variable (CSA adoption for individual i).

X_{ik} are the explanatory variables (socio-demographics, farm characteristics, etc. for individual i).

β_K are the coefficients of the explanatory variables.

γ_j are the cut-off points for the different adoption levels (j)

$\Phi$is the cumulative normal distribution function.

3. Results

3.1. Household Characteristics

3.1.1. Gender of Household Head

The findings reveal a nuanced relationship between gender, household leadership, and CSA adoption. Male-headed households (MHH) significantly increase the likelihood of adopting integrated soil fertility management (p = 0.022) but negatively influence the adoption of drought-tolerant seeds (p = 0.045). Conversely, female-headed households (FHH) do not exhibit statistically significant effects on CSA adoption, though they are negatively associated with integrated soil fertility practices (p = 0.084). These results suggest that gendered decision-making structures, resource access, and labor constraints shape CSA adoption patterns.

Both qualitative and quantitative findings highlight the central role of men in household-level farming decisions, often prioritizing cash crops over climate-adaptive practices. A male farmer noted, *"As the man of the house, I have to decide which farming methods we use, but I also consider my wife's opinion since she is the one who works on the farm daily."* This statement aligns with the statistical finding that male-headed households drive certain CSA adoptions, likely due to greater control over financial and land resources. Similarly, a female farmer living with disability echoed, *"As a woman heading my household, I find it difficult to access farm inputs because most suppliers prefer dealing with men."*

The data also confirm that FHHs often exhibit greater autonomy in adopting CSA practices but face systemic barriers. As a widow explained, *"I make all farming decisions, but I struggle with access to resources like land and credit."* This highlights a paradox: while women in household leadership roles have more direct control over farm management, their limited access to capital, labor, and agricultural networks restricts their ability to implement CSA practices fully.

The qualitative evidence challenges the non-significant statistical findings for FHHs. Several female participants emphasized that women leading households prioritize CSA for food security: *"When a woman is the head of the household, she is more likely to adopt CSA because she directly manages the farm and wants better yields."* Yet, these qualitative accounts are not strongly reflected in the quantitative model, suggesting potential moderating factors such as economic constraints, labor availability, or social capital disparities.

Additionally, the quantitative finding that MHHs are less likely to adopt drought-tolerant seeds contradicts the perception that men have better access to resources. A possible explanation is that men's preference for high-revenue cash crops may lead them to underinvest in risk-mitigating CSA strategies like drought-resistant varieties. As one widow articulated, *"Men often prioritize cash crops, while women focus on sustainable practices that improve food security."*

A recurring theme in the qualitative responses is the reliance of FHHs on community support. One male farmer observed, *"When a woman is the head of the house, she often seeks advice from the group before making big farming decisions."* This suggests that female farmers, particularly widows and single mothers, compensate for resource constraints by leveraging social networks. However, this approach may not always translate into CSA adoption if the group's priorities do not align with climate adaptation strategies.

Moreover, labor constraints emerge as a critical barrier for female-headed households, particularly for labor-intensive CSA practices like agroforestry and minimum tillage. A widow in the FGD noted, *"I depend on my sons to help with heavy tasks, but if they are not around, I struggle to implement some CSA practices like deep tillage."* This underscores the need for labor-saving technologies and gender-sensitive extension services to support CSA adoption among resource-constrained women.

3.1.2. Marital Status

Male-headed households significantly increase the likelihood of adopting integrated soil fertility management (p = 0.022) but negatively influence the adoption of drought-tolerant seeds (p = 0.045). Conversely, FHH does not affect CSA adoption statistically significantly, though they are negatively associated with integrated soil fertility practices (p = 0.084). These results suggest that gendered decision-making structures, resource access, and labor constraints shape CSA adoption patterns.

Marital status appears to have limited direct influence on CSA adoption, with no statistically significant results except for a marginal negative effect on drought-tolerant seeds (p = 0.059). The weak influence of marital status suggests that other household dynamics—such as financial decision-making, labor availability, and risk tolerance—play a more significant role in determining CSA engagement. These results challenge the assumption that joint decision-making in married households necessarily enhances CSA adoption, indicating that interventions should target broader economic and structural barriers rather than focusing solely on marital status.

Both qualitative and quantitative findings emphasize the pivotal role of men in household-level farming decisions, often prioritizing cash crops over climate-adaptive practices. A male farmer noted, *"Married farmers like me are careful about trying new methods because we have to provide for the family first."* This aligns with the statistical finding that MHHs drive certain CSA adoptions, likely due to greater control over financial and land resources. Similarly, a female farmer with a disability stated, *"Since I am married, my husband and I discuss new farming methods together, and he usually supports CSA adoption if it seems beneficial."* This suggests that CSA adoption can be more effective when spousal cooperation is present.

However, access to land and resources remains challenging for many women, particularly widows and divorced farmers.

A widow expressed, *"I do not own the land I farm; it belongs to my in-laws. This makes it difficult for me to invest in long-term CSA methods."* This highlights the structural barriers that prevent widowed and divorced women from fully participating in CSA. Another widow added, *"As a widow, I sometimes struggle to access land preparation services because men are prioritized when tractors are available."* This reflects broader systemic inequities where women, despite being primary cultivators, remain marginalized in resource distribution.

While statistical analysis suggests that marital status is not a primary determinant of CSA adoption, qualitative narratives indicate that it influences decision-making autonomy and risk tolerance. Married women often cited the need to seek spousal approval before implementing CSA practices. In contrast, unmarried women and widows showed greater decision-making freedom but encountered resource constraints. A young female farmer remarked, *"Widows and single mothers are more open to CSA because they want to maximize farm productivity for their families."* However, this flexibility does not necessarily lead to higher adoption rates due to economic limitations and labor shortages.

Table 1. *Estimates of the ordinal probit model on social-demographic determinants of CSA adoption.*

Variables	CC	DB	ZP	IC	AF	RP	MC	IS
HH characteristics								
Male HHH	0.165 (0.344)	-0.356 (0.045)*	-0.232 (0.456)	-0.032 (0.874)	0.207 (0.257)	-0.258 (0.296)	-0.05 (0.831)	0.494 (0.022)*
Female HHH	-0.079 (0.602)	0.091 (0.576)	0.072 (0.794)	0.012 (0.941)	-0.127 (0.450)	0.093 (0.623)	-0.039 (0.817)	-0.315 (0.084)
Marital status	0.131 (0.184)	-0.176 (0.059)	0.004 (0.975)	-0.007 (0.946)	0.052 (0.612)	-0.065 (0.608)	-0.062 (0.599)	0.061 (0.609)
Literacy	0.105 (0.285)	0.285 (0.002)*	0.0624 (0.717)	0.164 (0.104)	-0.039 (0.711)	0.247 (0.036)*	0.062 (0.502)	-0.152 (0.171)
Family size	-0.150 (0.213)	0.124 (0.278)	0.3881 (0.105)	0.398 (0.002)*	-0.532 (0.716)	0.191 (0.233)	0.305 (0.018)*	-0.001 (0.994)
Farmer experience	0.223 (0.009)*	0.260 (0.004)*	-0.263 (0.036)*	0.305 (0.002)*	0.078 (0.401)	0.105 (0.396)	0.090 (0.296)	0.176 (0.066)
Lead farmer	0.064 (0.666)	0.071 (0.597)	0.597 (0.002)*	-0.026 (0.869)	0.972 (0.516)	-0.047 (0.763)	0.287 (0.033)*	0.159 (0.319)
Farm-land characteristics								
Cultivated Land size	0.096 (0.102)	0.019 (0.719)	-0.156 (0.093)	0.028 (0.621)	0.054 (0.400)	0.096 (0.183)	-0.027 (0.637)	-0.004 (0.940)
Land tenure	0.013 (0.429)	-0.020 (0.204)	0.003 (0.882)	-0.017 (0.316)	-0.039 (0.056)	-0.013 (0.508)	-0.035 (0.031)*	-0.000 (0.967)
Economic and social capital								
Income source	0.337 (0.359)	-0.079 (0.833)	1.004 (0.070)	-0.257 (0.514)	0.227 (0.548)	0.004 (0.991)	0.622 (0.132)	0.034 (0.923)
Group member	-0.750 (0.015)*	0.248 (0.462)	-0.479 (0.567)	-0.688 (0.010)*	-0.539 (0.114)	0.551 (0.159)	-0.571 (0.051)	-0.033 (0.906)
Credit access	-0.036 (0.817)	-0.276 (0.038)*	-0.028 (0.902)	-0.134 (0.373)	0.501 (0.003)*	0.261 (0.112)	-0.064 (0.623)	0.161 (0.299)

Table 1. *Continued.*

Variables	HB	CR	MN	KG	DI	WP	Overall
HH characteristics							
Male HHH	0.083 (0.739)	0.115 (0.549)	0.073 (0.700)	-0.100 (-0.691)	-0.725 (0.288)	-1.222 (0.098)	0.144 (0.246)
Female HHH	-0.207	-0.216	-0.741	0.027	0.000	0.677	-0.143

Variables	HB	CR	MN	KG	DI	WP	Overall
	(0.256)	(0.157)	(0.614)	(0.888)	(0.999)	(0.156)	(0.246)
Marital status	-0.067 (0.577)	-0.116 (0.259)	0.021 (0.847)	-0.121 (-0.442)	-0.498 (0.152)	-0.557 (0.193)	-0.046 (0.538)
Literacy	0.068 (0.498)	0.073 (0.445)	0.137 (0.097)	0.153 (0.192)	-0.029 (0.910)	0.018 (0.956)	0.109 (0.162)
Family size	0.330 (0.019)*	0.324 (0.010)*	0.173 (0.121)	0.210 (0.254)	0.273 (0.489)	-0.071 (0.886)	0.169 (0.082)
Farmer experience	0.117 (0.233)	0.208 (0.017)*	0.197 (0.030)*	0.282 (0.014)*	0.616 (0.067)	-0.447 (0.227)	0.100 (0.164)
Lead farmer	0.0669 (0.701)	0.129 (0.411)	-0.127 (0.381)	0.154 (0.369)	-0.236 (0.520)	-0.668 (0.119)	0.547 (0.000)*
Farm-land characteristics							
Cultivated Land size	0.117 (0.064)	0.161 (0.004)*	0.015 (0.769)	-0.021 (0.769)	0.015 (0.927)	-0.237 (0.215)	0.101 (0.025)*
Land tenure	-0.011 (0.524)	-0.011 (0.475)	0.000 (0.972)	-0.009 (0.669)	-0.041 (0.405)	-0.063 (0.153)	0.012 (0.352)
Economic and social capital							
Income source	-0.215 (0.566)	0.024 (0.945)	0.022 (0.945)	0.773 (0.069)	-0.824 (0.336)	-6.127 (0.990)	0.127 (0.656)
Group member	-0.333 (0.356)	-0.394 (0.132)	0.039 (0.894)	-0.159 (0.672)	0.525 (0.533)	-1.85 (1.000)	-0.794 (0.000)*
Credit access	0.156 (0.332)	-0.328 (0.018)*	-0.131 (0.306)	0.014 (0.948)	0.867 (0.020)*	-0.698 (0.085)	-0.434 (0.000)*

CC: Cover Cropping, DB: Digging basins, ZP: Zai Pits, IC: Intercropping, AF: Agroforestry, RP: Ripping, Mc: Mulching, IS: Improved seeds, HB: Herbicide Use, CR: Crop Rotation

The finding that MHHs are less likely to adopt drought-tolerant seeds contradicts the expectation that men's greater resource access would enhance CSA adoption. A possible explanation is that men prioritize short-term profitability over long-term resilience strategies. As one widow articulated, *"Men often prioritize cash crops, while women focus on sustainable practices that improve food security."* This underscores a critical gendered divergence in agricultural decision-making, with women strongly inclined toward long-term sustainability.

The qualitative data further reveal the impact of marital status on labor division, training participation, and willingness to experiment with CSA. Single farmers, particularly women, struggle with workload distribution. A female farmer with disabilities noted, *"As a single farmer, I sometimes struggle to keep up with CSA practices because I have no one to share the workload with."* This sentiment was echoed by another widow: *"Widows like me face challenges in attending CSA training because we have many responsibilities, and there's no one to take care of the farm when I am away."* These challenges suggest that providing labor-saving technologies and childcare support could improve CSA adoption among widows and single mothers.

Conversely, young unmarried farmers seem more willing to experiment with CSA. A young male farmer noted, *"Young unmarried farmers are more flexible in experimenting with CSA because they don't have too many responsibilities yet."* This suggests an opportunity to design youth-targeted CSA initiatives that capitalize on their adaptability and openness to innovation.

3.1.3. Literacy

The findings affirm the critical role of literacy in facilitating CSA adoption, particularly for drought-tolerant seeds ($p = 0.002$) and rotational planting ($p = 0.036$). Educated farmers are more likely to engage with new agricultural technologies, benefiting from enhanced access to extension services, financial institutions, and climate information. The additional analysis further underscores this trend, revealing a significant positive association between literacy and CSA adoption (p = 0.049). Notably, farmers with at least secondary education represent a substantial proportion of CSA adopters, while those without formal education exhibit lower adoption.

However, the lack of significance across other CSA practices suggests that literacy alone is not a universal driver of adoption. While it enhances farmers' capacity to process information and assess risks, complementary factors—such as economic incentives, extension outreach, and access to inputs—remain crucial. This finding aligns with broader research indicating that education enhances technology uptake but requires an enabling environment to translate knowledge into practice.

3.1.4. Family Size

Larger family size significantly increases the likelihood of adopting integrated cropping systems (p = 0.002), manure application (p = 0.018), and conservation tillage (p = 0.019), suggesting that households with more members benefit from greater labor availability, which facilitates the implementation of labor-intensive CSA practices. However, the non-significant influence on other CSA practices implies that while larger families provide workforce advantages, adoption decisions may still be constrained by financial limitations and knowledge gaps. These findings align with prior studies [23, 24] highlighting the labor-intensity factor in CSA adoption, but also reveal the complexities of balancing household priorities, as labor availability does not automatically translate to widespread CSA adoption.

The qualitative analysis further illustrates these dynamics. Youth female participants noted that while large families have the manpower to implement CSA, food security remains the primary concern, limiting the willingness to experiment with unfamiliar techniques: *"In large families, we have more labor to implement CSA, but feeding everyone is the priority, so we can't take big risks with new methods."* Conversely, smaller households often struggle with labor-intensive practices such as mulching and agroforestry: *"Smaller families may struggle with labor-intensive CSA practices."* Despite these constraints, larger families sometimes prioritize CSA for long-term sustainability: *"When there are many children, we think about future sustainability, so CSA is important."*

Widowed farmers echoed similar sentiments, emphasizing that while children can contribute to farm work, their absence—whether due to school or migration—creates labor gaps. One widow explained: *"My children help with farming activities, but when they are in school, I struggle to do everything alone."* Others noted that larger households can manage resource-intensive CSA practices like composting more effectively: *"Larger families can manage labor-intensive CSA practices like composting better than smaller households."* However, those living alone face severe constraints: *"Since I live alone, I can only implement CSA practices that require minimal labor."*

For farmers with disabilities, household size also plays a crucial role in determining CSA adoption. One participant highlighted how family support facilitates implementation: *"In our large family, everyone contributes to the farm, so it is easier for us to implement new CSA practices that require more labor."* On the other hand, small families struggle with the labor demands of conservation farming: *"I have a small family, so I struggle with CSA practices like mulching and water conservation that need extra hands."* Aging farmers with smaller households face unique challenges, often depending on hired labor: *"My children are grown and have moved to the city, so I have to rely on hired labor, which makes CSA adoption expensive for me."*

These findings suggest that while larger family size provides a labor advantage for CSA adoption, other socio-economic factors—such as financial constraints, knowledge access, and household priorities—mediate the extent to which these practices are implemented studies [23, 24]. There is a need for CSA interventions that account for varying household structures, ensuring that both large and small households receive adequate support to maximize adoption and long-term sustainability.

3.1.5. Farmer Experience

Farmer experience plays a crucial role in CSA adoption, significantly increasing the likelihood of adopting conservation agriculture (p = 0.009), drought-tolerant seeds (p = 0.004), and crop rotation (p = 0.017). Experienced farmers tend to possess more profound knowledge of climate variability, allowing them to implement resilience-enhancing strategies more effectively. This aligns with existing research emphasizing experiential learning as a key driver of sustainable agriculture. The significance levels across multiple CSA practices highlight the potential for leveraging experienced farmers as peer educators.

Qualitative insights reveal both consistencies and contradictions in how experience shapes CSA adoption. Among adult male farmers, long-term exposure to farming practices fosters both confidence and skepticism. One farmer remarked, *"I have been farming for over 20 years, and I know which methods work and which ones are just trends,"* reflecting the cautious approach that seasoned farmers often take toward new practices. Conversely, another participant noted, *"New farmers are eager to try CSA because they don't have old habits to break,"* suggesting that openness to innovation is often higher among less experienced farmers. Despite this skepticism, experienced farmers frequently blend traditional techniques with modern CSA methods, as illustrated by the statement, *"With experience, you learn to combine traditional methods with modern CSA practices."*

Farmers with disabilities echoed similar views, reinforcing that experience enables better assessment of CSA effectiveness. One participant emphasized, *"I have been farming for over 20 years, so I can tell which CSA practices work best for my land."* However, resistance to change remains a barrier, particularly for older farmers: *"New farmers are more willing to try CSA methods because they are still learning, but older farmers prefer their traditional ways."* While experienced farmers acknowledge the importance of CSA, some remain hesitant to take risks on unfamiliar techniques: *"With my experience, I know that adopting CSA is important, but I am hesitant to take risks on unfamiliar methods."* Younger farmers preferred technology-driven CSA solutions: *"Younger farmers like me are more interested in technology-based CSA solutions."*

Female farmers provided additional insights into the role of experience in CSA adoption. Like their male counterparts, they rely heavily on past knowledge, sometimes slowing the adoption process: *"I have farmed for 20 years, and I know what works best for my land."* However, many have recognized the benefits of CSA, as one farmer shared: *"I was hesitant at first, but after farming for many years, I see the benefits of mulching and crop rotation."* Their perspective also underscores the need for targeted training and awareness-building for new farmers: *"New farmers need more training to trust CSA methods."* These findings suggest that while experience provides valuable insights into CSA effectiveness, it can also create resistance to change.

3.1.6. Lead Farmer Status

Findings underscore the pivotal role of lead farmers as catalysts for CSA adoption, particularly in zero-tillage ($p = 0.002$) and minimum tillage ($p = 0.033$). As early adopters, lead farmers demonstrate the benefits of CSA, potentially reducing risk perception and fostering community peer learning. Additional analysis further substantiates their influence, showing a strong positive association between lead farmer status and CSA adoption ($p < 0.001$). Lead farmers account for 31% of adopters compared to only 19% in the general farming population, illustrating their outsized impact in shaping agricultural practices.

However, the lack of significance in other CSA practices suggests that leadership alone does not automatically translate into widespread adoption without institutional and technical reinforcement. While lead farmers successfully champion specific conservation practices, their effectiveness in driving holistic CSA adoption depends on structured support, including tailored extension services, access to inputs, and financial incentives. This aligns with broader research on farmer-to-farmer extension models, which thrive when complemented by institutional backing. Without these mechanisms, even lead farmers face challenges in convincing their peers to adopt new methods, as one farmer with a disability noted: *"It is hard to convince other farmers to adopt CSA if they do not see immediate benefits."*

The qualitative findings highlight how lead farmers perceive their roles and responsibilities in CSA adoption. Among female lead farmers, there is a strong sense of accountability for guiding their communities. One farmer emphasized, *"As a lead farmer, I test new CSA methods before advising other women in my group,"* reinforcing the idea that lead farmers act as intermediaries between extension officers and the broader farming community. Another echoed this sentiment, stating, *"Farmers in my village trust my advice because I have been trained by extension officers,"* illustrating the credibility that formal training confers.

Similarly, male lead farmers recognize their influence in knowledge dissemination and demonstration. One participant stated, *"As a lead farmer, people expect me to try new methods first and then show them if they work,"* underscoring the expectation that lead farmers validate CSA practices before widespread adoption. Another noted, *"Farmers trust what they see in my field more than what they hear in meetings,"* highlighting the importance of practical demonstrations in influencing adoption. This aligns with the broader principle of experiential learning, where observable results carry more weight than theoretical discussions.

For farmers with disabilities, the role of lead farmers extends beyond knowledge-sharing to include improved access to extension services and training opportunities. One participant observed, *"Being a lead farmer gives me better access to training and extension services, which makes it easier for me to adopt CSA."* This suggests that leadership status can serve as a pathway to greater resource availability, ultimately facilitating the adoption process. However, even lead farmers acknowledge the challenge of persuading others, reinforcing the need for additional support mechanisms to enhance their influence. These findings highlight the need for targeted interventions that amplify the role of lead farmers in CSA adoption. Expanding their responsibilities to encompass a broader suite of CSA techniques—through training, resource provision, and policy support—could enhance adoption rates at scale.

3.2. Farm-Land Characteristics

3.2.1. Cultivated Land Size

Manure application ($p = 0.004$) and cover cropping ($p = 0.025$) were significantly influenced by larger cultivated land size, suggesting that landowners with extensive plots had more flexibility in implementing soil conservation techniques. The weak influence on other CSA practices implied that land size alone did not dictate adoption, as financial constraints and labor requirements still played a role. Farmers with more land were more willing to experiment with CSA practices that required long-term investment. These results aligned with research emphasizing the need for land-tenure security in CSA adoption. The findings highlighted the importance of policies that enhanced land access and ownership for smallholders.

3.2.2. Land Tenure

The relationship between land tenure security and CSA adoption presents a counterintuitive dynamic. While tenure security is often assumed to foster CSA adoption, initial findings indicate that secure tenure significantly reduces the likelihood of adopting minimum tillage ($p = 0.031$). This challenges conventional wisdom, suggesting that farmers with long-held or inherited land may be more resistant to shifting away from conventional practices. This reluctance may stem from generational knowledge transfer, perceived soil stability, or a lower sense of urgency regarding land degradation.

Further analysis refines this understanding by revealing that inherited land ($p = 0.403$) and leased/rented land ($p = 0.473$) show no significant relationship with CSA adoption. However, land purchased by the farmer exhibits a significant positive association with CSA adoption ($p = 0.023$). This suggests that those who actively invest in land through purchase may be more inclined to adopt CSA practices due to higher stakes in long-term land productivity, financial capital access, or exposure to modern agricultural practices at the point of acquisition. These findings highlight that tenure security alone does not drive CSA adoption; rather, the mode of land acquisition—particularly through purchase—plays a more influential role.

The qualitative findings further illuminate these patterns. Farmers with disabilities expressed concerns about tenure insecurity limiting their ability to invest in long-term CSA strategies. One farmer noted, *"I do not own the land I farm on, so I cannot make long-term investments like agroforestry."* Others highlighted gendered decision-making dynamics, such as, *"My husband owns the land, and I have to get his approval before making any farming changes."* Conversely, those with secure ownership saw CSA as a viable investment: *"Since I have a title deed, I feel secure to try new CSA practices without fear of losing my land."* However, uncertainty in tenure was a common barrier, as illustrated by a respondent farming on rented land: *"We farm on rented land, and since we are not sure how long we will have access, we avoid CSA practices that take time to show benefits."*

Gender disparities in land tenure decision-making emerged across multiple focus groups. In the adult female FGD, one participant remarked, *"I farm on my husband's land, but I cannot make big decisions like planting trees or irrigation without his approval."* This sentiment was echoed in the widows' FGD, where another participant stated, *"Without a title deed, I cannot access loans to invest in CSA practices like irrigation."* Women who had secured land ownership emphasized the transformative potential of tenure security, with one noting, *"I was able to adopt CSA techniques because my name is on the title deed, so no one can take my land."* These findings underscore the importance of gender-sensitive land policies to enhance women's agency in CSA adoption.

For men and youth, land tenure security was similarly pivotal. An adult male farmer described the limitations of leasing land: *"I cannot make big changes on the farm because the land is not mine; I lease it, and the owner decides what I can do."* Another highlighted the long-term benefits of ownership: *"Those of us with title deeds can invest in long-term CSA practices like agroforestry because we know the land is ours."* Among young female farmers, land tenure insecurity was cited as a significant constraint, with one participant noting, *"Women face challenges in accessing land, and without secure tenure, it is difficult to commit to CSA practices."* Another emphasized short-term decision-making among tenants: *"Those who lease land focus on short-term gains and hesitate to adopt CSA techniques that take time to show results."*

These findings illustrate the nuanced relationship between land tenure security and CSA adoption. While ownership provides stability and encourages long-term investments, inherited and customary land arrangements often have decision-making constraints that hinder adoption. Leasing and renting land, particularly on short-term agreements, further discourages CSA adoption due to uncertainty and lack of control over land-use decisions. Addressing these structural barriers through tenure reform, gender-sensitive land policies, and incentives for long-term land investments could enhance CSA adoption and ensure more sustainable farming practices across diverse farmer categories.

3.3. Economic and Social Capital

3.3.1. Income Source

Income sources do not significantly influence most CSA practices, except for a marginal positive effect on zero-tillage adoption ($p = 0.070$). This suggests that diversified income streams may not necessarily translate into higher CSA adoption unless complemented by financial incentives and advisory services. The findings highlight the need for targeted financial products that support CSA investments. Given the low significance, income diversification alone is insufficient in driving CSA adoption. These results reinforce the importance of integrating CSA promotion with economic empowerment programs.

3.3.2. Group Membership

Initial statistical results indicate a negative correlation between general group membership and key CSA practices such as Cover Cropping ($p = 0.015$) and intercropping ($p = 0.010$). However, deeper analysis highlights that membership in self-help groups (SHGs) has a significant positive effect on CSA adoption (8.782, $p = 0.012$). This suggests that not all group structures influence CSA adoption uniformly. While some broad-based farmer groups may introduce competing priorities or information asymmetries that hinder CSA adoption, SHGs—often characterized by strong social cohesion and shared economic goals—create a supportive environment for adoption.

Qualitative insights further illustrate the positive role of group membership in facilitating CSA adoption. Many farmers emphasized the importance of peer learning, collective bargaining, and access to financial resources through group networks. A male farmer noted, *"I joined a farmer group because they give us information on better farming practices and access to training on CSA,"* reinforcing the role of groups in knowledge dissemination. Similarly, a female farmer highlighted, *"Through my women's farming group, I learned* *about composting and water conservation,"* demonstrating how gendered farmer groups enhance access to CSA-specific knowledge. Widows and youth farmers echoed similar sentiments, with one widow stating, *"I used to farm alone, but after joining a women's farming group, I now have access to training and financial support."* These narratives underscore how group membership can mitigate barriers to CSA adoption by fostering collective learning, resource pooling, and improved market linkages.

Despite these benefits, exclusion from farmer groups presents a critical challenge, particularly for marginalized farmers. A farmer with a disability remarked, *"I am not in any farmer group, so I often miss out on CSA training opportunities."* Similarly, another participant observed, *"Farmers who are not in groups struggle to get information on CSA practices."* These statements highlight the risk of CSA knowledge and resource access being concentrated within organized groups, potentially sidelining non-members. As such, interventions to strengthen group dynamics must also ensure inclusivity, particularly for vulnerable populations who may face social or financial barriers to joining formal farmer groups.

The findings suggest that farmer groups, particularly SHGs and women's farming groups, play a crucial role in driving CSA adoption. These groups enhance knowledge sharing, reduce the cost of farm inputs through collective bargaining, and improve market access for CSA produce. However, the differential effects of group structures indicate the need for tailored interventions that optimize the role of farmer organizations while addressing the barriers non-group members face.

3.3.3. Access to Credit

Credit Access to credit emerges as a critical determinant of CSA adoption, shaping farmers' ability to invest in short-term and long-term resilience strategies. Quantitative results indicate a significant positive association between credit access and agroforestry ($p = 0.003$), suggesting that farmers with financial resources are more inclined to adopt sustainability-focused practices that yield benefits over time. Conversely, the negative correlation with drought-tolerant seeds ($p = 0.038$) implies hesitation toward high-risk investments that require immediate returns. These findings reinforce the argument that while financial access facilitates capital-intensive CSA investments, risk aversion among smallholder farmers—particularly in economic uncertainty—remains a barrier to adopting short-term CSA strategies.

Qualitative insights further illuminate the intricate ways credit access (or the lack thereof) influences CSA adoption, highlighting key barriers such as collateral requirements, gender disparities, and the role of informal savings groups. A male farmer emphasized the financial constraints limiting CSA adoption: *"Without credit, it is hard to adopt CSA because some practices need upfront investment, and we don't always have the money."* Similarly, a widow shared her frustration: *"I tried applying for a loan, but they asked for a title deed, which I don't have."* These testimonies underscore the structural limitations that hinder smallholder farmers—especially those without formal land ownership—from securing credit for agricultural investments.

Gendered disparities in credit access further exacerbate financial exclusion. Women farmers frequently cited collateral requirements as a significant obstacle, exemplified by one participant's statement: *"Women farmers are often asked for collateral, which we don't have, so we can't access loans easily."* The intersection of gender and financial exclusion is particularly evident among widows and young female farmers, who reported additional difficulties in accessing credit due to institutional biases favoring male farmers. A female youth participant noted: *"Women struggle to access credit because financial institutions often favor men who have assets."* This aligns with previous studies highlighting the entrenched socio-economic barriers that limit women's participation in formal credit markets, ultimately constraining their ability to invest in CSA [12].

In response to these barriers, informal financial mechanisms—particularly savings and credit groups—play a crucial role in bridging the credit gap. Many farmers emphasized the value of collective financing structures in supporting CSA investments. One participant remarked: *"Belonging to a savings group allows me to borrow small loans for CSA inputs."* Likewise, another farmer stated: *"Our farmers' group helped us secure a small loan, which I used to buy drought-resistant seeds."* These findings suggest that while formal credit institutions remain largely inaccessible to many smallholder farmers, community-based financial models provide a viable alternative, enabling farmers to make incremental investments in CSA practices.

Despite these alternative credit mechanisms, high loan interest rates pose another significant challenge. A widow explained: *"The interest rates on loans are too high, and CSA practices take time to show returns."* This concern was echoed by other farmers, who highlighted the misalignment between the financial sector's short-term lending expectations and the longer-term benefits of CSA. Such contradictions indicate the need for specialized agricultural credit products that align repayment structures with CSA's return-on-investment timeline.

Expanding access to credit—particularly through gender-inclusive policies, innovative financial products, and strengthened savings cooperatives—could accelerate CSA adoption by mitigating upfront investment barriers. However, financial interventions must be carefully tailored to account for the diverse realities of smallholder farmers, ensuring that credit systems support—not constrain—the transition to climate-resilient agriculture.

4. Discussion

4.1. Household Characteristics

The relationship between gender and CSA adoption is highly nuanced, revealing both structural constraints and behavioral patterns that influence decision-making in smallholder farming households. MHH are significantly more likely to adopt integrated soil fertility management but are less inclined to adopt drought-tolerant seeds. FHHs do not show statistically significant effects on CSA adoption but are negatively associated with integrated soil fertility practices.

These results align with previous studies highlighting the gendered nature of agricultural decision-making [25, 26]. Research suggests that MHHs generally have better access to land, credit, and extension services, which facilitates the adoption of capital-intensive practices [27, 28] such as integrated soil fertility management. Conversely, the negative relationship between MHHs and drought-tolerant seed adoption could reflect a preference for high-revenue cash crops over long-term resilience strategies [29].

The qualitative findings provide additional layers of understanding. Women-headed households face significant barriers to accessing resources, reinforcing structural inequalities. As women are often primary caregivers, their ability to engage in labor-intensive CSA practices is constrained, as noted in previous literature labor allocation in agriculture studies [23, 24]. Furthermore, the reliance of FHHs on community networks suggests that social capital plays a compensatory role in decision-making. Studies have shown that women are more likely to engage in collective farming approaches, leveraging peer knowledge and cooperative labor [30, 31].

The disparity between qualitative and quantitative findings for FHHs suggests that economic and social constraints may moderate their ability to adopt CSA despite strong interest and agency in decision-making. One critical area for future research is gendered resource access and social capital. While female-headed households demonstrate agency in decision-making, they face systemic barriers to accessing credit, land, and extension services. Exploring how informal networks and social capital can mitigate these constraints may offer insights into gender-sensitive policy interventions that enhance CSA adoption among women farmers.

Marital status does not strongly influence CSA adoption, with no statistically significant results except for a marginal negative effect on drought-tolerant seeds. This finding contradicts the common assumption that joint decision-making in married households enhances technology uptake [32]. Qualitative insights suggest that marital status affects decision-making autonomy and resource allocation. Married women often require spousal approval to implement CSA, whereas widows and single women exhibit more autonomy but face financial and labor constraints. These findings resonate with the literature on intra-household bargaining power and agricultural investment [25, 26, 33].

Moreover, systemic barriers, such as land tenure insecurity among widows, further hinder CSA adoption. Previous research in Africa has documented how widowed and divorced women often lack formal land ownership, limiting their ability to engage in sustainable farming practices [34]. Addressing these structural inequalities through legal reforms and targeted interventions could enhance CSA adoption among vulnerable groups.

The positive association between literacy and CSA adoption, particularly for drought-tolerant seeds and rotational planting, underscores the role of education in agricultural technology uptake. This finding is consistent with the Technology Adoption Model (TAM) by Davis 1986, which posits that knowledge and information processing capabilities enhance the likelihood of adopting new practices [35]. Studies in sub-Saharan Africa have found that educated farmers are more likely to engage in sustainable agricultural practices due to better access to extension services and information [34, 36].

However, the non-significance of literacy in other CSA practices suggests that education alone is not a panacea. Economic incentives, infrastructural support, and extension outreach remain critical factors influencing adoption [34]. Future research should investigate how literacy interacts with other socio-economic variables, such as access to digital agricultural platforms. As digital agricultural platforms and mobile extension services become more prevalent, understanding how literacy—particularly digital literacy—affects knowledge acquisition and technology adoption could have significant policy implications. Future research should assess whether digital solutions can bridge information gaps and facilitate broader CSA adoption, particularly among resource-constrained farmers.

Larger family size significantly increases the likelihood of adopting integrated cropping systems, manure application, and conservation tillage. This result suggests that labor availability is a crucial determinant of CSA adoption, corroborating studies identifying household labor as a key factor in implementing labor-intensive practices [24]. However, the qualitative findings reveal complexities in this relationship. While larger families benefit from increased labor availability, food security concerns often precede CSA adoption. This aligns with research indicating that risk-averse households prioritize immediate food production over long-term sustainability strategies [37, 38]. Conversely, smaller households struggle with labor-intensive CSA practices, highlighting the need for labor-saving technologies and mechanization support.

Additionally, gender and age dynamics within larger households influence CSA adoption. Due to migration and shifting aspirations, youth engagement in CSA remains challenging [39]. With shifting aspirations and increasing rural-to-urban migration, young people are often disengaged from traditional farming. Future studies should explore the role of youth labor in CSA adoption and whether targeted youth programs can bridge labor gaps in smallholder farming systems.

Additionally, land tenure security continues to be a determining factor in agricultural investment decisions. Widowed and single women, in particular, often face legal and cultural barriers to land ownership, limiting their ability to implement long-term CSA practices. Investigating how land tenure policies influence the willingness of marginalized groups to invest in CSA could provide a foundation for policy reforms that promote equitable access to land and agricultural resources.

Finally, applying behavioral economics frameworks to CSA adoption could offer new perspectives on farmer decision-making. Understanding risk perception, financial incentives, and cognitive biases that influence the adoption of CSA practices could enhance the design of interventions aimed at increasing adoption rates. Research that integrates behavioral insights into agricultural policy and extension programs could yield more effective and context-specific strategies for scaling CSA.

4.2 Farm-Land Characteristics

The results indicate that larger cultivated land sizes significantly influence the adoption of manure application and cover cropping, implying that landowners with expansive plots exhibit a higher propensity to implement soil conservation techniques. This aligns with other findings that argue that larger farms provide greater flexibility in allocating resources for sustainable land management [40]. However, the weak influence of land size on other CSA practices suggests that land size alone is not a sufficient determinant of adoption. This supports findings that highlight how financial constraints and labor requirements remain substantial obstacles to CSA adoption, irrespective of land size [41].

Moreover, farmers with larger landholdings may be more inclined to experiment with CSA practices that require long-term investment, as supported by the agricultural intensification theory (Schultz, 1964) [40]. This implies that policies enhancing land tenure security and financial support could amplify CSA adoption rates among smallholders, particularly those constrained by resource limitations.

The relationship between land tenure security and CSA adoption presents a counterintuitive dynamic. While tenure security is typically assumed to foster CSA adoption, the significant reduction in minimum tillage adoption among securely tenured farmers suggests resistance to shifting away from conventional farming methods. This contradicts the established notion that secure land tenure enhances sustainable agricultural investments [42, 43]. One possible explanation is that farmers with long-held or inherited land prioritize traditional practices due to generational knowledge transfer, perceived soil stability, or a lower sense of urgency regarding land degradation [44].

Further analysis reveals that land purchased by the farmer exhibits a significant positive association with CSA adoption, suggesting that those who actively invest in land are more inclined to adopt CSA practices. This finding aligns with Franc-Dabrowska (2018), who argue that land purchase serves as a proxy for financial capital access [45] and exposure to modern agricultural practices [46]. The qualitative data corroborate this, with farmers citing ownership security as a critical factor in adopting agroforestry and other CSA techniques. The gendered constraints in land tenure further underscore the need for policies promoting women's land ownership [47], thus enhancing women's agricultural productivity and investment in sustainable practices.

The findings emphasize the necessity of tenure reforms that go beyond security alone and incorporate access to financial services, advisory support, and gender-sensitive policies to enhance CSA adoption. Addressing tenure insecurity through targeted interventions could facilitate broader CSA adoption, particularly among marginalized groups such as tenants, women, and youth farmers.

4.3. Economic and Social Capital

The marginal positive effect of income sources on zero-tillage adoption suggests that while diversified income streams may provide some financial flexibility, they do not independently drive CSA adoption. This is consistent with studies highlighting that financial incentives and advisory services are critical in overcoming adoption barriers [33]. The findings underscore the importance of integrating CSA promotion with economic empowerment programs, such as microfinance schemes and value-chain development, to ensure that income generation translates into sustainable agricultural investments.

The negative correlation between general group membership and key CSA practices such as cover cropping and intercropping suggests that not all farmer groups promote CSA adoption uniformly. However, self-help groups (SHGs) significantly positively affect CSA adoption, supporting the argument that strong social cohesion and shared economic goals enhance adoption rates. These findings align with Pretty and Ward (2001), who emphasize the role of social capital in sustainable agriculture.

Qualitative insights further reinforce the role of farmer groups in facilitating CSA adoption through peer learning, collective bargaining, and improved access to resources. The gendered dimensions of group membership, as seen in women's farming groups fostering CSA knowledge dissemination, echo the conclusions of Handayani et al. (2024) [48] regarding the importance of gender-responsive agricultural extension services. However, excluding marginalized farmers from group structures presents a critical challenge, necessitating inclusive interventions that expand CSA knowledge beyond organized groups.

Access to credit emerges as a crucial determinant of CSA adoption, significantly influencing agroforestry adoption while showing a negative correlation with drought-tolerant seeds. These findings conflict with evidence from Anastassiadis et al. (2025) [49], which suggests that financial liquidity enables capital-intensive investments but does not necessarily reduce risk aversion in short-term decision-making. The reluctance to invest in drought-tolerant seeds may stem from uncertainty regarding their immediate economic benefits, as posited by Simtowe (2019) [50].

Gender disparities in credit access further exacerbate adoption barriers. Structural biases in formal financial institutions disproportionately disadvantage women farmers. This study's findings echo these concerns, with qualitative data highlighting collateral requirements as a primary obstacle. The role of informal savings groups in bridging the credit gap suggests that community-based financial mechanisms could serve as viable alternatives to formal credit institutions, a strategy supported by evidence from Phil-Ugochukwu (2024) [51]. Given the nuanced interplay of gender and financial inclusion observed in this study, subsequent research should delve deeper into the gendered dimensions of capital allocation, risk appetite, and financial literacy among smallholder farmers.

High loan interest rates pose another significant barrier, as echoed in research by Vishwanatha and Eularie Carter (2017) [52], which emphasizes the need for financial products tailored to smallholder farmers. A promising research avenue lies in examining the catalytic role of financial services in overcoming barriers to CSA investment. research should examine the role of financial mechanisms in enabling CSA adoption, particularly among marginalized groups such as women and youth. Investigating the effectiveness of targeted financial instruments, such as climate-resilient credit products, blended finance models, and weather-indexed insurance, can inform the development of inclusive financing strategies that align with smallholder farmers' needs. Finally, further exploration is needed at the intersection of CSA practices and digital innovations. The integration of precision agriculture, mobile advisory services, and artificial intelligence-driven climate forecasting in smallholder settings remains underexplored. Research should assess the accessibility, usability, and economic viability of these technologies in different agroecological zones.

5. Conclusions

This study aimed to identify the key factors that shape CSA adoption patterns, focusing on gendered household characteristics, farmland attributes, and economic and social capital. Additionally, the research evaluated how social capital, particularly group membership and access to credit, can enhance or hinder CSA adoption, with particular attention to gender, youth, and disability dynamics. The study achieved these objectives through quantitative and qualitative analyses, yielding insights into the barriers and opportunities for CSA adoption among smallholder farmers.

The findings reveal that household characteristics, including gender dynamics and land tenure, significantly influence CSA adoption. Male-headed households (MHHs) are more likely to adopt integrated soil fertility management practices but are less inclined to use drought-tolerant seeds. In contrast, female-headed households (FHHs) negatively associate with integrated soil fertility management, though no significant differences are observed in overall CSA adoption. These results highlight the resource constraints that FHHs face, which limit their ability to implement CSA practices.

Qualitative findings underscore the systemic barriers women and farmers with disabilities face, such as limited access to credit, land, and extension services, which hinder CSA implementation. However, social capital, particularly through community networks, emerges as a compensatory factor, facilitating knowledge-sharing and collaborative decision-making, thus enabling some farmers to overcome these barriers.

The study also found that marital status influences CSA adoption, with married households experiencing marginally negative effects on drought-tolerant seed adoption due to the need for spousal approval for decision-making. In contrast, widowed and single women exhibited greater decision-making autonomy, though they faced other constraints related to finance and labor.

The study highlights the critical role of land tenure and farm size in shaping CSA adoption. Larger landholdings facilitate the adoption of practices such as manure application and cover cropping, although financial and labor constraints persist regardless of farm size. Farmers with inherited or long-held land are less likely to adopt minimum tillage, suggesting a preference for traditional farming methods. Conversely, farmers who have purchased land are more likely to adopt CSA practices, underscoring the importance of investment incentives in promoting sustainable agricultural practices.

Social capital, especially membership in self-help groups (SHGs), is positively associated with CSA adoption, demonstrating the value of peer learning and collective action. Additionally, access to credit is a crucial determinant for capital-intensive CSA practices, such as agroforestry.

The study's findings suggest several policy implications. Improving tenure security and financial access can ensure more equitable participation in CSA adoption. Tenure reforms should be coupled with financial support mechanisms to enhance CSA adoption. Additionally, addressing the persistent gender gap in access to credit is critical to overcoming adoption barriers for women. Targeted, inclusive financial interventions, alongside tailored support for different household types, are essential for promoting the widespread adoption of climate-smart agricultural practices.

Future research should explore the intersectionality of gender, youth, and disability in more depth, with a focus on specific barriers faced by these groups in accessing CSA opportunities. Additionally, exploring the role of digital solutions and technology in enhancing CSA adoption among resource-constrained farmers is crucial in the evolving landscape of climate-smart agriculture.

Abbreviations

CSA	Climate-smart Agriculture
FGD	Focus Group Discussions
MHH	Male-headed Households
FHH	Female-headed Households
SGHs	Self-help Groups

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Rohin Otieno Onyango (PhD$_{\text{Candidate}}$) is a Monitoring, Evaluation, Research, and Learning (MERL) expert with over 12 years of experience leading donor-funded initiatives across Eastern and Southern Africa. He is currently the Regional Director of MERL at Inkomoko, where he oversees strategic MEL initiatives across five countries. Rohin has conducted over 25 evaluations, supporting organizations such as the World Bank, USAID, and the Bill & Melinda Gates Foundation. His expertise spans impact assessment, third-party monitoring, and capacity building, particularly in public health, entrepreneurship, and climate resilience. He holds a Master's in Development Studies (Distinction) from St. Paul's University, Kenya, and is completing a PhD in Development Studies from the same institution. Rohin has also obtained certifications in public health research ethics, mixed methods research, and project management. Fluent in English and Swahili, he has worked extensively across more than 10 countries, shaping data-driven, evidence-based development programs.

Dr. Daniel Muasya Nzengya (PhD) is the Director of the Directorate of Research & Innovations at St. Paul's University, Limuru, and the Academic Director of the Doctor of Philosophy in Development Studies program at the same institution. He holds a Ph.D. in International Development and Sustainability from Arizona State University, USA, an MSc in Environmental Studies, and a BSc in Wildlife Management from Moi University, Kenya. His research focuses on community development, climate change adaptation, water and sustainable development, and human impacts on ecosystems. Dr. Nzengya has served as a Senior Research Associate at Arizona State University and a Lecturer at Africa University, Zimbabwe. He has led numerous international research and consultancy projects and has published extensively on climate adaptation, livelihoods, and environmental sustainability. He is also the founding chair of St. Paul's University Institutional Review Board (IRB) and actively participates in global climate and development forums.

Dr. Lilian Kidula Lihasi (PhD) is an agricultural innovation and development practitioner with over 20 years of experience in research, extension, policy, and rural development. She holds a PhD in Agricultural and Rural Innovations (2017), an MSc in Agricultural Extension (2008), and a BSc in Agriculture and Home Economics (1992), all from Egerton University, Kenya. Dr. Lihasi specializes in participatory action research, gender equity, and inclusive food systems. She has served as a lecturer, reviewer for the *Journal of Global Entrepreneurship Research*, and consultant on agricultural innovation, finance access, and stakeholder engagement across Africa. She has worked with governments, universities, and development organizations to strengthen climate-smart agriculture, entrepreneurship, and sustainable livelihoods. Her research interests focus on inclusive development, technology transfer, and community-driven solutions for resilient agricultural systems.

Research Field

Rohin Onyango: Monitoring and evaluation, Program impact assessment, Climate resilience, Development studies, Public health research, Entrepreneurship, Gender and economic empowerment, Mixed methods research, Policy analysis and evaluation, Data-driven decision making.

Daniel Nzengya: Sustainable urbanization, Climate change adaptation, Community development, Water and sustainable development, Natural resource management, Environmental planning and management, Human impacts on ecosystems, Sustainable livelihoods, Wildlife conservation, Participatory research methods.

Lilian Lihasi: Agricultural extension and education, Rural development and livelihoods, Gender and social inclusion, Climate-smart agriculture and resilience, Agricultural innovation systems, Stakeholder engagement and participatory research, Food systems and sustainability, Entrepreneurship and agribusiness, Policy and governance in agriculture, Value chain development and market linkages.