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Research Article

Strengthening Climate-Smart Agriculture-Responsive Extension in Kenya: Evidence on Inclusion and Effectiveness for Smallholder Farmers

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Abstract

Despite Kenya's policy commitment to Climate-Smart Agriculture (CSA) and progressive reforms in agricultural extension, significant gaps remain in ensuring equitable access to and effective services, particularly in arid and semi-arid regions. This study examines the delivery and perception of CSA-responsive extension services among smallholder farmers in Tharaka Nithi County, focusing on three key dimensions: inclusion (gender and disability), feedback mechanisms, and provider type (public versus private). Utilizing a cross-sectional mixed-methods approach with 418 respondents, the study integrates quantitative analysis with qualitative insights to evaluate access to extension services and CSA adoption. The findings indicate that private sector-led extension services reached a more diverse group of farmers and were more strongly associated with CSA adoption than public sector-led services. Although gender and disability alone did not yield statistically significant differences in access, their combined effect approached significance, indicating the presence of intersectional barriers. Feedback mechanisms also influenced outcomes: field visits and community meetings effectively promoted CSA adoption, particularly for farmers with disabilities, whereas Short Message Service (SMS) messaging had limited impact. Education and farming experience emerged as significant factors facilitating adoption. Overall, the findings highlight the limitations of conventional, top-down extension systems and underscore the necessity for more participatory, inclusive, and locally adapted approaches. This study advocates for a transition toward a multi-actor, learning-centered CSA-responsive extension model to ensure that climate resilience strategies equitably reach and benefit all farmers, especially those situated at the last mile of service delivery.

Keywords

Climate-Smart Agriculture, Extension Services, Smallholder Farmers, Gender, Disability Inclusion, Agricultural Advisory

1. Introduction

1.1. Background

As climate change continues to escalate across sub-Saharan Africa, Climate-Smart Agriculture (CSA) emerges as a pivotal strategy for adaptation. The success of CSA, however, largely depends on the proficiency of agricultural extension systems in converting climate knowledge into practical actions for farmers [1, 2]. While some research studies pre-

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dominantly view extension as a channel for disseminating agronomic knowledge [3], other scholars emphasize its broader potential to enhance adaptive capacity and drive behavioral change among smallholder farmers [4]. Nonetheless, an ongoing discourse persists on whether extension should be conceptualized as a transactional platform for knowledge transfer or as a transformative arena for co-creation, co-learning, and empowerment.

Kenya's agricultural policy environment is marked by commitments at both the national and county levels to incorporate CSA through improved extension services. The Kenya Climate Smart Agriculture Strategy (KCSAS) and its Implementation Framework present a comprehensive national vision focused on enhancing resilience, reducing emissions, and achieving productivity gains [5, 6]. Supporting policies, such as the National Agricultural Sector Extension Policy (NASEP) and the Kenya Agricultural Sector Extension Policy (KASEP), advocate for advisory systems that are pluralistic, demand-driven, and informed by climate considerations [7]. Nevertheless, the actual experiences of smallholder farmers, especially in arid and semi-arid land (ASAL) regions such as Tharaka Nithi, frequently diverge from these policy objectives, raising important questions about the effectiveness and contextual suitability of policy implementation [8, 9].

Empirical research underscores the persistent structural inequities in accessing CSA-related extension and advisory services. Rural and remote communities encounter disproportionate challenges due to understaffed extension systems, infrastructure deficiencies, and linguistic or literacy barriers [10-12]. Furthermore, gendered norms and power asymmetries further restrict equitable participation in CSA-responsive extension services [13, 14], an advisory system explicitly aligned with the core objectives of CSA, productivity, resilience, and mitigation, while being inclusive, adaptive, and locally contextualized. Although digital innovations have been promoted to address limitations in extension services, they frequently perpetuate existing exclusions when fundamental constraints, such as digital literacy, access to services, network coverage, and device affordability, remain unaddressed [15, 16]. These patterns indicate that access to extension is not merely a logistical issue but is embedded within the intersecting structures of systemic injustice that extension models seldom examine.

Beyond the issue of access, a more critical examination is warranted regarding the epistemic relevance of the content and methodologies employed in CSA-responsive extension. An expanding body of literature suggests that conventional approaches, which prioritize high-yield varieties or climate-resilient inputs, often fail to resonate with the socioeconomic realities and decision-making frameworks of smallholder farmers [17, 18]. Primarily, these top-down, prescriptive extension models prevail, offering minimal scope for co-creation, experiential learning, or adaptation to local contexts [19, 20]. Consequently, even well-intentioned CSA interventions may encounter limited adoption or unintended consequences if they do not engage with the lived knowledge systems and adaptive practices of farmers [17, 18]. This disconnect highlights a methodological oversight in many CSA-responsive extension programs: the presumption that scientific validity inherently translates to practical relevance.

The feedback and accountability frameworks that define the interactions between farmers and extension services remain insufficiently explored. Traditional approaches, such as field days and demonstration plots, are sporadic and often misaligned with the timing and cropping cycles of farmers [21], [22]. While information and communication technology (ICT) tools provide opportunities for scalability and swift feedback, their design often favors one-way information dissemination over interactive dialogue and reflective learning [16, 23]. Recent studies highlight that the absence or weakness of feedback mechanisms impedes the ability of extension systems to respond promptly to the evolving needs of farmers, thereby diminishing trust and effectiveness [24, 25]. These challenges highlight a systemic shortcoming in developing learning ecosystems that are adaptive, inclusive, and capable of supporting behavioral change in uncertain conditions.

1.2. Transition of Agricultural Extension in Kenya

The phased transition of agricultural extension services in Kenya, as summarized in Table 1, reflects an interplay between political shifts, development paradigms, and technological advancements. From the settler-focused colonial advisory system to the state-led post-independence model, extension initially served as a tool of exclusion before becoming a means of centralized national development [26, 27]. The World Bank-supported Training and Visit (T&V) system, introduced under the Structural Adjustment Programs (SAPs) in the 1980s, brought technical rigor but struggled with rigidity, cost, and sustainability [30].

The subsequent transition to participatory and decentralized approaches in the 1990s emphasized farmer empowerment and policy experimentation [28, 29], culminating in the National Agricultural Extension Policy (2001). Since the 2000s, Kenya has adopted a pluralistic, market-oriented, and digital extension model that features a wide range of actors, including NGOs, private sector providers, and digital platforms, while also integrating gender and climate-smart practices [31, 32]. However, persistent challenges remain, ranging from coordination and quality assurance gaps to inequitable access to services in underserved regions. These transitions reveal not only an operational evolution but also a paradigmatic shift from top-down knowledge transfer to multi-actor, adaptive learning systems.

1.3. Kenya’s Extension Policies

The Kenya Climate Smart Agriculture Implementation Framework (KCSAIF) 2018-2027 outlines an ambitious agenda to modernize agricultural extension and advisory services as levers for enhancing climate resilience, productivity, and market orientation among smallholder farmers. Specifically, it emphasizes the mainstreaming of CSA knowledge, the expansion of agro-weather advisory systems, and the establishment of robust linkages between farmers, researchers, and extension services [6]. Anchored in decentralization and digital transformation, the policy promotes participatory approaches, private sector involvement, and the use of ICT to support localized planning and knowledge dissemination. Nonetheless, these policy aspirations are not new; they build on a legacy of earlier reform attempts under the National Agricultural Extension Policy (NAEP, 2001), National Agricultural Sector Extension Policy (NASEP, 2012), and Kenya Agricultural Sector Extension Policy (KASEP, 2023), which similarly sought to diversify, decentralize, and integrate efficient and sustainable agricultural extension services within Kenya's broader transformation agenda.

Table 1. A Timeline of Agricultural Extension Reforms in Kenya.

Period	Pre-1963	1963-1980s	1980s-1990s	1990s-2000s	2000s-Present
Extension Model	Settler-Focused Advisory System	State-Led Extension System	World Bank Supported Training and Visit (T&V) System	Participatory & Decentralized Models	Pluralistic, Market-Oriented & Digital Extension
Core Features	Targeted settler (European) farms; Research stations focused on export crops; African farmers excluded from formal services	Government-run, nationwide coverage; Emphasis on food security, cash crops; Uniform messaging by frontline officers	Regular, scheduled visits to farmers; Frequent training for extension officers; Conventional and hierarchical structure	Farmer Field Schools (FFS) and participatory methods; National Agricultural Extension Policy (2001) introduced; Gradual decentralization and inclusion of NGOs	Multi-actor delivery: Gov't, NGOs, private, ICT, farmer groups; Use of mobile platforms, radio, video extension; CSA, gender/youth inclusion; County level planning under 2010 Constitution
Drivers of Change	Independence movement; Demand for inclusive agricultural support	National development agenda; Green Revolution-inspired push for productivity	Donor-driven reform (World Bank); Pressure for systematic, efficient extension delivery	Criticism of T&V; Global shift toward farmer-centred approaches; Governance reforms and early digital experimentation	Devolution; Digital innovation; Market integration; Climate change imperatives
Challenges	Marginalization of smallholder African farmers; Limited adoption of modern farming techniques in rural Kenya	National development agenda; Green Revolution-inspired push for productivity	Donor-driven reform (World Bank); Pressure for systematic, efficient extension delivery	Weak coordination; Limited reach to remote areas; Policy fragmentation and donor dependency	Coordination and quality assurance gaps; Inequitable access to tech-based services

However, studies suggest a significant implementation gap between this progressive policy vision and on-the-ground realities. While digital platforms, early warning systems, and participatory methods are widely referenced in official documents, studies show that their application remains uneven, fragmented, and often inaccessible to rural and marginalized populations [33, 34]. Public extension systems continue to grapple with chronic underfunding, weak coordination across county and national levels, and limited accountability structures [34, 35]. Meanwhile, private providers, although often better resourced and more responsive, tend to cluster in high-potential zones and reinforce exclusionary dynamics through market-based logics [36, 37]. Notably, gender-disaggregated analysis is conspicuously lacking in both policy and practice, despite empirical evidence highlighting the systematic exclusion of women from extension benefits due to sociocultural barriers, time poverty, and limited decision-making agency [10, 38]. The policy's assumptions about uniform access to ICT and extension platforms also overlook deep infrastructural inequities and digital literacy gaps—particularly in arid and semi-arid lands where CSA is most urgently needed.

This disconnect raises critical questions about the conceptual and institutional architecture of Kenya’s CSA-responsive extension model. While KCSAIF correctly identifies key pillars—multi-actor coordination, ICT-based knowledge dissemination, and decentralized planning—its implementation remains conventional and insufficiently attentive to local realities, power dynamics, and intersectional exclusions. Participatory platforms are often underutilized or tokenistic, and research-extension linkages remain weak, especially in translating agro-climatic data into usable, actionable advice for smallholder contexts [39, 40]. Moreover, despite the policy’s call for harmonization, extension services remain fragmented across counties and among various actors, with minimal knowledge sharing and accountability.

1.4. Theoretical Framework

Kenya's transition toward post-2025—driven by evolving extension systems—raises a key question: How can future extension models embed responsiveness, enable local agency, and sustain equitable innovation ecosystems? This gains urgency amid technological change, climate volatility, and pressure for inclusive, data-driven agricultural services. As agriculture becomes more digitally mediated, extension must shift from traditional delivery toward adaptive, networked innovation models. Innovation Systems Theory (IST) helps explore these questions by viewing innovation as a dynamic, networked process. Moreover, IST emphasizes institutional architectures and co-evolution among public, private, and civic actors [41, 42]. Applied to Kenya's CSA-responsive extension, IST enables understanding of how innovations exist within socio-technical regimes where institutions, markets, ecological risks, and digital infrastructure converge. Thus, IST provides tools to reimagine extension as an adaptive innovation ecosystem focused on climate resilience and social equity.

While IST offers an integrative framework, it has conceptual limitations. Critics highlight its ambiguity in defining system boundaries, informal knowledge systems, and power asymmetries. IST has been critiqued for emphasizing economic and technological aspects over social justice and sustainability [43], particularly relevant in Kenya, where CSA innovation must be technically sound and socially inclusive. Methodologically, IST struggles with operationalizing feedback loops and capturing actor agency [44], especially among marginalized groups. To enhance explanatory power, this study combines IST with Structuration Theory and Transition Theory. Structuration Theory examines how agency shapes institutional structures, addressing IST's under-theorization of power dynamics [45]. Transition Theory analyzes systemic shifts in agricultural extension models from state-led approaches to decentralized ecosystems [46]. IST's strength in mapping institutional architectures and analyzing actor relationships provides a foundation for understanding CSA-responsive extension models as evolving systems of innovation and resilience.

Applying IST to rethinking CSA-responsive extension in Kenya enables assessment of how innovation emerges and evolves within a multi-actor ecosystem. Kenya's CSA-responsive extension landscape—with diverse actors from state agents to digital firms—demonstrates the systemic interplay IST examines. IST positions smallholder farmers as innovation co-creators within institutional and ecological contexts that shape adaptive capacities. The Kenyan case demonstrates how enabling environments for CSA—including devolved governance and digital infrastructure—function as interconnected subsystems [3, 4]. IST helps identify systemic blockages (policy incoherence, digital divides) and leverage points (innovation hubs, feedback loops) that can strengthen CSA outcomes.

1.5. Statement of the Problem

Kenya has progressively reformed its agricultural extension system since the early 2000s, embracing a pluralistic, market-oriented, and digitally enabled approach with a policy emphasis on CSA. However, a persistent gap remains between policy intent and on-farm implementation among smallholder farmers [7]. The Kenya Climate Smart Agriculture Strategy (KCSAS) and related frameworks envision a resilient, low-emission, and inclusive agricultural sector [3, 4], reinforced by policies such as NASEP and KASEP, which advocate for decentralized, demand-driven, and climate-responsive advisory services.

However, evidence reveals that smallholder farmers—especially women, youth, and those in resource-constrained or ecologically fragile areas—face heightened barriers in accessing CSA-relevant information, inputs, and support systems [21]. Furthermore, extension services remain unevenly distributed, often favoring better-resourced counties. Additionally, extension uptake in covered regions is hindered by poor delivery mechanisms [3, 47] and limited engagement [48]. This disconnect signals the need to critically rethink how CSA-responsive extension is designed, delivered, and institutionalized to ensure it is equitable, adaptive, and effective in addressing Kenya’s climate and development imperatives.

This study engages an inflection point in Kenya’s agricultural transition, where escalating climate risks demand not only technical adaptation but also institutional responsiveness and systemic reform. Centered in Tharaka Nithi County, it applies Innovation Systems Theory (IST) to interrogate the design, delivery, and adoption of CSA-responsive extension services, focusing on their accessibility, relevance, and feedback mechanisms. Using a mixed-methods, cross-sectional approach, the study generates critical insights to inform the future of Kenya’s pluralistic extension system and contribute to assessing agricultural extension pathways for climate resilience, drawing on evidence from Kenya’s smallholder farmers.

1.6. Purpose of the Study

The overall purpose of the study is to assess how CSA-responsive extension services are delivered and experienced by smallholder farmers in Kenya, particularly in Tharaka Nithi County.

1.7. Objectives of the Study

The objectives of the study were to:

Examine equity in access to CSA-responsive extension services by comparing gender and disability-based disparities across public and private sector delivery models.

Assess the effectiveness of public versus private sector-led extension services in facilitating CSA adoption among smallholder farmers.

Investigate smallholder farmers' perceptions of CSA-responsive extension feedback mechanisms.

1.8. Significance of the Study

This study contributes to the understanding and improvement of CSA-responsive extension systems within Kenya's evolving agricultural landscape. As climate variability increasingly threatens smallholder livelihoods, this study offers evidence on how CSA-responsive extension services are accessed, understood, and applied by marginalized groups—particularly women, youth, and farmers with disabilities—who are often excluded from mainstream support. By examining Kenya's pluralistic extension architecture through the lens of Innovation Systems Theory, the study offers insights into the institutional, social, and communication barriers that influence the success or failure of CSA interventions on the ground

2. Materials & Methods

2.1. Study Location

This study was conducted in Mukothima Ward, situated in Tharaka Nithi County on the eastern slopes of Mount Kenya (see Figure 1). Spanning approximately 2,564.4 km² and located between latitudes 0°07'-0°26' South and longitudes 37°19'-37°46' East, the county lies about 200 kilometers north of Nairobi. It shares borders with Embu, Meru, Kirinyaga, Nyeri, and Kitui counties. Tharaka Nithi is ecologically bifurcated into highland and semi-arid zones, forming a transitional landscape that is particularly susceptible to climate variability and extreme weather events. These conditions render it an ideal site for assessing the impacts of climate change on smallholder agriculture [49].

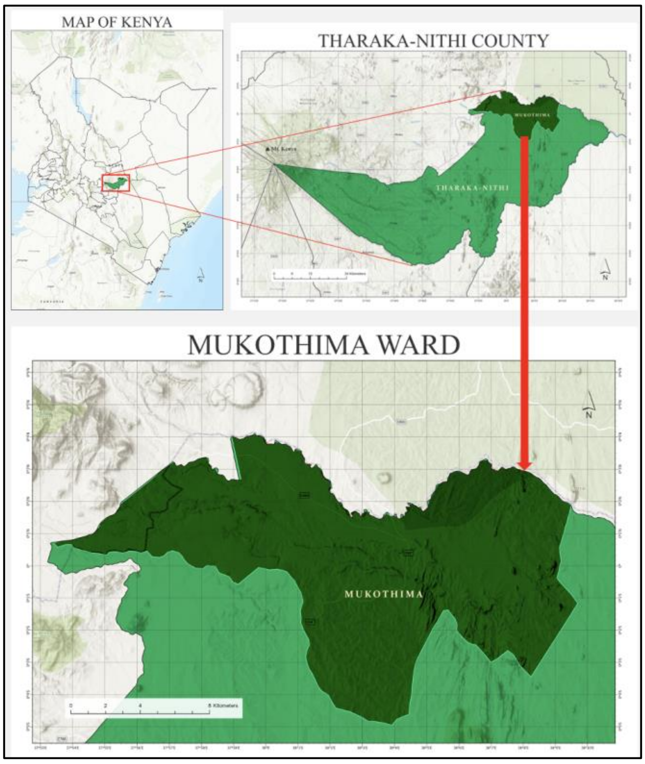

Figure 1. *Study Location.*

The region experiences a bimodal rainfall regime, characterized by the long rains (April-June) and relatively dependable short rains (October-December) [50]. Precipitation patterns are spatially heterogeneous, ranging from roughly 500 mm annually in the semi-arid lowlands to over 2,200 mm in the humid highlands. Temperature variation is equally pronounced, with highland areas registering 14℃-30℃ and lowland zones frequently exceeding 36℃ during dry spells, occasionally surpassing 40℃. These climatic gradients directly influence land-use dynamics, water resource availability, and the seasonality of agricultural production [51].

Agriculture remains the economic backbone of Tharaka Nithi county, employing nearly 80% of the population [52]. Production systems are highly diversified by altitude: the highlands support cash crop cultivation—particularly coffee and tea—alongside staple crops such as maize and beans, while the lowland and midland areas engage primarily in agro-pastoralism, with an emphasis on livestock and drought-tolerant cereals [53]. The county's agroecological complexity spans from Upper Midland zones (UM2-UM4) to Intermediate Lowland zones (IL5-IL6), creating micro-variations in production potential

Hydrologically, the area is interlaced with seasonal rivers and streams that feed into the Tana River, supporting smallholder irrigation efforts. Mukothima Ward was purposively selected for this study due to its agroecological heterogeneity, high climate sensitivity, and the centrality of agriculture to household livelihoods. The ward encapsulates broader challenges characteristic of Kenya's arid and semi-arid lands (ASALs), including erratic rainfall, prolonged droughts, and escalating soil degradation.

2.2. Research Design and Methods

This study adopted a partially mixed concurrent equal status design [54], in which quantitative and qualitative components were given equal methodological priority. Integration of the two strands occurred at the interpretation phase, consistent with Leech and Onwuegbuzie's (2009) guidance on mixed methods design. To ensure representativeness, stratified random sampling was applied. Stratification was informed by administrative subunits and agroecological diversity within the ward, allowing for disaggregated insights into household dynamics and agricultural practices across ecological zones.

Quantitative data were gathered using KoBo Collect, a mobile-based platform that enhanced data accuracy and real-time validation. A total of 418 household surveys were completed, exceeding the target sample of 384, resulting in a response rate of 109%. The target was derived using Cochran's (1963) formula for sample size determination, ensuring statistical robustness for population-level inference.

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

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 gathered through six focus group discussions (FGDs), each representing a distinct farmer demographic: adult women, adult men, widows, male youth, female youth, and persons with disabilities (n = 6 per group). The FGDs were facilitated by trained moderators, with research assistants responsible for detailed note-taking. Prior to participation, all individuals provided informed consent, having been fully briefed on the study's purpose and procedures. To ensure data reliability and support rigorous thematic analysis, sessions were audio-recorded with participants' permission.

Ethical clearance was obtained 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 qualitative strand formed an integral component of a broader mixed-methods PhD study, enabling the triangulation of quantitative findings with rich, context-specific narratives. The combined approach strengthened the study's validity and offered insights into the adaptive strategies and lived realities of smallholder farmers.

2.3. Statistical Methods

We applied descriptive and inferential statistics to examine access to CSA-responsive extension services and their effect on adoption outcomes. Descriptive statistics mapped access patterns across public sector-led and private sector-led modalities, while factorial ANOVAs tested for differences by gender and disability. Levene's test confirmed homogeneity of variances, and partial eta squared (η^2) quantified effect sizes. This approach allowed us to assess both main and interaction effects, with attention to equity in service delivery.

To examine the determinants of Climate-Smart Agriculture (CSA) adoption, we estimated a series of hierarchical linear regression models, with the Cumulative CSA Adoption Score as the dependent variable. Model 1 (Equation 2) establishes a baseline using farmer-level socioeconomic characteristics, including income, education, and farming experience. Model 2 (Equation 3) introduces access to public and private sector-led services to assess their additional explanatory power. Model 3 (Equation 4) further incorporates an interaction term between public sector-led and private sector-led extension access to test whether their combined effect on CSA adoption is synergistic or attenuating.

$$CSA_i = \beta_0+\beta_1 Income_i+\beta 2 Education_i + \beta_3 FarmingExperiencei + \varepsilon \quad (2)$$

$$CSA_i = \beta_0+\beta_1 Incomei+\beta_2 Education_i+\beta_3 FarmingExperience_i+\beta 4 Publicxt_i+\beta 5 PrivateExt_i+\varepsilon_i \quad (3)$$

$$CSA_i = \beta_0+\beta_1 Incomei+\beta_2 Educationi+\beta_3 FarmingExperience_i+\beta_4 PublicExt_i+\beta_5 PrivateExt_i+\beta_6(PublicExt_i \times PrivateExt_i)+\varepsilon_i \quad (4)$$

Where

β_i as the *regression coefficient* for the *i-th predictor variable*, which quantifies the strength and direction of the relationship between that predictor and the dependent variable.

ε as the *error term* (or residual), representing the difference between the observed value and the value predicted by the model.

We also modeled the influence of feedback mechanisms using multiple regression and bivariate correlations. Diagnostic checks confirmed model validity (e.g., VIF < 2, Durbin-Watson ≈ 1). Disaggregated analyses explored how gender and disability shaped channel effectiveness, providing insight into inclusive extension design.

3. Results

3.1. Equity in Access

Descriptive findings reveal significant disparities in farmers' access to institutional CSA-responsive extension services. Among the 418 respondents, only 36% (n = 152) reported regular access to public sector-led CSA-responsive extension, while 64% (n = 266) reported no such access. This gap highlights limitations of public agricultural advisory systems in promoting climate-resilient practices.

3.1.1. Public Sector-Led CSA-Responsive Extension

The study revealed modest group-level differences. Female respondents reported slightly higher access to public sector-led extension services (M = 2.60) than males (M = 2.57), while access was higher among respondents with disabilities (M = 2.78) compared to those without (M = 2.61). The subgroup of male farmers with disabilities reported the highest average access (M = 3.75); however, this finding is based on a very small sample (n = 4), and should therefore be interpreted with caution due to the potential instability of the estimate.

Statistical tests, however, found no significant main effects of either gender ($F(1, 414) = 3.05$, $p = .081$, $\eta^2 = .007$) or disability ($F(1, 414) = 3.20$, $p = .074$, $\eta^2 = .008$) on access. The interaction between gender and disability approached significance ($F(1, 414) = 3.70$, $p = .055$, $\eta^2 = .009$). Assumptions for the analysis were met; Levene's test confirmed homogeneity of variances ($F = 0.31$, $p = .821$). Taken together, the quantitative results are statistically inconclusive. Yet, the observed patterns hint at possible intersectional dynamics shaping access—particularly among male farmers with disabilities—which warrant qualitative examination rather than firm inferential claims.

Qualitative findings from focus group discussions with farmers living with disabilities suggest intersectional experiences that influence access to and engagement with extension services. Male farmers with disabilities—despite representing a small subgroup—often positioned themselves as coordinators or supervisors on the farm, relying on spouses or hired labor while actively seeking agricultural knowledge, sometimes benefiting from visibility and leadership roles in community-based farmer groups.

In contrast, female farmers with disabilities faced additional mobility and caregiving burdens, yet they maintained critical roles in CSA implementation, often taking on tasks such as planting, weeding, and harvesting. Across the board, public sector-led extension officers were seen as less responsive or proactive than their private sector counterparts, with access often hinging on group membership and prior relationships. For instance, an FGD participant noted,

"Whenever we need help from government officials, we cannot easily access them, and even if we do, it's very rare"-Female Farmer with Disability.

These insights highlight that although statistical effects were limited and subgroup sizes small, the lived experiences of farmers, particularly at the intersection of gender and disability, offer meaningful context that enriches our understanding of extension equity in CSA delivery.

3.1.2. Private Sector-Led CSA-Responsive Extension

Access to private sector-led extension services was consistently high across all demographic groups, with mean scores exceeding 4 on a 5-point scale. Female farmers with disabilities reported an average score of 4.16, while their male counterparts reported the highest access at 4.50. *Factorial ANOVA results showed no statistically significant differences in access based on gender ($F(1, 414) = 0.29$, $p = .592$, $\eta^2 = .001$), disability status ($F(1, 414) = 1.25$, $p = .264$, $\eta^2 = .003$), or their interaction ($F(1, 414) = 0.52$, $p = .470$, $\eta^2 = .001$).* Assumptions of equal variances were met (Levene's $F = 0.56$, $p = .642$), supporting the validity of these comparisons.

Given these non-significant results and small group sizes (e.g., for farmers with disabilities), any observed differences in means were interpreted descriptively rather than as evidence of systematic disparities. However, from the qualitative perspectives, some disparities among vulnerable groups were highlighted. One farmer with Disability noted, *"For the NGO, once you make the phone call, they tell you where to find them. On a given day, they will visit your group, which makes it easier to do demos with them."* Female Farmer with Disability

These findings indicate that private sector-led CSA-responsive extension services are perceived as broadly accessible, with no evident disparities across gender or disability lines. This may reflect the inclusive design or adaptive delivery strategies often characteristic of private sector-led programming.

3.2. Effectiveness of CSA-Responsive Extension

This study sought to compare the effects of public sector-led versus private sector-led extension on CSA adoption in Tharaka Nithi County. To do so, we estimated a two-stage linear regression model, using the Cumulative Adoption Score as the dependent variable, which captures the extent to which farmers have implemented a range of CSA strategies.

In the first model, we included only socio-economic controls: education level, years of farming experience, and household income. This model in Table 2 explained a modest proportion of the variance in CSA adoption ($R^2 = 0.018$; $F(3, 414) = 2.57$, $p = 0.054$). Both education ($B = 62.70$, $p = 0.017$) and farming experience ($B = 51.94$, $p = 0.043$) were positively and significantly associated with adoption, while income was not statistically significant ($p = 0.732$). These results reveal that human capital, rather than financial capital, plays a more critical role in shaping farmer adoption behavior in this context.

Table 2. Hierarchical Regression Predicting Cumulative CSA Adoption Score.

Model	R	R^2	Adj. R^2	SE Estimate	F (df1, df2)	p-value
1	.135	.018	.011	376.30	2.57 (3, 414)	.054
2	.287	.083	.071	364.65	14.45 (2, 412)	<.001
3	.288	.083	.069	365.06	9.63 (3, 411)	<.001

Predictors in Model 1: Income, Education, Farming Experience
Model 2 adds: Access to Public and Private Extension
Model 3 adds: Public × Private Extension Interaction
Dependent Variable: Cumulative CSA Adoption Score

In the second model (see Table 2), we introduced predictors reflecting access to extension services—specifically, regular access to public sector-led and private sector-led extension. In the third model, we added an interaction term between the two. The inclusion of these variables significantly improved model fit ($\Delta R^2 = 0.064$, $p < 0.001$), increasing the total explained variance to $R^2 = 0.083$. Regular access to private sector-led extension was positively associated with CSA adoption (B = 70.83); although this effect approached significance (p = 0.066), it did not meet conventional thresholds. Public sector-led extension access, however, was not a significant predictor (B = 73.76, p = 0.232), nor was the interaction term (p = 0.787), indicating that simultaneous access to both extension modalities does not generate either synergistic or antagonistic effects.

3.3. Feedback Mechanisms

The adoption of CSA practices among smallholder farmers in Tharaka Nithi County revealed some variability (M = 721.29, SD = 378.42, N = 418), highlighting a broad spectrum of engagement levels. A closer examination of feedback mechanisms illustrated in Figure 2 showed that community meetings were the most widely accessed channel, with 84% of respondents reporting participation. This was followed by field visits (57%), radio broadcasts (33%), and SMS platforms (22%). These patterns suggest a continued reliance on interpersonal, community-based engagement over digital or mass media channels, particularly in rural settings.

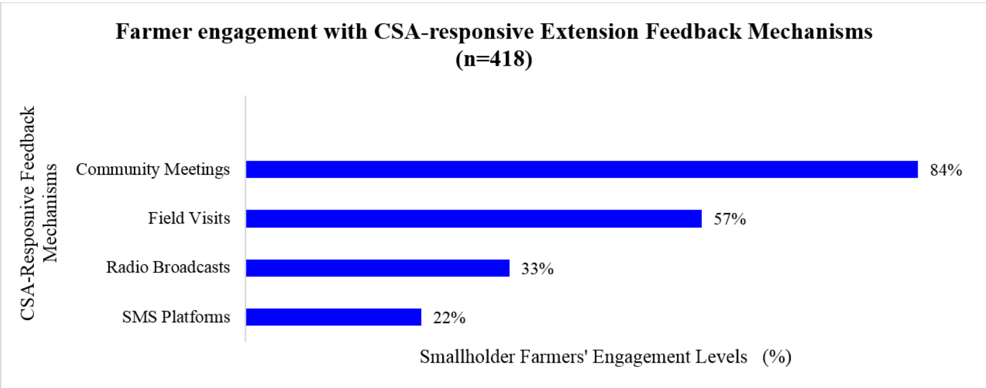

Figure 2. Farmer Engagement with CSA-responsive Extension Feedback Mechanisms.

3.3.1. Feedback Mechanisms and CSA Adoption

Bivariate correlation analysis revealed that field visits had the strongest positive relationship with CSA adoption (r =.370, p <.001), followed by community meetings (r =.247, p <.001). Although radio was weakly but positively associated with adoption (r = 0.086, p = 0.039), SMS showed no meaningful relationship (r = -0.036, p = 0.234), suggesting that its reach or relevance may be limited in this context.

To further explore the relative influence of feedback mechanisms on CSA adoption, a multiple linear regression model was estimated. The model (see Table 3) was statistically significant, F(4, 413) = 20.51, p <.001, and accounted for approximately 16.6% of the variance in CSA adoption (R^2=.166, Adjusted R^2=.158). The Durbin-Watson statistic of 1.086 indicated no concern for autocorrelation among residuals, supporting the validity of the model.

Collinearity among predictors was assessed and found to be within acceptable bounds. Tolerance values ranged from 0.724 to 0.946, and Variance Inflation Factors (VIF) ranged from 1.057 to 1.381, well below critical thresholds. Condition indices also suggested no structural multicollinearity, reinforcing the stability of the model estimates.

Table 3. *Model Summary on the Effect of CSA-responsive Extension Feedback Mechanisms on Adoption.*

Model	R	R^2	Adj. R^2	Std. Error	F (df)	p-value
1	.407	.166	.158	347.31	20.51 (4, 413)	<.001

Predictors: Field Visits, SMS, Community Meetings, Radio
Dependent Variable: Cumulative CSA Adoption Score

3.3.2. Gender and Disability Effects

When disaggregated by gender and disability, participation patterns suggest that in-person methods (such as community meetings and field visits) reached a broader segment of male and non-disabled farmers. Meanwhile, interaction terms (e.g., Radio × Gender, Field Visits × Disability) indicate differentiated exposure along demographic lines, highlighting that inclusivity may vary across different feedback mechanisms.

Pearson correlation analyses provided further insight into the relative effectiveness of each channel. Field visits exhibited the strongest positive association with CSA adoption ($r = 0.370$, $p < 0.001$), followed by community meetings ($r = 0.247$, $p < 0.001$). The correlation for radio was weak ($r = 0.086$, $p = 0.039$), and although statistically significant, the effect size is minimal. SMS messaging showed no meaningful association with CSA adoption ($r = -0.036$).

Among interaction variables, field visits ($r = 0.376$, $p < 0.001$) and community meetings ($r = 0.268$, $p < 0.001$) for farmers with disabilities showed moderate correlations with CSA adoption. However, these results were interpreted cautiously due to the small sample size of this subgroup.

Qualitative evidence from the FGD with farmers living with disabilities reinforces the quantitative conclusion that face-to-face communication—particularly field visits and group-based community meetings—is the most effective and inclusive channel for CSA adoption, especially among persons with disabilities. Participants consistently emphasized the importance of in-person demonstrations and localized training, citing these approaches as more accessible, practical, and tailored to their needs compared to more impersonal methods such as radio or written communication.

The presence of private sector-led advisors—often more responsive and better embedded within farmer groups—was credited with bridging communication gaps that public sector-led extension systems frequently failed to address. For instance, a male FGD participant cited that,

"The extension officers are not many, and those around only stay in their offices, unlike in the past… NGOs come and educate us on farming, finding a market for our produce, how to live and eat healthy. NGOs help a lot. They call us to such forums and educate us on how to reap from farming." —Male Farmer.

Another female farmer added that;

"They [referring to private sector-led extension officers] *come with their seeds and manure, then show us how to plant, and we get a good harvest. We take what we have been taught and go do it on our farms."* —Female Farmer with Disability.

These insights reveal that while the effectiveness of feedback mechanisms varies across demographics, direct and interactive methods are particularly critical for marginalized farmers, whose limited mobility and access often exclude them from mainstream agricultural information flows.

To explore the combined influence of feedback mechanisms and demographic modifiers, a multivariate linear regression model was estimated (Model $R^2 = 0.187$, Adj. $R^2 = 0.163$; $F(12, 405) = 7.75$, $p < 0.001$). The model, summarized in Table 4, explained approximately 19% of the variance in CSA adoption, indicating a meaningful but partial account of adoption behavior.

Table 4. *Simplified Regression Results Predicting Cumulative CSA Adoption Score.*

Model	R	R^2	Adj. R^2	SE Estimate	F (df1, df2)	p-value
1	.432	.187	.163	346.27	7.75 (12, 405)	<.001

Predictors: Field Visits, SMS, Community Meetings, Radio, and their interactions with Gender and Disability
Dependent Variable: Cumulative CSA Adoption Score

Among the predictors, field visits (B = 388.26, p =.081) had a marginally significant positive effect, while community meetings specifically for farmers with disabilities emerged as a significant driver of adoption (B = 256.20, p =.047). In contrast, interaction terms involving gender and digital channels (e.g., *Radio* × *Gender*, *SMS* × *Disability*) did not yield significant results, perhaps reflecting lower baseline access or engagement with these platforms.

Among the predictors, field visits (B = 388.26, p =.081) showed a positive association with CSA adoption, though this effect did not reach conventional levels of statistical significance. In contrast, community meetings specifically for farmers with disabilities emerged as a significant driver of adoption (B = 256.20, p =.047). However, given the likely small sample size of farmers with disabilities, this result, while statistically significant, warranted cautious interpretation and replication in future studies with larger subgroup representation. Interaction terms involving gender and digital channels (e.g., Radio × Gender, SMS × Disability) did not yield significant results.

4. Discussion

4.1. Equity in Access

The The study reveals persistent inequities in access to CSA-responsive extension services, with public sector-led initiatives lagging behind. Despite robust policy frameworks such as the Kenya Climate Smart Agriculture Implementation Framework (KCSAIF) and the National Agricultural Sector Extension Policy (NASEP), only 36% of respondents reported consistent access to public sector-led services. This reflects an enduring implementation gap, especially in arid and semi-arid lands (ASALs) such as Tharaka Nithi [6, 7, 34]. Institutional underfunding, weak coordination, and top-down delivery models continue to undermine the public system's capacity to meet the needs of diverse farming populations [13, 15].

In contrast, private sector-led extension emerged as significantly more inclusive. Mean access scores above 4 across gender and disability subgroups, coupled with non-significant demographic gaps, suggest a more equitable reach. These findings echo prior research showing that non-state actors are often more agile in designing participatory and context-specific interventions [37, 38]. However, high average access values may mask underlying disparities—a potential ceiling effect that warrants further exploration.

The marginally significant interaction between gender and disability in public sector-led access (p = 0.055) underscores the need for intersectional analysis. Elevated access among male farmers with disabilities could reflect localized outreach, unintentional targeting, or social capital advantages. These findings point to the nuanced ways in which overlapping identities mediate access to services—complexities often obscured by conventional demographic categories [12, 17]. The evidence reveals that CSA-responsive extension remains an unevenly distributed resource, rather than a universal public good. Realizing its equity potential demands a structural shift toward models that institutionalize feedback, center farmers' lived realities, and integrate intersectionality as a core design principle [22, 23, 44].

4.2. Effectiveness of CSA-Responsive Extension

The results contribute to longstanding debates about the comparative effectiveness of extension modalities in driving CSA adoption. The positive association between private sector-led extension and CSA adoption—though only marginally significant—stands in contrast to the public sector's lack of observable impact. These findings align with critiques of under-resourced, fragmented public extension systems across sub-Saharan Africa, which often fail to meet local needs or facilitate adaptive responses [6, 34, 35]. The better performance of private sector-led services may reflect participatory and co-learning-based approaches, which literature has identified as more effective in marginal and heterogeneous environments [12, 16, 36]. Yet, the absence of significant interaction effects between public and private access underscores a broader systemic weakness: pluralism alone does not guarantee synergy. Without coherent coordination, aligned content, and synchronized timing, fragmentation prevails [29, 37, 39].

Moreover, the finding that education and farming experience, but not income, were significant predictors of adoption reinforces the central role of human capital and experiential knowledge in climate adaptation [4, 13]. These insights support Innovation Systems Theory (IST), which conceptualizes extension as a dynamic, multi-actor learning ecosystem rather than a top-down transfer mechanism [41, 42]. Reconfiguring Kenya's extension system will therefore require more than integrating private actors. It calls for a fundamental shift toward interactive, inclusive, and responsive knowledge systems that engage farmers not as passive recipients but as co-producers of innovation.

4.3. Feedback Mechanisms

Field visits and community meetings emerged as the most effective CSA feedback mechanisms—particularly for farmers with disabilities—highlighting the enduring relevance of interpersonal, trust-based engagement in rural extension. These findings align with extensive literature on the efficacy of face-to-face learning in building trust, enhancing knowledge retention, and catalyzing behavior change [4, 16]. In contrast, digital platforms such as SMS and radio, despite their policy prominence, showed weak or non-significant associations with adoption. This highlights concerns about digital exclusion, particularly where literacy, affordability, and technological relevance continue to be barriers [11, 12, 36]. Over-reliance on ICT-based delivery may risk reinforcing existing inequalities unless deliberately adapted for inclusive use.

The differential effectiveness of feedback mechanisms across gender and disability subgroups further points to systemic design limitations. While interpersonal feedback mechanisms were broadly inclusive, digital modalities failed to generate meaningful engagement among marginalized groups. These patterns highlight how communication infrastructure itself can embed exclusionary dynamics, despite rhetorical commitments to gender-sensitive and pluralistic extension [6, 7, 25]. Framed through IST, these findings support a reconceptualization of CSA-responsive extension as a socially embedded process. Effective communication requires more than dissemination—it demands co-learning, reflexivity, and embedded feedback loops that can adapt to shifting socio-ecological conditions and power asymmetries [41, 42, 46].

5. Conclusions and Recommendations

This study notes that while Kenya has made policy progress toward pluralistic, CSA-responsive extension remains uneven and structurally limited—particularly within public sector-led models in marginalized areas. In contrast, private sector-led approaches show more inclusivity for women and persons with disabilities, though fragmentation persists. These findings suggest that pluralism alone is insufficient; practical CSA-responsive extension demands coordinated, participatory, and adaptive systems that prioritize equity and farmer agency. To meet post-2025 goals and align with the Malabo Agenda, Kenya must reconfigure its extension architecture into hybrid CSA-responsive systems—grounded in co-production, digital equity, and social accountability. Investing in inclusive feedback loops and community-based feedback mechanisms will be crucial to building a responsive and resilient extension ecosystem that can effectively confront climate challenges and enhance smallholder livelihoods.

6. Recommendations for Future Studies

Future research should investigate how the structure and responsiveness of CSA-responsive extension feedback loops influence farmers' decision-making in the face of climate uncertainty. It is essential to examine the comparative effectiveness of bundled, multi-channel approaches—including digital, Artificial Intelligence (AI), face-to-face, and private sector-led modalities—in sustaining the long-term adoption of CSA. Additionally, studies should investigate how institutional incentives, information quality, and the governance of extension systems impact the design and uptake of CSA advisories. Longitudinal and mixed-methods research that connects feedback quality with agronomic outcomes and climate resilience metrics will be crucial for guiding adaptive extension reform across diverse agroecological settings.

Abbreviations

CSA	Climate-Smart Agriculture
NGO	Non-Governmental Organization
ANOVA	Analysis of Variance
ICT	Information and Communication Technology
KCSAIF	Kenya Climate Smart Agriculture Implementation Framework
KCSAS	Kenya Climate Smart Agriculture Strategy
NASEP	National Agricultural Sector Extension Policy
KASEP	Kenya Agricultural Sector Extension Policy
VIF	Variance Inflation Factor
IST	Innovation Systems Theory

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

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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.