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Effects of extension service on the uptake of climate-smart sorghum production practices: Insights from drylands of Ethiopia

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A B S T R A C T

The promotion of climate-resilient practices (CRPs) requires the development of the capacity of farmers to adopt these practices owing to the knowledge-intensive nature of technologies. Extension services serve as a conduit for facilitating the conceptualization of CRPs and are instrumental in improving the resiliency and mitigation of climate change. We used a social-ecological framework and a multivariate probit model to analyze the drivers of the CRP uptake in moisture-stressed areas in Ethiopia, with a particular focus on extension services. Unlike previous studies that investigated a single technology, we considered a bundle of technologies. We focused on the use of two capital-intensive CRPs (drought-resistant seed and inorganic fertilizer) and four knowledge-intensive CRPs (minimum tillage, farmyard manure, water-saving technology, and crop residue retention). The role of extension services in promoting other CRPs beyond input and capital-intensive technologies was insignificant. Heterogeneity analysis revealed that the correlation between extension services and the adoption of other knowledge-intensive natural resource management practices holds irrespective of the proximity to the extension service providers. This finding highlights the need for targeted and tailored interventions that support farmers to address the challenges faced by them in moisture-stressed areas. Accordingly, we propose continuously improving the ability of the extension service providers to promote climate-change adaptation knowledge and practices. This should be accompanied by efforts to strengthen a pluralistic extension system, improve land tenure security, and decrease transaction costs for farmers through output market linkages.

1. Introduction

Climate-induced adversities pose significant challenges to numerous rural farmers in sub-Saharan Africa (SSA) as most agricultural practices are rainfed (Ojo and Baiyegunhi, 2019). In the coming decades, a crucial challenge for agriculture in SSA will be meeting food demands without further undermining the environment. Approximately 65% of the agricultural land in SSA is degraded (Zingore et al., 2015), contributing to low yield. A major driver behind land degradation that causes low yield is intensive soil preparation using a hoe or plow combined with the removal or burning of crop residues, which exposes the soil to climatic hazards such as the rain, wind, and sun. This process is particularly severe in the hot savannah zone (Rockström et al., 2009).

Embracing climate-smart agricultural practices plays a pivotal role in mitigating the effects of climate change (Zerssa et al., 2021). These practices include techniques such as agroforestry, integrated soil fertility management, and water harvesting, which are vital for enhancing the resilience of smallholder farming systems and reducing greenhouse gas emissions. There is a large body of empirical literature linking the adoption of climate-resilient practices (CRPs) with productivity and welfare outcomes in Eastern and Southern Africa; however, the focus of most of the existing literature has been in high-potential agricultural areas (e.g., Ngoma et al., 2016; Kotu et al., 2017; Naab et al., 2017; Adeagbo et al., 2021; Kudama, 2021; Diro et al., 2022; Kehinde et al., 2022; Negera et al., 2022; Waaswa et al., 2022; Tufa et al., 2023; Vatsa et al., 2023; Ziro et al., 2023; Njogu et al., 2024; Mpala and Simatele, 2024). Results from these studies indicate that despite the numerous benefits and opportunities associated with climate-smart agricultural

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practices, their uptake by smallholder farmers in Africa has remained low. The low adoption rates can be attributed to a range of factors, including access to extension services, farmer experience, access to credit, size of land, group membership, labor availability, sex, education, and land tenure, among others (Deressa et al., 2009; Bryan et al., 2013; Ngwira et al., 2013; Meijer et al., 2015; Moges and Taye, 2017; Makate et al., 2019; Antwi-Agyei et al., 2021; Nyang'au et al., 2021). Understanding the main determinants of CRP adoption in the context of moisture-stressed areas is therefore important to formulate policies for areas where the CRP adoption rates are relatively low compared with those in the rainfed and potential growing areas, and the factors influencing this adoption are unique.

Previous studies analyzed the drivers and barriers of CRP adoption in SSA by predominantly focusing on maize, legumes, rice, and wheat commodities as there is a large-scale promotion by the donor community and international research institutes (e.g., Baumhardt et al., 2017; Rockström et al., 2009; Naab et al., 2017; Adeagbo et al., 2021; Tufa et al., 2023; Vatsa et al., 2023; Asante et al., 2024; Geda et al., 2024; Mpala and Simatele, 2024); however, the determinants of the adaptation strategies employed by sorghum farmers are yet to be explored. For example, Tufa et al. (2023) investigated the drivers and barriers of CRP adoption on maize farming systems in Malawi, Zambia, and Zimbabwe. Similarly, Geda et al. (2024) examined the determinants of CRP adoption in the Arsi Zone, Oromia region of Ethiopia, by taking the case of wheat producers. As sorghum is often hailed as a climate-resilient crop that can withstand harsh environmental conditions and adapt to various climates (Peng et al., 2020), it is considered a potential crop that can address Ethiopia's food and feed demand, particularly in moisture-stressed areas.

To address this knowledge gap, this study sought to investigate the factors influencing CRP adoption in moisture-stressed sorghum-producing areas in Ethiopia, with a particular focus on extension service. This study complements existing research on the uptake of CRPs in Ethiopia and contributes to the literature in two fundamental ways. First, this study complements previous research by analyzing not only the components of CRPs, such as improved seed and inorganic fertilizer, but also the joint effect of climate-change mitigation and adaptation strategies. Existing evidence predominantly focuses on single climate-smart technologies, such as soil and water conservation technologies (Gebremikael et al., 2005; Tenywa and Bekunda, 2009; Teshome et al., 2016; Moges and Taye, 2017), minimum tillage (Ngoma et al., 2016; Grabowski et al., 2016), integrated soil management (Temesgen et al., 2008), crop residue retention (Valbuena et al., 2015; Raza et al., 2022; Gai et al., 2021), chemical fertilizer (Chianu and Tsujii, 2004; Musafiri et al., 2023), and improved variety (Simtowe et al., 2016; Ashu et al., 2023; Mwebaze et al., 20244). Joint CRP adoption by smallholder farmers appears to have been disregarded in previous studies. Improved seeds and mineral fertilizers alone are insufficient; rather, sustainable land-use practices, particularly those that increase water and nutrient capture, are imperative for improving the resilience of smallholder farming systems (Tufa et al., 2023). The multifaceted nature of CRPs requires a more comprehensive understanding of the perspectives of farmers and their appreciation of these strategies (Kangogo et al., 2021). Thus, a holistic approach and better understanding of the joint CRPs adoption by farmers is warranted. This study focused on six CRPs, namely, minimum tillage, drought-resistant seed, farmyard manure, water-saving technology, crop residue retention, and inorganic fertilizer.

Second, this study further exploits the effect of extension services in promoting CRPs. As the promotion and implementation of CRPs are knowledge-intensive, understanding how extension services access influences the CRP uptake of farmers is critical. However, the role of the agricultural extension service in promoting farmer adoption of CRPs in the context of moisture-stressed areas in developing countries remains largely unexplored. The positive role of agricultural extension services on CRP adoption in developing countries has been extensively analyzed by numerous empirical studies (e.g., Mesfin et al., 2018; Ngoma et al., 2016; Kotu et al., 2017; Naab et al., 2017; Adeagbo et al., 2021; Antwi-Agye and Stringer, 2021; Kudama, 2021; Diro et al., 2022; Kehinde et al., 2022; Negera et al., 2022; Waaswa et al., 2022; Tufa et al., 2023; Ziro et al., 2023; Njogu et al., 2024). Existing studies that attempted to bridge this gap considered the extension service as being accessed or not. Treating access alone to account for the agricultural extension service provision could generate biased results as the extension system in Ethiopia is affected by location and distance and thus sometimes creates spatial imbalances. Regassa et al. (2021) claimed that the high turnover and low motivation levels of extension officers in remote areas pose challenges to equitable service provision and exacerbate geographical welfare disparities. In addition, Mesfin et al. (2022) stated that the concentration of agricultural extension officers is higher in high-potential agricultural areas and that this could facilitate CRP adoption. Herein, we seek to understand how extension service access influences the CRP adoption of smallholder farmers based on the proximity of farmers to the service providers with evidence from Ethiopia's sorghum value chain. Ethiopia provides an interesting case study as it has the highest extension agent-to-farmer ratio among other countries[1] and has heavily invested in extension infrastructure. Ethiopia's extension system remains predominantly public (Davis et al., 2020; Mesfin et al., 2022), and the country has a plan to shift to a pluralistic extension system to effectively promote climate-smart agricultural technologies. Hence, this study will support this effort by providing empirical evidence on the impact of public agricultural extension services on the adoption of climate change adaptation practices in environmentally affected areas.

The remaining part of the article is structured as follows: Section 2 describes the data collection procedures and sampling techniques, whereas Section 3 presents the empirical approaches. Sections 4–12 present the study's main findings. Section 13 discusses the major results. Section 14 provides the conclusion.

2. Research methodology

The study sites and respondents were identified using a multistage sampling procedure that involves a combination of purposive and random sampling. A survey was conducted in seven moisture-stressed sorghum-growing districts in Ethiopia. The sorghum-producing regions, districts, and subdistricts (*kebeles*) were purposively identified based on the current sorghum production potential and status. Two regional states (Amhara and Oromia) were selected. Four districts in the Oromia region (Babile, Fedis, Gololcha, and Shenen-Kolu) and three in the Amhara region (Kobo, Habru, and Kalu) were included (Figs. 1 and 2).

The districts represent the low-potential and risk-prone agroecological zone (semi-arid) with a low and erratic rainfall distribution. A total of 654 households were randomly selected and interviewed face-to-face in 2021 (see Appendix Table 1 for sample distribution). Plot-level data were collected from 1598 plots to analyze the adoption of climate-smart sorghum production practices. Following previous studies and considering the CRPs commonly used by farmers in Ethiopia, data were collected on six CAPs: minimum tillage (Ngoma et al., 2016; Negera et al., 2022), drought-resistant seed (Adeagbo et al., 2021; Negera et al., 2022), farmyard manure (Teklu et al., 2023; Diro et al., 2022), water-saving technology (Vatsa et al., 2023; Negera et al., 2022), crop residue retention (Kehinde et al., 2022), and inorganic fertilizer (Njogu et al., 2024). This research design enabled us to collect binary adoption decisions by farming households and count variables to reflect the intensity of CRPs adoption. The survey was conducted from January to March 2021 under the close supervision of researchers from the

[1] There were 21 extension officers for every 10,000 farmers—the highest ratio in Africa (see Mesfin et al., 2022).

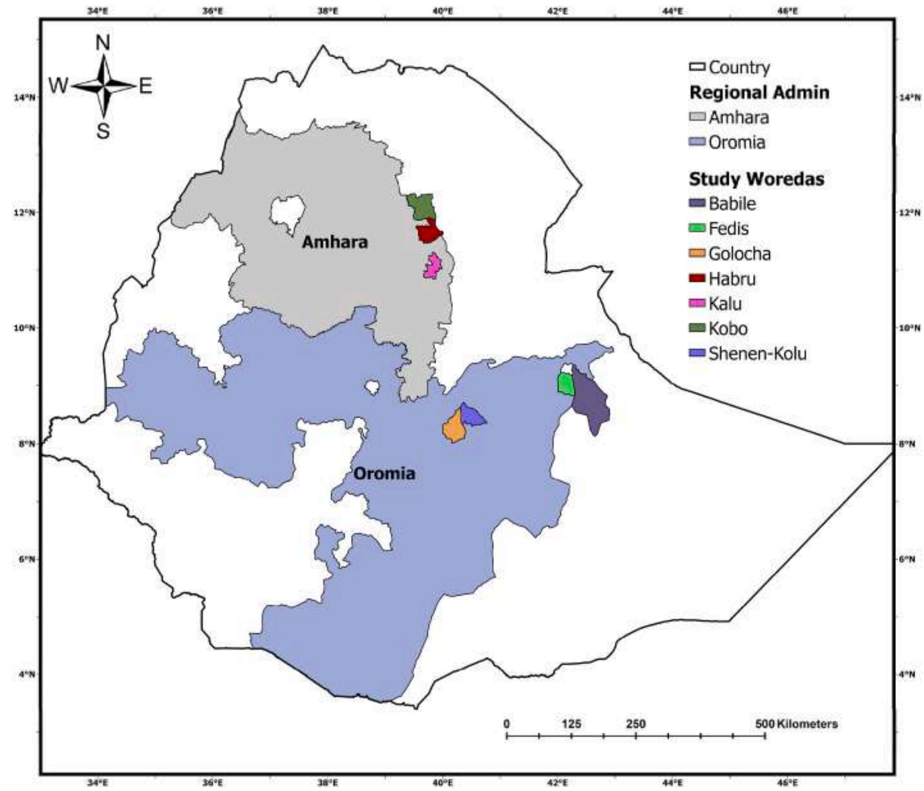

Fig. 1. Map showing the study areas.

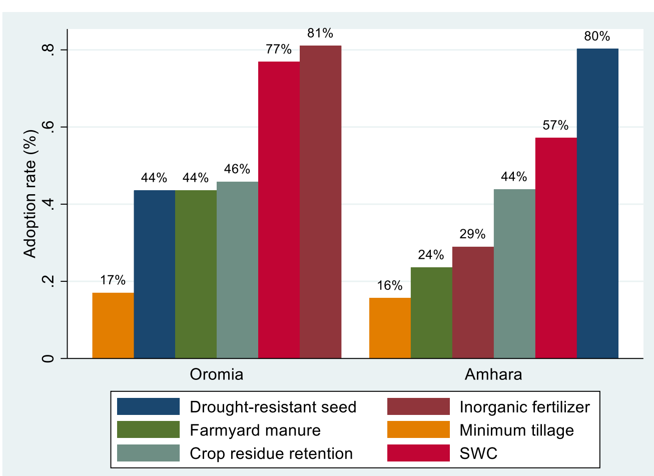

Fig. 2. CRPs practices by sorghum farmers and adoption level by region.

Ethiopian Institute of Agricultural Research and was administered by experienced enumerators using computer-assisted personal interviews, a face-to-face data collection technique.

3. Analytical framework

The theoretical framework used to guide this research process combines both social and ecological approaches to analyze the adaptation strategies of the farmers and the effects of extension systems (McGuire and Sperling, 2013). Socioecological approaches focus on understanding the dynamic interrelations among various personal and environmental factors, paying attention to the social, institutional, and cultural contexts of people–environment relations. Resilience refers to the amount of disturbance a system can withhold before shifting to a different regime (Walker et al., 2006).

The decision to adopt a specific CRP strategy depends on an unobservable latent variable (utility of the farmer), which is determined by several explanatory variables, such as (1) household characteristics, including sex, educational level, experience with sorghum farming, and household size; (2) farm and nonfarm assets, including land and livestock; (3) institutional support, such as extension service as well as input and output markets; and (4) biophysical factors, such as soil quality and agro-ecology, among others. This study considered a set of six climate-smart adoption strategies frequently implemented by sorghum growers in the study areas. These practices include the adoption of improved drought-tolerant sorghum seed, inorganic fertilizer use, manure application, reduced tillage, residue application, and soil–water conservation practices. The adoption of the technologies is assumed to be an interdependent and simultaneous choice decision, i.e., the adoption decision of one CRP strategy depends on the adoption decision of another CRP strategy. This assumption is informed by the fact that CRPs tend to significantly affect crop yields more when all three CRP principles are implemented (TerAvest et al., 2019) and have been promoted as such. Furthermore, Jew et al. (2020) noted that the partial application of CRP principles gives a lower yield than full CRPs. Under this situation, employing single-equation models, such as probit, logit, tobit, and multinomial econometric models, would ignore the interdependence and simultaneous choice decision. The advantage of the multivariate probit (MVP) model is that it uses concurrent interdependent equations for adopting different agricultural technologies (Khanna, 2002; Belderbos et al., 2004; Gillespie et al., 2004; Ndiritu et al., 2014; Liverpool-Tasie et al., 2019). In addition, it enables us to determine if certain CRP practices are considered to be substitutes or complements to each other. A detailed description of the MVP model two-stage estimation approach is expressed as follows:

The first stage equation is estimated as

$$Y_{ic}^{*} = \left[\beta_c' X_{ic} + \varepsilon_{ic}\right]; c = 1, 2, \ldots 6 \quad (1)$$

where Y_{ic}^* is a latent dependent variable representing a level of utility derived from the household adoption of the six CRP strategies. The higher the utility, the greater the probability of adoption of CRP innovations. X_{ic} denotes the vector of observed characteristics of the household *i*.

Following Cappellari and Jenkins (2003), the second stage equation is a form of a binary decision, which can be estimated using a probit model where the response probability depends on a set of parameters, which are a function of the standard normal cumulative distribution.

$$Y_{ic} = \begin{cases} 1 \; if \; Y_{ic}^* > 0, and \\ 0 \; otherwise \end{cases} \tag{2}$$

where $\varepsilon_{ic}, c = 1, 2....6,$ are error terms distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix V, with V having a value of 1 on the leading diagonal and correlations $\rho_{jk} = \rho_{kj}$ as off-diagonal elements.

$$V = \begin{vmatrix} 1 & \rho_{12} & \rho_{13} & \cdots & \rho_{1m} \\ \rho_{21} & 1 & \rho_{23} & \cdots & \rho_{2m} \\ \rho_{31} & \rho_{32} & 1 & \cdots & \rho_{3m} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ \rho_{m1} & \rho_{m2} & \rho_{m3} & \cdots & 1 \end{vmatrix} \tag{3}$$

The MVP model was estimated using the Geweke–Hajivassiliou–Keane smooth recursive conditioning simulator. For each observation, a likelihood contribution was calculated for each replication, and the simulated likelihood contribution was the average of the values derived from all the replications. The simulated likelihood function for the sample as a whole was then maximized using maximum likelihood (Liverpool-Tasie et al., 2019). The existence of a perfect linear relationship among the predictors and constant error variance was checked. A variance inflation factor (VIF) was estimated to check the presence of multicollinearity, and all the explanatory variables had >10 (see Appendix Table 2) with a mean VIF value of 1.21, indicating that the perfect linear relationship of explanatory variables is not an issue in our model. In addition, robust standard errors were reported to correct for possible heteroskedasticity.

4. Data and descriptive statistics

The descriptive statistics for factors that were hypothesized to affect the adoption of climate-smart sorghum production practices are presented in Table 1. Several previous studies were consulted for the selection of the predictors. The results indicate that 94% of the respondents were men. The average farm size owned was 1.53 ha, indicating that the area is dominated by smallholder and subsistence production. Mixed crop and livestock production were practiced, with a tropical livestock unit of 3.2, which is closer to the national average of 3.5. Institutional variables (distance to output and input markets and extension access) were directly associated with the transaction costs of accessing information as well as input and output markets. The result indicate that households were at a distance of 4.2 and 6.6 km from the main input and output markets. Approximately 90% of the respondents were in contact with extension agents.

5. Outcome variables: adaptation strategies to climate change

Table 2 presents the descriptive statistics of CRPs adopted by sorghum farmers. It shows that 65% of the farmers adopted improved sorghum seed and water-saving technologies and ~50% adopted inorganic fertilizer. Inorganic fertilizer use was extremely low compared with that for other cereals. Only 45% of the farming households used nitrogen, phosphate, sulfur (NPS) fertilizer in sorghum production, whereas 34% used urea. Regarding quantity, only 20.8 kg of NPS and 13.6 kg of urea were used against the recommended rate of 100 and 50 kg, respectively. Manure use refers to the application of livestock waste to farm plots. The use of manure is among the major components of a sustainable agricultural system, with the potential benefits of long-term maintenance of soil fertility, organic matter content, and supply of different important nutrients. Herein, 32% of the respondents applied manure to their sorghum plots, 45% used crop residue, and only 16% adopted minimum tillage practices. The analysis further revealed that there were heterogeneities in the types of CRPs adopted by the study region. The Oromia region adopted more inorganic fertilizers, soil, water conservation, and manure, whereas the Amhara region adopted drought-tolerant sorghum seed.

Table 1
Description and descriptive statistics of explanatory variables.

Variable	Description of variables	Mean	SD
Sex	Sex of household head (1 = male)	0.94	0.24
EducHH	Years of education of HH head	3.05	3.26
Family size	Number of individuals in the household	5.74	2.10
Distance to market	Distance to output markets, in km	6.60	4.46
Access to ext. contacts	1 if HH has access to extension, 0 otherwise	0.90	0.30
Dist input dealer	Distance to input markets, in km	4.2	2.94
Farm size	Total land owned by HH, in ha	1.53	1.00
Perception of soil fertility status (base = good)	Dummy: 1 if soil fertility is perceived as good/medium or poor, 0 otherwise		
Good		0.49	0.5
Medium		0.45	0.50
Poor		0.05	0.22
Land tenure	1 if the HH rented in land, 0 otherwise	0.12	0.32
Farming experience	Years of household experience in sorghum production	22.33	11.12
TLU	Total tropical livestock unit (TLU)	3.23	1.84
Log_asset	Household agricultural and nonagricultural asset	10.18	1.31
Location	1 if HH is from the Oromia region, 0 otherwise	0.404	0.49

Table 2
Definitions and descriptive statistics of outcome variables.

Variables	Measurements	Mean (SD[a])
Drought-resistant seed (DRS)	1 if drought-tolerant and early maturing sorghum seed is used; 0 otherwise	0.65 (0.48)
Inorganic fertilizer (IF)	1 if nitrogen, phosphate, sulfur (NPS), and urea fertilizers are applied, 0 otherwise	0.5 (0.5)
Farmyard manure (FM)	1 if manure is used in the farm, 0 otherwise	0.32 (0.46)
Minimum tillage (MT)	1 if minimum tillage is adopted, 0 otherwise	0.16 (0.37)
Crop residue retention (CRR)	1 if crop residue is applied to the farm, 0 otherwise	0.45 (0.49)
Water-saving technology (WST)[b]	1 if soil and water conservation is adopted on the farm, 0 otherwise	0.65 (0.48)
Observations		654

[a] Note: SD stands for standard deviation.
[b] Soil and stone bunds, terrace, mulching, tied-ridging and irrigation through rainwater harvesting from surface runoff were considered to be water-saving technologies.

6. Determinants of the choice of adaptation strategies of sorghum farmers

Table 3 presents the correlation matrix results on the choice of adaptation strategies from the MVP model. The likelihood ratio test (chi^2 (15) = 292.391; $P \geq 0.000$) rejected the null hypothesis of the independence of the error terms across the six equations (adoption of drought-resistant sorghum seed, inorganic fertilizer use, farmyard

Table 3
Complementarities and substitutabilities among CAP practices.

	Improved seed	Inorganic fertilizer	Farmyard manure	Minimum tillage	Crop residue	WST
Improved seed	1					
Inorganic fertilizer	−0.404[b] (0.064)	1				
Farmyard manure	−0.021 (0.063)	0.071 (0.063)	1			
Minimum tillage	−0.210[a] (0.069)	0.118 (0.077)	0.572[b] (0.060)	1		
Crop residue	−0.073 (0.066)	0.076 (0.064)	0.201[b] (0.059)	0.311[b] (0.066)	1	
WST	0.238[b] (0.069)	0.009 (0.064)	−0.251[b] (0.071)	−0.680[b] (0.044)	−0.343[b] (0.060)	1

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho32 = rho42 = rho52 = rho62 = rho43 = rho53 = rho63 = rho54 = rho64 = rho65 = 0: chi^2 (15) = 292.391 Prob > chi^2 = 0.0000, where rho1 = early maturing sorghum variety; rho2 = inorganic fertilizer; rho3 = manure; rho4 = minimum tillage; rho5 = crop residue; rho6 = soil and water conservation.
Robust standard errors in parenthesis.
*$P < 0.1$.
[a] $P < 0.05$.
[b] $P < 0.01$.

manure application, reduced tillage, residue application, and SWC practices). This clearly demonstrates that the adoption decisions of the CRPs were jointly made and that the use of the practices was correlated and justified the choice of the MVP model rather than the competing univariate probit model.

The estimated pairwise correlation coefficients of the error terms were statistically significant for 9 of the 15 pairs, with 4 showing a positive correlation (complementary) and the rest showing a negative correlation (substitutive). For example, the correlation between improved seed and SWC, manure and minimum tillage, manure and crop residue, and minimum tillage and crop residue retention were complementary, whereas the correlation between improved seed and minimum tillage and improved seed and inorganic fertilizer was substitutive. Interestingly, the correlation between inorganic fertilizer and improved seed was negative, which was associated with the prevailing moisture stress that significantly limits fertilizer use in the area. The results provide strong evidence that although complementarities are present, caution should be taken in fully promoting CRPs practices like rainfedfarming areas, because of the apparent low yield response of some of the CRP components in moisture-stressed areas. The correlation of the CRP components result is somewhat different from similar studies in SSA (Tufa et al.; Negere et al., 2022). For example, Tufa et al. (2023) reported the complementarities of most of the conservation agricultural practices in Zambia, Malawi, and Zimbabwe, where maize farmers prefer a combination or full CRPs owing to the maximum yield benefits. In the same vein, Ojo and Baiyegunhi (2019) found complementarities among all the adaptation strategies used by rice farmers in southwest Nigeria. Understanding the reasons for the tradeoff for some of the CRPs strategies in moisture-stressed areas would be a worthwhile area of inquiry for future research.

7. Parameter estimates: determinants of climate change adaptation strategies

Next, we turn to the determinants of adopting climate-change adaptation strategies from the MVP model. The result from the MVP model estimation is presented in Table 4. A total of 14 regressors were included in the MVP model, and the variables of interest are household characteristics (e.g., farm size) as well as institutional (access to extension and markets) and environmental determinants (perception of soil quality and agroecology).

8. Household characteristics

The results from the coefficient estimates of the MVP model indicate that male household heads are more likely to adopt new drought-

Table 4
Estimates of the MVP for the determinants of climate-resilient practices (N = 653).

Variables	DRS	IF	FM	MT	CRR	WST
Socioeconomic factors						
Gender	0.431*	−0.113	−0.161	−0.101	−0.119	0.567[b]
EducHH	−0.028	0.055[b]	−0.019	−0.038 [b]	0.031[c]	0.020
Family size	0.019	−0.038	0.037	−0.017	−0.023	0.076[a]
Farming experience	0.001	0.005	−0.007	−0.018[a]	0.004	0.006
TLU	0.006	−0.015	−0.029	−0.056 [c]	0.019	0.001
Log_asset	0.037	0.149 [b]	0.084[c]	0.124[b]	−0.165[a]	−0.177[a]
Farm size	−0.118[b]	0.170 [b]	−0.003	0.153[b]	−0.088	−0.080
Institutional factors						
Distance to market	−0.030[b]	−0.042[b]	−0.003	−0.010	−0.009	−0.017
Access to ext. contacts	−0.537[a]	0.480[b]	0.018	0.225	−0.139	0.058
Dist input dealer	0.027	0.035	−0.007	0.001	0.016	0.034
Land tenure	0.240	−0.286[c]	0.031	−0.058	−0.225	−0.229
Environmental factors						
Perception of soil fertility status (base = good)						
Medium	−0.089	0.129	0.001	−0.128	0.003	0.168
Poor	0.046	0.212	−0.364	−0.255	−0.362	0.196
Location	−0.905[a]	1.733[a]	0.595[a]	0.089	−0.013	0.327
Constant	1.789	−3.649	−1.330	−2.155	2.113	0.758
Observations	653					
Wald chi^2 (84)	483.69					
Prob > chi^2	0.0000					
Log pseudolikelihood	−2027.62					

The reported figures are coefficients from the MVP model.
a, b, and c represent significance levels at 1%, 5%, and 10%, respectively.

tolerant and early maturing sorghum seed as well as soil and water conservation practices than women. Numerous studies have reported that being a woman negatively influences the adoption of improved agricultural technologies, which are associated with the values and norms of society that give mobility and freedom to men (Rola-Rubzen et al., 2020; Yokamo, 2020). The adoption of soil–water conservation practices by male farmers could be attributed to its labor-intensive nature. The labor-intensive nature of soil–water conservation practices is also confirmed by the positive and significant effect of family size.

Empirical findings in southern Africa indicate that female household heads are more likely to adopt CRPs that are less labor intensive, such as crop rotation, intercropping, and mulching. Tufa et al. (2023) found that female farmers are more likely to adopt crop rotation and intercropping in Malawi and mulching in Zimbabwe. Furthermore, men often have more awareness and knowledge about the benefits of soil and water conservation practices and access to resources, such as financial, land, and agricultural input and output markets, than women. This can limit their ability to invest in and benefit from soil and water conservation practices, potentially leading to lower adoption rates than men (Parks et al., 2014). Moreover, men are more involved in agricultural associations and networks than women. These associations can provide access to information, resources, and support for adopting soil and water conservation practices and other agricultural technologies, including improved seed. For instance, in our study, we found that a higher number of male farmers (22%) were taking part in leadership positions in their communities than female farmers (13%). Therefore, men may be more likely to adopt agricultural innovations due to their participation in such associations (Parks et al., 2014; Rola-Rubzen et al., 2020).

Others have found that sociocultural norms, beliefs, and gender roles in decision-making power play a pivotal role in the adoption of CRPs. These norms and beliefs may limit women's ability to engage in activities outside of their socially assigned traditional roles (Croppenstedt et al., 2013; Murage et al., 2015; Makate et al., 2018; Kumasi et al., 2019; Olaosebikan et al., 2019; Serote et al., 2021). Thus, targeting women in capacity building on climate-responsive technology is important by keeping in mind the constraints posed by land tenure (Kumasi et al., 2019) and differences in agricultural decision-making (Ziro et al., 2023).

Education of the household heads affects the adoption of crop residue and inorganic fertilizer positively, which is consistent with the results of other studies (Musa, 2015; Feyisa, 2020; Radović-Marković et al., 2020; Kudama, 2021; Tufa et al., 2023; Ziro et al., 2023). Higher educational levels increase the capacity and speed of processing CRPs information (Kotu et al., 2017), thereby increasing the likelihood of farmers adopting new agricultural practices to cope with climate change, corroborating the findings of Silvestri et al. (2012) and Tufa et al. (2023). Meanwhile, we found that those who were highly educated and practiced farming longer were less likely to adopt the minimum tillage component. This finding is contrary to other studies conducted on the capacity of the farmers to adopt climate-adaptation strategies in Ethiopia (Moges and Taye, 2017), Ghana (Kotu et al., 2017), Kenya (Ziro et al., 2023), Nigeria (Ojo and Baiyegunhi, 2019), as well as Malawi, Zambia, and Zimbabwe (Tufa et al., 2023) but is consistent with the findings by Negere et al. (2022). Though minimum tillage is often considered to be a sustainable approach to farming, experience with this practice can have negative effects on crop productivity, particularly in areas where water is a key limiting factor for crop growth. The complementarities between minimum tillage and other CRP practices (inorganic fertilizer and crop residue retention) in our result (see Table 3) suggest that implementing minimum tillage in moisture-stressed areas often requires the combination of other conservation agriculture components to minimize the negative impacts. It is, therefore, imperative to approach the adoption of minimum tillage in moisture-stressed areas with caution.

9. Institutional determinants

Empirical findings have indicated that access to the output market is a critical factor incentivizing the adoption of CRPs by smallholder farmers as it facilitates the purchase of agricultural inputs and marketing of production. The coefficient of distance to output markets is negative and statistically significant for adopting improved seed and inorganic fertilizer, consistent with the findings of previous studies (Teklewold, 2013; Manda et al., 2016).

We found that access to extension services positively and significantly influenced the adoption of inorganic fertilizer use. The subsidized and publicly dominated inorganic fertilizer is only channeled to farmers by the public extension system in Ethiopia. This finding is consistent with those of Mesfin et al. (2022). However, extension access was negative for the uptake of drought-resistant sorghum seed. This could be attributed to the underdeveloped sorghum seed system. Most new varieties are distributed either by the formal research institutes at demonstration plots or via the informal farmer-to-farmer seed exchange mechanism. Because extension agents are not the custodians of the technology, farmers may opt to access the technology from other informal sources, such as relative farmers, community-based seed producer associations, or the market. It is concerning to find the insignificant effect of extension service in the remaining CRP components in moisture-stressed areas as opposed to the rainfed farming system in Ethiopia. A large body of evidence suggests that the interaction of farmers with extension officers influenced the adoption of technologies in Africa (e.g., Mburu et al., 2024; Tufa et al., 2023). Negere et al. (2022), for example, noted a positive and significant association between extension contact and climate-smart agricultural practices among farmers in highland and rainfed Bale mountain areas in Ethiopia. The insignificant effect of public extension service could be attributed to the limited engagement of nonstate actors, coupled with capacity gaps in the promotion of climate-change adaptation knowledge and practices in moisture-stressed areas. As posited by Adeagbo et al. (2021), in moisture-stressed areas where farmers face increased challenges and risks due to limited water availability, the effectiveness of public extension services in promoting climate-smart adaptation strategies is limited.

10. Asset variables

We found that some CRP components, including minimum tillage, are being practiced by wealthier farmers (more land holdings and assets), corroborating the findings of Tufa et al. (2023) and Ziro et al. (2023). Meanwhile, the coefficient of livestock measured by TLU is negative and significant in influencing the choice of minimum tillage adaptation strategy. This is due to several reasons. First, livestock need space for grazing, which reduces the available land for crop cultivation (Martin et al., 2016). This can limit the amount of land smallholder farmers can allocate for minimum tillage practices. Second, livestock can contribute to soil compaction and erosion. This can make it difficult for smallholder farmers to effectively implement minimum tillage practices as compacted and eroded soil hinders proper seed germination and plant growth. In addition, livestock produces manure, which can be used as a natural fertilizer. However, managing and incorporating livestock manure into the soil requires additional resources, labor, and knowledge. This additional burden may discourage smallholder farmers from adopting minimum tillage practices.

As regards the influence of other wealth variables on the choice of CRPs, as measured by the amount of land designated for sorghum and physical assets, our results are mixed. The presence of contradictory evidence regarding wealth could be attributed to the subsidized nature of conservation agriculture interventions. The majority of farmers participating in these programs receive support from development organizations. The overreliance on NGOs and donor funding to promote and expand the adoption of climate adaptation strategies in Africa is explained by Mpala and Simatele (2024).

This study also confirms land tenure insecurity as a relevant factor that is negatively and significantly influencing the choice of inorganic fertilizer use adaptation strategy, which aligns with the findings of other developing countries (Ramirez and Shultz, 2000; Kurgat et al., 2020; AntwiAgyei et al., 2021). The uncertainty associated with lease ownership or the continuation of the lease contract deters the adoption of irreversible land improvement practices (Ziro et al., 2023). As reported by Kim et al. (2005), farmers become less likely to adopt conservation practices if their land tenure is not secure. Furthermore, Gebrehiwot and Van Der Veen (2013) explained that the adoption of technologies is associated with the nature of land tenure, particularly individual or leasehold land. Rampa and Lovo (2023) investigated the impact of the land registration and certification program undertaken in the Tigray region, Ethiopia, on agricultural productivity and climate change mitigation. The authors confirmed increased adaptation to climate change by tenure-secured farm households even in times when adverse climate and weather events occurred and concluded that the tenure security of the farmers increased the adoption of climate-smart agricultural practices. Furthermore, farmers in the study area viewed land as a factor of production and a long-term investment security. Hence, land tenure security was an incentive for some farmers to invest in strategic climate-resilient measures requiring high initial capital.

11. Agroecology

Below et al. (2012) and Ojo and Baiyegunhi (2019) in their study demonstrated the significant role that location plays in climate-change adaptation. We obtained mixed findings as regards the impact of agroecology on the choice of CRPs. Farm households living in the Oromia region are more likely to adopt farmyard manure and inorganic fertilizer than the Amhara region, whereas the converse is true when it comes to drought-tolerant improved seed adoption. These findings suggest why a better understanding of local context matters in promoting climate adaptation strategies and why a one-size-fits-all approach is not applicable across different regions. Therefore, accounting the heterogeneities of the farming households to various local factors becomes crucial in developing practical and context-specific CRP strategies.

12. Robustness results

In this study, we recognized that the decision to use extension services is potentially endogenous. There might be unobserved farmer-related factors (such as farmer motivation or ability) that might be positively associated with the decision of the farmers to access extension services to adopt CRPs. As a robustness check, we attempted to mitigate this concern by using proximity of producers to the service provider and determine if our results are maintained for farmers closer to the service providers (Tables 5 and 6). In addition, we determined whether the role of extension service is important if farmers uptake more than one CRP practice. We employed a Poisson model to understand the drivers of intensification of adaptation strategies. The full estimation results for the model are shown in Appendix Table 3. In all regressions, we found a consistently insignificant relationship between the effects of extension services on the adoption of CRP practices by smallholder farmers. We argued that identifying a consistent and insignificant correlation between public extension service and the adoption and intensity of CRP practices is extremely informative for designing targeted and tailored extension service interventions to stimulate the adoption of climate adaptation strategies in moisture-stressed areas in Ethiopia.

13. Discussion: the role of extension service

Unlike previous studies, this study focused on the joint effect of climate change mitigation and adaptation strategies, with a particular focus on the role of extension services in stimulating the adoption of CRPs by farmers in moisture-stressed areas in Ethiopia. Our results indicate that the effect of extension services is insignificant in promoting CRPs beyond the usual capital-intensive and yield-increasing technologies (seed and inorganic fertilizer). This is a disturbing finding because CRPs are more knowledge-intensive than conventional tillage (Congress et al., 2010), and thus, access to extension service is expected to enhance adaptation strategies toward climate change among rural communities (Mwalukasa, 2013). The study findings are contrary to those of similar empirical studies conducted in Eastern and Southern Africa (Bryan et al., 2013; Asfaw and Branca, 2018; Negere et al., 2022; Tufa et al., 2023; Ziro et al., 2023) as well as Asia (Jena et al., 2023).

Table 5
Estimates of the MVP for the determinants of climate-resilient practices for the nearest tercile (N = 231).

Variables	DRS	IF	FM	MT	CRR	WST
Socioeconomic factors						
Gender	0.498	−0.263	−0.068	−0.067	0.115	0.692[b]
EducHH	−0.028	−0.003	−0.060[c]	−0.083[c]	0.001	0.056[c]
Family size	0.003	0.0001	−0.012	0.014	0.027	0.034
Farming experience	−0.002	−0.015	−0.023[b]	−0.040[a]	0.0001	−0.001
TLU	0.028	−0.068	−0.052	−0.056	−0.046	−0.007
Log_asset	−0.054	0.235[b]	0.121	0.073	−0.227[a]	−0.038
Farm size	−0.096	0.058	0.029	0.207[b]	−0.131	0.003
Institutional factors						
Distance to market	−0.046[c]	−0.036	−0.028	0.011	0.029	−0.070[a]
Access to ext. contacts	−0.99[a]	0.740[b]	0.033	0.170	0.038	−0.123
Dist input dealer	0.018	0.067[b]	−0.033	−0.001	−0.023	0.087
Land tenure	0.176	−0.328	0.092	0.252	−0.651[b]	−0.043
Environmental factors						
Perception of soil fertility status (base = good)						
Medium	−0.006	0.129	−0.092	−0.283	−0.046	0.523[b]
Poor	0.216	0.357[c]	−0.509	0.116	0.538	−0.355
Location	−0.602[b]	1.718[a]	1.044[a]	−0.332	−0.273	0.850[a]
Constant	3.927	−4.610	−1.083	−1.245	2.197	−0.175
Observations	231					
LR chi^2 (15) =	113.25					
Prob > chi^2	0.0000					
Log pseudolikelihood	−664.46					

The reported figures are coefficients from the MVP model.
a, b, and c represent significance levels at 1%, 5%, and 10%, respectively.
The nearest tercile is the closest distance between a farming household and the extension service provider in kebele (lowest administration unit).

Table 6
Estimates of the MVP for the determinants of climate-resilient practices for the farthest tercile (N = 146).

Variables	DRS	IF	FM	MT	CRR	WST
Socioeconomic factors						
Gender	0.363	0.408	−0.939	3.129[a]	−0.230	−0.089
EducHH	−0.067	0.092[c]	0.010	−0.001	−0.084*	0.002
Family size	0.119	−0.138[b]	0.067	−0.078	−0.043	0.165[b]
Farming experience	−0.014	0.022	0.004	−0.011	−0.031[b]	0.015
TLU	−0.126[c]	0.002[b]	−0.008	0.028	0.118[c]	−0.031
Log_asset	0.246[b]	−0.121	0.022	0.216	−0.266[b]	−0.179
Farm size	−0.139	0.403[b]	0.105	0.251	0.150	−0.206
Institutional factors						
Distance to market	−0.056	−0.09[b]	−0.003	−0.050	−0.049	0.061[b]
Access to ext. contacts	−1.008[b]	0.638	−0.470	0.484	0.069	−0.615
Dist input dealer	0.023	0.024	0.042	0.023	0.069	−0.083[c]
Land tenure	1.325[b]	−0.261	0.130	−0.120	−0.600	−0.397
Environmental factors						
Perception of soil fertility status (base = good)						
Medium	−0.113	0.220	0.110	−0.158	0.063	−0.258
Poor	0.093	0.782	−0.388	−1.361	−0.245	0.659
Location	−1.857[a]	2.325	0.052	0.827[b]	−0.245	−0.286
Constant	2.019	−1.876	0.815	−7.515	3.188	3.391
Observations	146					
LR chi^2 (15) =	63.27					
Prob > chi^2	0.0000					
Log pseudolikelihood	418.41					

The reported figures are coefficients from the MVP model.
a, b, and c represent significance levels at 1%, 5%,and 10%, respectively.
The farthest tercile is the remote distance between a farming household and the nearest extension service provider in kebele (lowest administration unit).

Although Ethiopia's public extension service has been praised for its extensive geographic and personnel coverage (Davis et al., 2020), our findings suggest that the CRP adoption has been limited to capital- and input-intensive agricultural technologies. We argue that the insignificant impact of public extension services on the adoption of other knowledge-intensive natural resource management practices in moisture-stressed areas could be attributed to skill gaps among extension service providers and the limited role of nonstate actors. Nonstate actors, including NGOs, international research institutes, and the private sector, play a pivotal role in accelerating the adoption of climate-smart agricultural technologies in southern and eastern Africa (Tufa et al., 2023; Mpala and Simatele, 2024). Because most CRP practices are promoted and funded by donors and are project-based, their long-term viability is dependent on the observation of immediate and short-term effects on beneficiaries. High-potential farming systems, rather than areas prone to extreme weather events, is a low-hanging fruit for observing success stories in climate-smart technology.

The quality and methods of extension service could also be the possible reason behind the insignificant results of extension services. Ethiopia, like other African countries, such as Malawi and Zambia, uses the model farmer and trainer approach to provide group extension services. Typically, extension agents train model farmers or the development team leader who is already a model farmer. The team leader passes on the acquired skills or knowledge to the group members. For several decades, extension officers and model farmers have been the primary local actors. The structure enables the delivery of group extension services and the outreach to a large number of beneficiaries. However, the lower-level extension structure is misused for various sociopolitical issues other than agricultural extension and rural development (Leta et al., 2018). After the recent government restructuring in 2018, one to five farmer groups operating in a *kebele* are completely inoperative (MoA, 2022). Furthermore, extension agents lack the necessary tools and inputs to provide effective skill training within farmer training centers (Leta et al., 2018). This, in turn, limits extension agents from transmitting practical and farmer-tailored skills. Tufa et al. (2023) also stated that the training of trainers approach may not be effective for CRPs as it is knowledge-intensive and that lead farmers may be unable to understand and transfer knowledge to other farmers. Farmers in Malawi, for example, complained of receiving conflicting messages about CRP practices due to knowledge gaps.

From a policy perspective, it is important to consider alternative approaches and strategies specifically tailored to address the unique challenges faced by farmers in moisture-stressed areas when promoting climate-smart agriculture practices. Moreover, beyond merely increasing personnel staff and bringing extension services closer to the community, extension officers must be equipped with skills in climate-change adaptation knowledge and practices to be effective change agents.

The role of pluralistic extension service (PES) is also integral in facilitating the uptake of CRPs beyond the promotion of yield-enhancing technologies. In Ethiopia, despite the moniker extension service being public-run enterprises, several stakeholders or institutes are involved in the provision of agricultural advisory services. Of the >3000 NGOs registered and operating in the country, approximately a thousand are working in agriculture and natural resource management arenas. However, the extension services are provided in a fragmented and disorganized manner that deprives the recognition and sustainability of the initiatives on the phase-out of the projects/programs. Rather, the duplication of efforts is not uncommon here and there. The efforts of multiple stakeholders or civil society organizations are not coordinated or aligned in a way that creates synergy and plays a complementary role. Furthermore, the contribution of different actors often remains unrecognized despite their actual presence in many aspects. This has been changing in recent years, and private sector participation has gained attention and support from policymakers. The extension coverage of the country usually focuses on central and high-potential areas. Peripheral areas in the far-flung are not reached by private and other development actors (MoA, 2022). Therefore, to enhance CRP adoption, it is important for policymakers to strengthen the PES by organizing different stakeholders and implementing proper enabling policy to enhance the ability of the different extension providers to develop innovative extension approaches that can foster the uptake of climate-smart practices, particularly in marginal areas in the country. Furthermore, the traditional extension system should seek to train farmers on climate change and adaptation as well as accelerate the uptake of CRP technologies in moisture-stressed areas using innovative digital technologies, such as video-mediated extension services (Abate et al., 2023; Van Campenhout et al., 2020), which had been piloted in potential areas in the country. For instance, using two rounds of experimental evidence, the video-mediated extension approach significantly reaches a wider audience than the government's conventional extension approach and leads to higher levels of farmer understanding and uptake of technologies (Abate et al., 2023).

14. Concluding remarks

Sorghum is a strategic food security crop produced for different purposes in Ethiopia. It is also considered one of the important staple crops supporting climate resilience in moisture-stressed areas in the country. Because of the soaring price of teff, the major staple crop in Ethiopia, sorghum has emerged as an important substitutable food commodity. Thus, promoting yield-enhancing climate-smart technologies is crucial for improving the food security role of sorghum production in Ethiopia in areas prone to weather-induced shocks. Hence, this study attempted to analyze the adoption of multiple climate-smart sorghum production technologies (minimum tillage, drought-resistant seed, farmyard manure, water-saving technology, crop residue retention, and inorganic fertilizer) in moisture-stressed areas in Ethiopia using a MVP model.

The results of the correlation matrix from the MVP model are informative as they indicate the complementarities and tradeoffs between the various CRP components. We observed positive correlations between the use of drought-resistant seed and WSC, farmyard manure and minimum tillage, farmyard manure and crop residue, and minimum tillage and crop residue retention, suggesting that these adaptation practices complement each other. However, the correlation between improved seed, minimum tillage, and seed and inorganic fertilizer was substitutive, indicating possible tradeoffs between these CRP practices. The results provide strong evidence that although complementarities are present, caution should be practiced in fully promoting CRP technologies like rainfed farming areas as our result differs from CRP technology's joint adoption studies in Eastern and Southern Africa.

Certain insights stand out among the MVP regression analysis results for the six CRP practices. The study results confirm that land tenure insecurity creates a disincentive for adopting yield-enhancing technologies, such as inorganic fertilizer. We found a tradeoff between livestock ownership and minimum tillage practices. This tradeoff, however, has been offset by the complementarities of minimum tillage and manure application as livestock produce manure, which can be beneficial for soil fertility when properly managed. Furthermore, the findings confirm the relevance and importance of commonly measured socioeconomic and institutional control variables, such as sex, education, family size, and output market.

While public extension services have been effective in promoting CRPs in numerous literature in Eastern and Southern Africa, their impact on promoting other CRP practices beyond improved seed and inorganic fertilizer appears insignificant in moisture-stressed areas in Ethiopia. This result is unexpected as CRPs are more knowledge-intensive than conventional tillage. Beyond increasing personnel numbers and bringing extension services closer to the community, the lack of capacity building of the public extension services has contributed to the ineffectiveness in promoting CRPs in moisture-stressed areas. Extension officers must be equipped with basic skills in climate-change adaptation knowledge and practices to be effective change agents. This calls for the continuous capacity building of public extension services to make them more effective in service delivery. As CRPs are mainly promoted by nonstate actors, such as donors and international organizations, disadoption is common when the project funds run out (Tufa et al., 2023), posing a sustainability issue. A vibrant extension system also supports the transition from project-driven to public-oriented extension to promote sustainable climate-smart agriculture technologies. In addition, it is imperative to strengthen pluralistic extension systems to stimulate the uptake of climate-smart practices in the country.

The present study has several limitations. First, it makes a binary differentiation between adopters and non-adopters of CRP components using cross-sectional data. However, the adoption of an agricultural innovation is time-variant, and some adopters may give up the practice after certain periods. In this case, the use of panel data would be an important extension, and thus, future studies should examine the dynamic effects of the behavioral changes of the farmers with regard to CRP adoption along with the drivers of disadoption. Second, although these results are generated from seven districts from the two regional states of Ethiopia, we believe that having representative districts from the two major sorghum-producing regions supports the generalization (external validity) of our findings to other moisture-stressed sorghum-producing areas that face more or less similar social and environmental obstacles.

CRediT authorship contribution statement

Mesay Yami: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation. **Mekonnen Sime:** Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Adane Hirpa:** Writing – review & editing, Formal analysis, Conceptualization. **Shiferaw Feleke:** Writing – review & editing, Writing – original draft. **Tahirou Abdoulaye:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declared that they have no conflict of interest.

Data availability

Data will be made available on request.

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Appendix

Table A.1
Sample size and distribution

Region	District	Freq.	Percent
Amhara	Kobo	152	23.03
	Habru	125	18.94
	Kalu	118	17.88
Oromia	Fedis	62	9.39
	Babile	72	10.91
	Gololcha	86	13.03
	Shenenkolu	45	6.82
	Total	660	100

Source: Own survey data

Table A.2
Collinearity Diagnostics of the predictor variables used in the model (N = 653)

Variable	VIF	SQRT VIF	Tolerance	R squared
Gender	1.09	1.04	0.9161	0.0839
Education	1.30	1.14	0.7696	0.2304
Family size	1.27	1.13	0.7876	0.2124
Extension access	1.09	1.04	0.9171	0.0829
Input distance	1.17	1.08	0.8552	0.1448
Land size	1.12	1.06	0.8899	0.1101
Soil fertility	1.06	1.03	0.9411	0.0589
Rented land	1.03	11.02	0.9673	0.0327
Experience in sorghum production	1.41	1.19	0.7108	0.2892
Livestock	1.02	1.01	0.9796	0.0204
Asset	1.27	1.13	0.7857	0.2143
Agro-ecology	1.69	1.30	0.5911	0.4089
Mean VIF	**1.21**			

Table A.3
Determinants of the adoption of multiple adaptation strategies

Variables	Average Marginal effect	Std.Err.	z	P > z
Socioeconomic factors				
EducHH	0.014	0.003	4.530	0.000[a]
Farming experience	0.002	0.001	1.550	0.121
Family size	0.019	0.005	3.910	0.000[a]
Farm size	0.026	0.008	3.300	0.001[a]
TLU	−0.001	0.005	−0.170	0.865
Log_asset	−0.009	0.007	−1.230	0.220
Institutional factors				
Distance to market	0.001	0.002	0.640	0.524
Access to ext. contacts	0.058	0.047	1.220	0.222
Dist input dealer	−0.000	0.004	−0.120	0.907
Land tenure	0.021	0.023	0.930	0.355
Environmental factors				
Perception of soil fertility status (base = good)				
Medium	−0.003	0.019	−0.150	0.884
Poor	0.019	0.033	0.570	0.570
Location	−0.064	0.024	−2.600	0.009[a]
N		653		

Note: a, b and c represents significance level at 1%, 5% and 10% respectively.

References

Abate, G.T., Bernard, T., Makhija, S., Spielman, D.J., 2023. Accelerating technical change through ICT: evidence from a video-mediated extension experiment in Ethiopia. World Dev. 161, 106089 https://doi.org/10.1016/j.worlddev.2022.106089.

Adeagbo, O.A., Ojo, T.O., Adetoro, A.A., 2021. Understanding the determinants of climate change adaptation strategies among smallholder maize farmers in South-west, Nigeria. Heliyon 7 (2), e06231. https://doi.org/10.1016/j.heliyon.2021.e06231.

Antwi-Agyei, P., Amanor, K., Hogarh, J.N., Dougill, A.J., 2021. Predictors of access to and willingness to pay for climate information services in north-eastern Ghana: a gendered perspective. Environmental Development. https://doi.org/10.1016/j.envdev.2020.100580.

Asante, B.O., Ma, W., Prah, S., Temoso, O., 2024. Promoting the adoption of climate-smart agricultural technologies among maize farmers in Ghana: using digital advisory services. Mitig. Adapt. Strategies Glob. Change. https://doi.org/10.1007/s11027-024-10116-6.

Asfaw, S., Branca, A., 2018. In: Lipper, et al. (Eds.), Climate Smart Agriculture, Natural Resource Management and Policy, vol. 52. https://doi.org/10.1007/978-3-319-61194-51.

Ashu, E., Tenaye, A., Tassew, W., 2023. Determinants of improved chickpea variety adoption: the case of southern Ethiopia. Applied Food Research. https://doi.org/10.1016/j.afres.2022.100245.

Baumhardt, R.L., Schwartz, R.C., Jones, O.R., Scanlon, B.R., Reedy, R.C., Marek, G.W., 2017. Long-term conventional and no-tillage effects on field hydrology and yields of a dryland crop rotation. Soil Sci. Soc. Am. J. 81, 200–209. https://doi.org/10.2136/sssaj2016.08.0255.

Belderbos, R., Carree, M., Diederen, B., Lokshin, B., Veugelers, R., 2004. Heterogeneity in R&D cooperation strategies. Int. J. Ind. Organ. 22 (8–9), 1237–1263. https://doi.org/10.1016/j.ijindorg.2004.08.001.

Below, T.B., Mutabazi, K.D., Kirschke, D., Franke, C., Sieber, S., Siebert, R., Tscherning, K., 2012. Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Global Environ. Change 22 (1), 223–235.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., Herrero, M., 2013. Adapting agriculture to climate change in Kenya: household strategies and determinants. J. Environ. Manag. https://doi.org/10.1016/j.jenvman.2012.10.036.

Cappellari, L., Jenkins, S.P., 2003. Multivariate Probit regression using simulated maximum likelihood. STATA J. 3, 278–294. https://doi.org/10.1177/1536867x0300300305.

Chianu, J., Tsujii, H., 2004. Determinants of farmers' decision to adopt or not adopt inorganic fertilizer in the savannas of northern Nigeria. Nutrient Cycl. Agroecosyst. 70, 293–301. https://doi.org/10.1007/s10705-004-0715-z, 2004.

Congress, I., Derpsch, R., Friedrich, T., Consultant, I., Sol, S., 2010. The adoption of conservation agriculture worldwide. ISCO Congress 8–12.

Croppenstedt, A., Goldstein, M., Rosas, N., 2013. Gender and agriculture: inefficiencies, segregation, and low productivity traps. World Bank Res. Obs. 28, 79–109. https://doi.org/10.1093/wbro/lks024.

Davis, K., Suresh, C.B., Ragasa, C., 2020. Agricultural extension: global status and performance in selected countries. Ebrary.ifpri.org (n.d.). Retrieved. https://ebrary.ifpri.org/digital/collection/p15738coll2/id/133965. (Accessed 25 May 2024).

Deressa, T., Hassan, R., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environ. Change 19 (2). https://doi.org/10.1016/j.gloenvcha.2009.01.002.

Diro, S., Tesfaye, A., Erko, B., 2022. Determinants of adoption of climate-smart agricultural technologies and practices in the coffee-based farming system of Ethiopia. Agric. Food Secur. https://doi.org/10.1186/s40066-022-00385-2.

Feyisa, B.W., 2020. Determinants of agricultural technology adoption in Ethiopia: a meta-analysis. Cogent Food Agric. 6 (1), 1855817 https://doi.org/10.1080/23311932.2020.1855817.

Grabowski, H., Long, G., Mortimer, R., Boyo, A., 2016. Updated trends in US brand-name and generic drug competition. J. Med. Econ. 19 (9), 836–844. https://doi.org/10.1080/13696998.2016.1176578.

Gai, H., Yan, T., Zhang, A., Batchelor, W.D., Tian, Y., 2021. Exploring factors influencing farmers' continuance intention to crop residue retention: evidence from rural China. Int. J. Environ. Res. Publ. Health. https://doi.org/10.3390/ijerph18147412.

Gebrehiwot, T., van der Veen, A., 2013. Farm level adaptation to climate change: the case of farmer's in the Ethiopian highlands. Environ. Manag. 52 (1), 29–44. https://doi.org/10.1007/s00267-013-0039-3.

Gebremichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G., Moeyersons, J., 2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, Northern Ethiopia. Soil Use Manag. 21, 287–297.

Geda, M., Haji, J., Jemal, K., Zeleke, F., 2024. Determinants of adoption of climate-smart agricultural technologies in wheat production in Arsi Zone, Oromia Region of Ethiopia. Discover Food. https://doi.org/10.1007/s44187-024-00077-9.

Gillespie, J.M., Davis, C.G., Rahelizatovo, N.C., 2004. Factors influencing the adoption of breeding technologies in U.S. Hog production. J. Agric. Appl. Econ. 36 (1), 35–47. https://doi.org/10.1017/s1074070800021842.

Jena, P.R., Tanti, P.C., Maharjan, K.L., 2023. Determinants of adoption of climate resilient practices and their impact on yield and household income. Journal of Agriculture and Food Research 14, 100659. https://doi.org/10.1016/j.jafr.2023.100659, 100659.

Jew, E.K.K., Whitfield, S., Dougill, A.J., Mkwambisi, D.D., Steward, P., 2020. Farming systems and conservation agriculture: technology, structures and agency in Malawi. Land Use Pol. 95, 104612 https://doi.org/10.1016/j.landusepol.2020.104612.

Kangogo, D., Dentoni, D., Bijman, J., 2021. Adoption of climate-smart agriculture among smallholder farmers: does farmer entrepreneurship matter? Land Use Pol. https://doi.org/10.1016/j.landusepol.2021.105666.

Kehinde, M.O., Shittu, A.M., Ogunnaike, M.G., Oyawole, F.P., Fapojuwo, O.E., 2022. Land tenure and property rights, and the impacts on the adoption of climate-smart practices among smallholder farmers in selected agroecologies in Nigeria. Bio base Appl. Econ. 11 (1), 75–87. https://doi.org/10.36253/bae-9992.

Kim, S., Gillespie, J.M., Paudel, K.P., 2005. The effect of socioeconomic factors on the adoption of best management practices in beef cattle production. J. Soil Water Conserv. 60 (3), 111–120.

Kotu, B.H., Alene, A., Manyong, V., Hoeschle-Zeledon, I., Larbi, A., 2017. Adoption and impacts of sustainable intensification practices in Ghana. Int. J. Agric. Sustain. 15 (5), 539–554. https://doi.org/10.1080/14735903.2017.1369619.

Kudama, G., 2021. Determinants of improved wheat variety adoption in horo district, Oromia region, Ethiopia. Int. J. Econ. Bus. 7 (2), 48–55.

Khanna, M., 2002. Non-mandatory approaches to environmental protection. J. Econ. Surv. 15 (3), 291–324. https://doi.org/10.1111/1467-6419.00141.

Kumasi, T.C., Antwi-Agyei, P., Obiri-Danso, K., 2019. Small-holder farmers' climate change adaptation practices in the Upper East Region of Ghana. Environ. Dev. Sustain. 21, 745–762. https://doi.org/10.1007/s10668-017-0062-2.

Kurgat, B.K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., Rosenstock, T.S., 2020. Adoption of climate-smart agriculture technologies in Tanzania. Front. Sustain. Food Syst. 4, 55. https://doi.org/10.3389/fsufs.2020.00055.

Leta, G., 2018. The Ethiopian agricultural extension system and its role as a "development actor": cases from southwestern Ethiopia. Ph.D. Dissertation at the Center for Development Research (ZEF). University of Bonn. http://hss.ulb.uni-bonn.de/2018/5176/5176.pdf.

Liverpool-Tasie, L.S.O., Sanou, A., Tambo, J.A., 2019. Climate change adaptation among poultry farmers: evidence from Nigeria. Climatic Change. https://doi.org/10.1007/s10584-019-02574-8.

Makate, C., Makate, M., Mutenje, M., Mango, N., Siziba, S., 2019. Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. Environmental Development. https://doi.org/10.1016/j.envdev.2019.100458.

Makate, M., Nelson, N., Makate, C., 2018. Farm household typology and adoption of climate-smart agriculture practices in smallholder farming systems of southern Africa. African J. Sci. Technol. Innov. Develop. 10, 421–439. https://doi.org/10.1080/20421338.2018.1471027.

Manda, J., Alene, A.D., Gardebroek, C., Kassie, M., Tembo, G., 2016. Adoption and impacts of sustainable agricultural practices on maize yields and incomes: evidence from rural Zambia. J. Agric. Econ. 67 (1), 130–153. https://doi.org/10.1111/1477-9552.12127.

Martin, R., Linstädter, A., Frank, K., Müller, B., 2016. Livelihood security in face of drought – assessing the vulnerability of pastoral households. Environ. Model. Software 75, 414–423. https://doi.org/10.1016/j.envsoft.2014.10.012.

Mburu, M., Mburu, J., Nyikal, R., Mugera, A., Ndambi, A., 2024. Role of agricultural extension in learning for uptake and intensification of less-practiced dairy climate-smart practices in Kenya. Cogent Food Agric. 10 (1) https://doi.org/10.1080/23311932.2024.2330182.

McGuire, S.J., Sperling, L., 2013. Making seed systems more resilient to stress. Global Environ. Change 23, 644e653.

Meijer, S.S., Catacutan, D., Ajayi, O.C., Sileshi, G.W., Nieuwenhuis, M., 2015. The role of knowledge, attitudes, and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. Int. J. Agric. Sustain. 13 (1), 40–54. https://doi.org/10.1080/14735903.2014.912493.

Mesfin, H., Tessema, Y.M., Tirivayi, N., Nillesen, E., 2022. The impact of agricultural extension service on the uptake of various agricultural technologies in Ethiopia. Afr. Dev./Afr. Développement 47 (4), 77–106. https://www.jstor.org/stable/48722442.

Ministry of Agriculture (MoA), 2022. Baseline Survey on the Existing Agricultural Extension Service & Training Need Assessment: Cases of the Pilot Commodities for Tri-lateral Cooperation. Ministry of Agriculture, Addis Ababa, Ethiopia.

Moges, D., Taye, A., 2017. Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. https://www.sciencedirect.com/science/article/pii/S2095633916300879.

Mpala, T.A., Simatele, M.D., 2024. Climate-smart agricultural practices among rural farmers in Masvingo district of Zimbabwe: perspectives on the mitigation strategies to drought and water scarcity for improved crop production. Front. Sustain. Food Syst. 7, 1298908 https://doi.org/10.3389/fsufs.2023.1298908.

Musafiri, C.M., Kiboi, M., Macharia, J., Ng'etich, O., Okoti, M., Mulianga, B., Kosgei, D. K., Zeila, A., Ngetich, F., 2023. Use of inorganic fertilizer on climate-smart crops improves smallholder farmers' livelihoods: evidence from Western Kenya. Social Sciences & Humanities Open. https://doi.org/10.1016/j.ssaho.2023.100537.

Mwebaze, P., Macfadyen, S., Barro, P., Bua, A., Kalyebi, A., Bayiyana, I., Tairo, F., Colvin, J., 2024. Adoption determinants of improved cassava varieties and intercropping among East and Central African smallholder farmers. https://doi.org/10.1002/jaa2.112.

Murage, A.W., Pittchar, J.O., Midega, C.A.O., Onyango, C.O., Khan, Z.R., 2015. Gender specific perceptions and adoption of the climate-smart push–pull technology in eastern Africa. Crop Protect. 76, 83–91. https://doi.org/10.1016/j.cropro.2015.06.014.

Mwalukasa, N., 2013. Agricultural information sources used for climate change adaptation in Tanzania. Libr. Rev. 62 (4/5), 266–292. https://doi.org/10.1108/lr-12-2011-0096.

Naab, J.B., Mahama, G.Y., Yahaya, I., Prasad, P.V.V., 2017. Conservation agriculture improves soil quality, crop yield, and incomes of smallholder farmers in north western Ghana. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5478712.

Negera, M., Alemu, T., Hagos, F., Haileslassie, A., 2022. Determinants of adoption of climate smart agricultural practices among farmers in Bale-Eco region, Ethiopia. https://doi.org/10.1016/j.heliyon.2022.e09824.

Ndiritu, S.W., Kassie, M., Shiferaw, B., 2014. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. Food Pol. 49, 117–127. https://doi.org/10.1016/j.foodpol.2014.06.010.

Njogu, J.W., Karuku, G., Busienei, J., Gathiaka, J.K., 2024. Assessing determinants of scaling up pathways for adopted CSA climate smart agricultural practices: evidence from climate smart villages in nyando basin, Kenya. Cogent Food Agric. 10 (1) https://doi.org/10.1080/23311932.2024.2316362.

Ngoma, H., Mulenga, B.P., Jayne, T.S., 2016. Minimum tillage uptake and uptake intensity by smallholder farmers in Zambia. African Journal of Agricultural and Resource Economics 11 (4), 249–262.

Ngwira, A.R., Thierfelder, C., Lambert, D.M., 2013. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renew. Agric. Food Syst. 28 (4), 350–363. https://doi.org/10.1017/S1742170512000257.

Nyang'au, J.O., Mohamed, J.H., Mango, N., Makate, C., Wangeci, A.N., 2021. Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub-county, Kisii, Kenya. Heliyon, e06789. https://doi.org/10.1016/j.heliyon.2021.e06789.

Ojo, T.O., Baiyegunhi, L.J.S., 2019. Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. Land Use Pol. 103946 https://doi.org/10.1016/j.landusepol.2019.04.007.

Olaosebikan, O., Abdulrazaq, B., Owoade, D., Ogunade, A., Aina, O., Ilona, P., et al., 2019. Gender-based constraints affecting biofortified cassava production, processing and marketing among men and women adopters in Oyo and Benue States, Nigeria. Physiol. Mol. Plant Pathol. 105, 17–27. https://doi.org/10.1016/j.pmpp.2018.11.007.

Parks, M.H., Christie, M.E., Bagares, I., 2014. Gender and conservation agriculture: constraints and opportunities in the Philippines. https://doi.org/10.1007/s10708-014-9523-4.

Peng, J., Kim, M., Kim, K., Sung, K.I., 2020. Climatic Suitability Mapping and Driving Factors Detection for Whole Crop Maize and Sorghum–Sudangrass Hybrid Production in the South Area of the Korean Peninsula and Jeju Island. Wiley-Blackwell. https://doi.org/10.1111/grs.12270.

Radović-Marković, M., Kabir, S., Jovičić, E., 2020. Gender and technology adoption among farmers in Banglash. Int. Rev. 3–4, 12–28. https://doi.org/10.5937/intrev2003012r.
Ramírez, O.A., Shultz, S.D., 2000. Poisson count models to explain the adoption of agricultural and natural resource management technologies by small farmers in central American countries. J. Agric. Appl. Econ. 32 (1), 21–33. https://doi.org/10.1017/s1074070800027796.
Rampa, A., Lovo, S., 2023. Revisiting the effects of the Ethiopian land tenure reform using satellite data. A focus on agricultural productivity, climate change mitigation and adaptation. World Dev. 171, 106364 https://doi.org/10.1016/j.worlddev.2023.106364.
Raza, M.H., Abid, M., Faisal, M., Yan, T., Akhtar, S., Adnan, K.M.M., 2022. Environmental and health impacts of crop residue burning: scope of sustainable crop residue management practices. Int. J. Environ. Res. Publ. Health. https://doi.org/10.3390/ijerph19084753.
Regassa, M.D., Abate, G., Kubik, Z., 2021. Incentivising and retaining public servants in remote areas: a discrete choice experiment with agricultural extension agents in Ethiopia. J. Agric. Econ. 72 (3), 878–900. https://doi.org/10.1111/1477-9552.12432.
Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., Damgaard-Larsen, S., 2009. Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil Tillage Res. 103 (1), 23–32. https://doi.org/10.1016/j.still.2008.09.013.
Rola-Rubzen, M.F., Paris, T.R., Hawkins, J., Sapkota, B., 2020. Improving gender participation in agricultural technology adoption in Asia: from rhetoric to practical action. https://doi.org/10.1002/aepp.13011.
Serote, B., Mokgehle, S., Du Plooy, C., Mpandeli, S., Nhamo, L., Senyolo, G., 2021. Factors influencing the adoption of climate-smart irrigation technologies for sustainable crop productivity by smallholder farmers in arid areas of South Africa. Agriculture 11, 1222. https://doi.org/10.3390/agriculture11121222.
Silvestri, S., Bryan, E., Ringler, C., Herrero, M., Okoba, B., 2012. Climate change perception and adaptation of agro-pastoral communities in Kenya. Reg. Environ. Change 12 (4), 791–802. https://doi.org/10.1007/s10113-012-0293-6.
Simtowe, F., Asfaw, S., Abate, T., 2016. Determinants of agricultural technology adoption under partial population awareness: the case of pigeonpea in Malawi. Agric. Econ. https://doi.org/10.1186/s40100-016-0051-z.
Teklu, A., Simane, B., Bezabih, M., 2023. Multiple adoption of climate-smart agriculture innovation for agricultural sustainability: empirical evidence from the upper blue nile highlands of Ethiopia. Clim. Risk Manage. 100477 https://doi.org/10.1016/j.crm.2023.100477.
Teklewold, H., Kassie, M., Shiferaw, B., 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. J. Agric. Econ. 64 (3), 597–623. https://doi.org/10.1111/1477-9552.12011.
Temesgen, M., Rockstrom, J., Savenije, H.H.G., Hoogmoed, W.B., Alemu, D., 2008. Determinants of tillage frequency among smallholder farmers in two semi-arid areas in Ethiopia. Phys. Chem. Earth, vol. 33. University Press, Cambridge, pp. 183–191.
Tenywa, M., Bekunda, M., 2009. Managing soils in Sub-Saharan Africa: challenges and opportunities for soil and water conservation. Journal of Soil and Water Conservation January 2009 64 (1), 44A–48A. https://doi.org/10.2489/jswc.64.1.44A.
TerAvest, D., Wandschneider, P.R., Thierfelder, C., Reganold, J.P., 2019. Diversifying conservation agriculture and conventional tillage cropping systems to improve the wellbeing of smallholder farmers in Malawi. Agric. Syst. 171, 23–35. https://doi.org/10.1016/j.agsy.2019.01.004.
Teshome, A., de Graaff, J., Kassie, M., 2016. Household-level determinants of soil and water conservation adoption phases: evidence from North-Western Ethiopian highlands. Environ. Manag. 57.
Tufa, A.H., Kanyamuka, J.S., Alene, A., Ngoma, H., Marenya, P.P., Thierfelder, C., Banda, H., Chikoye, D., 2023. Analysis of adoption of conservation agriculture practices in southern Africa: mixed-methods approach. Front. Sustain. Food Syst. 7, 1151876 https://doi.org/10.3389/fsufs.2023.1151876.
Valbuena, D., Tui, S., Erenstein, O., Teufel, N., Duncan, A., Abdoulaye, T., Swain, B., Mekonnen, K., Germaine, I., Gérard, B., 2015. Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. Agric. Syst. https://doi.org/10.1016/j.agsy.2014.05.013.
Van Campenhout, B., Spielman, D.J., Lecoutere, E., 2020. Information and communication technologies to provide agricultural advice to smallholder farmers : experimental evidence from Uganda. Am. J. Agric. Econ. https://doi.org/10.1002/ajae.12089.
Vatsa, P., Ma, W., Zheng, H., Li, J., 2023. Climate-smart agricultural practices for promoting sustainable agrifood production: yield impacts and implications for food security. https://doi.org/10.1016/j.foodpol.2023.102551.
Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A., Ngeno Kipkemoi, J., 2022. Climate-Smart agriculture and potato production in Kenya: review of the determinants of practice. Clim. Dev. 14 (1), 75–90. https://doi.org/10.1080/17565529.2021.1885336.
Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., Schultz, L., 2006. A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecol. Soc. 11 (1) https://doi.org/10.5751/es-01530-110113.
Yokamo, S., 2020. Adoption of improved agricultural technologies in developing countries: literature review. International Journal of Food Science and Agriculture 4 (2), 183–190. https://doi.org/10.26855/ijfsa.2020.06.010.
Zerssa, G.W., Feyssa, D.H., Kim, D., Eichler-Löbermann, B., 2021. Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. https://doi.org/10.3390/agriculture11030192.
Ziro, J.S., Kichamu-Wachira, E., Ross, H., Palaniappan, G., 2023. Adoption of climate resilient agricultural practices among the Giriama community in South East Kenya: implications for conceptual frameworks. Front. Clim. 5, 1032780 https://doi.org/10.3389/fclim.2023.1032780.
Zingore, S., Mutegi, J., Agesa, B., Tamene, L., Kihara, J., 2015. Soil degradation in subSaharan Africa and crop production options for soil rehabilitation. Better Crops 99 (1), 24–26.