

CLIMATE-SMART AGRICULTURE PRACTICES ADOPTION AMONG SMALLHOLDER COFFEE FARMERS: INSIGHTS FROM AGRICULTURAL COOPERATIVES IN SOUTHERN HIGHLANDS, TANZANIA

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Abstract. Climate change remains one of the most urgent environmental challenges globally, with agriculture among the sectors most adversely affected. In Tanzania, the coffee industry is particularly vulnerable, with climate-related stresses significantly undermining productivity and profitability. In response, the Government of Tanzania and key coffee-sector stakeholders have intensified efforts to promote the adoption of climate-smart agriculture (CSA) practices. This study assessed the level of adoption of climate-smart agriculture (CSA) practices promoted by government and coffee-sector stakeholders across 17 agricultural cooperatives in Mbinga, Nyasa, Rungwe, Mbeya, Ileje, and Mbozi districts. A mixed-methods approach was employed, incorporating household surveys, semi-structured questionnaires, focus group discussions, and observations, to collect primary data. Secondary data were obtained through a review of reports from the Tanzania Coffee Research Institute (TaCRI) and the Tanzania Coffee Board (TCB). The findings show that 70.42% of respondents have implemented at least three CSA practices. Predictor variables such as coffee varieties, pest and soil management practices, agroforestry, and conservation techniques play a crucial role in shaping CSA outcomes. Together, these variables explain a substantial portion of the observed variation, underscoring their importance in promoting sustainable farming practices. The findings further reveal that most smallholder farmers affiliated with agricultural cooperatives have adopted at least two climate-smart agriculture (CSA)

practices. This reflects the positive influence of government initiatives and the efforts of other key stakeholders, including cooperatives, in supporting CSA adoption. The study concludes that interventions by the Government of Tanzania and coffee sector stakeholders have significantly contributed to the uptake of climate-smart agriculture practices among cooperative members. These efforts have enhanced coffee productivity and strengthened farmers' capacity to adapt to climate challenges. It is recommended that coffee stakeholders bolster agricultural cooperatives to attract more farmers and accelerate the dissemination of good agricultural practices (GAPs), thereby improving CSA adoption. Key stakeholders – particularly TCB, TaCRI, Moshi Co-operative University (MoCU), agricultural cooperatives, NGOs, and private sector actors – should continue to support farmers in adopting CSA practices. Additionally, smallholder farmers are encouraged to actively participate in CSA-related extension services and training to enhance their knowledge, increase productivity, and expand their influence within cooperatives and policy platforms.

Keywords: practices, climate-smart agriculture, smallholder coffee farmers, adoption, climate change

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INTRODUCTION

Climate change is reshaping global ecological and production systems, posing a critical challenge to the agricultural sector. Its impacts are especially pronounced in crop and livestock production, in farmer support institutions such as cooperatives, and in high-value commodity crops like coffee (Njau and Kumburu, 2024). Coffee remains one of the most widely consumed beverages worldwide (Sänger, 2018; ICO, 2019). Since the 1990s, global demand has increased by 50%, driven by rising domestic consumption in producing countries and emerging markets such as China, South Korea, and Turkey (Sänger, 2018). However, the adverse effects of climate change – including prolonged droughts and floods, erratic rainfall patterns, pest and disease outbreaks, and widespread environmental degradation – are increasingly evident. Studies by Bilen et al. (2022) and Jawo et al. (2023) show that rising temperatures and rainfall variability create favourable conditions for pests and diseases that reduce coffee growth and yields.

Global demand for coffee is further influenced by demographic changes and income dynamics across regions (ICO, 2022). For countries to benefit from this expanding demand, the production of sustainable coffee that incorporates climate mitigation and adaptation measures is essential. In response, the Government of Tanzania has introduced several strategies to address the impacts of climate change on agriculture. These include the National Climate Change Strategy (NCCS), which outlines key climate risks requiring technical and institutional interventions (URT, 2012).

Additional initiatives include the Agriculture Climate Resilient Plan (ACRP), designed to accelerate the uptake of climate-smart agriculture (CSA), strengthen risk management against climate-related shocks, and enhance knowledge systems for climate action (URT, 2014). Similarly, the Climate Smart Agriculture Programme (CSAP) for Tanzania (2015–2025) focuses on sustainably increasing agricultural productivity to meet evolving consumer preferences under challenging climate conditions (URT, 2015). Despite these efforts, productivity among smallholder coffee farmers – who contribute 90% of national coffee production – remains low at 340–360 kg/ha. Tanzania's average annual coffee production stands at 66,000 metric tonnes, far below the national target of 300,000 metric

tonnes of clean coffee by 2025/26. To close this gap, the coffee sector has invested in initiatives that support smallholder farmers in adopting CSA practices to boost coffee productivity.

CSA practices promoted within the coffee sector include the use of high-yielding, disease-resistant varieties with superior beverage quality; integrated pest management (IPM), incorporating biological control, crop rotation, and cultural practices to reduce pesticide use; and strategies such as intercropping, irrigation, organic manure application, and soil and water conservation techniques like mulching and cover cropping. Despite these initiatives, limited empirical evidence exists regarding the specific CSA practices adopted by smallholder farmers. This study, therefore, assesses the CSA practices currently adopted and implemented by smallholder farmers in the Southern Highlands of Tanzania, with the aim of understanding their contribution to improving coffee productivity.

Theoretical and Conceptual Grounds

Understanding how farmers adopt new agricultural practices is crucial for enhancing coffee productivity among smallholders. This study draws on Rogers' Diffusion of Innovation (DOI) theory (1962), which explains why individuals choose to adopt new ideas or technologies. Rogers (1995) defines adoption as a decision to use an innovation in place of a previous practice. According to this framework, farmers' adoption behaviour can be understood through the lens of utility maximisation: a farmer will adopt a new technology if the expected utility from that technology exceeds that of the existing alternative. In this study, climate change-related challenges represent the major constraints that farmers seek to overcome. The climate-smart agriculture (CSA) variables examined include improved coffee varieties, integrated pest management, integrated soil fertility management, soil and water conservation, agroforestry practices, and crop diversification. Based on this theoretical framework, the study models the household's decision to adopt CSA practices as follows. The adoption of CSA practice by the i^{th} farm household ($i = 1, \dots, N$) which is facing a decision on whether or not to adopt CSA on its plot p ($i = 1, \dots, N$), is assumed to be a function of smallholder farmers as well as farm specific characteristics, x (age, sex, marital status, education, household size, farm size, extension services) and an error term with zero mean.

MATERIALS AND METHODS

Study area and sampling methodology

The study was carried out in six purposely selected districts – Mbinga, Nyasa, Rungwe, Mbeya, Ileje, and Mbozi. These districts were chosen because, despite being Tanzania's leading coffee-producing areas, they remain highly vulnerable to climate variability, drought, erratic rainfall, and outbreaks of coffee pests and diseases. These climatic and biophysical challenges negatively affect key stages of coffee production, including flowering, maturation, and harvesting. To analyse the effects of adopting climate-smart agriculture (CSA) practices, a multistage stratified random sampling approach was employed. Agricultural Marketing Cooperative Societies (AMCOS), also referred to as agricultural cooperatives in this study, formed the sampling frame within each district. Each AMCOS consisted of all registered farm households, from which the primary units of analysis – the households – were randomly selected. After selection, households were stratified into two groups: adopters and non-adopters of CSA technologies.

Sample size

The sample size was determined following Cochran's (1977) formula:

$$n = \frac{Z^2 pq}{e^2} \quad (1)$$

The Cochran formula was applied using a 95% confidence level, a 5% margin of error (appropriate for large samples with a small allowable difference between sample estimates and true population values), and $p = 0.5$ (used when the population proportion is unknown, as it yields the maximum sample size). The resulting sample size calculation is shown below:

$$\begin{aligned} n &= \frac{Z^2 pq}{e^2} = \frac{1.96^2 \times 0.5 \times 0.5}{0.05^2} = \frac{(3.846) \times (0.25)}{0.0025} = \\ &= \frac{0.9604}{0.0025} = 384.16 \approx 384 \end{aligned}$$

Where, n = is the desired sample size; $p = 0.5$ is the assumed proportion of smallholder farmers expected to adopt CSA practices; $q = 1 - p = 0.5$ is the assumed proportion of smallholder farmers not expected to adopt CSA practices; $e = 0.05$ is the margin of error (desired precision at 5%); and $Z = 1.96$ is the critical value corresponding to a 95% confidence level. To ensure adequate

representation across the six study districts and improve statistical robustness, the sample size was proportionally distributed according to the relative population of smallholder coffee farmers in each district. However, to further minimise the margin of error and increase the precision and confidence of the results, a slightly larger sample size of 386 was used in this study.

Analytical framework

The study utilised descriptive statistics and econometric analysis. Descriptive analysis was conducted using means, frequencies, percentages, and tabular summaries, while the econometric analysis employed a multivariate probit regression model (MVP). The MVP model was used to estimate the factors influencing the adoption decisions of CSA practices in coffee production. This model was selected because it allows for the simultaneous estimation of several correlated binary outcomes (Greene, 2003). Additionally, the model accounts for correlations among disturbance terms that may arise from interrelationships between practices (Chekol et al., 2023; Moshi et al., 2016; Rahman and Chima, 2015).

The CSA practice variables in this study include improved coffee varieties (Cv), integrated pest management (IPM), integrated soil fertility management ($ISFM$), soil and water conservation (Sw), agroforestry practices (Af), and crop diversification (Cd), all of which are disseminated to smallholder coffee farmers through agricultural cooperatives in the study area. The decision to adopt one practice may influence the decision to adopt another, making adoption inherently multivariate. Farmers are more likely to adopt a combination of practices to address production constraints than to rely on a single practice. Adoption decisions typically occur over time, following awareness campaigns and farmers' evaluation of the usefulness of a technology, rather than instantaneously (Rogers, 1995). Therefore, this study applied a multivariate probit model to analyse the joint adoption of multiple CSA practices and to account for correlations among adoption decisions. The MVP model is appropriate for capturing household variations in CSA adoption and estimating multiple binary outcomes jointly.

The selection of CSA practices by a household, defined as the household's decision to adopt climate-smart agriculture technologies, is expressed as follows:

$$Y_{ik}^* = \beta_r X_{ik} + \varepsilon_{ik} \quad (2)$$

and

$$Y_{ik} = \begin{cases} 1, & \text{if } Y_{ik}^* > 0 \\ 0, & \text{Otherwise} \end{cases} \quad (3)$$

Where Y_{ik}^* is a latent variable that captures the observed and unobserved preferences associated with the i^{th} choice of CSA. Y_{ik} represents the binary dependent variables, X_{ik} represents the explanatory variables, β_i is the parameter to be estimated, and ε_{ik} represents the multivariate normally distributed stochastic error term.

The dependent variables in the MVP model consist of six dummy variables corresponding to the CSA practices: improved coffee varieties (*Cv*), integrated pest management (*IPM*), integrated soil fertility management (*ISFM*), soil and water conservation (*Sw*), agroforestry practices (*Af*), and crop diversification (*Cd*). Adopters are smallholder coffee farmers who used one or more of these technologies, whereas non-adopters are those who did not adopt them.

The explanatory variables typically considered in modelling adoption decisions include household and farm characteristics, technology attributes, resource ownership, institutional factors, and access to information (Chekol et al., 2023; Moshi et al., 2016; Rahman and Chima, 2015). Guided by insights from the reviewed literature, this study hypothesised that household, farm, and plot characteristics, together with institutional factors, shape the adoption of CSA practices among smallholder coffee farmers in the study districts.

In the multivariate probit (MVP) framework, the error terms are assumed to jointly follow a multivariate normal distribution with a zero conditional mean. The variance is normalised to unity, where U_{cv} , U_{ipm} , U_{isfm} , U_{sw} , U_{af} , U_{cd} , and the symmetric covariance matrix Σ is given by:

$$\Sigma = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} & \dots & \rho_{1m} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} & \dots & \rho_{2m} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} & \dots & \rho_{3m} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 & \dots & \rho_{4m} \\ \vdots & \vdots & \vdots & \vdots & 1 & \rho_{5m} \\ \rho_{1m} & \rho_{2m} & \rho_{3m} & \rho_{4m} & \dots & 1 \end{bmatrix} \quad (4)$$

Particularly important are the off-diagonal elements in the covariance matrix, which represent unobserved correlations among the stochastic components of the different CSA practices. This assumption implies that

equation (3) provides an MVP model that jointly represents the decision to adopt – or not adopt – each farming practice. Allowing for non-zero off-diagonal elements accommodates correlation among the error terms of the latent equations, reflecting unobserved characteristics that influence the selection of alternative CSA practices. A likelihood ratio test was conducted to assess the null hypothesis that the correlation coefficients (ρ statistics) are jointly equal to zero, against the alternative that at least one ρ is non-zero.

Data analysis

The study employed both descriptive statistics and econometric analyses. Descriptive statistics were used to summarise the data through means, frequencies, percentages, and tables. Econometric analysis was conducted using the multivariate probit model (MVP) to identify the factors influencing the adoption of CSA practices. The MVP approach simultaneously models the effects of explanatory variables on multiple practices while accounting for potential correlation among the unobserved disturbances and the interrelationships between adoption decisions (Moshi et al., 2016). Such correlations may arise due to complementarities (positive correlation) or substitutability (negative correlation) between practices. Failing to account for these unobserved factors and interrelationships can result in biased and inefficient estimates. All analyses were performed using STATA version 15, and results were summarised in Excel 2013.

FINDINGS AND DISCUSSION

Socio-demographic characteristics

The descriptive analysis shows that the average age of smallholder farmers in the study areas is 49 years. Among them, 25.8% of CSA adopters and 15.9% of non-adopters fall within the 46 to 60 year age group. According to Njau and Matto (2024), individuals in this age range tend to be influential and actively engaged in community activities. In addition, other studies (ICO, 2022; Msangi et al., 2024; Nchanji et al., 2024) indicate that agriculture is still dominated by older farmers, with limited involvement from youth. In terms of gender, 48.8% of adopters were male, and 31.9% were female, reflecting the predominance of men in coffee farming. This pattern is consistent with findings by ICO (2022) and Koss Jean (2024). Njau and Matto (2024) further

Table 1. Socio-economic characteristics of respondents in the study areas

Variables	Adopters (N = 386)		Non-adopters (N = 235)		All (N= 621)	
	frequency	%	frequency	%	t	P > t
Age group						
18–35 years	65	10.50	22	3.50	0.7684	0.2213
36–45 years	91	14.70	74	11.90		
46–60 years	160	25.80	99	15.90		
>60 years	70	11.30	40	6.40		
Sex						
Male	303	48.80	198	31.90	1.7641	0.078
Female	83	13.40	37	6.00		
Marital status						
Married	378	60.90	227	36.60	1.8980	0.0291
Single	6	1.00	0	0.00		
Divorced	2	0.30	8	1.30		
Level of education (years)						
Not attended school	9	1.40	4	0.60	2.0025	0.023
Primary	349	56.20	207	33.30		
Secondary	26	4.20	18	2.90		
College	2	0.30	4	0.60		
Adult education	0	0.00	2	0.30		
House hold size						
1–2 person	19	3.10	6	1.00	1.1821	0.1188
3–4 person	106	17.10	56	9.00		
5–6 person	138	22.20	98	15.80		
Above 6 persons	123	19.80	75	12.10		
Visits by extension officers						
Once	378	60.9	218	35.1	2.5702	0.0052
Twice	2	0.3	17	2.7		
More than twice	6	1.0	0	0.0		
Members of agricultural cooperatives						
No	25	4.0	165	26.6	22.504	0.000
Yes	361	58.1	70	11.3		
Training on CSA practices						
No	42.00	6.8	110.00	17.7	11.029	0.000
Yes	344.00	55.4	125.00	20		
Other sources of household income						
No	14.00	2	6.00	1	1.6718	0.0475
Yes	372.00	60	229.00	37		

Source: own elaboration.

note that women are disproportionately affected by climate change, highlighting the need for targeted efforts to enhance their participation in climate-related initiatives. The results also indicate that 60.9% of adopters and 36.6% of non-adopters were married, and the difference between the two groups is statistically significant ($p = 0.029$). Marital status may influence CSA adoption because it is often associated with land ownership (Kaba and Emana, 2024). Regarding education, 56.2% of adopters and 33.3% of non-adopters had attained primary education. Formal education was found to significantly increase the likelihood of adopting new technologies ($p = 0.023$), supporting evidence from Balula and Ngaiza (2024), Dissanayake et al. (2022), Hailemariam et al. (2024), and Kinyangi (2014). This suggests that most farmers were sufficiently literate to recognise the benefits of CSA practices. Household size data show that 22.2% of adopters and 15.8% of non-adopters had 5–6 household members, with average household sizes of 5 and 6 persons, respectively. The difference between groups was not statistically significant, implying that household size may not strongly influence CSA adoption decisions. The findings also reveal that 60.9% of adopters and 35.1% of non-adopters had contact with extension officers at least once per season. This statistically significant difference ($p = 0.0052$) highlights the crucial role of extension services in disseminating agricultural innovations, as previously documented by Hailemariam et al. (2024) and Pamphil (2023).

Membership in agricultural cooperatives was reported by 58.1% of adopters compared with only 11.3% of non-adopters. The mean difference is statistically significant ($p = 0.000$), suggesting that cooperative membership enhances farmers' access to information, collective learning and support systems that facilitate CSA adoption. Similar conclusions were reached by Ndauka and Matotola (2023) and Shirima (2022). Training exposure also appeared to be influential: 55.4% of adopters and 20% of non-adopters had attended training related to CSA practices, with the difference being statistically significant ($p = 0.000$). This underscores the importance of training in increasing farmers' awareness and understanding of climate change, thus promoting the uptake of CSA technologies. These results are consistent with Jha et al. (2020) and Matata et al. (2010). Finally, 60% of adopters and 37% of non-adopters reported having alternative income sources beyond coffee – such as other crops, livestock, or small and medium enterprises. The

statistically significant difference ($p = 0.0475$) suggests that income diversification may positively influence the likelihood of adopting CSA practices.

Adoption and uptake rates of climate-smart agriculture practices

The findings show that 70.42% of respondents were adopters of CSA practices, while 29.58% were non-adopters. Additionally, 49.9% of smallholder farmers in the study areas reported adopting improved coffee varieties (Table 2). This adoption rate is substantially higher than the 3% reported by Kiwelu et al. (2021) in Mbinga and Mbozi Districts, and the 29.2% reported by Mhando and Mdoe (2018) in the Southern Highlands of Tanzania. In comparison, Diro and Erko (2019) established a 53.56% adoption rate among Ethiopian farmers. Collectively, these findings suggest a significant increase in the uptake of improved coffee varieties within the study areas. The results further indicate that 91.3% of respondents adopted integrated pest management (IPM) technologies, which include biological, cultural, and chemical methods for controlling coffee pests. These uptake levels are comparable to findings by Sanga and Mahonge (2013), who reported a 73% adoption rate of IPM technologies among bean farmers in Mbeya District. Similarly, 83.1% of farmers had adopted integrated soil fertility management (ISFM) practices, including the use of inorganic fertilisers (62.2%) and organic

Table 2. Type of CSA practices adopted by smallholder farmers

CSA practices descriptions	Rate of adoption in percentage (%)	
	adopters	non-adopters
Coffee varieties	49.9	50.1
Integrated pest management (IPM)	91.3	8.7
Integrated soil fertility management (ISFM)	83.1	16.9
Agroforestry	63.9	36.1
Soil and water conservation (S&WC)	61.8	38.2
Crop diversification	72.5	27.5
Average	70.42	29.58

Source: own elaboration.

manure (55.4%). These adoption levels are higher than the 44% reported by Mbunduki (2024). Previous studies by Maro (2014), Mponela et al. (2023), and Mutuku et al. (2017) highlight the role of ISFM in improving soil fertility. The findings also show that 63.9% of respondents planted shade trees in their coffee farms as part of income diversification and climate mitigation strategies. Shade trees contribute to climate resilience by regulating microclimates and supporting coffee growth. Studies by Zella and Lunyelele (2024) and Klara (2020) document the benefits of shade trees, including microclimate regulation, soil fertility enhancement, biodiversity conservation, and pest and disease management. Furthermore, 76.5% of respondents practised soil and water conservation (S&WC) techniques, such as mulching, constructing trenches to control soil erosion, and harvesting rainwater. Adili (2024) and Amado (2024) emphasise S&WC as vital strategies for mitigating the impacts of climate change on agricultural systems. Finally, 72.5% of respondents engaged in crop diversification as a component of climate-smart agriculture. In addition to coffee, banana was commonly intercropped, while other crops such as beans and maize were cultivated in separate plots. Earlier studies by Mhando and Mdoe (2018), Mwakalobo (2005), and Otieno et al. (2019) highlight how income and crop diversification strategies contribute to improved coffee productivity in Tanzania's Southern Highlands.

Multivariate regression model estimates

A multivariate regression model was employed to examine the factors influencing coffee farmers' adoption of specific climate-smart agriculture (CSA) practices. Table 3 presents the key model diagnostics, including

the number of observations, estimated parameters, root mean square error (RMSE), R-squared values, F-ratios, and corresponding p-values for each of the regression models. All six univariate models yielded statistically significant p-values, indicating the predictors included in the model were reliable and relevant in explaining variations in CSA adoption. The R-squared values further show that the six predictor variables accounted for 58%, 48%, 52%, 34%, 62%, and 61% of the variance in their respective outcome variables.

Variables affecting the choice of improved coffee varieties

The findings presented in Table 4 indicate that marital status ($p = 0.029$), household size ($p = 0.030$), visits from extension officers ($p = 0.005$), coffee yield ($p = 0.000$), household income ($p = 0.094$), and membership in agricultural cooperatives ($p = 0.000$) had a positive and significant influence on the adoption of improved coffee varieties in the study areas. Conversely, the size of land under coffee cultivation ($p = 0.000$) was found to have a negative effect on adoption, likely due to the high perceived costs associated with investing in improved varieties across larger farm areas. Similar observations regarding the influence of age, education level, and household income on adoption decisions have been reported by Diro and Erko (2019), Kiwelu et al. (2021), and Kurgat et al. (2020). Overall, the findings underscore the role of socio-economic characteristics, farm-specific factors, and institutional support in shaping farmers' decisions to adopt improved coffee varieties. Strengthening these elements or addressing related constraints may help enhance the uptake of climate-smart agriculture (CSA) practices among smallholder farmers in the study areas.

Table 3. Variables estimated in the Multivariate Regression Model

Equation	Obs	Parms	RMSE	R-sq	F	P
Coffee varieties	606	12	0.327	0.581	74.994	0.000
Integrated pest management (IPM)	606	12	0.208	0.476	49.021	0.000
Integrated soil fertility management (ISFM)	606	12	0.265	0.520	58.441	0.000
Agroforestry	606	12	0.398	0.337	27.452	0.000
Soil and water conservation	606	12	0.301	0.616	86.450	0.000
Crop diversification	606	12	0.282	0.613	85.631	0.000

Source: own elaboration.

Table 4. Coefficient estimates of the multivariate probit model for the adoption of specific CSA practices

Variables	Access		Manure		Weeding		Pruning		IPM		ISFM		Mulch		Agro		Rainw		Farming	
	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.	coef.	std. err.
Age	0.222***	0.071	-0.106	0.065	0.015	0.054	0.039	0.047	-0.048	0.034	-0.140***	0.044	0.075	0.066	0.142**	0.050	-0.014	0.068	-0.331***	0.049
Sex	-0.085	0.047	-0.153*	0.043	0.027	0.036	-0.031	0.031	-0.012	0.023	0.014	0.029	-0.110*	0.043	0.043	0.033	0.177***	0.045	0.035	0.032
Marital status	-0.033	0.067	0.003	0.062	0.113*	0.051	-0.048	0.044	-0.212***	0.033	-0.128**	0.042	-0.082	0.062	0.022	0.047	-0.203**	0.064	-0.013	0.046
Level of education	0.279**	0.116**	-0.259*	0.107*	0.140	0.089	-0.130	0.076	0.062	0.056	-0.110	0.072	0.024	0.108	-0.092	0.082	0.067	0.112	-0.167*	0.080
Household size	-0.138***	0.050	-0.001	0.046	0.082*	0.039	-0.011	0.033	-0.048*	0.025	-0.020	0.031	-0.117**	0.047	-0.058	0.035	-0.046	0.049	0.143***	0.035
Visit of extension officers	-0.076	0.053	0.098*	0.049	0.114**	0.040	0.180***	0.035	0.027	0.026	0.055	0.033	-0.068	0.049	0.161***	0.037	0.023	0.051	0.256***	0.036
Land size under coffee	0.008	0.033	-0.139***	0.030	-0.499***	0.025	-0.317***	0.022	-0.174***	0.016	-0.273	0.020	0.368	0.030	-0.393	0.023	-0.020	0.031	0.247	0.022
Coffee yield	0.224***	0.040	0.099***	0.037	0.485***	0.030	0.355***	0.026	0.225***	0.019	0.307***	0.025	-0.396***	0.037	0.405***	0.028	0.002	0.038	-0.197***	0.027
Household income	0.177***	0.046	0.027	0.042	0.128***	0.035	0.227***	0.030	-0.045**	0.022	0.082***	0.029	-0.035	0.043	0.272***	0.032	-0.151***	0.044	-0.002	0.032
Membership of agric. cooperative	0.024	0.059	0.071	0.055	-0.021	0.046	0.041	0.039	0.127***	0.029	0.087**	0.037	0.017	0.055	-0.030	0.042	0.046	0.057	-0.043	0.041
_cons	-2.251	0.464	0.961	0.428	-3.560	0.356	-1.872	0.307	-0.315	0.226	-0.494	0.289	3.387	0.433	-2.763	0.327	0.849	0.448	3.199	0.320

Coefficient in parentheses ***p < 0.01, **p < 0.05, *p < 0.1 represent level of significance respectively.

Determinants of IPM adoption

Integrated pest management (IPM) encompasses recommended techniques used to manage coffee pest infestations. The findings indicate that both coffee yield ($p = 0.000$) and farmer training on climate-smart agriculture practices (CSA) ($p = 0.000$) significantly and positively influence the adoption of IPM practices. In contrast, marital status ($p = 0.000$), household size ($p = 0.048$), land area under coffee cultivation ($p = 0.002$), and membership in an agricultural cooperative ($p = 0.048$) were found to negatively affect IPM adoption. These findings suggest that the adoption of IPM practices is linked to farmers' utility considerations, particularly their aim to increase productivity while minimising production costs through IPM strategies. The positive effect of training aligns with technology adoption theory, which emphasises the importance of information and knowledge sharing. Farmers who are well-informed about a particular practice are more likely to adopt it compared to those with limited knowledge. Effective adoption of IPM technologies requires farmers to possess sufficient knowledge and the capacity to evaluate their effects on productivity. Smallholder farmers with greater awareness are more likely to recognise the benefits and apply these technologies effectively than those with limited information. As noted by Magina (2011), IPM involves a combination of cultural, biological, and chemical methods for managing coffee pests, underscoring the need for a holistic and informed approach to pest control.

Determinants of ISFM adoption

The findings on integrated soil fertility management (ISFM) indicate that several factors positively and significantly influence its adoption. These include visits from extension officers ($p = 0.097$), higher coffee yields ($p = 0.000$), membership in an agricultural cooperative ($p = 0.003$), and participation in CSA-related training ($p = 0.013$). In contrast, ISFM adoption was negatively and significantly associated with age ($p = 0.004$), marital status ($p = 0.002$), land size under coffee cultivation ($p = 0.031$), and household income ($p = 0.021$), suggesting that these variables may act as barriers to the uptake of CSA practices. The negative influence of age suggests that older farmers are less likely to adopt CSA practices, possibly due to limited exposure to new technologies, shorter planning horizons, or reduced willingness to adopt unfamiliar practices. Similarly, married

households and farmers with larger land sizes were less likely to adopt ISFM technologies, potentially due to the higher capital requirements needed to implement new technologies across larger farm areas. These findings are consistent with studies by Alela et al. (2024), Maro (2014), and Sanginga and Woomer (2009), which also highlight the critical role of socio-economic characteristics and institutional support in shaping the adoption of ISFM technologies. Overall, the results reinforce the importance of addressing these constraints to promote wider uptake among smallholder farmers.

Determinants of agroforestry adoption

In this study, agroforestry is defined as an integrated land use system that incorporates trees, crops, and sometimes livestock within a coordinated farming environment. The findings indicate that the respondent's sex ($p = 0.009$) and the size of land under coffee cultivation ($p = 0.000$) positively and significantly influence the adoption of agroforestry practices. In contrast, household size ($p = 0.012$) and coffee yield ($p = 0.000$) were found to negatively and significantly affect adoption. These results are consistent with findings by Waktola and Fekadu (2021) and Wienhold and Goulao (2023), who reported that adoption of coffee shade agroforestry technologies had a positive and statistically significant relationship with age and the area under coffee production ($p = 0.000$), while landholding size showed a positive but non-significant association.

Factors influencing the adoption of soil and water conservation

Soil and water conservation is especially important in highland coffee-growing areas, where intense rainfall frequently causes severe soil erosion, undermining soil health and reducing coffee productivity. The results show that farmers' age ($p = 0.004$), frequency of extension officer visits ($p = 0.000$), coffee yield ($p = 0.000$), and membership in agricultural cooperatives ($p = 0.000$) all had positive and significant effects on the adoption of conservation practices such as mulching and minimum tillage. In contrast, land area under coffee cultivation ($p = 0.000$) was negatively associated with adoption, possibly due to the greater labour and resource requirements needed to implement these practices on larger plots. These findings are consistent with earlier studies by Diro et al. (2022), Fikirie (2021), and Jia et al. (2024), which highlight the roles of both

household characteristics and farm attributes in shaping the uptake of soil and water conservation measures.

Determinants of crop diversification farming practices adoption

The study found that the adoption of crop diversification as a climate-smart agriculture (CSA) strategy was significantly and positively influenced by visits from extension officers ($p = 0.000$), coffee yield ($p = 0.000$), and membership in an agricultural cooperative ($p = 0.000$). In contrast, the respondents' level of education ($p = 0.091$), land size under coffee cultivation ($p = 0.003$), and household income ($p = 0.064$) had negative effects on adoption. These results imply that larger households are more likely to adopt crop diversification to enhance income generation and household food security. Increased interaction with extension officers also encourages the uptake of diversified farming practices as part of climate change adaptation measures. Additionally, increases in land dedicated to coffee production may lead smallholder farmers to consider alternative crops to meet household needs. Similar findings were reported by Valérie et al. (2024), who documented the influence of comparable socio-economic and institutional factors on the adoption of crop diversification as a strategy for climate change mitigation. Conversely, the study found that age ($p = 0.000$), household size ($p = 0.029$), and coffee yield ($p = 0.000$) had a statistically significant negative impact on the adoption of crop diversification practices. This suggests that older farmers, those with larger households, and farmers achieving higher coffee yields may be less inclined to diversify their crops.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that decisions regarding whether to adopt climate-smart agriculture (CSA) practices and the extent to which they are used are highly interconnected. Smallholder farmers in the study areas do not adopt CSA practices in isolation; rather, the adoption of one practice often complements or reinforces the adoption of others. This pattern reflects the influence of multiple interacting factors – including cooperative membership, pest management strategies, and the choice of coffee varieties – which collectively determine the extent to which farmers implement CSA practices. These findings emphasise the need for coordinated and

multisectoral efforts to support CSA uptake. To strengthen CSA adoption among smallholder farmers, greater collaboration among key coffee-sector stakeholders is essential. The Government of Tanzania should enhance policy, legal, and institutional frameworks to improve the effectiveness and efficiency of CSA implementation. This requires aligning agricultural and environmental policies with CSA objectives, improving coordination across institutions, and ensuring that adequate resources are available to support farmers. Such measures should be complemented by efforts to strengthen household income, enhance farm management skills, and build institutional capacity within the sector. Stronger partnerships are also needed between government agencies, agricultural cooperatives, and major coffee-sector support institutions – such as the Tanzania Coffee Board (TCB), Tanzania Coffee Research Institute (TaCRI), Moshi Cooperative University (MoCU), NGOs, and private sector actors – to promote sustainable and climate-resilient coffee production. Finally, smallholder farmers are encouraged to actively engage with extension services and training programmes focused on CSA practices. Regular participation will enhance their knowledge and technical capacity, enabling more informed decision-making, improved productivity, and better access to institutional support and market opportunities. Increased engagement will also strengthen farmers' collective influence within cooperatives and policy forums, further supporting sustainable growth of the coffee sector.

Areas for further research

While this study established that 70.42% of respondents adopted at least three CSA practices, it did not identify which combinations generate the greatest productivity gains. Future research could therefore explore the synergistic effects of different CSA practice combinations on coffee yield resilience. Such analysis would help determine whether certain bundles of practices offer superior benefits compared to adopting them individually. Additionally, because the study focused primarily on smallholder farmers affiliated with agricultural cooperatives, an important research gap remains regarding farmers who are not members of such institutions. Investigating the socio-economic and institutional constraints faced by non-cooperative farmers could support the development of more inclusive CSA adoption strategies. Furthermore, although this study assessed the level of CSA adoption among smallholder farmers, it did not evaluate

the economic outcomes associated with these practices. Future studies could examine how CSA adoption affects profitability, cost-benefit dynamics, and yield performance at the household level. Such evidence would be valuable for informing policy decisions and guiding stakeholders in promoting sustainable and economically viable coffee production.

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