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Research article

Awareness and adoption of climate-resilient practices by smallholder farmers in central and upper Eastern Kenya

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ABSTRACT

Climate change and soil fertility decline are major hurdles to agricultural ecosystems. Despite the importance of climate-resilient practices (CRPs) in enhancing food security, poverty alleviation and nutritional security, awareness and adoption remain low in most developing countries, including Kenya. We assessed the determinants of simultaneous awareness and adoption of CRPs and their intensity in Central Highlands of Kenya. The CRPs considered in this study were inorganic fertilizer and manure integration, manure, mulching, crop residues, cover crop, crop rotation and intercrop. The study used a cross-sectional survey design and collected data from 400 smallholders in Central Highlands of Kenya. The data were analyzed using descriptive statistics, multivariate probit and Poisson regression. Our findings showed that awareness and adoption of specific CRPs and their intensity were determined by occupation, age, farming experience, household size, soil fertility management, climate change adaptation, agricultural training, and geographical location. Smallholders' agricultural training was an important determinant of awareness, adoption level, and intensity. Our findings underscored the need for agricultural policymakers and extension systems to design farmer-driven training programs for enhanced awareness and adoption of CRPs.

1. Introduction

The agricultural agroecosystems face the triple challenges of feeding a growing population, enhancing smallholders' livelihoods and promoting environmental protection [1]. The low agricultural productivity challenges are exaggerated by climate change and soil fertility decline [2,3]. The impacts of climate change and soil fertility decline are more pronounced in developing countries in sub-Saharan Africa, including Kenya [4,5]. The effects of climate change and soil fertility decline are exacerbated by the over-dependence on rainfed agriculture and limited adoption of climate-resilient practices [6,7]. Therefore, to feed the ever-growing

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population in Kenya, there is a pressing need to adopt sustainable agricultural approaches.

A range of farmers' agricultural practices fall in the category of Sustainable Agricultural Practices (SAPs) [8,9]. Users of SAPs also derive economic benefits (productivity and profitability), social benefits (promote smallholders' livelihoods), and environmental protection advantages (including climate change mitigation, soil fertility amelioration, and reduction of land degradation) from their use [10–12]. This study uses the term "climate-resilient practices" (CRPs) to emphasise the growing need for SAPs that can enhance smallholders' response to the threats imposed by climate change. The study focused on the following CRPs: fertilizer + manure integration, animal manure application, mulching, crop residue retention, cover cropping, crop rotation and intercropping. Except for mineral fertiliser, which is input-intensive, the other practices fall in the category of nature-based solutions aimed at addressing environmental stresses [13]. We focus on climate-resilient practices that are specifically aimed at addressing soil fertility constraints and climate change.

The technology adoption process involves a sequence of events, including awareness, interest, evaluation, trial, and adoption [14]. An important feature of this process is gathering information about innovative practices [15]. According to Doss [16], the main knowledge constraints to adoption are a lack of awareness of the existence of new technology or its benefits and a poor understanding of the cost of implementation vis a vis the benefits. Dimara and Skuras [17] use the term "awareness" synonymously with "farmer learning" to mean the acquisition of information before the adoption of a new technology. The CRPs in our study were not entirely new technologies; hence, the term awareness was used to refer to a farmer hearing about a given CRP and learning more about it [18]. It was operationalized by asking the farmers to indicate whether they "knew about" the practices. We defined adoption as the use of any identified CRPs by the farmer at the time of the study. Intensity of adoption referred to the number of individual CRPs the farmer used at the time of the study.

Smallholders are faced with a decision to adopt one or more CRPs [19]. According to Mugwe et al. [20], farmers constantly pick up new technologies to expand their portfolio and drop some of those already in use, with these decisions being motivated by various factors. The use of multiple technologies has also been captured by Wainaina et al. [13], who found complementarities among the technologies. Adopting one practice could lead to adopting or not adopting the second one based on whether the practices act as complements or substitutes [21]. Additionally, the adoption level is influenced by the initial investment cost and technical know-how requirements [22]. Smallholders are more willing to adopt CRPs that require a low initial investment and are easy to implement.

Limited awareness and adoption of some CRPs is a serious hurdle in fully realizing the potential gains. The adoption of CRPs is determined by the expected utility of the smallholders [19]. Therefore, smallholders are likely to adopt practices with higher utility. Additionally, the adoption of the CRPs is influenced by smallholders' level of awareness. Understanding smallholders' awareness and adoption trends is vital to solving agriculture's triple challenges. Empirical evidence finds that socioeconomic (gender, age, experience, among others), institutional (extension, group membership, credit), and biophysical characteristics influence the awareness and adoption of CRP [23–26]. Important socioeconomic factors explaining awareness and adoption include education, gender, age, experience, occupation, land holding, family size and tropical livestock unit [18.27, 28]. Institutional characteristics such as credit access, agricultural training, group membership, and extension have been found to affect awareness and adoption [21,27]. Biophysical characteristics such as soil fertility status, soil fertility change, soil testing and geographical location predict the awareness and adoption of climate-resilient practices [28–30].

Numerous empirical studies have investigated the adoption of climate-smart agricultural practices [7,19,31]. However, studies that assess the determinants of joint awareness and adoption of various climate-resilient practices in Kenya are sparse. This study assesses the socioeconomic, institutional and biophysical determinants of climate-resilient practices awareness and adoption in the Central Highlands of Kenya.

2. Materials and methods

2.1. Study area description

We conducted the study in Gatanga and Meru South sub-counties in Murang'a and Tharaka-Nithi in the central highlands of Kenya. The two sub-counties are in the same agroecological zones (AEZs) and have similar cropping activities and land use practices [32]. The sub-counties experience bimodal rains, with long rains occurring between March and June and short rains from October through December. Gatanga sub-county lies in five AEZs: Lower Highlands (LH1), Upper Highlands (UH1), Upper Midlands (UM1, UM2 and UM3) [33]. The sub-county receives annual rainfall amounts ranging between 900 and 1400 mm. The main soils are well-drained, extremely deep *Nitisols* with moderate to high soil fertility [32]. The sub-county has a population of 187 987 persons, 55 461 households, and a population density of 354 persons per square kilometre [34].

Meru South sub-county has eight AEZs: Lower Highlands (LH1), Upper Midlands (UM1, UM2 and UM3), Lower Midlands (LM3, LM4 and LM5) and Intermediate Lowlands (L5), Jaetzold et al., 2007). The long-term annual rainfall ranges between 600 and 1800 mm [33]. The main soils are *Humic Nitisols* with moderate to high soil fertility [35]. Meru South had a population of 144 290 persons, 42 594 households and 312 persons per square kilometre [34].

Food and cash crops thrive well in the central highlands of Kenya. Maize is the primary food crop grown in the central highlands of Kenya under a smallholder system [36]. The other food crops in the central highlands of Kenya include beans (*Phaseolus vulgaris*), peas (*Pisum sativum),* sorghum (Sorghum bicolor) and millet (*Pennisetum glaucum*). Cash crops include coffee (*Coffea arabica*), tea (*Camellia sinensis*), tobacco (*Nicotiana tabacum*), Napier grass (*Pennisetum purpureum*) and banana (*Musa balbisiana*) cropping systems.

2.2. Sampling

In this study, we targeted smallholder farmers in central and upper Eastern Kenya. The sample size was calculated following Cochran [37].

$$ss = \frac{z^2 p(1\text{-}p)}{E^2} = \frac{1.96^2 \times 0.5(1\text{-}0.5)}{0.0693^2} = 200 \qquad \text{Equation 1}$$

where ss = sample size, z = z value (e.g. 1.96 for 95 % confidence level), p = percentage picking a choice, expressed as decimal (0.5), 1-p and E = 6.93 % allowable error, expressed as decimal (0.0693). Therefore, 200 household heads were sampled from each sub-county, resulting in 400 households/respondents.

We employed a cross-sectional survey design in the actual data collection. We performed a multistage sampling procedure to collect data from individual household heads. First, we performed a total population sampling to select all the wards in the study area. Secondly, we used a proportionate-to-size sampling procedure to determine the number of households sampled in each ward. Thirdly, we randomly sampled the individual household heads using a sampling frame obtained from ward agricultural officers.

We recruited and trained ten trained enumerators to administer a semi-structured interview schedule. The enumerators were residents of the respective sub-counties and were conversant with the geography of the study area, both spoken and written English and local dialect; hence, they could freely interact with the respondents. Before data collection, we trained the enumerators on correctly interpreting the questions and engaged them in pretesting the research tool. Following pretesting, the interview schedule was revised to capture ground factual variables. The authors closely supervised actual data collection. The interview schedule had questions on farmer and farmer characteristics, institutional factors and CRPs awareness and adoption (Supplementary material).

2.3. Study variables

We had two sets of dependent variables. First, the awareness and adoption level of seven CRPs: inorganic fertilizer and manure integration, manure, mulching, crop residues, cover crop, crop rotation and intercrop. Second, the intensity of awareness and adoption (the number of CRPs) a farmer was aware of or adopted. Therefore, we had four dependent variables, namely i) awareness level, ii) adoption level, iii) intensity of awareness and iv) intensity of adoption. We selected the independent variables to include socioeconomic, institutional and biophysical factors, based on the authors' expertise in the subject and literature.

2.4. Data analysis

We performed all the statistical analysis using Stata 15 software. Before data analysis, we conducted data coding and cleaning and calculated the tropical livestock unit (TLU). The TLU calculation is an essential transformation where all the livestock are converted to a single unit. We employed descriptive statistics, multivariate probit regression and Poisson regression. The descriptive statistics implemented included the mean, standard error of the mean, frequency and percentages.

2.4.1. Multivariate probit model

Smallholder farmers are faced with a decision to adopt multiple CRPs. The decision to adopt the multiple CRPs could be modeled using the binary probit model. However, the binary probit model only analyzes the adoption of a single technology at a time [19]. The adoption of one practice could be conditional on the adoption of other practices. Therefore, in assessing the determinants of joint awareness and adoption of CRPs, interdependencies between error terms of different practices, namely inorganic fertilizer and manure integration, manure, mulching, crop residues, cover crop, crop rotation and intercrop, are assumed. The multivariate probit model estimates the determinants of joint awareness and adoption of the CRPs [24]. In this study, we employed multivariate probit regression to analyze simultaneous awareness and adoption of the seven CRPs, similar to Kpadonou et al. [24]. The utility of awareness or adoption of CRPs is a latent variable determined by observed characteristics and multivariate distribution of the error terms (Equation (2)).

$$U_{in}^{*} = X_i B_n + \mathcal{E}_i \ (n = FM, M, Ml, Cr, CC, R, IC) \qquad \text{Equation 2}$$

Where U_{in}^{*} is the net utility of awareness and adoption from the nth source; X_i vector of observed household characteristics, B_n vector coefficients to be estimated, FM,M, Ml, Cr, CC, R and IC are the fertilizer and manure integration (FM), manure (M), mulching (Ml), crop residues (Cr), cover crop (CC), crop rotation (R) and intercropping practices (IC); $\mathcal{E}_i$ normally distribute multivariate error terms. A farmer will choose to adopt CRPs only if the gains from that source outweigh not adopting. Therefore, this is a binary choice as described in equation (3).

$$U_{ik}^{*} = \begin{cases} 1 \text{ if } U_{ik}^{*} > 0 \\ 0 \text{ otherwise} \end{cases} \qquad \text{Equation 3}$$

Before multivariate probit analysis, we tested the null hypothesis that pairwise multivariate correlation coefficients (rho) of error terms are equal to zero.

2.4.2. *Poisson regression*

The number of practices a smallholder farmer is aware of or adopted is a count variable. Given that the dependent variables are count, they can be analyzed using Poisson regression model or a negative binomial regression model [38]. The Poisson regression is based on the assumption that mean and variance of the outcome variable are equal. On the other hand, an additional term to account for the excess variance is added in negative binomial regression model. The dependent variables were defined as awareness and adoption intensity. The dependent variables could be analyzed using Poisson regression [39–41]. Previous studies investigating intensity of CRPs employed Poisson Regression [41,42]. Before performing Poisson regression, we tested for overdispersion that could cause the standard deviation to exceed the mean. We used both deviance and the Pearson Chi-Square test to examine for over-dispersion [43]. The model was tested for the assumption and was plausible for the Poison regression. The Poisson regression on awareness intensity of CRPs showed a Deviance goodness-of-fit of 103.6014 with pro > chi square (383) = 1.0000 and Pearson goodness-of-fit of 101.0942 with pro > chi square (383) = 1.0000. The Poisson regression on adoption intensity of CRPs revealed a Deviance goodness-of-fit of 177.4065 with pro > chi square (383) = 1.0000 and Pearson goodness-of-fit of 159.5108 with pro > chi square (383) = 1.0000. We assumed the number of CRPs i a farmer was aware of or adopted had a Poisson distribution with the rate $P_i \times \lambda_{i.}$ Where P_i is the number of CRPs a farmer was aware of or adopted, log (λ_i) is the linear predictor. Assuming the number of climate-resilient practices (U) aware or adopted by a farmer had a Poisson distribution, the covariates' effect could be modeled using a log-linear model (equation (4)).

$$In\ U = \beta o + \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + +\beta_j X_j \qquad \text{Equation 4}$$

To predict the value of U as a count variable, we took the exponents on both sides to yield equation (5).

$$Y = e.^{\beta o + \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + +\beta_j X_j} \qquad \text{Equation 5}$$

Where the dependent variable (U) is the CRPs aware or adopted by a farmer, the intercept (B_o), regression coefficients (β_1, $\beta_2 \ldots \beta_j$), and intensity of awareness and adoption determinants (X_1, $X_2 \ldots X_j$).

3. Results and discussion

3.1. *Descriptive characteristics*

The response rate was 397 (99.25 %). Our findings revealed that farmer characteristics are central to agricultural investments (Table 1). Age is an important variable in awareness and adoption studies as it is instrumental in understanding human perceptions and behavior [44]. Previous studies showed that age could have a mixed influence on adoption and awareness [21]. From our results, the average age of the farmers was 52.09 years, indicating that smallholders belonged to the active age bracket. Farming experience is an essential factor in adoption decision-making. The farmers had a farming experience of 24.22 years. Experienced farmers have the requisite knowledge to decide whether to adopt a technology or not based on the expected utility. The study showed that the average household size was 4.08, indicating a moderate family size in the study area. In awareness and adoption studies, family size is used as an indicator of sources of information and supply of labor [25,45]. Most (60 %) household heads were male. Male-headed households could have higher adoption of climate change response strategies due to resource endowment compared to their female counterparts. Women tend to have less access to secured land tenure and limited access to technology information and extension than men [46]. Wambua et al. [47] revealed that male dominance in controlling production resources enhances bean productivity. Our findings showed a higher (94 %) proportion of literate farming household heads (farming household heads who could read and write). Previous studies highlighted education as an important variable in the awareness and adoption of climate change response strategies [18,19,48]. We found that most (92 %) household heads' occupation was farming. Occupation is an essential variable in awareness and

Table 1
Descriptive variables of the sampled households.

Variable Description	Abbreviation	Unit	Mean ± SE	Min	Max
Gender of the household head (HHH), 1 male, 0 female)	HHH male	% hhs	0.60 ± 0.03	0	1
Education level of the HHH (0 no formal, 1 primary and above)	HHH literate	% hhs	0.94 ± 0.01	0	1
Main occupation of the HHH (1 agriculture, 0 otherwise)	HHH agriculture main occupation	% hhs	0.92 ± 0.01	0	1
Age of HHH (years)	HHH age	years	52.09 ± 0.77	21	102
Family size of the household	HH size	number	4.08 ± 0.09	1	11
Farming experience of the household head (years)	HHH farming experience	years	24.22 ± 0.77	1	68
HHH accessed agricultural training (1 yes, 0 No)	Agricultural training	% hhs	0.25 ± 0.02	0	1
HHH was a member in the agricultural group (1 yes, 0 No)	Group membership	% hhs	0.35 ± 0.02	0	1
Total land size (acres)	Total land size	acres	1.76 ± 0.08	0.20	12.00
Rented in land size (acres)	Rented in size	acres	0.09 ± 0.02	0.00	3.00
Land size under cultivation (acres)	Arable land size	acres	1.32 ± 0.07	0.13	9.00
Tropical Livestock Unit[a]	TLU	unit	2.12 ± 0.26	0.00	65.23
Farmer perceived soil fertility status was good (1 yes, 0 No)	Soil fertility good	% hhs	0.58 ± 0.03	0	1
Farmer perceived soil fertility status had improved (1 yes, 0 No)	Soil fertility improved	% hhs	0.22 ± 0.02	0	1
Household from County (1 Tharaka-Nithi, 0 Murang'a)	Tharaka-Nithi	% hhs	0.50 ± 0.03	0	1

[a] The tropical livestock unit calculated following Jahnke [49].

adoption studies as it influences the time dedicated to farming operations. Musafiri et al. [42] revealed that households heald whose main occupation is farming dedicate more time and resources to improve productivity.

This study showed that one-quarter of the household heads were members of agricultural groups. This suggested that group membership in the study area was low. Group membership is key in enhancing awareness and adoption as groups act as sources of knowledge and pooling of resources to access agricultural support [36]. Further to this study, around one-third (35 %) of farming households had access to agricultural training. The findings suggested low penetration of extension services among the farming households. Extension agents play a critical role in creating awareness of innovative agricultural practices that influence adoption decisions among smallholders.

The arable land ranged from 0.13 to 9.00 acres, with an average of 1.32 acres. Though the arable land size was small, there was potential expansion through renting in and utilizing uncultivated land. Land size is an important variable as it indicates the resources available for allocation to different innovative practices. Previous studies showed a positive influence of land size on awareness and adoption of improved agricultural practices [23,24,31]. The tropical livestock unit (TLU) ranged from 0 units to 65.23 units and an average of 2.12 units. The herds of livestock kept by smallholder farmers are an essential factor indicating crop-livestock integration and manure production.

Further, 58 % of the sampled smallholders perceived soil fertility as good. Soil fertility perception is key in adoption decisions. Smallholders who perceive soil fertility on their agricultural land as good could be reluctant to implement ameliorating practices. Additionally, 22 % of the smallholders perceived that the soil fertility was improving. Smallholder perceptions of soil fertility and degradation are essential in making amelioration decisions [50].

3.2. Awareness and adoption level of climate-resilient practices

Across the seven CRPs, the awareness level was higher than the adoption level except for crop rotation (Table 2). Our findings were similar to Mango et al. [23], who found that the awareness level was greater than the adoption level across most Southern African soil and water conservation practices. The discrepancies between awareness and adoption under crop rotation could be attributed to inconsistencies in their measurement methods where smallholders' perceptions are used [23]. Additionally, farmers can copy from their neighbors, assuming that the practice could be beneficial. Smallholder farmers' awareness of CRPs ranged from low (3.8 %) under mulching to high (98.5 %) under fertilizer manure integration. We observed similar trends in the adoption, with the lowest rate (2.0 %) under mulching and the highest (91.4 %) under fertilizer manure integration. Awareness and adoption level of agricultural innovations in sub-Saharan Africa ranges from low to high [19,21,23,40].

3.3. Awareness and adoption intensity of climate-resilient practices

The intensity of awareness ranged from 2 to 6 climate-resilient practices (Table 3). Indicating that every farmer was aware of at least two CRPs. Most (33.3 %) of the farming household heads were aware of four CRPs. Regarding adoption intensity, all (100 %) farmers had adopted at least one practice out of the seven as assessed in the study. Our findings were consistent with those of Kpadonou et al. [24] and Musafiri et al. [19], who confirmed that most smallholders adopt at least one agricultural innovation in sub-Saharan Africa. However, the adoption intensity ranged from 1 to 6 practices. Approximately one-third (32.5 %) of the farmers adopted three practices. The findings indicated that adoption intensity varies across specific practices and households.

3.4. Correlation of error terms

The covariates of error terms were correlated; the awareness model statistics had a chi^2 (21) = 63.3248 and Prob > chi^2 = 0.0000, while the adoption model had a chi^2 (21) = 121.619 and Prob > chi^2 = 0.0000 (Table 4). Our results implied that there were interdependencies between the practices' awareness and adoption. Therefore, we rejected the null hypothesis that all coefficients are jointly equal to zero. Additionally, the multivariate model showed a good fit (model Wald chi-square = 281.57, prob > chi^2 = 0.0000, and log pseudo-likelihood −1102.13 of awareness model and model Wald chi-square = 286.28, prob > chi^2 = 0.0000, and log pseudo-likelihood −1089.2842 of adoption model), (Tables 5 and 6). We rejected the hypothesis that the covariates of error terms were not correlated. The study showed several pairwise correlations of climate-resilient practices (Table 4). Our findings confirm the interdependence in awareness and adoption of climate-resilient practices, which could be due to the synergetic or substitute nature of

Table 2
Awareness and adoption of climate-resilient practices.

Technology	Awareness	Adoption
Fertilizer and manure integration	391 (98.5)	363 (91.4)
Animal Manure	358 (90.2)	334 (84.1)
Mulching	15(3.8)	8 (2.0)
Crop residue	139 (35.0)	131 (33.0)
Cover crop	146 (36.8)	124 (31.2)
Crop rotation	265 (66.8)	275 (69.3)
Intercropping	360 (90.7)	259 (65.2)

Value in parenthesis are percentages.

Table 3
Intensity of awareness and adoption.

Intensity	Awareness		Adoption	
	Aware	Percentage (%)	Adopters	Percentage (%)
0	0	0.00	0	0.00
1	0	0.00	22	5.54
2	22	5.54	36	9.07
3	87	21.91	129	32.49
4	132	33.25	85	21.41
5	95	23.93	72	18.14
6	61	15.37	52	13.10
7	0	0.00	0	0.00

Table 4
Correlation coefficient of the multivariate probit model error terms.

Technologies combination	Awareness				Adoption			
	Coef.	Std. Err	Z	P>|z|	Coef.	Std. Err	Z	P>|z|
rho21	−0.201	0.309	−0.65	0.515	**0.284****	0.138	2.06	0.039
rho31	**0.779****	0.370	2.11	0.035	0.296	0.198	1.49	0.135
rho41	0.152	0.219	0.70	0.487	**0.200***	0.107	1.87	0.062
rho51	−0.164	0.194	−0.85	0.398	0.096	0.108	0.89	0.374
rho61	0.072	0.189	0.38	0.703	**0.212****	0.102	2.08	0.038
rho71	0.185	0.455	0.41	0.684	**0.289****	0.113	2.55	0.011
rho32	**−0.412***	0.211	−1.96	0.051	−0.397	0.254	−1.56	0.118
rho42	0.053	0.140	0.38	0.704	**0.217****	0.102	2.13	0.033
rho52	**0.255****	0.119	2.14	0.032	0.022	0.099	0.22	0.825
rho62	0.026	0.119	0.22	0.827	**0.212****	0.091	2.34	0.019
rho72	0.140	0.287	0.49	0.627	**0.661*****	0.110	6.02	0.000
rho43	−0.003	0.162	−0.02	0.985	0.087	0.125	0.70	0.486
rho53	−0.143	0.164	−0.87	0.385	**0.212***	0.128	1.65	0.099
rho63	0.064	0.153	0.42	0.674	−0.146	0.131	−1.12	0.263
rho73	0.210	0.367	0.57	0.568	−0.108	0.165	−0.66	0.511
rho54	**0.459*****	0.097	4.74	0.000	**0.169***	0.088	1.92	0.054
rho64	**0.343*****	0.096	3.56	0.000	**0.431*****	0.091	4.74	0.000
rho74	0.216	0.143	1.52	0.129	**0.281*****	0.093	3.01	0.003
rho65	0.034	0.090	0.37	0.708	**0.319*****	0.090	3.53	0.000
rho75	0.024	0.169	0.14	0.888	0.050	0.093	0.54	0.592
rho76	0.232	0.163	1.43	0.154	0.025	0.087	0.29	0.772

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho74 = rho65 = rho75 = rho76 = 0: Awareness model: $\text{chi}^2(21) = 63.3248$ Prob $> \text{chi}^2 = 0.0000$, Adoption model: $\text{chi}^2(21) = 121.619$ Prob $> \text{chi}^2 = 0.0000$: 1 = Fertiliser; 2 = manure; 3 = mulching; 4 = crop residue; 5 = cover crop; 6 = crop rotation; 7 = inter cropping.
***$P \leq 1$ %, **$P \leq 5$ %, *$P \leq 10$ %.

practices. The awareness or adoption of a given practice could be conditional on another.

Regarding awareness, mulching & fertilizer + manure, manure & cover crop, crop residue & cover crop and crop residue, and crop rotation had a significant positive correlation (Table 4). The findings indicated that the awareness of positively correlated practices acted as compliments. Therefore, awareness of the first practice could lead to awareness of the second. However, our findings showed a significant negative correlation between manure and mulching. This suggested that the awareness of mulching and manure acted as substitutes. The findings are interesting, given that most smallholders use crop residues for livestock feeding. However, there are conflicting interests between using the crop residue as mulch or feeding livestock, which is the main source of manure in the study area [36]. Therefore, smallholders aware of manure could receive information on crop residue as livestock feed.

The study established a positive and significant correlation between adopting fertilizer and manure integration with manure, crop residue, crop rotation and intercropping. Also, manure was significantly and positively correlated to crop residue, crop rotation and intercropping. Similarly, cover crops positively and significantly correlated with crop residue and crop rotation. Finally, crop residue exhibited a positive and significant relationship with cover crops, crop rotation, and intercropping. Our findings highlighted that various practices acted as complements. This implied that smallholders jointly adopted various practices to enjoy the synergetic benefits. Our findings align with the findings of Aryal et al. [51] and Musafiri et al. [19], who reported the existence of simultaneous adoption of innovative practices due to complementary gains among smallholders.

3.5. Determinants of simultaneous awareness and adoption of climate-resilient practices

The results of the determinants of awareness and adoption level are presented in Tables 5a and 5b. Household head gender

Table 5a

Determinants of the climate-resilient practices awareness level.

Variable	Fertilizer and manure integration	Manure	Mulching	Crop residue	Cover crop	Crop rotation	Intercropping
HHH Gender	−0.242	−0.067	−1.124**	−0.248	−0.055	0.142	−0.655
	0.114	0.053	0.571	0.183	0.006	0.052	0.466
HHH Literacy	0.545*	0.063	0.140	−0.120	0.824**	−0.149	0.227
	0.315	0.004	0.047	0.116	0.354	0.130	0.031
Main occupation	−0.670**	−5.251	−1.144***	−0.087	−0.696**	0.208	−0.465*
	0.283	1.347	0.402	0.046	0.273	0.041	0.117
HH age	−0.823	3.155**	−2.873*	2.365***	2.405***	0.636	0.782
	0.754	1.405	1.607	0.837	0.781	0.254	0.467
HH size	−0.245	0.959**	−1.805***	0.549	1.116***	0.734**	0.437
	0.118	0.054	0.541	0.343	0.327	0.334	0.256
HHH farming experience	0.524*	−0.892	1.552**	−0.991***	−0.371	−0.444	−0.015
	0.274	0.575	0.703	0.303	0.286	0.217	0.008
Agricultural training	0.153	1.210**	−0.492	0.262	0.378**	−0.025	0.465
	0.067	0.476	0.067	0.166	0.165	0.008	0.290
Group membership	0.207	0.161	−0.149	0.128	−0.106	−0.267*	−0.443*
	0.150	0.062	0.010	0.121	0.083	0.161	0.252
Arable land	−0.007	0.215*	−0.102	0.078	0.052	0.040	0.072
	0.002	0.116	0.093	0.052	0.023	0.006	0.029
Tropical Livestock Unit	0.143	−0.004	0.215	0.102	−0.022	0.015	−0.195
	0.095	0.003	0.188	0.100	0.006	0.004	0.112
Soil fertility status good	0.254*	0.006	0.539*	0.069	−0.147	0.213	−0.105
	0.142	0.004	0.302	0.051	0.007	0.157	0.064
Soil fertility status improved	0.337**	0.384	1.093***	−0.092	0.221	−0.295	0.144
	0.164	0.177	0.298	0.040	0.067	0.180	0.087
Tharaka-Nithi	0.352**	1.805***	−0.213	0.619***	−0.292*	1.302***	−4.967
	0.137	0.435	0.154	0.153	0.150	0.163	1.292
Constant	0.753	0.874	3.335	−3.680***	−4.678***	−1.196	2.635
	0.191	0.435	2.399	1.330	1.237	0.326	1.845
Model Wald chi-square	281.57						
Prob > chi-square	0.0000						
Log pseudo-likelihood	−1102.13						
Observations	397						

*** P ≤ 1 %, **P ≤ 5 %, *P ≤ 10 %.

significantly and negatively influenced mulching awareness and inter-cropping adoption level (Table 5a). The findings indicated that female-headed households were more likely to be aware of mulching and adopt inter-cropping. This finding could be linked to resource ownership, where female-headed households could be aware of or adopt less resource-intensive practices. Given the male dominance in the endowment of production resources control in the study area, they could adopt labour-intensive practices while females could adopt labour-saving ones. Differences in resource endowment between female-headed and male-headed households could lead to variances in adopting agricultural practices [52]. Therefore, women could adopt less labour and resource-intensive practices like crop rotation.

As hypothesized, literacy positively and significantly influenced the awareness level of fertilizer + manure and cover crops. Literacy positively and significantly determined the adoption of crop residue. The findings implied that literate smallholders were more likely to be aware of fertilizer + manure, cover crops, and adopt crop residues. The findings confirm the importance of education in the awareness and adoption of innovative agricultural practices. The findings agree with Kpadonou et al. [24], Autio et al. [53] and Musafiri et al. [19], who reported that education is essential in driving awareness and adopting innovative agricultural practices.

Unexpectedly, the household head's main occupation negatively and significantly influenced the awareness level of inorganic fertilizer and manure integration, mulching, cover crop and intercropping and the adoption level of intercropping. The results implied an inverse relationship between the household head's main occupation of farming and climate-resilient practices awareness and adoption. Smallholders with off-farm income may have a wider social network, which can influence both awareness and adoption. Our findings corroborated those of Mairura et al. [18], who found that the main occupation of farming negatively and significantly influenced adoption of inorganic fertilizer manure integration and mulching in Kenya.

Household head age showed mixed results in terms of awareness of innovative practices. The study revealed age's positive and significant influence on awareness of manure, crop residue and cover crop while negatively and significantly determining mulching. Regarding adoption level, age consistently positively and significantly influenced manure use, crop residue and intercropping. The findings implied that age had a mixed influence on awareness but an essential factor in promoting awareness. An increase in age leads to an increase in awareness of manure, crop residue, and cover crops, as well as the adoption of manure, crop residue, and intercropping while lowering mulching awareness levels (tables 5a and 5b). The increased awareness of mulching among young farmers could be attributed to their ability to gather innovative information [54]. The positive and significant influence of age on awareness and adoption could be endorsed to smallholders' accumulated knowledge that is essential in identifying information and production needs over time. Similar to our findings, Tamirat et al. [55] found that older farmers were more likely to adopt innovative agricultural practices.

Table 5b
Determinants of the climate-resilient practices adoption level.

Variables	Fertilizer and manure integration	Manure	Mulching	Crop residue	Cover crop	Crop rotation	Intercropping
HHH Gender	0.025	−0.054	−0.004	0.139	−0.096	0.074	**−0.295****
	0.211	0.173	0.389	0.151	0.151	0.141	**0.148**
HHH Literacy	0.209	0.167	−0.408	**0.626***	0.220	0.223	−0.263
	0.473	0.355	0.618	**0.345**	0.322	0.296	0.375
Main occupation	−4.478	−0.403	−0.634	0.040	0.043	−0.115	**−0.861*****
	114.909	0.344	0.661	0.280	0.275	0.274	**0.308**
HH age	−0.546	**1.670***	0.083	**2.064****	0.945	0.174	**2.481*****
	1.103	**0.908**	2.062	**0.842**	0.820	0.782	**0.824**
HH size	0.062	**0.863****	**−2.162*****	0.427	**0.809****	0.006	**0.764****
	0.533	**0.369**	**0.784**	0.330	**0.328**	0.309	**0.341**
HHH farming experience	0.151	−0.256	0.824	−0.172	−0.455	−0.158	**−0.758****
	0.395	0.332	0.820	0.312	0.303	0.280	**0.308**
Agricultural training	−0.084	0.187	−0.325	0.124	0.259	**0.349****	0.227
	0.250	0.215	0.478	0.171	0.174	**0.170**	0.176
Group membership	**0.554****	0.245	−0.007	0.257	**−0.342****	−0.046	**−0.261***
	0.245	0.189	0.418	0.158	**0.163**	0.150	**0.156**
Arable land	**−0.157****	0.022	−0.248	0.045	−0.008	**0.095***	0.085
	0.066	0.058	0.167	0.053	0.054	**0.051**	0.062
Tropical Livestock Unit	−0.098	**0.186***	0.384	0.075	−0.016	0.026	−0.164
	0.152	**0.106**	0.326	0.103	0.101	0.094	0.102
Soil fertility status good	−0.017	−0.127	0.494	0.230	0.155	**0.343****	−0.047
	0.214	0.175	0.429	0.153	0.153	**0.144**	
Soil fertility status improved	−0.118	−0.076	**1.321*****	−0.024	0.150	**−0.270***	**0.397****
	0.225	0.193	**0.422**	0.177	0.176	**0.160**	**0.174**
Tharaka-Nithi	**−0.914*****	**0.338****	0.147	**−1.012*****	**−1.151*****	0.039	**−0.875*****
	0.238	**0.172**	0.418	**0.153**	**0.154**	0.140	**0.149**
Constant	6.998	−1.893	−1.876	**−4.529*****	−1.730	−0.049	−1.660
	1.149	1.411	3.180	**1.316**	1.270	1.224	1.289
Model wald chi-square	286.28						
Prob > chi-square	0.0000						
Log pseudo-likelihood	−1089.2842						
Observations	397						

*** P ≤ 1 %, **P ≤ 5 %, *P ≤ 10 %.

Table 6
Determinants of climate-resilient practices awareness and adoption intensity.

Variables	Awareness intensity				Adoption intensity			
	Coef.	Std. Err	Z	P>|z|	Coef.	Std. Err	Z	P>|z|
HHH gender	−0.023	0.052	−0.45	0.653	0.002	0.055	0.04	0.967
HHH literacy	0.063	0.116	0.55	0.585	0.109	0.119	0.91	0.360
HHH main occupation	−0.117	0.090	−1.29	0.196	**−0.183***	0.094	−1.94	0.052
HHH age	**0.006****	0.002	2.40	0.017	**0.008**[a]	0.002	3.28	0.001
HH Size	**0.026***	0.014	1.81	0.071	0.031	0.015	2.08	0.038
HHH farming experience	**−0.005****	0.002	−2.15	0.031	**−0.006****	0.002	−2.46	0.014
Agriculture training	**0.132****	0.058	2.28	0.023	**0.122****	0.062	1.97	0.049
Group membership	−0.033	0.053	−0.62	0.536	0.022	0.056	0.39	0.693
Arable land	0.012	0.018	0.68	0.495	0.019	0.018	1.07	0.283
Tropical Livestock Unit	0.001	0.005	0.23	0.816	−0.004	0.005	−0.82	0.413
Soil fertility status is good	0.005	0.059	0.08	0.935	0.045	0.062	0.72	0.470
Soil fertility status improved	0.039	0.063	0.62	0.537	0.032	0.067	0.49	0.627
Tharaka-Nithi	**0.121****	0.050	2.41	0.016	**−0.299**[a]	0.053	−5.66	0.000
constant	**1.144**[a]	0.183	6.24	0.000	**1.085**[a]	0.190	5.71	0.000
Model wald chi square (13)	39.45				68.62			
Prob > chi square	0.0015				0.0000			
Log pseudo likelihood	−750.62				−758.75			
Observations	397				397			

[a] P ≤ 1 %, **P ≤ 5 %, *P ≤ 10 %.

The awareness of climate-resilient practices such as manure, cover crop and crop rotation increased with increased household size, ceteris paribus. However, larger households were less likely to be aware of mulching. Concerning adoption, household size positively and significantly influenced manure, cover crop and intercropping while negatively predicting mulching. The findings confirm the mixed influence of family size on awareness and adoption of innovative agricultural practices. This suggested that the sign depends on the demand for the information and required labor, which could vary across small and large family sizes. Our findings were consistent with Makate et al. [31] and Asule et al. [25], who found that household size could negatively or positively influence awareness and adoption levels.

Experience exerted a positive and significant influence on awareness of inorganic fertilizer, manure integration, and mulching, as well as a negative and significant influence on crop residue. This implied that experienced smallholder farming households were more likely to be aware of fertilizer + manure and mulching and less aware of crop residue. Regarding adoption level, we found that farming experience negatively and significantly influenced intercropping. All other factors held constant; an increase in experience could lead to a decline in the propensity of adopting intercropping. Experienced households are more likely to get information from extension agents, thus increasing awareness [23]. Additionally, with experience, smallholders could prioritize the information and adoption needs based on expected utility. Therefore, older farmers could have a lower propensity for awareness and adoption if the practice is expected to yield lower utility.

Agricultural training had a positive and significant influence on the level of awareness of manure and cover crops. Similarly, the study showed a positive and significant prediction of agricultural training on the level of adoption of crop rotation. The findings suggested that agricultural training increases manure and cover crop awareness and crop rotation adoption level, ceteris paribus. The findings could be explained by the importance of extension support in disseminating agricultural information that leads to the adoption of promoted practices. Our findings corroborated those of Zakaria et al. [27] and Oyetunde-Usman et al. [21], who highlighted that extension is key to enhancing awareness and adopting innovative agricultural practices.

Group membership exerted a negative and significant influence on crop rotation and intercropping. However, group membership had a positive and significant prediction on fertilizer + manure but negatively determined the adoption level of cover crop and intercropping. Ceteris paribus, group members had a lower propensity for crop rotation, intercropping awareness, and cover crop and intercropping adoption level. The propensity of inorganic fertilizer and manure integration adoption was higher among group members. The negative prediction of group membership on awareness and adoption of climate-resilient practices such as crop rotation, cover and intercropping could be explained by smallholders implementing them based on traditional experience and as a normal cropping approach in the study area. Thus, those who join groups could be exposed to and adopt labour-intensive and costly practices such as inorganic fertilizer and manure integration applications. Our findings were consistent with Belachewa et al. [56], who found that being a member of an agricultural association improved knowledge gain and access to information about innovative agricultural practices.

Arable land size influenced the manure awareness level positively and significantly at a 10 % significance level. Regarding adoption level, arable land size showed a positive and significant influence on crop rotation and a negative and significant influence on inorganic fertilizer and manure integration (Table 5b). The finding implied that the increase in arable land increased manure awareness and crop rotation adoption while reducing the likelihood of adopting inorganic fertilizer and manure integration. This could be attributed to the cost of the practice; inorganic fertilizer and manure integration are expensive compared with only using manure, where smallholders mostly use manure from their livestock [36]. Crop rotation is more practical under large land parcels. Similar to our findings, Cipriano et al. [57] found that land size positively and significantly influenced crop rotation in the Democratic Republic of Congo and Mozambique. Our findings were consistent with the findings by Ali et al. [58] that farm size negatively and significantly influenced the adoption of inorganic fertilizer and manure integration in Ghana.

Tropical livestock units positively and significantly influenced the adoption of manure at a 10 % significance level. The findings suggested that the manure adoption level increased with an increase in the livestock units. This can be attributed to manure being the source of soil fertility amelioration in the study area. Our findings corroborated those of Musafiri et al. [19], who found that TLU was an important positive determinant of the adoption of climate-smart agricultural practices. Soil fertility perceptions are essential predictors of awareness and adoption of CRPs. Regarding awareness, good soil fertility and fertility status improved positively and significantly predicted inorganic fertilizer, manure integration, and mulching. Soil fertility status positively and significantly influenced crop rotation adoption at a 5 % significance level. Soil fertility status improved and significantly influenced the adoption level of mulching and intercropping while negatively and significantly predicting crop rotation. Our findings underscored the importance of soil fertility perceptions on the awareness and adoption of agricultural approaches. However, the direction of influence is practice-specific dependent. This implied that soil fertility perceptions influenced the adoption level. Previous research has highlighted the importance of soil fertility perceptions in shaping information access and adoption of improved practices in the central highlands of Kenya [18,19,25,54].

The geographical location (site) exerted mixed influence on the awareness and adoption level of CRPs. The study showed a positive and significant influence of site on the awareness of inorganic fertilizer and manure integration, crop residue and crop rotation, and a negative and significant influence on cover crop. Concerning adoption level, we found a negative and significant influence of site on inorganic fertilizer and manure integration, crop residue, cover crop and intercropping and a positive and significant influence on manure. In this case, a positive sign indicates more awareness or adoption in Tharaka Nithi and a negative sign in Murang'a (Table 5a–b). Geographical, social and economic differences between sites could explain the differences. Similar to our findings, Makate et al. [31] found that geographical location was essential in adopting climate-smart agriculture innovations in South Africa.

3.6. Awareness and adoption intensity of climate-resilient practices

The results for Poisson regression on the determinants of awareness and adoption intensity are presented in Table 6. The test statistics revealed that the Poisson regression model was suitable for assessing both awareness and adoption intensity of CRPs. The household head's main occupation was a negative determinant of CRP adoption intensity. This implied that participation in non-agricultural activities increased the odds of adopting several technologies. The findings aligned with the increased investment of off-farm incomes in innovative approaches since some are labour-intensive and expensive. The results revealed that the age of the household head exerted a positive and significant influence on the awareness intensity of climate-resilient practices. This implied that aged farmers were more aware of soil fertility practices than their young counterparts. This could be explained by the experience accumulated over time, thus the ability to be aware of several practices. In agreement with our results, Oyetunde-Usman et al. [21] revealed that age was a significant and positive determinant of the adoption intensity of sustainable agricultural practices in Nigeria. The results showed a positive significant influence of the number of family members on the intensity of awareness. The finding indicated an increase in the number of members, which results in awareness of more practices. This could be explained by family members acting as sources of information. Therefore, households with many family members could have diversified sources of information, leading to enhanced adoption.

We found that household experience had a negative significant influence on the intensity of awareness and adoption. This suggested that experienced households were less likely to be aware of or adopt multiple CRPs. We expected that experience could exert a positive and significant influence on awareness and adoption intensity since experienced farmers are expected to be aware of various technologies leading to increased adoption. However, experienced farmers could be reluctant to gather new information, which could lower the adoption of innovative approaches. Again, experience comes with age, and old farmers are mostly risk-averse [59]. Therefore, the risk-aversion nature of the experienced farmers could explain the negative prediction.

Agriculture training showed a positive significant prediction on awareness and adoption intensity. The findings suggested that access to agricultural training enhanced the propensity of awareness and adoption of multiple agricultural practices. Training is key in passing technical know-how that enhances the adoption of innovative practices. Our findings corroborated those reported by Kpadonou et al. [24] and Oyetunde Usman et al. [021] that agricultural training plays a central role in improving the adoption of agricultural practices.

Geographic location positively and negatively influenced intensity awareness and adoption, respectively. This suggested that smallholder farmer residences in Tharaka Nithi enhanced awareness intensity but reduced adoption intensity compared with their counterparts in Murang'a. The higher awareness level in Tharaka Nithi could be attributed to intensive extension services and information needs than in Murang'a [25]. On the other hand, the higher adoption intensity in Murang'a could be explained by an increased need to enhance agricultural productivity in the study area.

4. Conclusion and policy recommendations

Climate-resilient practices are critical in improving soil fertility and mitigating adverse effects of climate change enhancing food security, reducing poverty, and improving smallholders' livelihoods. Despite the benefits above, awareness of and adoption of climate-resilient practices remain low in most developing countries, including Kenya. We assessed the determinants of simultaneous awareness and adoption of CRPs in the Central Highlands of Kenya. We used cross-section survey data collected from 400 smallholders in the Central Highlands of Kenya. The results revealed that awareness and adoption levels ranged from low to high. We established both complements and substitutes between various CRPs. We found that the awareness and adoption of specific CRPs and their intensity were determined by occupation, age, farming experience, household size, agricultural training and geographical location. Across the significant dependent variables, awareness level, adoption level, and intensity of adoption, household main occupation showed a significant negative influence. Farming experience negatively determined awareness and adoption intensity. Additionally, we found that perceptions of soil fertility played a central role in shaping awareness and adoption levels. We draw three key policy recommendations: (i) Most CRPs were complements, indicating joint awareness and adoption; (ii) Agricultural policymakers at both National and Devolved governments should consider the interdependence between the CRPs in awareness campaigns and adoption promotion in Kenya and other developing countries and (iii) Since numerous socioeconomic, institutional and biophysical factors influence the awareness and adoption of CRPs in Kenya, both National and Devolved governments policymakers should incorporate these determinants in promoting the practices. Pro-farmer agricultural training at local and national levels is an important determinant of awareness, adoption level, and intensity. Policymakers and stakeholders should support farmer-driven training programs at local and national levels for enhanced awareness and adoption of the CRPs.

5. Consent to participate

The participants were informed of the purpose of the study, and the participation was voluntary. Informed consent was first obtained from the smallholder farmers who participated in the study. The participants were assured of anonymity and confidentiality of their personal information.

6. Consent to publish

Not applicable.

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Ethics approval

The study adhered to the research ethics guidelines recommended by the Board of Postgraduate Studies at the University of Embu. The processes involved undergoing a research ethics review. The study does not involve human or animal subjects; thus, ethical approval was not necessary. During data collection, informed consent was sought from the participants. The study obtained informed consent from the interviewed farmers. The study ensured that the principle of anonymity and voluntary participation was respected. The enumerators were trained to seek informed consent from the interviewees and agree on voluntary participation in the study.

Data availability

Data available from the corresponding author upon reasonable request.

Code availability

The STATA commands are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Pamellah A. Asule: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Collins Musafiri:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **George Nyabuga:** Writing – review & editing, Supervision, Conceptualization. **Wambui Kiai:** Writing – review & editing, Supervision, Conceptualization. **Milka Kiboi:** Writing – review & editing, Validation, Methodology, Conceptualization. **Gian Nicolay:** Writing – review & editing, Validation, Resources. **Felix K. Ngetich:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e38368.

References

[1] OECD, Three Key Challenges Facing Agriculture and How to Start Solving Them, 2019. (Accessed 2 August 2023).

[2] A.R.M. Al-Tawaha, H. Günal, J. Křeček, R.H.C. Zamfir, H.K. Patel, R.V. Vyas, C.H.C. Zamfir, I. Celik, S. Khalid, A. Aleksanyan, A.R. Al-Tawaha, Soil fertility decline under climate change, in: Sustainable Soil and Land Management and Climate Change, CRC Press, 2021, pp. 127–145.

[3] I. Amanullah, I. Ortas, The declining trend of soil fertility with climate change and its solution, Climate Change and Agriculture: Perspectives, Sustainability and Resilience (2022) 179–208.

[4] B.K. Kogo, L. Kumar, R. Koech, Climate change and variability in Kenya: a review of impacts on agriculture and food security, Environ. Dev. Sustain. 23 (2021) 23–43.

[5] M.M. Maja, S.F. Ayano, The impact of population growth on natural resources and farmers' capacity to adapt to climate change in low-income countries, Earth Systems and Environment 5 (2021) 271–283.

[6] C. Ragasa, A. Dankyi, P. Acheampong, A.N. Wiredu, A. Chapoto, M. Asamoah, R. Tripp, Patterns of adoption of improved rice technologies in Ghana, International Food Policy Research Institute Working Paper 35 (2) (2013) 6–8.

[7] M. Nyasimi, P. Kimeli, G. Sayula, M. Radeny, J. Kinyangi, C. Mungai, Adoption and dissemination pathways for climate-smart agriculture technologies and practices for climate-resilient livelihoods in Lushoto, Northeast Tanzania, Climate 5 (3) (2017) 1–22.

[8] W. Zeweld, G. Van Huylenbroeck, G. Tesfay, S. Speelman, Smallholder farmers' behavioural intentions towards sustainable agricultural practices, J. Environ. Manag. 187 (2017) 71–81.

[9] C.R. Foguesatto, J.A.R. Borges, J.A.D. Machado, A review and some reflections on farmers' adoption of sustainable agricultural practices worldwide, Science of the total environment 729 (2020) 138831.

[10] E. Bryan, C. Ringler, B. Okoba, J. Koo, M. Herrero, S. Silvestri, Can agriculture support climate change adaptation, greenhouse gas mitigation and rural livelihoods? Insights from Kenya, Climatic Change 118 (2013) 151–165.

[11] C. Mbow, P. Smith, D. Skole, L. Duguma, M. Bustamante, Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa, Curr. Opin. Environ. Sustain. 6 (2014) 8–14.

[12] N.P. Awazi, N.M. Tchamba, Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in sub-Saharan Africa, Afr. J. Agric. Res. 14 (7) (2019) 379–388.
[13] P. Wainaina, S. Tongruksawattana, M. Qaim, Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya, Agric. Econ. 47 (3) (2016) 351–362.
[14] E.M. Rogers, Diffusion Networks. Networks in the Knowledge Economy, 2003, pp. 130–179.
[15] G. Feder, R.E. Just, D. Zilberman, Adoption of agricultural innovations in developing countries: a survey, Econ. Dev. Cult. Change 33 (2) (1985) 255–298.
[16] B.D. Doss, D.C. Atkins, A. Christensen, Who's dragging their feet? Husbands and wives seeking marital therapy, J. Marital Fam. Ther. 29 (2) (2003) 165–177.
[17] E. Dimara, D. Skuras, Adoption of agricultural innovations as a two-stage partial observability process, Agric. Econ. 28 (3) (2003) 187–196.
[18] F.S. Mairura, C.M. Musafiri, M.N. Kiboi, J.M. Macharia, O.K. Ng'etich, C.A. Shisanya, J.M. Okeyo, D.N. Mugendi, E.A. Okwuosa, F.K. Ngetich, Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya, Weather Clim. Extrem. 34 (2021) 100374.
[19] C.M. Musafiri, M. Kiboi, J. Macharia, O.K. Ng'etich, D.K. Kosgei, B. Mulianga, M. Okoti, F.K. Ngetich, Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? Heliyon 8 (1) (2022) e08677.
[20] J. Mugwe, D. Mugendi, M. Mucheru-Muna, R. Merckx, J. Chianu, B. Vanlauwe, Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya, Exp. Agric. 45 (1) (2009) 61–75.
[21] Z. Oyetunde-Usman, K.O. Olagunju, O.R. Ogunpaimo, Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria, International Soil and Water Conservation Research 9 (2) (2021) 241–248.
[22] E. Wauters, E. Mathijs, The adoption of farm level soil conservation practices in developed countries: a meta-analytic review, Int. J. Agric. Resour. Govern. Ecol. 10 (1) (2014) 78–102.
[23] N. Mango, C. Makate, L. Tamene, P. Mponela, G. Ndengu, Awareness and adoption of land, soil and water conservation practices in the Chinyanja Triangle, Southern Africa, International Soil and Water Conservation Research 5 (2) (2017) 122–129.
[24] R.A.B. Kpadonou, T. Owiyo, B. Barbier, F. Denton, F. Rutabingwa, A. Kiema, Advancing climate-smart-agriculture in developing drylands: joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel, Land Use Pol. 61 (2017) 196–207.
[25] P.A. Asule, C.M. Musafiri, G. Nyabuga, W. Kiai, F.K. Ngetich, C. Spurk, Determinants of simultaneous use of soil fertility information sources among smallholder farmers in the central highlands of Kenya, Commun. Soil Sci. Plant Anal. 53 (15) (2022) 1979–1998.
[26] F.K. Ngetich, F.S. Mairura, C.M. Musafiri, M.N. Kiboi, C.A. Shisanya, Smallholders' coping strategies in response to climate variability in semi-arid agro-ecozones of Upper Eastern Kenya, Social sciences & humanities open 6 (1) (2022) 100319.
[27] A. Zakaria, S.B. Azumah, M. Appiah-Twumasi, G. Dagunga, Adoption of climate-smart agricultural practices among farm households in Ghana: the role of farmer participation in training programmes, Technol. Soc. 63 (2020) 101338.
[28] O.C. Ajayi, S. Franzel, E. Kuntashula, F. Kwesiga, Adoption of improved fallow technology for soil fertility management in Zambia: empirical studies and emerging issues, Agrofor. Syst. 59 (2003) 317–326.
[29] B.Y. Fosu-Mensah, P.L. Vlek, D.S. MacCarthy, Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana, Environ. Dev. Sustain. 14 (2012) 495–505.
[30] C. Mulwa, P. Marenya, M. Kassie, Response to climate risks among smallholder farmers in Malawi: a multivariate probit assessment of the role of information, household demographics, and farm characteristics, Climate Risk Management 16 (2017) 208–221.
[31] C. Makate, M. Makate, N. Mango, S. Siziba, Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa, J. Environ. Manag. 231 (2019) 858–868.
[32] M.N. Kiboi, K.F. Ngetich, A. Fliessbach, A. Muriuki, D.N. Mugendi, Soil fertility inputs and tillage influence on maize crop performance and soil water content in the Central Highlands of Kenya, Agric. Water Manag. 217 (2019) 316–331.
[33] R. Jaetzold, H. Schmidt, Z.B. Hornet, C.A. Shisanya, Farm Management Handbook of Kenya, 2nd Edition. Natural Conditions and Farm Information, Vol. 11/C. Eastern Province, Ministry of Agriculture/GTZ, Nairobi, Kenya, 2007.
[34] KPHC, Kenya Population and Housing Census, Population by County and Sub-county, vol. 1, 2019. Nairobi Kenya.
[35] K.F. Ngetich, J. Diels, C.A. Shisanya, J.N. Mugwe, M. Mucheru-Muna, D.N. Mugendi, Effects of selected soil and water conservation techniques on runoff, sediment yield and maize productivity under sub-humid and semi-arid conditions in Kenya, Catena 121 (2014) 288–296.
[36] C.M. Musafiri, J.M. Macharia, O.K. Ng'etich, M.N. Kiboi, J. Okeyo, C.A. Shisanya, E.A. Okwuosa, D.N. Mugendi, F.K. Ngetich, Farming systems' typologies analysis to inform agricultural greenhouse gas emissions potential from smallholder rain-fed farms in Kenya, Scientific African 8 (2020) e00458.
[37] W.G. Cochran, Sampling Techniques, John Wiley & Sons, 2007.
[38] W. Gardner, E.P. Mulvey, E.C. Shaw, Regression analyses of counts and rates: Poisson, overdispersed Poisson, and negative binomial models, Psychol. Bull. 118 (3) (1995) 392.
[39] W.H. Greene, FIML Estimation of Sample Selection Models for Count Data, 1997.
[40] W.H. Greene, *Functional Form And Heterogeneity In Models For Count Data* (Foundations and Trends in Econometrics), now Publishers Inc, 2007.
[41] K.A. Darkwah, J.D. Kwawu, F. Agyire-Tettey, D.B. Sarpong, Assessment of the determinants that influence the adoption of sustainable soil and water conservation practices in Techiman Municipality of Ghana, International soil and water conservation research 7 (3) (2019) 248–257.
[42] C.M. Musafiri, M. Kiboi, J. Macharia, O.K. Ng'etich, D.K. Kosgei, B. Mulianga, M. Okoti, F.K. Ngetich, Smallholders' adaptation to climate change in Western Kenya: considering socioeconomic, institutional and biophysical determinants, Environmental Challenges 7 (2022) 100489.
[43] S. Coxe, S.G. West, L.S. Aiken, The analysis of count data: a gentle introduction to Poisson regression and its alternatives, J. Pers. Assess. 91 (2) (2009) 121–136.
[44] S.J. Hong, C.S.M. Lui, J. Hahn, J.Y. Moon, T.G. Kim, How old are you really? Cognitive age in technology acceptance, Decis. Support Syst. 56 (2013) 122–130.
[45] W. Legesse, J. Haji, M. Ketema, B. Emana, Determinants of adoption of sustainable land management practice choices among smallholder farmers in Abay Basin of Oromia, Ethiopia. J. Dev. Agric. Econ. 13(1) (202) 1-9.
[46] G. Oseni, P. Corral, M. Goldstein, P. Winters, Explaining gender differentials in agricultural production in Nigeria, Agric. Econ. 46 (3) (2015) 285–310.
[47] S. Wambua, E. Birachi, A. Gichangi, J. Kavoi, J. Njuki, M. Mutua, M. Ugen, D. Karanja, Influence of productive resources on bean production in male-and female-headed households in selected bean corridors of Kenya, Agric. Food Secur. 7 (2018) 1–8.
[48] E.O. Otieno, M.N. Kiboi, N. Gian, A. Muriuki, C.M. Musafiri, F.K. Ngetich, Uptake of integrated soil fertility management technologies in heterogeneous smallholder farms in sub-humid tropics, Environmental Challenges 5 (2021) 100394.
[49] H.E. Jahnke, Livestock Production Systems and Livestock Development in Tropical Africa, vol. 35, Kieler Wissenschaftsverlag Vauk, Kiel, 1982.
[50] G.B. Tesfahunegn, Farmers' perception on land degradation in northern Ethiopia: implication for developing sustainable land management, Soc. Sci. J. 56 (2) (2019) 268–287.
[51] J.P. Aryal, D.B. Rahut, S. Maharjan, O. Erenstein, Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India, in: Natural Resources Forum, vol. 42, Blackwell Publishing Ltd., Oxford, UK, 2018, pp. 141–158, 3.
[52] C. MacLaren, K.T. Aliyu, W. Waswa, J. Storkey, L. Claessens, B. Vanlauwe, A. Mead, Can the right composition and diversity of farmed species improve food security among smallholder farmers? Front. Sustain. Food Syst. 6 (2022) 744700.
[53] A. Autio, T. Johansson, L. Motaroki, P. Minoia, P. Pellikka, Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya, Agric. Syst. 194 (2021) 103284.
[54] P.A. Asule, C. Musafiri, G. Nyabuga, W. Kiai, F.K. Ngetich, C. Spurk, C. Determinants of simultaneous use of soil fertility information sources among smallholder farmers in the central highlands of Kenya, Agriculture 13 (2023) 1729.
[55] T.W. Tamirat, S.M. Pedersen, K.M. Lind, Farm and operator characteristics affecting adoption of precision agriculture in Denmark and Germany, Acta Agric. Scand. Sect. B Soil Plant Sci 68 (4) (2018) 349–357.
[56] A. Belachew, W. Mekuria, K. Nachimuthu, Factors influencing adoption of soil and water conservation practices in the northwest Ethiopian highlands, International soil and water conservation research 8 (1) (2020) 80–89.

[57] I.M. Cipriano, D.O. Onautsu, T.D. Tarassoum, I.I. Adejumobi, B.A. Bolakonga, Uptake of conservation agriculture technology through farmer field schools in the Democratic Republic of Congo and Mozambique, Journal of Agricultural Extension. 26 (1) (2022) 44–58.

[58] E.B. Ali, J.A. Awuni, G. Danso-Abbeam, Determinants of fertilizer adoption among smallholder cocoa farmers in the Western Region of Ghana, Cogent Food Agric. 4 (1) (2018) 1538589.

[59] T. Nielsen, A. Keil, M. Zeller, Assessing farmers' risk preferences and their determinants in a marginal upland area of Vietnam: a comparison of multiple elicitation techniques, Agric. Econ. 44 (3) (2013) 255–273.