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Determinants of adoption of climate-smart agricultural technologies and practices in the coffee-based farming system of Ethiopia

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Abstract

Objectives: This study explored the adoption status of different Climate Smart Agricultural (CSA) practices and factors that influence their adoption for sustainable soil resource utilization in the changing climate.

Methodology: We used quantitative and qualitative primary data collected from smallholder farmers and other stakeholders from major coffee-growing regions of Ethiopia: Oromia, and Southern Nations, Nationalities, and Peoples (SNNP). We used the multivariate probit (MVP) model to study factors that influence the adoption of climate-smart agricultural technologies, namely, manure application, minimum tillage, intercropping, use of improved forage, and physical soil and water management practices.

Results: The study result shows that 35% of farmers apply manure on their farm plots. Minimum tillage is also applied to 36% of farms. Intercropping improved forages and physical soil and water management structures are adopted by 45, 19, and 47% of farmers, respectively. The finding of the study indicates the positive and significant effect of education, extension (access to extension services and participation on field days), and ownership of communication devices specifically radio on the adoption of climate-smart agricultural practices.

Recommendations: Concerning bodies must pay due attention to problems affecting effective farmers-extension linkage. The positive effect of radio ownership on technology adoption also suggests the need for increased accessibility of FM radio channels to farmers to be aware of climate change and innovative agricultural technologies, practices, and information that mitigate the problem.

Keywords: Adoption, Climate-smart, Forage, Intercropping, Minimum tillage, And multivariate

Introduction

The development of the agricultural sector is the most efficient poverty reduction measure in countries where the economy is heavily based on agriculture. However, the adverse effects of climate change remain to be a major threat to agriculture [1, 2]. The change is already having an impact on agriculture and food security [1]. An increase in mean temperature, changes in rain patterns, changes in water availability, sea-level rise, and salinization are some features of climate change that affect agriculture, forestry, and fisheries both directly and indirectly. The change leads to reductions in natural resource bases (biodiversity, soil, and water), reductions in production, and lower incomes, especially in vulnerable areas. Moreover, the effects extend to influencing global food prices, altering yields and quality of crops produced around the world, and affecting the nutritional value of foods, and food security [1, 3, 4].

Ethiopia's nature-dependent agricultural sector associated with the country's geographical location, topography, and low adaptive capacity made the country highly vulnerable to adverse effects of climate change

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[5]. The country has been historically suffering from natural catastrophes and is prone to extreme weather events especially shocks related to rainfall and drought. These are the main causes of food production deficits and high livelihoods vulnerability [6]. Consequently, climate change is emerging as a big challenge to Ethiopian agriculture and poverty alleviation efforts [7].

To combat the adverse effects of climate change, several measures have been suggested in attempts to reduce the vulnerability of smallholder farmers who are highly affected by the changes. One of such intervention is climate-smart agriculture (CSA). CSA, a concept developed by Food and Agricultural Organization (FAO), is an approach to developing the technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change [1]. It integrates the three dimensions of sustainable development (economic, social, and environmental) by jointly addressing food security, ecosystem management, and climate change challenges. It is comprised of three main pillars, namely, sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions.

Different studies have been conducted on the adoption of climate-smart agricultural practices in Ethiopia [8–21]. However, all of these studies were conducted separately for different improved practices (soil and water conservation measures, organic fertilizer, inorganic fertilizer, conservation tillage, and others). Since CSA is not a single specific agricultural technology or practice that can be universally applied; any study on CSA should include more than one technology or practice. It is believed that the adoption of a climate-smart agricultural practice affects the adoption of the other practices positively or negatively. Thus, observing the adoption of more than one practice is crucial to exploring farmers' practices of climate change mitigation and other production constraints. Unlike other studies mentioned above, this study investigates the relationship between the adoption of different climate-smart agricultural practices, namely, manure application, conservation tillage, soil and water management, use of improved forages, and intercropping.

The purpose of the study is to examine climate-smart agricultural technologies' adoption status and explore demographic, socio-economic, and institutional factors affecting the adoption of climate-smart agricultural technologies. The study also analyzes the interrelationship between the adoptions of different climate-smart agricultural technologies and practices.

The remainder of this article is as follows. The next section presents the study methodology which embraces study areas, the data type used, sampling procedures, data analysis methods used, and model specification. The result part of this article highlights both descriptive and econometric results. The last section summarizes conclusions and policy recommendations as well as suggestions for future research.

Methodology

Study area and the data

The study uses quantitative and qualitative primary data collected from smallholder farmers and other stakeholders (district and zone officials and experts) from major coffee-growing regional states of Ethiopia: Oromia and SNNP. Gedeo, Sidama, Kafa, and Sheka zones from the SNNP regional state and Ilubabor, Jimma, West Wollega, and Kellem Wollega zones from the Oromia regional state were coffee-producing zones selected for the study (Fig. 1).

Sampling and data collection

A multistage sampling technique is employed to select the sample from a population that involved both purposive and random sampling techniques. First, regions and zones are purposively selected based on the number of coffee growers, the area allocated to coffee, and the quantity of coffee produced. Accordingly, Oromia and SNNP regional states are chosen for the study, because these regional states alone account for 89% of coffee growers, 97% of the coffee area, and 99% of coffee production in the country [22]. Second, districts and peasant associations in the study regions are selected using a random sampling technique. Finally, households are randomly chosen from the sampling frame of coffee grower populations at the peasant association levels. Eventually, a total of 953 sample households are selected for the study (584 from SNNP and 369 from Oromia Regional states) (Table 1). Data is collected from the sampled households through a structured questionnaire administered by enumerators.

Method of data analysis and model specification

Descriptive statistics summarizes and describes the collected and cleaned data (Tables 4, 5 and 6; Figs. 2 and 3). Farmers adopt a mix of technologies to enhance declining soil fertility and mitigate climate change. This implies that the adoption decision is inherently multivariate, and attempting univariate modeling would exclude useful economic information about interdependent and simultaneous adoption decisions [23]. A multivariate probit (MVP) model was used to determine the factors that influenced the adoption of multiple climate-smart agricultural technologies (Minimum Tillage, Manure Application, and

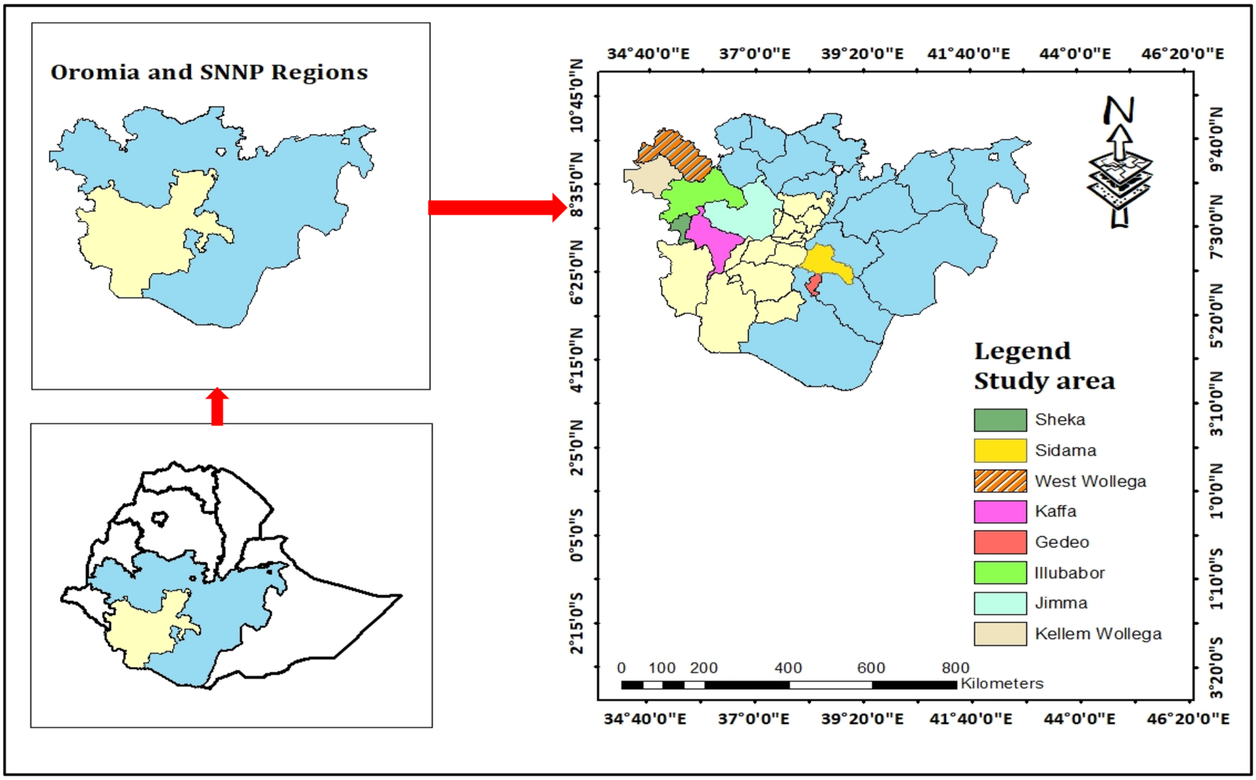


Fig. 1 Map of the study area

Table 1 Total sample size and sample distribution along study zones and regions

Region	Zone	Total sample size	% Of the total
SNNP	Gedeo	199	21
	Sidama	200	21
	Sheka	81	8
	Kafa	104	11
	Sub-total	584	61
Oromia	Ilubabor	121	13
	Jimma	107	11
	West Wollega	105	11
	Kellem Wollega	36	4
	Sub-total	369	39
Grand Total		953	100

Physical Soil and Water Management Practices). The approach simultaneously models the influence of the set of explanatory variables on each of the different agricultural technologies, while allowing for the potential correlation between unobserved disturbances, as well as the relationship between the adoptions of different technologies [24]. Failure to capture unobserved factors and interrelationships among adoption decisions regarding different practices will lead to bias, inefficient estimates, and inconsistent policy recommendations [25, 26].

The model was also used by recent studies by Tekle-wold et al. [27], Kassie et al. [28], Maguza-Tembo et al. [29], Koppmair et al. [30], and Ali and Michael [31]. The adequacy of the MVP method over suitable bivariate models such as logit and probit was confirmed by observing the existence of a significant correlation between the adoption of study technologies or practices.

Climate-smart agricultural practices in Ethiopia include integrated watershed management, integrated soil fertility management, sustainable land management, conservation agriculture, agroforestry, crop residue management, composting, promotion of improved livestock feed, and rangeland management [32]. The land is the main limiting factor of production in rural areas. Farmers use different techniques to increase productivity per unit of land sustainably. Thus, the use of one improved practice affects the use of the other.

Accordingly, the observed outcome of climate-smart agricultural technologies adoption can be modeled following random utility formulation. Consider *i*th farm household ($i = 1, 2, 3, \ldots\ldots N$) which is facing a decision on whether or not to adopt Manure Application (MA), Minimum

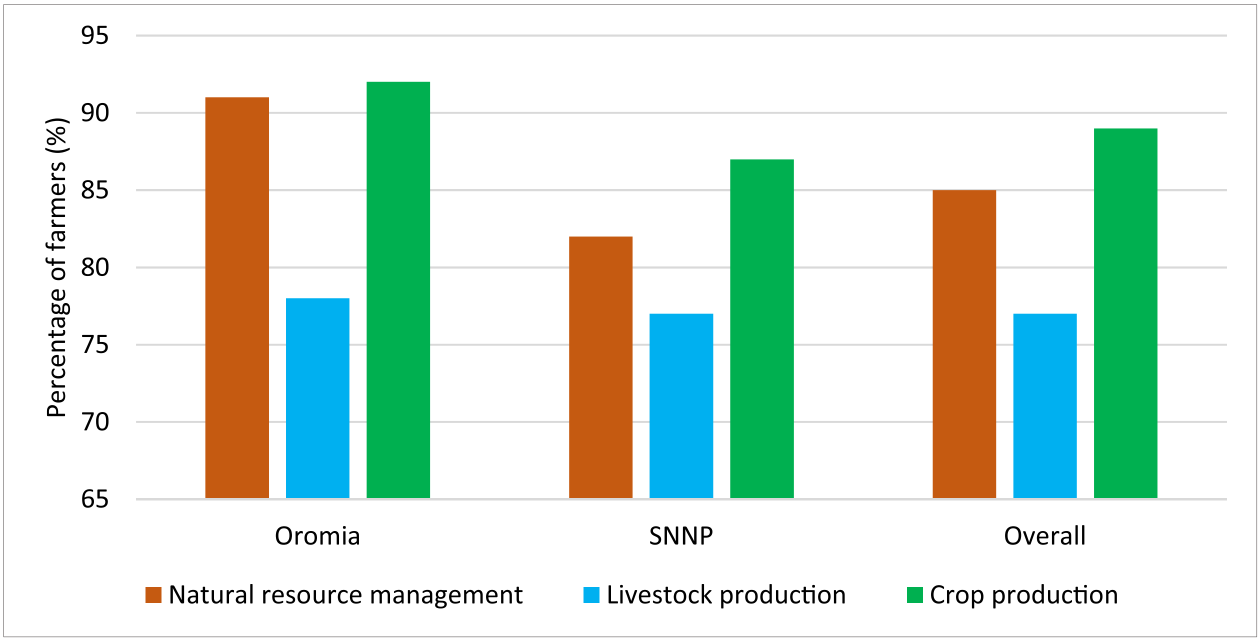
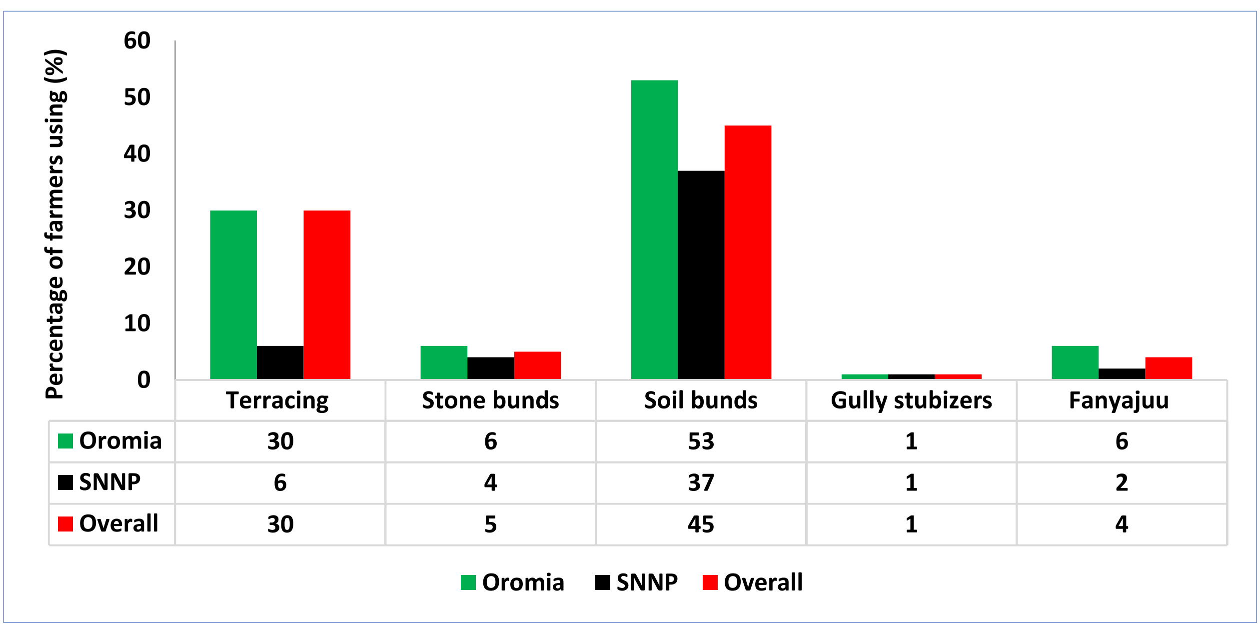


Fig. 2 Farmers' access to extension services along the study regions in %. Natural resource Management: $Chi^2 = 16.36$; P value = 0.000; Livestock production: $Chi^2 = 0.04$; P value = 0.843; Crop production: $Chi.^2 = 4.83$; P value = 0.028



	Terracing	Stone bunds	Soil bunds	Gully stubizers	Fanyajuu
Oromia	30	6	53	1	6
SNNP	6	4	37	1	2
Overall	30	5	45	1	4

Fig. 3 Type physical soil and water conservation structures used in %

Tillage (MT), Intercropping (IC), use of Improved Forage (IF) and Physical soil and water management practices (PM) (Table 2).

Let U_0 represents benefits to the farmer from unimproved agricultural practices (unimproved farming) and let U_k represent the benefit of adopting the Kth technology (MA, MT, IC, IF, PM) denoting the use of Manure Application (MA), Minimum Tillage (MT), Intercropping (IC), use of Improved Forage (IF) and Physical soil and water management practices (PM).

Table 2 Number of farmers using these climate-smart agricultural technologies/practices

Improved technologies or practices	Total number of sample farmers	Number of farmers using the technology or practice
Manure application	953	335
Minimum tillage	953	345
Intercropping	953	429
Improved forage	953	179
Physical soil and water management practices	951	451

The farmer decides to use the Kth technology if $Y^{*}_{\mathrm{ipk}} = U^{*}_{k} - U_0 > 0$. The net benefit ($Y^{*}_{\mathrm{ipk}}$) that the farmer derives from Kth improved practice (technology) is a latent variable determined by observed household and location characteristics (X_{ip}) and unobserved characteristics (U_{ip}):

$$Y^{*}_{\mathrm{ipk}} = X'_{\mathrm{ipk}}\beta_j + U_{\mathrm{ipk}}, \text{ where } (k = \mathrm{MA, MT, IC, IF, PM}) \quad (1)$$

Using the indicator function, the unobserved preferences in Eq. (1) translate into the observed binary outcome equation for each choice as follows:

$$Y_k = \begin{cases} 1 & \mathit{if}\ Y^{*}_{ipk} > 0 \\ 0 & \mathit{otherwise} \end{cases} (k = \mathrm{MA, MT, IC, IF, PM}) \quad (2)$$

where $k = 1, 2, \ldots$, m denotes the type of CSA. In Eq. (1), the assumption is that a rational βth farmer has a latent variable Y_{ipk} which captures the unobserved characteristics or demand associated with the kth choice of CSA. This latent variable is assumed to be a linear combination of observed characteristics X'_{ipk}, factors that affect the adoption of kth CSA, as well as unobserved characteristics captured by the stochastic error term U_{ipk}. The vector of parameters to be estimated is denoted by β_j. Given the latent nature of Y^{*}_{ipk}, the estimations are based on observable binary discrete variables Y_{ipk} which indicates whether or not a farmer undertook a particular CSA on plot ρ.If adoption of a particular practice is independent on whether or not a farmer adopts another practice and error terms are normally distributed, then Eqs. (1) and (2) specify univariate probit models, where information on farmers' adoption of one farming practice does not alter the prediction of the probability that they will adopt another practice. However, if the adoption of several farming practices is possible, a more realistic specification is to assume that the error terms in Eq. (1) jointly follow a multivariate normal (MVN) distribution, with zero conditional mean and variance normalized to unity, where $U_{\mathrm{ipk}} \sim$ MVN $(0, \varepsilon)$ and the covariance matrix ε. Hence in the multivariate model, where the adoption of several technologies is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalized to unity (for identification of the parameters) where (μ_{MA}, μ_{MT}, μ_{IC}, μ_{IF}, μ_{PM}) ~ MVP $(0, \varepsilon)$ and the symmetric covariance matrix ε is given by

$$\varepsilon = \begin{bmatrix} 1 & \rho_{MAMT} & \rho_{MAIC} & \rho_{MAIF} & \rho_{MAPM} \\ \rho_{MTMA} & 1 & \rho_{MTIC} & \rho_{MTIF} & \rho_{MTPM} \\ \rho_{ICMA} & \rho_{ICMT} & 1 & \rho_{ICIF} & \rho_{ICPM} \\ \rho_{IFMA} & \rho_{IFMT} & \rho_{IFIC} & 1 & \rho_{IFPM} \\ \rho_{PMMA} & \rho_{PMMT} & \rho_{PMIC} & \rho_{PMIF} & 1 \end{bmatrix}$$

ρ is the pairwise correlation coefficient of the error terms with regards to any two of the estimated adoption equations in the model. The correlation between the stochastic components of different improved agricultural practice adoptions is represented by the off-diagonal elements in the variance–covariance matrix [33]. The correlation is based on the principle that the use of a particular improved agricultural practice may depend on another (complementarity or positive correlation) or may be influenced by an available set of substitutes (negative correlation). If these correlations in the off-diagonal elements in the covariance matrix become non-zero, it justifies the application of a multivariate probit instead of a univariate probit for each technology. Table 3 shows the explanatory variables we used in econometric models and definition of the variables.

Descriptive statistics of the variables

The study considers different explanatory variables that could affect the adoption of improved agricultural technologies and practices. The descriptive results of the study show that about 90% of farmers were male-headed households. About 54% and 37% of farmers have access to radio and credit services, respectively. More than 85% of the farmers have also access to the extension services of soil and water management which is really encouraging despite the quality of the services. However, only 24% of the farmers participate in field days. About 25% of farmers also participate in off-farm income-generating activities. Coffee is the main cash crop in the study areas. The study included improved coffee variety adoption as an explanatory variable, since the adoption of improved coffee could affect the adoption of other improved agricultural technologies and practices. The study result shows 60% of the farmers adopt improved coffee varieties (Table 4).

Farmers' mean age is 42.6 years with a minimum of 21 and a maximum of 90 years. The average family size of

Table 3 Variables included in the model and their descriptions

Variables	Variable type	Description of the variables
Region	Dummy	Study regions/location [1 = Oromia; 2 = SNNP]
Sex	Dummy	Sex of the household head [1 = Male; 2 = Female]
Radio ownership	Dummy	Ownership of functional radio [0 = No; 1 = Yes]
Credit access	Dummy	Household head access to credit [0 = No; 1 = Yes]
Extension service on soil and water management	Dummy	Household head access to extension advises and training [0 = No; 1 = Yes]
Participation on field days	Dummy	Household head access to natural resource management field days and field visits [0 = No; 1 = Yes]
Participate in off-farm income-generating activities	Dummy	Household head participation in non-farm income generating activities [0 = No; 1 = Yes]
Improved coffee variety adoption	Dummy	Household head use of improved coffee varieties [0 = No; 1 = Yes]
Age	Continuous	Age of the household head in completed years
Family size	Continuous	Number of dependent family members in the household
Household head education level (years)	Continuous	Education level of the household head in completed years
Distance from homestead to farm plots in km	Continuous	Accessibility of farm plots in kilometers
Total land in hectares	Continuous	Total land owned by the household head in hectares
Tropical Livestock Unit (TLU) in numbers	Continuous	Number of livestock the household head owned in TLU

Table 4 Description and summary statistics of dummy explanatory variables

Variables	Mean	SD
Region	0.612	0.487
Sex	0.902	0.297
Radio ownership	0.540	0.498
Credit access	0.372	0.381
Extension service on soil and water management	0.852	0.355
Participation on field days	0.243	0.229
Participate in off-farm income-generating activities	0.251	0.224
Improved coffee variety adoption	0.601	0.495

Table 5 Description and summary statistics of continuous explanatory variables

Variables	Mean	SD	Min	Max
Age	42.62	12.28	21	90
Family size	6.328	2.343	1	17
Household head education level (years)	4.811	3.489	0	16
Distance from homestead to farm plots in km	2.631	2.557	0.5	11
Total land in hectares	1.756	1.788	0.01	12
Tropical Livestock Unit (TLU) in numbers	4.154	4.126	0	19

the respondents is 6.3. The minimum education level of the household head is 0 (illiterate) and the maximum is 16 years with a mean of 4.8 completed years. The study shows that 10% of the household heads are illiterate. The mean distance from homestead to farm plots is 2.6kms with a maximum of 11kms. The mean total land in the study area is 1.8 hectares. The farmers have also on average owned 4.2 Tropical Livestock Units (TLU) (Table 5).

Numerous farmers in developing countries continue to cultivate crops and raise livestock in the same ways that have been used in their communities for generations due to poor farmers-extension linkage and limited access to inputs and markets. This survey reveals that 86%, 78%, and 85% of the respondents had access to extension services on crop production, livestock production, and natural resource management, respectively. Alongside, farmers in the Oromia region have better access to extension services than the SNNP region counterparts (Fig. 2).

Regarding field days, more than 20% of the overall respondents participate in demonstrations or field days in both regions. The proportion of farmers who have access to training and field days are similar across regions (21% for SNNP and 19% for Oromia) for there is no statistically significant difference ($Chi^2 = 0.6775$; $P = 0.410$).

Communication in agriculture is crucial for producers to adopt the new agricultural technologies, sell the output, purchase the inputs and mitigate the agricultural risks and disasters. Communications technologies are the devices used to transfer and/or receive information and knowledge. The study assesses households' communication asset ownership along the study regions. The result exhibits that the majority of farmers own mobile phones (63%) and functional radio (54%) in both study regions. Only a few farmers with access to electric power own TV (11%). There is a significant difference between the Oromia and SNNP regions in the ownership of these communication technologies. A large number of farmers in

SNNP own both mobile phones and TV compared to farmers in the Oromia region (Table 6).

Table 6 Communication asset ownership between the study regions (%)

Assets	Oromia	SNNP	Overall	Ch^2	*P* value
Mobile Phone	58	69	63	5.92	0.000***
Functional Radio	63	45	54	18.92	0.000***
Functional TV	8	13	11	3.96	0.035**

** $P < 0.05$; *** $P < 0.01$

Results and discussion

Adoption patterns of climate-smart agricultural practices

Due to the undulling topography of the coffee farming system and high intensity of soil acidity and termites, as well as large space between coffee plants, farmers are using different techniques of climate-smart agricultural practices to mitigate the problems and increase productivity per unit of land. The major ones include fallowing, area closure, use of inorganic fertilizers, manure application, application of decomposed coffee husk, conservation tillage, intercropping, cover cropping in coffee, the use of improved fodder, crop rotation, and soil and water management practices. In this study, we consider five climate-smart agricultural practices common in the study area. These include manure applications, conservation tillage, intercropping, use of improved fodder, and adoption of physical soil and water management practices.

Manure application

In rural areas, farmers are using livestock manure as fertilizer for crop cultivation. Manure can increase yields by improving soil organic matter content. It also improves the soil water holding capacity and thus increases efficiency in the use of inorganic fertilizer [34]. Manure application is common practice in the coffee-based farming systems of the country and that is the reason why Ethiopia is known for its organic coffee. However, the use of manure depends on the ownership and number of livestock herds the farmer has. Though no significant difference between the regions in manure use, 37% and 34% of farmers in the Oromia and SNNP regions, respectively, are applying manure on their land with an overall mean of 35% ($Chi^2 = 1.03$; *P* value $= 0.310$). The better use of manure in Oromia is due to the high ownership of cattle. The SNNP region especially Gedeo and Sidama are highly populated and the likelihood of cattle rearing is low.

Minimum tillage

Minimum tillage involves minimizing the number of tillage operations by making only limited slots for placing the seed, either using specialized machines (seeders) that open up small furrows in which the seed is placed or by manually using hoes or dipsticks to bore holes into which seeds are placed. Its purpose is to minimize soil disturbance, since the rest of the field is left untilled [35, 36].

Farmers use minimum tillage to mitigate the effect of termites and soil acidity in the study areas. The use of minimum tillage is higher at SNNP (44%) than in the Oromia (24%) region with an overall mean of 36%. There is a significant difference between regions in the adoption of minimum tillage ($Chi^2 = 53.50$; *P* value $= 0.000$). Farmers in SNNP operate on a small plot of land and plowing the land yearly could decline the soil fertility. Thus, they prefer minimum tillage to mitigate erosion which is the primary cause of soil fertility loss.

Intercropping

Intercropping is the growing of two or more crops simultaneously on the same field [37]. The main purpose of intercropping is to increase productivity per unit of land and reduce pest damage. Farmers also use intercropping to reduce risks in crop production; if one crop fails, the other survives and compensates in yield to some extent [38].

The study result shows that there is a significant difference between the regions in the use of intercropping. About 20 and 61% of the farmers in Oromia and SNNP regions, respectively, are applying intercropping with an overall mean of 45%. There is a statistical difference between the regions in practicing intercropping ($Chi^2 = 148.31$; *P* value $= 0.000$). Farmers in SNNP regions are highly populated and own small plots of land. This drives them to intercrop *enset* (the main staple food crop in the area), haricot bean, *khat*, maize, and other crops in coffee and fruit trees.

Improved forage

Improved forage crops have diversified advantages. The primary benefits are to produce a high amount of quality herbage to be used as feed for livestock. On the other hand, they complement crop production by maintaining soil fertility by fixing nitrogen or when used as mulch. Besides, forage crops could be grown as a component in integrated natural resource management to prevent soil erosion, control weeds, pests, and diseases [39].

The study found a significant difference between regions in improved forage use though the mean adoption rate is low (19%) ($Chi^2 = 38.22$; *P* value $= 0.000$). Only 9% of farmers in Oromia and 25% in SNNP regions are using improved forage crops. The reason could be a high population of dairy cattle in SNNP than in the Oromia region. The adoption rate of improved dairy cows is 3% in

Oromia and 11% in the SNNP region. On the other hand, farmers in Oromia especially in the study zones have a large size of farmland (Mean grazing land = 0.224 hectares) and have no problem of feed due to the existence of communal grazing lands. In the SNNP region, the average land owned by an individual farmer is very low and the mean grazing land is 0.144 hectares which are significantly lower than the Oromia region (0.224 hectares) ($t = 2.47$; P value = 0.042). Thus, they use the efficient improved forage to feed their dairy cattle on their limited land. Farmers in the study areas are using different types of improved fodder grasses, the most commonly used ones included Elephant grass, Alfalfa, and Vetch.

Physical soil and water management practices

Reducing soil and land degradation is the main challenge for sustainable development. The degradation of soil and land has adverse impacts on food security, water quality and availability, human health, and social and economic activities [40]. Addressing soil and land degradation through sustainable management of soil and land using physical conservation methods offers tremendous potential for climate change adaptation and mitigation. Moreover, it helps to increase and sustain land productivity as well as to enhance water availability.

The findings on the use of different soil and water conservation structures exhibit that 49% of the sample households in the Oromia region uses the structures, while it is 44% for the SNNP region. There is a significant difference between regions in the adoption of physical soil and water conservation structures ($Chi^2 = 32.86$; P value = 0.000). The Oromia region is characterized by undulling topography and high soil acidity. Termite is also the main production constraint in the region. Conservation structures are recommended to combat termites and reduce soil acidity. This drives the Oromia farmers to adopt conservation structures than those in the SNNP region. On average, 47% of the households are using soil and water conservation structures on their land along the study regions.

Soil bund is a commonly used conservation structure in the study regions. Out of the adopters of physical soil and water conservation measures, 45% of the households are applying soil bunds which are 53% Oromia and 37% in the SNNP region. The use of terracing and stone bunds also follows soil bund use among the farmers of the study areas (Fig. 3).

Econometric result

With significant Wald Chi-square statistic ($chi^2(70) = 668.57$, $p < 0.001$) and Chi-square statistic for the log-likelihood ratio test ($chi^2(10) = 76.53$, $P < 0.001$), the results of the multivariate probit model for adoption decisions show that the decisions whether or not to adopt one climate-smart agricultural practice (technology) are dependent on the adoption decision of the other technologies. The result, thus, supports the use of a multivariate probit model.

The pairwise coefficients of intercropping and manure application, use of improved forage and manure application, physical soil and water conservation and manure application, physical soil and water conservation and minimum tillage, use of improved forage and intercropping, physical soil and water conservation and intercropping and physical soil and water conservation and the use of improved forage are positively and significantly correlated indicating complementarity among the paired practices.

Intercropping and manure application are positively and significantly correlated. SNNP, where *enset* is a dominant crop, is a prominent area with the practice of intercropping. In the same manner, *enset* growers always use manure and ash for *enset* production. The results indicate the complementarity of the two practices.

Likewise, the use of improved forage and manure applications are positively and significantly related. Inorganic fertilizer is the most expensive input and accounts for the highest cost in crop production. Farmers who have forage grasses own unquestionably dairy cattle. Thus, they mostly use the manure of their cattle for crop production rather than using expensive inorganic fertilizers.

Furthermore, a positive and significant relationship is seen between the adoption of physical soil and water conservation structures and manure applications. Farmers usually construct physical structures on highly depleted land and apply manure to rehabilitate soil fertility. The same is true for physical soil and water conservation and intercropping.

The difficulty of plowing between physical soil and water conservation structures has also made a positive and significant correlation between physical soil and water conservation, and minimum tillage.

The descriptive result shows that both the use of improved forage and intercropping are significantly high in the SNNP region, where the population density is high and per capita land holding is low. In such cases, farmers practice intercropping of improved forages with coffee, *enset*, and *Khat* to increase productivity per unit of land and to suppress weed under these main crops.

The result also reveals the positive and significant correlation between physical soil and water conservation, and the use of improved forage as farmers use the improved forages to stabilize the structures.

However, the pairwise coefficient of minimum tillage and manure application is negative and significant which implies the substitutability of the improved paired practices. The reason could be that farmers use non-selective herbicides before the application of minimum tillage

Table 7 Estimated model test and covariance of the correlation matrix

Correlation matrix	rho		Correlation matrix	Rho	
	Coefficient	SE		Coefficient	SE
MTMA	− 0.158***	0.053	IFMT	0.009	0.059
ICMA	0.227***	0.054	PMMT	0.118**	0.055
IFMA	0.141**	0.060	IFIC	0.077	0.061
PMMA	0.220***	0.054	PMIC	0.202***	0.057
ICMT	− 0.019	0.056	PMIF	0.265***	0.061

MT Minimum Tillge, *MA* Manure application, *IC* Intercropping, *IF* Improved Forage, *PM* Physical Soil and Water conservation Methods

Estimated covariance of the correlation matrix

rhoMTMA = rhoICMA = rhoIFMA = rhoPMMA = rhoICMT = rhoIFMT = rhoPMMT = rhoIFIC = rhoPMIC = rhoSWMIF = 0

$chi^2(10) = 76.5271$; $Prob > chi^2 = 0.000$

Number of draws = 5

Number of observations = 918

Wald $chi^2(70) = 668.57$; $Prob > chi^2 = 0.000$

rather than manure application. On the other hand, minimum tillage does not help the plant to simply use the soil nutrients which drives the farmers to use fast-reacting inorganic fertilizers than the use of manure (Table 7).

Factors affecting manure application

A positive and significant relationship is seen between household head age and the application of manure. Older farmers resist spending much money on inorganic fertilizer and energy. Instead, they apply manure to their farmlands. The result is consistent with Ketema and Bauer [8] who found a positive and significant relation between the age of the household head and the use of manure on farmlands. Family size negatively and significantly affects the use of manure. Farmers perceive that though manure is cheap, the yield of crops with the application of manure is not comparable to that of the yield obtained from the application of chemical fertilizers. Hence, farmers choose to use chemical fertilizer to secure family food demand. The result is contrary to Tao et al. [41] who found a positive relationship between family size and manure application. Distance from homestead to farm plots also affects the use of manure negatively and significantly due to the bulky nature of manure which hampers the transportation of manure to distant plots. The result is in line with Mesfin et al. [42]. Access to natural resource management extension affects the application of manure positively and significantly. The result is in line with Makokha et al. [43] and Abebe and Debebe [19]. Likewise, participation in field days affects the application of manure positively and significantly. The results exhibit the role of different extension approaches in enhancing technology adoption.

TLU or livestock ownership affects the use of manure positively and significantly. The more the livestock, the more manure is collected. The result corroborates with Mesfin et al. [42]. Farmers' access to credit negatively and significantly affects the application of manure. The reason could be that those farmers who have access to credit have a chance to purchase and use chemical fertilizers. The adoption of improved coffee varieties also affects the application of manure negatively and significantly. The adoption of improved coffee technologies increases income. Thus, adopter farmers opt for chemical fertilizer over manure to save their time and labor. The result also shows a positive and significant relationship between manure application and participation in off-farm income generation activities. Participation in off-farm income-generating activities is directly related to the household's income level. The low income of the farmers enhances them to participate in off-farm income-generating activities. The result contrasts with Makokha et al. [43], where a negative relationship between manure application and participation in off-farm income-generating activities was reported.

Factors affecting the use of minimum tillage

The age of the household head affects the adoption of minimum tillage negatively. This could be due to the perception of age-old farmers to plow farm plots frequently to increase productivity. The finding is in line with Ketema and Bauer [44] and Prakash et al. [45] and contrasts with Grabowski et al. [46]. The relationship between minimum tillage adoption and mean distance to farm plots were also positive which implies that distance from homesteads to farm plots enhances the adoption of minimum tillage which corroborates with the finding of Zulu-Mbata et al. [47]. The education of the household head affects the adoption of minimum tillage positively and significantly. The reason could be that educated farmers choose options that minimize time, money, and energy.

The result agrees with Ketema and Bauer [44], Prakash et al. [45], and Grabowski et al. [46].

Radio ownership of the household head affects the adoption of minimum tillage positively and significantly as information from radio listening enhances the adoption of improved technologies. Besides, farmers who have access to natural resource management extension services are more likely to use minimum tillage. The result is in line with Marenya et al. [16], Ketema and Bauer [44], and Prakash et al. [45]. Participation in field days also affects the adoption of minimum tillage positively and significantly. These three communications and extension services enhance the information exchange on improved agricultural technologies. Land size affects the adoption of minimum tillage positively and significantly. Those farmers who have more land opt to use minimum tillage at least on some plots to reduce the time, energy, and cost of plowing. Prakash et al. [45], Grabowski et al. [46], Zulu-Mbata et al. [47], and Ngoma et al. [48] also found the same result. Marenya et al. [16] also found a positive relationship between minimum tillage use and land size in Ethiopia which contrasts with the findings of the study in Kenya and Tanzania.

Factors affecting the use of intercropping

SNNP region has adopted more intercropping compared to the Oromia region. The area is highly populated and landholding per household is very low. In response, they use intercropping to increase productivity per unit of land. The age of the household heads and participation in off-farm income-generating activities also affect the adoption of intercropping positively and significantly. Female-headed households also use intercropping more compared to male-headed households. It is known that intercropping is a type of subsistence farming mainly practiced by resource-poor farmers, especially on land. Women household heads have a small land size and they usually use intercropping to diversify their crop produces. The negative relationship between credit access and adoption of intercropping also shows that those farmers who have access to credit do not choose intercropping. The reason could be farmers who have access to credit could rent land and produce on large land sizes rather than using intercropping. Both education and participation in field days affect the adoption of intercropping positively and significantly which shows the positive role of education and extension on the adoption of agricultural technologies. The positive relationship between the practice of intercropping and access to extension service conforms with Ketema and Bauer [44]. Land size and adoption of improved coffee varieties also affect the adoption of intercropping negatively and significantly due to the subsistence nature of intercropping practice which is also in line with Ketema and Bauer [44]. An increase in family size also enhances farmers' use of intercropping. The logic behind this could be that those farmers who have more family size use intercropping of cash crops for income and other crops to feed the family. The result also corroborates with Ketema and Bauer [44] but contrasts with Ekepu and Tirivanhu [49]. The negative relation between TLU and adoption of intercropping shows that those farmers who used intercropping have a small land size and they do not have adequate space to keep livestock.

Factors affecting the adoption of improved forage

SNNP region substantially adopts improved forage. The Hawassa–Shashemene milk shed is one of the prominent milk sheds in the country. There are many dairy farms and dairy cattle in these areas. Many development organizations have also participated in the popularization and diffusion of dairy cattle and improved feed. This drove the SNNP region to adopt improved forage as compared to the southwestern and western parts of the Oromia region which is far away from Addis Ababa and other large towns, where there is high consumption of milk and milk products.

Female-headed households are less likely to adopt improved forage crops than their male-headed counterparts. This was because they are relatively resource-poor especially land compared to male-headed households. Thus, they opt to give priority to planting food crops than forages to feed their family. The educational level of the household head affects the adoption of improved forage positively and significantly which is also agreeing with Lapar and Ehui [50]. Extension in natural resource management is directly related to the adoption of improved forage which is in line with Beshir [51] and Abebe et al. [52]. Both education and extension services affect the adoption of agricultural technologies positively through enhancing the search, evaluation, decision, and utilization of new information. Mean distance from farm plots has a negative and significant effect on the adoption of improved forage. If forage is planted far away from homesteads, it would be grazed by other animals during free grazing practices, which is yet a common practice in many areas. This is the reason why growing forage crops is limited to homesteads. The result is consistent with Abebe et al. [52].

TLU also affects the adoption of improved forage positively. Feed shortage is the most serious challenge in livestock production. Most of the grazing land is changing to farmlands due to high population growth and high food demand. Consequently, one of the options for livestock producers is the use of improved forage. The result also supports the findings of Beshir [51]. Coffee improved variety adoption affects the adoption of improved forage positively and significantly. Coffee is the main cash crop in the study area. The adoption of improved varieties of coffee affects both physical and social capital positively. The improvement of physical assets is in terms of livestock numbers and social capital in terms of improving the linkage between farmers and development agents. These both in turn enhance the adoption of improved forage.

Factors affecting the adoption of physical conservation structures

SNNP is negatively related to the adoption of physical soil and water conservation structures which implies that the region adopts less of the structures than the Oromia region. Oromia region farmers use the structures highly and significantly to combat the problem of termite and soil acidity which is substantially high in the area due to high soil erosion. The result also supports the finding of descriptive statistics. Source of information and knowledge such as ownership of radio and access to extension services affect the adoption of physical soil and water conservation structures positively and significantly. The positive relationship between the adoption of soil and water conservation structures and extension services was also found by Damtew et al. [13], Wordofa et al. [21], Birhanu and Meseret [53], Asfaw and Neka [54], and Issahaku and Abdulai [55]. Better exposure to education increases farmers' understanding of the benefits and constraints. However, the result contrasts with Belachew et al. [56]. Construction of physical soil and water conservation structures is capital, time, and labor-intensive. Both improved coffee variety adoption and TLU (Table 8) which help the farmers to generate more income positively and significantly affect the adoption of physical soil and water conservation structures. The result is consistent with Nigussie et al. [12], Issahaku and Abdulai [55], and Belachew et al. [56].

Conclusions and policy intervention

Many studies focus on the adoption of relatively expensive technologies, such as improved varieties, inorganic fertilizers, and agricultural machines. However, limited empirical studies have been conducted on the adoption of improved agricultural practices, such as intercropping, manure application, crop rotation with leguminous crops and forages, conservation tillage, and soil, and water management practices which are extremely important for climate change adaptation and mitigation. This study examines the adoption status of these Climate Smart Agricultural (CSA) practices and factors that influence their adoption using the Multivariate Probit Model (MVP).

The study result shows the low adoption status of climate-smart agricultural technologies in Ethiopia. The adoption rate of climate-smart agricultural technologies is very low as compared to African countries, particularly Southern African countries. The reason for this could be inadequate attention given to the practices or technologies by government and development partners. The extension system in the country focuses primarily on the popularization and diffusion of improved crop varieties to increase land productivity and production. However, this cannot be achieved if it is not supplemented by the use of climate-smart agricultural technologies which are the basis to mitigate and adapt to the changing climate. Thus, the government and other concerning bodies must give due attention to popularizing these technologies or practices. On other hand, farmers' indigenous knowledge of climate-smart agricultural practices should also be promoted to the next level in research and documented.

The result of the study also shows that adoption of one technology increases the adoption of multiple technologies, thus improving livelihoods, economic growth, and sustainable development in the region of Ethiopia, and other countries vulnerable to climate change. Thus, enhancing multi-technology popularization, diffusion and adoption are decisive to transform smallholder farmers to the next stage.

We also found a positive and significant effect of key public services particularly education, extension service, and media on the adoption of climate-smart agricultural practices. Thus, policymakers and public authorities must pay due attention to problems affecting effective farmers-extension linkage. Extension service is beyond expert assistance in the improvement of production and marketing. It also enables a flow of information and the transfer of knowledge and scientific findings. The agricultural extension workers have an effective and important role in helping farmers solve agricultural problems. Thus, extension workers must have a wide knowledge of various agricultural disciplines and they should have the ability to deal with farmers. The farmers' training center (FTC) system which is partially functioning should be strengthened to operate to its full capacity. The positive effect of radio ownership on technology adoption also suggests sustainable and up-to-date information and knowledge diffusion by strengthening FM radio channels at the farmers' level. This could enhance farmers' awareness and knowledge of climate change, and its innovative mitigation strategies.

Moreover, the study has also some limitations. There are a lot of climate-smart agriculture technologies and practices. However, the study emphasized only five improved technologies and/or practices. Future studies

Table 8 Multivariate Probit Model (MVP) result

Variables	Manure Application (MA)	Minimum Tillage (MT)	Intercropping (IC)	Improved forage (IF)	Physical soil and water Management (PM)
Region [SNNP]	− 0.045 (0.094)	0.726*** (0.095)	0.950*** (0.100)	0.944*** (0.124)	− 0.400*** (0.097)
Sex [Female]	0.042 (0.154)	0.052 (0.155)	0.378** (0.160)	− 0.529** (0.223)	− 0.118 (0.153)
Household head age in completed years	0.007* (0.004)	− 0.009** (0.004)	0.007* (0.004)	0.002 (0.005)	0.003 (0.004)
Household head education in completed years	0.016 (0.013)	0.037*** (0.013)	0.049*** (0.014)	0.060*** (0.016)	0.007 (0.014)
Family size in number	− 0.039** (0.019)	− 0.015 (0.019)	0.069*** (0.021)	0.013 (0.022)	− 0.000 (0.020)
Mean distance from farm plots in km	− 0.006* (0.027)	0.137*** (0.026)	− 0.015 (0.028)	− 0.051* (0.031)	− 0.028 (0.027)
Access to natural resource management extension [Yes]	0.491*** (0.135)	0.478*** (0.141)	− 0.055 (0.144)	0.325* (0.168)	1.034*** (0.128)
Participation on field days [Yes]	0.372*** (0.105)	0.226** (0.103)	0.211* (0.113)	0.192 (0.123)	0.178 (0.115)
Radio ownership [Yes]	0.100 (0.091)	0.216** (0.090)	0.096 (0.096)	0.007 (0.109)	0.211** (0.094)
Tropical Livestock Units (TLU) in numbers	0.011* (0.012)	− 0.019 (0.012)	− 0.067*** (0.013)	0.059*** (0.013)	0.038*** (0.013)
Total land in hectares	− 0.039 (0.030)	0.099*** (0.029)	− 0.091*** (0.034)	− 0.051 (0.034)	− 0.027 (0.031)
Improved coffee adoption [Yes]	− 0.154* (0.090)	0.025 (0.089)	− 0.183* (0.095)	0.032** (0.109)	0.334*** (0.092)
Household credit access [Yes]	− 0.231** (0.089)	0.067 (0.090)	− 0.207** (0.097)	0.032 (0.107)	0.001 (0.093)
Off-farm income-generating activities [Yes]	0.401*** (0.102)	− 0.151 (0.104)	0.528*** (0.112)	− 0.024 (0.121)	0.048 (0.108)
Constant	− 0.801*** (0.307)	− 1.067*** (0.310)	− 1.868*** (0.332)	− 4.156*** (0.437)	− 0.332 (0.311)

Numbers in the parenthesis are standard errors

*** ($P<0.01$); ** ($P<0.05$); * ($P<0.10$)

should observe other practices and technologies that farmers use to mitigate climate change and variability shocks, such as the use of new crop types and new varieties of different crops.

Abbreviations

CSA: Climate-smart agriculture; CSA: Central Statistical Agency; FAO: Food and Agricultural Organization; IC: Intercropping; IF: Improved forage; MA: Manure application; MT: Minimum tillage; MVP: Multivariate probit; PM: Physical soil and water management practices; SNNP: Southern Nation, Nationality and People; TLU: Tropical Livestock Units.

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Author contributions

All authors collected and analyzed both primary and secondary data. All authors read and approved the final manuscript.

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Availability of data and materials

The authors want to declare that they can submit the data at any time based on the publisher's request. The data sets used and/or analyzed during the current study will be available from the authors on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical clearance letters were collected from Jimma and Wondogenet Agricultural Research Centers to care for both the study participants and the researchers. During the survey, official letters were written for each district and peasant association, and informed verbal consent was obtained from each client, and confidentiality was maintained by giving codes for each respondent rather than recording their name. Study participants were informed that clients have full rights to discontinue or refuse to participate in the study. Hence, all participants throughout the research, including survey households, enumerators, supervisors, and key informants, were fully informed of the objectives of the study. They were approached friendly until the end of the study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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