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Research article

Measuring integrated smallholder soil fertility management practices in Megech watershed, Tana sub-basin, Ethiopia

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ABSTRACT

Nowadays, a combination of natural and man-made factors has led to a decline in the physical and chemical quality of the soil. In Ethiopia, declining soil fertility and quality that lead to low agricultural production are made worse by soil erosion and nutrient depletion. Adoption and implementation of integrated soil fertility management strategies have emerged as inevitabilities in terms of development in Ethiopia generally and in the Tana sub-basin of northwest Ethiopia specifically. This study was created to evaluate the Megech watershed's integrated smallholder soil fertility management methods' adoption factors, status, and scope. A total of 380 individual farmers were surveyed using a semi-structured questionnaire to gather primary data. Descriptive statistics and econometric estimating methods were combined in the study. The findings supported the use of inorganic fertilizer, tree planting, organic fertilizer, stone bunds, and soil bunds by households as the primary methods for managing soil fertility. The outcomes of the econometric model also show that households' adoption decisions for integrated soil fertility management practices are highly interdependent. Additionally, there were similar underlying factors that affected the status and intensity of implementing integrated soil fertility management practices. The research concluded that effective soil management policies and programs should be designed, and implemented by smallholder farmers, agricultural experts, research centers, and governmental and non-governmental organizations to improve the quality of soil for sustainable food production. Moreover, raising the affordability of financial services and strengthening smallholder farmers' access to education help to increase their income, which in turn encourages the use of integrated soil fertility management practices.

1. Introduction

Integrated soil fertility management is essential for increasing crop output in a cost-effective and environmentally friendly manner

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[1] and eliminates the spread of rural poverty and natural resources deprivation in sub-Saharan Africa [2–4]. Integrated soil fertility management refers to a set of soil fertility management practices and technologies that necessary include the use of fertilizer, organic inputs, and conservation practices united with knowing how to adapt it to local conditions for improving nutrients and enhancing crop productivity [1]. The depletion of soil fertility in smallholder farms is the essential biophysical reason for deteriorating per capita food production in many sub-Saharan African countries [5]. In Sub-Saharan African countries, agricultural production and food security still fall far short of global earnings [6]. The primary causes of this include the declining fertility of the soil, the rapid rise of the population, deforestation, unrestrained grazing, climate variability, land degradation, and the lack of integrated soil fertility management activities [7–9].

Ethiopia's economy is driven by agriculture, which contributes 37.57% to GDP [10]; 75% to the workforce, and 80% to export earnings [11]; 68% to national employment [12]. However, due to population pressure, poor agronomic techniques, frequent droughts, erratic rainfall, pests, insecure land ownership, and inadequate institutional finance, this sector's production has currently decreased [9,13,14]. Similarly, topographic conditions, the kind of soil, ecological, organizational, and socioeconomic elements all have a significant impact on the success of the Ethiopian agricultural sector [15,16]. A fundamental strategy for increasing soil fertility, crop, and water production, and smallholder farmers' income is as a result to accept and execute integrated soil fertility management practices [14,17].

On farmlands throughout the country, farmers continue to use inorganic fertilizers, organic fertilizers, soil bunds, crop rotations, crop residues and straws, fallow, stone bunds, and liming ineffectively [7,14,18,19]. An integrated approach to soil fertility

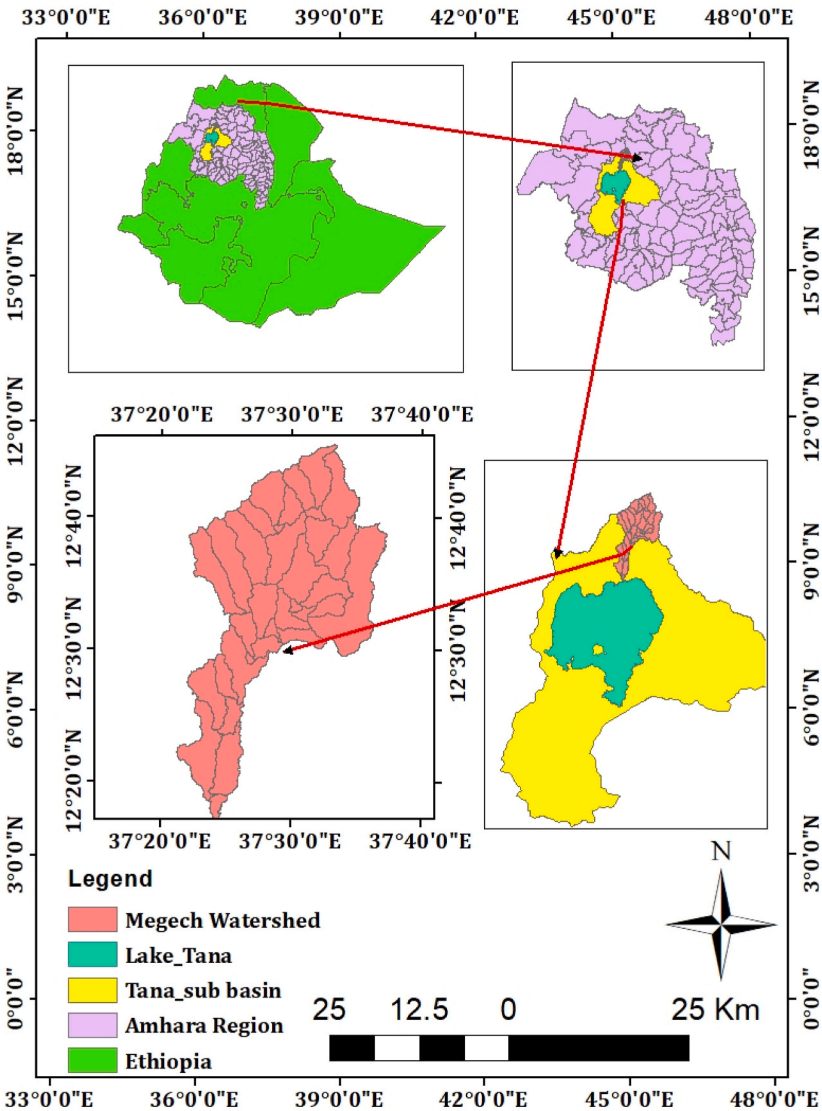

Fig. 1. Map of the study area.

management improves soil quality and fertility, boosts biodiversity, slows down environmental degradation, and ultimately boosts crop yields, income, and food security [9,20]. However, Ethiopian farmers are compelled to use fallow and marginal land on their farms to meet their needs due to their poor implementation and practices of soil conservation and management measures [21].

In Ethiopia, managing soil fertility is essential because desertification and land degradation are reducing the amount of land available to provide ecosystem services, which is one of the biggest conservation challenges. Enhanced and justifiable agricultural strengthening is needed to combat the country's poverty. However, strengthening, enhancing agricultural productivity, and bettering rural lifestyles are not possible without soil fertility speculation. Similarly, various social, economic, agro-climatic, topographical, technical, and environmental aspects have an impact on the adoption and application of soil fertility management for excellent output [7,14,17]. Moreover, Ethiopia has paid little attention to comprehending soil fertility management techniques and their drivers in a specific agricultural system. Due to the country's continual nutrient withdrawal, insufficient soil regeneration, and poor management practices, low fertility levels have also led to insufficient harvests.

Additionally, smallholder farmers have very distinct biophysical, socioeconomic, and professional backgrounds when it comes to regulating soil fertility. To create effective intervention methods, it is crucial to comprehend the varied indigenous soil fertility management systems and how they are impacted by different determining factors. In light of the foregoing, the study's objective was to empirically address the following fundamental research questions: What are the common integrated soil fertility management technologies invested by households?; What factors influence the intensity, status, and interdependence of investing in integrated soil fertility management practices on farmsteads among households? Therefore, the study's findings can close the knowledge gap regarding the impact of integrated soil fertility management practices on increasing agricultural productivity, food security, household

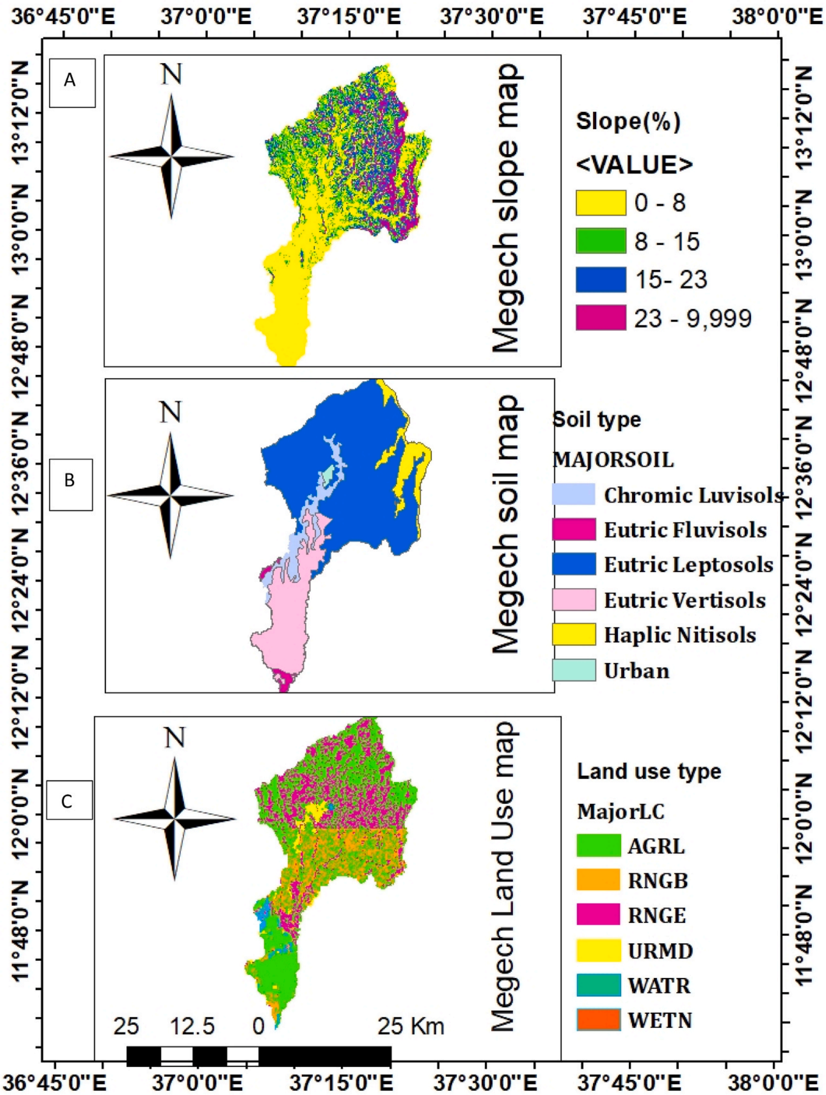

Fig. 2. Slope map A) Major soil type and distribution of the watershed B) and Land use land cover C).

income, and means of subsistence, as well as supporting efforts to better conserve biodiversity, protect the environment, and produce and market a variety of goods to boost the country's economy.

2. Research methods

2.1. Description of the study area

The Megech watershed of Ethiopia's northwest highlands served as the study's area. It is located in the Tana sub-basin and is roughly between the altitudes of 1785 m and 2920 m above sea level. Its geographic location is between the latitudes of 12°10′N and 12°50′N and the longitudes of 37°10′E and 37°40′E (Fig. 1). Similar to the other parts of the region, the rainfall of the watershed is erratic and varied temporarily and spatially. According to the general classification of the Agro-climate zone (based on annual rainfall, temperature, length of the growing period, and plant types) used in Ethiopia, the study area is located within the "Moist Weina Dega" Zone. Based on the rainfall, the climate of the area can be considered into two broad seasons; the dry season (winter) which lies between October to May, and the wet term (summer) extends from Jun to September, with slight rainfall during autumn and spring. The annual mean maximum, mean, and mean minimum temperatures are 24.5, 19.08, and 13.35 °C, respectively [22,23].

The primary means of income for households in the study area are the production of crops, vegetables, animals, honey, and spices. Maize, teff, wheat, sorghum, onion, red pepper, chickpea, and black and white cumin are the most extensively produced crops [24,25].

2.2. Land use land cover, slope and soil type of the watershed

The Megech watershed has large irrigable lands and currently, a large dam is constructing on the Megech River [26]. The dam is also expected to supply drinking water for Gondar city and rural villages in Northwest Ethiopia. Once the Dam is completed, it enables to irrigate 17,000 ha of land in the watershed [27]. The Megech River is the main tributary of Lake Tana, and it creates from the Semen Mountains and then flows in the southern direction. The upstream part of the watershed is categorized as a hilly and steep slope whereas the downstream part is flat low-lying land that is drained by Megech and Angereb Rivers (Fig. 2A). The most dominant soil type in this watershed is Eutric Leptosol (55.1%) followed by Eutirc vertisols (35.5%) and Eutric Fluvisols (3.7%) (Fig. 2B). As the land use map of Megech watershed distinguishes seven land-use classes, with agricultural cultivated land (55.4%), grassland (28.2%), and forest and shrubs (11.4%) urban with a moderate population of 4.04% being dominant in the study area (Fig. 2C).

2.3. Methods of data collection and sampling techniques

Data were gathered for this study from a variety of sources. Semi-structured questionnaires, focus group discussions, and key informant interviews were the main primary data collection techniques. Additionally, secondary information was gathered from administrative office records, published and unpublished papers, journals, books, websites, and other pertinent sources to further the inquiry.

The sampled households were chosen using a multi-stage sampling method. The Megech watershed was purposively chosen in the initial stage based on its unique experience and varied bio-physical and socio-economic qualities. In the second stage, households from the watershed were selected randomly from lists of all households in the watershed. Finally, 385 sampled households were selected through a systematic random sampling technique based on watershed size and heterogeneity of farm resources as stated in equation (1) following [28].

In calculating sample size, if there is no previous related work, a pilot survey is recommendable and will provide the necessary information to fix the value of P. However, for this study, due to budget and time constraints, the researcher could not carry out a pilot survey. Therefore, the following assumption is used regarding the value of P. When calculating sample size for proportion, there are two situations to be considered. First, if some approximation of P is known from a previous study, that value can be used in the formula. Second, if no approximation of P is known yet, one should use P = 0.5. This value will give a sample size sufficiently large to guarantee an accurate prediction [29].

$$n=\frac{Z^2pq}{e^2}=\frac{1.96^2(0.5*0.5)}{0.05^2}=385 \tag{1}$$

where; n = Sample size; Z = confidence level (α = 0.05, hence, Z = 1.96); p = proportion of the population containing the major interest, q = *1-p,* and e = allowable error. However, in this study, only 380 households were considered for analysis. The remaining 5 sampled households were rejected and not included in the data analysis due to non-sampling error.

2.4. Data analysis and model specification

Stata version 15 was used to handle and analyze quantitative data. Descriptive statistics and econometric estimating methods were combined in the study. The simultaneous use of various soil fertility management technologies is feasible in a multivariate model.

Consequently, a multivariate probit simulation model was used to account for the anticipated simultaneity issue [30–33]. The general form of the model is described in equation (2) following [34].

$$\begin{cases} Organicfert_i = X_{i1}\beta_{i1} + \delta_1 \\ Inorganicfert_i = X_{i2}\beta_{i2} + \delta_2 \\ Stonebund_i = X_{i3}\beta_{i3} + \delta_3 \\ Soilbund_i = X_{i4}\beta_{i4} + \delta_4 \\ Treeplanting_i = X_{i5}\beta_{i5} + \delta_5 \end{cases} \tag{2}$$

where: $Organicfert_i$, $Inorganicfert_i$, $Stonebund_i$, $Soilbund_i$ and $Treeplanting_i$ are binary variables taking values 1 when farmer j selects organic fertilizer, inorganic fertilizer, stone bund, soil bund, and tree planting integrated soil fertility management practices, respectively, and 0 otherwise; X_1 to X_5 are the vector of variables; β_1 to β_5 a vector of parameters to be estimated and δ_i disturbance term.

Moreover, the degree to which integrated soil fertility management practices were simultaneously adopted and used was evaluated using a two-equation seemingly unrelated regression model with a generic form indicated in equation (3) following [35,36].

$$\begin{cases} Y_1 = X_{i1}\beta_{i1} + \varepsilon_1 \\ Y_2 = X_{i2}\beta_{i2} + \varepsilon_2 \\ Y_3 = X_{i3}\beta_{i3} + \varepsilon_3 \\ Y_4 = X_{i4}\beta_{i4} + \varepsilon_4 \\ Y_5 = X_{i5}\beta_{i5} + \varepsilon_5 \end{cases} \tag{3}$$

where Yi's are the intensity of practicing soil fertility management tools on smallholder farmers' farm sites; β_i are the respective vector of coefficient, x's are vectors of covariates determining the intensity of soil fertility management practices, and ε_i are their random term.

2.5. The hypothesis of explanatory variables

Various factors affected the status and intensity of investing in integrated soil fertility management technologies in Northwest Ethiopia. Table 1 shows the measurement and description of hypothesized variables used in the econometrics models.

3. Result and discussions

3.1. Socio-economic characteristics of households

A total of 380 respondents were sampled, and 95.53% of them had male heads. The household's average age and years of farming experience were 47.74 and 27.26, respectively. Likewise, the number of livestock owned by households was 6.22 in the tropical livestock unit (TLU), implying the more livestock held the more manure and the betterment of soil fertility and health on the farm. On average, a household has 1.38 ha of land size available for agricultural practices, suggesting most smallholder farmers are engaged in subsistence farming with poor soil fertility. The study also found that a household has a mean of 4.92 family size in man-day equivalent, entailing a household to be endowed with family labor to invest in labor-intensive soil fertility management tools at their farm. The typical distance traveled by a household to reach the closest development center was 4.13 km, inferring a household

Table 1
Definition, measurement and hypothesis of the explanatory variables used in the analysis.

Dependent variables		Expected signs	
1. Adoption of Integrated Soil Fertility Management Practices (AISFMP): households decision to adopt various soil fertility management practices			
2. Intensity of Integrated Soil Fertility Management Practices (IISFMP): the amont of soil fertility management practices invested on household farm measured in meter cube (m^3)			
Variables	Variable description and Measurement	AISFMP	IISFMP
Age	Age of household head (year)	±	
Sex	Sex of household head (1 = male, 0 = female)	+	
Education	Education status of the household head (1 = literate, 0 otherwise)	+	+
Family size	Number of persons per household (Adult equivalent)	+	+
Land size	Total land holding size of the household head (hectare)	+	+
Livestock	Number of livestock owned (measured in Tropical livestock unit)	+	+
Experience	Number of years the household implemented integrated soil fertility management practices		+
Distance to development center	Distance of farmer's house from the development center (kilometer)	–	–
Credit access	Use of cash credit for integrated soil fertility management practices (1 = user, 0 = non-user)	+	
Cooperative membership	Membership of farmers in cooperatives (1 = member, 0 = non-member)	+	+
Non and off-farm activities	The household members who participate in non and offfarm activities (1 = participant, 0 = nonparticipant)	+	+
Training access	The household head who got training on soil and water conservation practices (1 = got training, 0 = not got training)	+	+
Perception of erosion	Perception of households on soil erosion (1 = percieved, 0 = not-percieved)	+	

traveling a long distance on foot to get various government-based agricultural extension services (Table 2).

The majority (56.58%) of the sampled households can also read and write. Additionally, most households (62.11% and 70.26%) did not receive credit services and off-farm or non-farm income for managing soil fertility, respectively. Furthermore, roughly 73.16% of households received training in investing in soil fertility management techniques (Table 2).

3.2. Household's status on soil fertility management practices

Table 3 showed that households on farms adopted and put into effect a variety of soil fertility management strategies. To regulate soil fertility, the majority of households (96.58%, 76.05%, and 73.95%) employed inorganic fertilizer, tree planting, and organic fertilizer, respectively. Moreover, in the northwest of Ethiopia, approximately 43.16% and 41.05% of households applied stone and soil bunds for soil fertility management. This study is in line with the finding of [37,38] revealed that farmers in Ethiopia use structural and non-structural measures to improve soil fertility. Additionally, for improved soil fertility and crop output, smallholder farmers have adopted and employed some integrated soil fertility management strategies [39].

3.3. Adoption of integrated soil fertility management practices

The Wald test result ($\chi 2$ (60) = 237.04, Prob > $\chi 2$ = 0.0000) is statistically significant at a 1% level, which indicates that the subclass of model coefficients is jointly significant and the model's explanatory power is satisfactory (Table 4).

As a result, the multivariate probit model reasonably matches the data. The values of the likelihood ratio test in the mode (LR ($\chi 2$ (10) = 76.972, Prob > $\chi 2$ = 0.0000 confirms that, the null hypothesis that the independence between the adoption decision of soil fertility management practices on smallholder farmers ($\rho 21 = \rho 31 = \rho 41 = \rho 51 = \rho 32 = \rho 42 = \rho 52 = \rho 43 = \rho 53 = \rho 54 = 0$) was rejected at 1% significance level (Table 4). This implies that there was a significant joint correlation for the five estimated coefficients across the equations used in the models. It also revealed that separate estimation of the adoption decision of soil fertility management practices was biased, but interdependent (Table 4).

The simulated maximum likelihood estimation result confirmed that the likelihood of households using organic fertilizer, inorganic fertilizer, stone bunds, soil bunds, and tree planting, respectively, was 73.9%, 96.7%, 43.6%, 41.2%, and 75.1%. Moreover, the likelihood of households simultaneously adopting and implementing the five soil fertility management practices was 8.6%, while their failure to adopt those soil fertility management practices was predicted to be 0.1% (Table 4).

The result of the multivariate probit model is presented in Table 5. The values of the coefficients show that policy-relevant variables such as households' age, education status, family size, land size, cooperative membership, livestock holding, credit access, training access, distance to development center, perception of erosion, off and on-farm income source had a significant consequence on households' willingness to adopt greatest soil fertility management practice (Table 5).

Age of household was negatively associated with the probability of adopting tree planting as a soil fertility management practice at a 1% level of significance (Table 5). It indicates that as the age of the household increased by a year, the probability of adopting and practicing tree planting decreased due to its labor-intensive nature. Therefore, aged households are unwilling to exercise tree planting as a soil fertility management practice on farmland. Similarly, this study is in line with other findings, they endorsed that younger farmers adopted and extensively used tree planting, soil conservation, and land management practices to recover soil fertility and improve crop production than older [40,41].

The education status of the household positively influenced the probability of adopting all soil fertility management practices at a 1% level of significance (Table 5). It implied that as compared to the non-educated, the educated households have a high probability of

Table 2
Mean and proportion households' characteristics (N = 380).

Continuous Variables		Mean	Standard Deviation
Age of respondent (years)		47.74	0.54
TLU (Tropical Livestock Unit)		6.22	0.24
Farming experience (years)		27.26	0.56
Land size (ha)		1.38	0.03
Family size (Man Day Equivalent)		4.92	0.20
Distance to development center (kilo meter)		4.13	0.22
Dummy Variable	**Response**	**Frequency**	**Percentage**
Credit access	Yes	144	37.89
	No	236	62.11
Sex of household	Male	363	95.53
	Female	17	4.47
Education status	Illiterate	165	43.42
	Literate	215	56.58
Off and nonfarm income source	Yes	113	29.74
	No	217	70.26
Access to training on soil fertility management	Yes	278	73.16
	No	102	26.84

Table 3
Proportion of soil fertility management practices adopted by households in the study area.

Decision	Soil Fertility Management Practices									
	Organic Fertilizer		Inorganic Fertilizer		Stone Band		Soil Band		Tree Planting	
	N	%	N	%	N	%	N	%	N	%
Yes	281	73.95	367	96.58	164	43.16	156	41.05	289	76.05
No	99	26.05	13	3.42	216	56.84	224	58.95	91	23.95
Total	380	100	380	100	380	100	380	100	380	100

Table 4
Overall model fitness, probabilities, and correlation matrix of the soil fertility management practices from the MVP model.

Variables	ρ1 (Organic Fertilizer)	ρ2 (Inorganic Fertilizer)	ρ3(Stone Bund	ρ4 (Soil Bund)	ρ5 (Tree Planting)
Predicted probability	0.739	0.967	0.436	0.412	0.751
Joint probability (success)	0.086				
Joint probability (failure)	0.001				
Estimated correlation matrix					
	ρ1 (organic fertilizer)	ρ2 (inorganic fertilizer)	ρ3 (stone bund)	ρ4 (soil bund)	ρ5 (tree planting)
ρ1 (organic fertilizer)	1				
ρ2 (inorganic fertilizer)	−0.226	1			
ρ3 (stone bund)	0.193**	−0.222*	1		
ρ4 (soil bund)	0.032	0.088	−0.345***	1	
ρ5 (tree planting)	0.339***	−0.187	0.576***	−0.365	1
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0					
χ2 (10) = 76.972 and prob > χ2 = 0.0000***					
Numbers of draw (#) 5					
Numbers of observation	380				
Log likelihood	−792.483				
Wald χ2 (60)	237.04				

Note: ***, ** and * shows the value that statistically significant at 1%, 5% and 10% level, respectively.

Table 5
Multivariate probit estimations for determinants of adoption of soil fertility management practices.

Variables	Coefficients (Std.Err)				
	Organic fertilizer	Inorganic fertilizer	Stone bund	Soil bund	Tree planting
Sex of household	−0.220 (0.359)	0.439 (0.578)	−0.238 (0.331)	−0.146 (0.344)	−0.278 (0.347)
Age of household	0.001 (0.008	−0.020 (0.018)	−0.002 (0.007)	0.012 (0.008)	−0.021 (0.009)***
Education status	0.234 (0.161)	0.691 (0.475)	0.407 (0.152)***	−0.077 (0.155)	0.626 (0.168)***
Family size	0.010 (0.027)	0.088 (0.130)	0.132 (0.043)***	0.010 (0.017)	−0.023 (0.020)
Cooperative membership	0.374 (0.180) **	0.907 (422) **	0.136 (0.167)	0.670 (0.174)***	0.318 (0.190)*
Land size	0.257 (0.145) *	1.221 (0.502) **	−0.242 (0.125)*	0.219 (0.134)	−0.232 (0.149)
Livestock holding	0.049 (0.022) **	−0.016 (0.036)	0.008 (0.017)	0.061 (0.021)***	0.089 (0.026)***
Non and off-farm activities	0.459 (0.184) **	−0.748 (0.436) *	0.133 (0.164)	0.452 (0.171)***	−0.217 (0.181)
Credit access	−0.136 (0.154)	−0.340 (0.405)	−0.290 (0.145)**	−0.291 (0.154)*	0.734 (0.175)***
Distance to development center	0.003 (0.002)	0.011 (0.008)	0.005 (0.002)***	−0.007 (0.002)***	0.006 (0.002)**
Training access	0.399 (0.164) **	−0.546 (0.404)	0.063 (0.155)	0.137 (0.163)	−0.289 (0.181)
perception of erosion	−0.123 (0.158)	−0.093 (0.401)	0.340 (0.146) **	−0.466 (0.150) ***	0.174 (0.165)
constant	−0.668 (0.506)	0.748 (0.929)	−0.934 (0.470) **	−0.424 (0.488)	1.047 (0.508) **

Note: Dependent variable; adoption of soil fertility management practices; ***, ** and * shows the value that statistically significant at 1%, 5% and 10% level, respectively.

adopting and implementing multiple soil fertility management practices such as stone band and tree planting. This can be clarified by the fact that a literate household has a virtuous understanding and information on the nature and effect of soil degradation. Other studies also confirmed that education has a positive and significant impact on the decision to adopt multiple sustainable agricultural land management practices [42,43].

Family size was positively related to the possibility of adopting and implementing the stone bund for soil fertility management at a 1% level of significance (Table 5). From this, it can be deduced that as the number of the family increased by a unit in man-day equivalent, the chance of adopting the stone bund also increased due to the labor-intensive nature of the practice. Therefore, a household endowed with family labor, adoption, and practicing labor-intensive soil fertility management on farmland is possible. This study is in line with the finding of [44,45]. Similarly, other research revealed that family size was positively linked with the likelihood of adopting multiple sustainable agricultural land management practices [46].

Cooperative membership of households has positively influenced the probability of adopting soil fertility management practices (organic fertilizer, inorganic fertilizer, soil bund, and tree planting) at 5%, 5%, 1%, and 10% levels of significance, respectively (Table 5). It implied that as compared to a non-member, a cooperative member household has a high probability of adopting and practicing soil fertility management practices attributed to the fact that the member household has enough information on the effect of soil erosion, good credit access, and supply of several farming inputs and apparatuses used for implementing it. This study is consistent with the findings of [47], who indicated that social capital, rural institutions, groups, and networks in the communities have a positive influence on the decision of adopting multiple sustainable agricultural practices on farmland.

The land size was positively and negatively related to the probability of adopting fertilizers and stone bunds for soil fertility management, respectively (Table 5). It implied that as the land size of the household increased by a hectare, the probability of using fertilizers increased. This is because of not losing much yield from the large farmlands. However, as the land size increases the chance of practicing stone bund decrease since it requires energy and transportation of stones. Therefore, a household with a large land size adopted and practiced fertilizers for improvement of agricultural production and soil health on the farmland than stone bund. This result is related to the finding of [48], who endorsed that farmland size was positively related to the probability of adopting fertilizer as a soil conservation practice. However, other studies found inconsistent with this finding [49,50].

Livestock number was positively associated with the probability of adopting organic fertilizers, soil bunds, and tree planting practices for soil fertility management (Table 5). It disguised that the probability of adopting soil fertility management practices increased, as a household livestock holding capacity increased in a unit in a tropical livestock unit. Therefore, livestock production plays a crucial role in soil fertility management as a source of manure and improvement of soil health on the farm. This study is consistent with the findings of [47,48,51] they showed that livestock ownership was positively related to the chance of adopting and using organic fertilizers (compost and manure) for soil fertility and quality improvement.

Non-farm and off-farm sources have significantly determined the likelihood of adopting soil fertility management practices at different levels of significance (Table 5). It implied that as compared to non-participated, participated households had a high probability of adopting and practicing less cost soil fertility management like organic fertilizer and soil bund than inorganic fertilizer on their farm site. This can be clarified by the fact that most farmers are cost-reluctant and frequently use labor-intensive soil fertility management practices than capital-intensive practices. This result is consistent with the finding of [52], who remarked that participation in non/off-farm activities was positively associated with the probability of adopting soil fertility and water conservation practices.

As depicted in Table 5, compared to non-trained households, conservation-trained households had a high probability of adopting soil fertility management practices, particularly organic fertilizer. This is because households who have to get training on soil and water conservation practices can use easily available organic fertilizers for improving and keeping the fertility of degraded soil more than others. This result is supported by other research that endorsed access to soil and water conservation training for the household positively influenced the probability of adopting soil fertility management practices [53–56].

Soil erosion perception positively and negatively influenced the likelihood of adopting stone bund and soil bund practices at 5% and 1% levels of significance, respectively (Table 5). As compared to the non-perceived, the perceived household had a high probability of adopting stone bunds as soil fertility management than the soil band. If the household perceived that the extent of soil erosion is high on the farm, they adopt and practice a hard and continuous soil fertility management like stone bund than an easily distracting soil bund practice. This study is in line with the finding of [44], who endorsed that the perception of erosion hazards was positively associated with the decision to adopt multiple and strong land management practices on farmland.

As compared to non-accessed, the credit-accessed household has a high probability of adopting and practicing tree planting than soil and stone bunds (Table 5). It implies credit accessed households have planted trees on large scale for multiple purposes such as improving soil fertility, firewood, charcoal, and source of income than single-function soil fertility management practices. This study is in line with the finding of [44,45,47], they showed that credit was a principal factor in adopting multiple capital-intensive land

Table 6
SUR model estimation results of the intensity of soil fertility management practices.

Variables	Coefficients (Std.Err)				
	Organic fertilizer	Inorganic fertilizer	Stone bund	Soil bund	Tree planting
Education status	0.174 (0.637)	−0.318 (0.273)	28.618 (20.201)	−6.723 (14.449)	166.401 (88.223) *
Family size in man day equivalent	−0.074 (0.073)	0.033 (0.031)	0.204 (2.325)	0.844 (1.663)	12.720 (10.152)
Farming experience in years	−0.007 (0.030)	−0.056 (0.013) ***	−0.226 (0.962)	0.747 (0.688)	−18.260 (4.201) ***
Cooperative membership	1.391 (0.731) *	0.546 (0.313) *	−17.729 (23.175)	71.816 (16.576) ***	130.548 (101.212)
Land size in hectare	1.628 (0.546) ***	1.493 (0.234) ***	−6.054 (17.312)	46.065 (12.383) ***	110.152 (75.606)
Livestock holding in tropical livestock unit	−0.022 (0.071)	−0.029 (0.031)	0.513 (2.264)	−2.907 (1.620) *	−4.010 (9.888)
Non and off-farm activities	1.717 (0.705) **	−0.356 (0.302)	42.596 (22.361)*	34.863 (15.994) **	139.304 (97.655)
Distance to development center in km	−0.016 (0.007) **	0.004 (0.003)	0.098 (0.215)	−0.266 (0.154) *	0.073 (0.941)
Training access on soil fertility management	−0.292 (0.676)	0.307 (0.290)	25.494 (21431)	44.089 (15.329) ***	−23.201 (93.595)
constant	1.732 (1.183)	2.558 (0.507) ***	38.293 (37.538)	26.045 (26.850)	361.570 (163.938) **
N = 380					
Breusch-Pagan test of independence: $\chi2$ (2) = 54.493***					

Dependent variable = Intensity of soil fertility management practices; ***, ** and * shows the value that statistically significant at 1%, 5% and 10% level, respectively.

management practices to improve soil fertility and crop productivities.

3.4. *Measuring the intensity of soil fertility management practices*

The seemingly unrelated regression (SUR) model estimation result of the intensity of soil fertility management practices has been reported in Table 6. The Breusch-Pagan test result endorsed that the null hypothesis of independence among soil fertility management practices was rejected at a 1% level of significance. Therefore, the SUR model was applied to estimate the simultaneous equations of soil fertility management practices. The result of the model revealed that the intensity of soil fertility management practices was significantly influenced by several policy-relevant variables (Table 6).

The education status of the household positively and significantly influenced the intensity of practicing soil fertility management practice at a 10% level of significance (Table 6). It implied that as compared to the illiterate, the literate household has massively practiced the entire soil fertility management on the farm. This can be explained by the fact that literate household has a bundle of skill and knowledge on soil fertility management practice's role in the reduction of soil degradation and keeping the soil healthy [21].

Membership in cooperatives has positively influenced the intensity of practicing soil fertility management practices like organic fertilizer, inorganic fertilizer, and soil bund at 10% and 1% levels of significance (Table 6). It disguised that as compared to non-members, cooperative members' households enormously practiced soil fertility management practices on their farms. This can be illustrated by the fact that member household has good access to and supply various farming inputs and apparatuses for long-term soil fertility management [57].

The land size was positively related to the intensity of practicing soil fertility management practices at a 1% level of significance that shows as the land size of the household increased by a hectare, the intensity of practicing soil fertility management practices was enlarged (Table 6). According to Ref. [48], a household with a large land size has highly used different soil fertility management practices like organic fertilizer, inorganic fertilizer, and soil bund for improvement of soil health and agricultural production on their farm site.

Livestock number was negatively associated with the intensity of practicing soil bund as soil fertility management practices at a 10% level of significance (Table 6). It implied that the intensity of practicing soil bund as soil fertility management tools decreased, as a household livestock holding capacity increased in a unit in tropical livestock unit. This can be clarified by the fact that the soil bund is highly susceptible to damage and demolished easily by livestock.

Non-farm and off-farm activities have positively influenced the intensity of practicing soil fertility management practices at 5% and 10% levels of significance (Table 6). It implied that as compared to the non-participated, the participants highly practiced soil fertility management practices. As the study of [52] revealed that households who have non-farm and off-farm income sources can use both capital- and labor-intensive soil fertility management practices more frequently than others. Contrary to this [48,58], reported that off/non-farm activity is negatively related to soil and water conservation investments.

Distance to the development center was negatively related to the intensity of practicing organic fertilizer as soil fertility management practice at 5% levels of significance (Table 6). It implied that as the distance to the development center increased by a kilometer, the intensity of practicing organic fertilizer soil fertility management practices declined. This can be explained by the fact that when the development center is far from the household, the farmer is reluctant to prepare and apply organic fertilizer on their farm.

Soil and water conservation training access have positively influenced the intensity of practicing soil bund and stone bund as soil fertility management tools at a 1% level of significance (Table 6). It implied that as compared to the non-trained, the trained household has highly implemented those practices at their farm site. This can be clarified by the fact that households who have accessed training on soil and water conservation practices can use both capital and labor-intensive soil fertility management practices more frequently than others [43].

4. Conclusion

This study examined the factors influencing households' decisions and the extent to which they invested in integrated soil fertility management tools on their farm using household survey data of smallholder farmers in the Megech watershed of the Tana Sub-Basin, Northwest Ethiopia.

According to the study's findings, the majority of households used and invested in the five main soil fertility management practices of organic fertilizer, tree planting, inorganic fertilizer, stone bunds, and soil bunds to enhance soil quality and agricultural output.

The outcomes of the econometrics model also supported the idea that common underlying determinants influenced the status and intensity of investing in integrated soil fertility management practices on agricultural sites. The multivariate probit model result shows that the probability of households practicing and using inorganic fertilizer, tree planting, and organic fertilizer for improving soil health and quality was high as compared to the stone bund and soil bund. The likelihood of households jointly adopting the soil fertility management tools was also high, suggesting that most farm households implemented the tools at the same time to improve soil health and boost productivity on their farm site.

Similarly, literate households are more likely to embrace soil fertility management because they have access to reliable knowledge about the causes and effects of soil degradation. Households with a large number of family sizes invested and practiced stone bunds for soil fertility management on the farm site due to the labor-intensive nature of the practice. Moreover, a cooperative member household has a high probability of adopting soil fertility management tools since they have enough information on the soil erosion effect, and good access, and supply of soil and water conservation inputs and apparatuses.

Due to the labor-intensive nature of the process, households with a wide range of family sizes adopted and used stone bunds for soil fertility management on the farm site. Livestock production is crucial in regulating soil fertility, as manure increases soil fertility and agricultural productivity on the farm site. Households who had access to training on soil and water conservation practices can use compost for improving soil fertility. Moreover, a household adopts and practices a hard and perpetual soil fertility management tool such as a stone bund if their perception is high on soil erosion than easily distracting soil fertility management practice soil bund. Additionally, a household adopts and uses a durable soil fertility management tool, such as a stone bund, if they believe that soil erosion is a bigger problem than a quickly distracting tool. In contrast to single-purpose soil fertility management approaches, households with access to finance have planted trees on a large scale for many purposes, such as enhancing soil fertility, producing firewood, and charcoal, and as a source of revenue.

Various policy-relevant variables had a substantial impact on the intensity of investing in soil fertility management tools on the farm. Due to its easily susceptible to damage and destroyed nature by livestock, the intensity of implementing and practicing soil bund decreased with livestock holding. Similarly, the adoption and use of soil fertility management techniques on farm sites decreased the farther they were from the development center. As compared to non-trained, households who had access to training on soil and water conservation used a combination of labor- and capital-intensive soil fertility management tools to improve the fertility of the soil.

The comprehensive findings of this analysis show that various policy-relevant variables play a resilient role in determining and shaping farmers' investment decisions, behavior, and extent in soil fertility management. In general, Ethiopia has a diverse agro-ecology across villages and districts which is suitable for adopting and investing in various soil fertility management techniques on their farm. Therefore, these findings can be used for reference and intervention by non-governmental organizations, international organizations, government ministries, and agencies, farmers, extension agents, community-based groups, researchers, and universities.

The study was limited spatially as well as temporally to make the study more representative in terms of a wider range of area, and time horizon. Moreover, the result of the study may have limitations to make generalizations. However, the result of the study applies to Ethiopia as well as other countries which have the same agroecology.

5. Recommendation

Sustainable and ongoing soil fertility management strategies should be developed and put into practice to improve soil fertility and quality. Therefore, policymakers should formulate policies and programs that encourage private incentives and credit supply to farm households to promote profitable and sustainable projects on soil fertility. The study endorsed that most rural households were illiterate, implying the policy maker should promote adult education to enhance their knowledge, skill, and attitude on the importance of investing in profitable integrated soil fertility management techniques on the farm.

The choice of soil fertility management practice is highly dependent on the capacity of the farmer to afford the such investment, so emphasis should be given to a proactive approach to achieve sustainable soil fertility management among smallholder farmers. Hence, soil fertility management and capacity-building training should be ongoing and appropriate for farm households.

Moreover, livestock production has a significant effect on the decision and intensity to use manure to improve the quality and fertility of the soil. Therefore, adopting high-yield breeds and fodder can boost livestock products, including manure in turn boost soil fertility.

In general, there should be great integration among farm households, agricultural experts, research centers, and governmental and non-governmental organizations in developing, designing, and implementing effective and profitable projects, policies, and programs to improve the quality of soil for sustainable and efficient agricultural production in Ethiopia. Further research should be conducted on the impacts of soil fertility management technologies on soil health, crop productivity, and household welfare at a national level.

Author Contribution Statement

Abebe Birara Dessie: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper. **Taye Melese Mekie**: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper. **Tadie Mirie Abate**: Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper**. Abdrie Setegn Belgu**: Conceived and designed the analysis Analyzed and interpreted the data; Wrote the paper. **Marye Aragew Zeleke**: Conceived and designed the analysis; Contributed analysis tools or data. **Daniel Geletaw Eshete**: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper. Haimanot B.Atinkut: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper. **Melaku Tarekegn Takele**: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper

Consent for publication

Not applicable.

Ethical approval and consent to participate

Ethical clearance letters were collected from the University of Gondar research and community service directorate and Amhara region office to care for both the study participants and the researchers. During the survey, official letters were written for each district and kebele/villages/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 a full right 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 in and free moods until the end of this research.

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Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare no conflict of interest.

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