Ecological Processes

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Factors that influence the implementation of sustainable land management practices by rural households in Tigrai region, Ethiopia

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Abstract

Background: Sustainable land management is considered as one of the useful approaches to combat the threat of various forms of land degradation in Ethiopia. Despite this, there is scant information regarding households' decision towards the implementation of sustainable land management practices. This paper, therefore, looks into the determinants for the continued use and choice of the sustainable land management practices by smallholder farmers and its productivity effect in three randomly chosen districts in Tigrai region, Ethiopia. The study uses data from household survey and key informant interviews. The paper employs a binary logit to analyze the determinants for the decision of continued use of sustainable land management practices, and a multivariate probit to analyze the simultaneous adoption decision of sustainable land management practices using cross sectional data collected from 230 randomly selected households. The impact of sustainable land management practices was also evaluated using propensity score matching.

Results: Farming techniques, wealth status, agro-ecological variations, and plot level characteristics were found to be associated with the implementation decision of sustainable land management practices by rural households. Besides, institutional supports and access to basic infrastructures influenced the overall continued use of sustainable land management practices and the preference of households toward these practices. The study also finds that the value of crop production of sustainable land management users was on average 77–100% higher than that of non-users.

Conclusions: The results of the current study confirm that the implementation of various sustainable land management practices are influenced by farming technologies deployed by rural households, agro-ecological variations, plot characteristics, and institutional supports. The findings also affirm that most of the sustainable land management practices are complementary to one another, and implementing two or more sustainable land management practices on a given plot is highly associated with higher value of crop production. Such complementarity highlights that the productivity effect of a given sustainable land management practice is enhanced by the use of the other ones.

Keywords: Continued use, Determinants, Plot level, Productivity effect, Sustainable land management practice, Tigrai

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Introduction

Land degradation has been the critical challenge for Sub-Saharan African (SSA) countries. The causes of land degradation are complex and vary from place to place. The major drivers of land degradation are generally grouped into two: proximate and underlying causes (Belay et al. 2015; Pingali et al. 2014). The proximate causes are more or less natural factors such as biophysical conditions, topographic and climatic conditions, and inappropriate land management practices, whereas the underlying factors are mostly anthropogenic, which include population growth, land tenure, and other socio-economic and policy related factors (Belay et al. 2015; Pingali et al. 2014).

FAO (2011) report shows that Africa loses over 50 tons of soil per hectare and nearly 4 million hectares of forest land annually, largely in humid and sub-humid West Africa. These evidences indicate that the natural resources in the continent have been excessively utilized and this resulted in land degradation which in turn affects the livelihood of African farmers as the majority of them rely on the direct use of natural resources for their very survival. The key drivers of land degradation in Africa in general and in sub-Saharan Africa in particular are similar to that of at global scale which include high demographic growth, weak incentive policy, poor legal and institutional frameworks, limited availability of grazing land, and poor knowledge regarding the environment (Diagana 2003; Hurni et al. 2010). Especially in countries with limited cultivable land and high population growth rates, fallow periods are no longer sufficient to allow soil fertility to be restored. Kenya, Ethiopia, Malawi, Burundi, and Rwanda are examples of this where crop yields have fallen consequently. In a response, farmers have been forced either to bring increasingly marginal lands into cultivation, or to migrate into tropical forest areas, exacerbating problems of land degradation and deforestation (FAO, 2011). The economic consequences of land degradation are also severe in Eastern Africa since nearly 65% of the population is rural and the main livelihood of about 90% of these rural populations relies on subsistence based agriculture (Kirui and Mirzabaev 2015).

The level of degradation in many SSA, including Ethiopia, is even more severe. Besides, addressing the proximate and underlying causes of the prevailing land degradation problems remains a critical policy challenge for Ethiopia since its economy enormously relies on subsistence agriculture. The major drivers of land degradation in Ethiopia include land shortage and lack of alternative livelihoods (induced by high population growth), forest clearance and high removal of vegetation cover, unsustainable cultivation practices, and overgrazing (FAO, 2011). Soil erosion and deforestation are the two more severe forms of land degradation that contribute to the poor performance of subsistence agriculture sector in Ethiopia (Bekele and Drake 2003; Bewket 2003). These land degradation problems have also far-reaching economic, social, and environmental influences (Pender and Gebremedhin 2007). With regard to cost of land degradation, various estimates show that it costs a considerable proportion of a country's national income. In Ethiopia, for instance, the cost of land degradation was about 3% of the total agricultural GDP in 1994 (Bojo and Cossells 1995). Sustainable land management, has, therefore, utmost importance to Ethiopia in which about 80% of its population is directly supported by the agriculture sector. It addresses land degradations and enhances the productive capacity of the natural resources base. In addition, in the absence of effective sustainable land management (SLM) practice, it is less likely to eradicate poverty (von Braun et al. 2014).

A number of studies have addressed important influencing factors that explain the adoption decision behavior of smallholder farm households toward various land conservation measures. For instance, a study conducted in north western part of Ethiopia by Adugna and Bekele (2007) revealed that economic variables such as plot ownership, livestock holding, family size, and land-to-labor ratio have an influence on adoption of land conservation practices. Furthermore, the major socio-economic factors that influence households decision to adopt soil and water conservation measures in Ethiopian highlands include sex and education level of household head, availability of labor force, cattle holding, and off/non-farm income (Adimassu and Kessler 2012; Amsalu and de Graaff 2007; Bekele and Drake 2003). On the other hand, biophysical characteristics of plots, topography, and agro-ecological variations also influence the adoption decision of soil and water conservation and other sustainable land management practices (de Graaff et al. 2008; Miheretu and Yimer 2017). World Bank (2007) and Yirga (2007) also reported that institutional factors such as land insecurity, access to credit, proximity to all weather road, and market access were likely to influence the adoption of and investments on sustainable land management practices in Ethiopia. The adoption of SLM practices by farm households has also been hurdled by wealth-related factors (von-Braun et al. 2013; Bewket 2007; Genanew and Alemu 2012; Shiferaw and Holden 1998). Furthermore, Amsalu and de Graaff (2007) revealed that the adoption level of SLM practices by self-motivated farmers remains very low and yet to bring the intended results in terms of improving the livelihoods of rural households.

With regard to the effectiveness of sustainable land management practice, mixed results have been reported particularly related to its impact on crop yield of farm plots. A study by Pender and Gebremdhin (2006), for instance, reported that farm plots that are treated with stone terraces experience a significant yield increment. Besides, an impact evaluation study conducted in Northern Ethiopia at household level revealed that those who introduced stone bund on their private plots experienced higher value of crop production as compared to those who did not (Kassie et al. 2008). Nevertheless, other studies revealed that the outcome of series of conservation measures introduced in Ethiopia, usually involving physical and biological structures such as terraces, bunds, and tree planting, among others, is less than desired (Berry 2003; Eyasu 2003). Besides, an inverse relationship between adoption of SLM practices and crop yield was found in areas characterized by high rainfall in western part of Amhara regional state of Ethiopia (Kassie et al. 2008).

There is also destruction of soil and water conservation structures in many parts of Ethiopia (Kassie 2009; Tadesse and Belay 2004) which pose a critical challenge on the sustainability of the already introduced land conservation measures. Such discrepancy of findings shows that the impact of SLM practice on the productivity of farm plots and level of acceptance varies across different landscapes and agro-ecological zones. The effectiveness of the introduced SLM practices on farmlands has been challenged by many factors such as inappropriate implementation approaches, too much focus on technical solutions, too little focus on addressing the proximate and undelaying causes of land degradations, and poor extension systems (Adimassu et al. 2016; Adimassu and Kessler 2012; Kassie 2009; Bewket 2007; Bekele 2003). Additional contributors to the ineffectiveness in terms of attaining the required results include top-down planning methodology, lack of community input, and low implementation capacity at local levels (Tongul and Hobson 2013). There are also evidences that policy-related challenges have contributed to the failure of land conservation efforts in terms of achieving the intended objectives in different parts of the country. For example, the findings of Nkonya et al. (2013) and von Braun et al. (2013) indicate that lack of strong policy action and low level of evidence-based policy framework are considered to be the critical challenges for the effectiveness of SLM practices.

As reviewed earlier, despite the abundance of research works in SLM and its crop productivity effect, the studies are extensively oriented towards the initial adoption but with no consideration to the continued use and multiple adoption decision of SLM practices. Most of the previous studies modeled the adoption of SLM practice as a binary: adopters and non-adopters. Such modeling would make it difficult to analyze the preference of households towards various SLM practices and simultaneous adoption decisions. Therefore, studying the simultaneous adoption behavior of farmers and the intensity of the use of SLM practices would be helpful to the existing body of knowledge. This is true since farmers are more likely to use a combination of SLM practices to deal with the land degradation problems faced instead of adopting just only a single conservation practice. The adoption decision is, therefore, explained in the form of preferences from a set of land conservation options. To this effect, a multivariate instead of bivariate approach, which excludes useful information contained in the interdependent and simultaneous adoption decisions, is employed to model the adoption decision. This paper, therefore, intends to examine the factors affecting households' decision to the implementation of multiple SLM practices and the productivity effect on farmlands as it would help to better understand the households' decision behavior towards land management practices on farm plots as well as institutional and biophysical factors that affect such decisions.

Methods

Study sites

The current study was conducted in three randomly selected districts[1] of Tigrai region, namely Atsibi-wenberta, Hintalo-wajerat, and Kola-tembien representing highland, midland, and lowland agro-ecological zones respectively as shown in Fig. 1. The first step in the random sampling procedure of the districts was obtaining the list of districts in the region based on their agro-ecological classification. Then after, one district from each ago-ecological zone, which makes up a total of three districts, was randomly selected using a lottery system. The study communities including the catchment areas within each selected district were purposively chosen using predefined criteria stated below. Lastly, the respondents from the selected catchments, both from treated and untreated, were randomly drawn using a lottery system. The total rural districts in the region are 34 in which sustainable land management practices have been implemented since the past few decades. This study selects three districts randomly (a lottery system) in which an attempt was made to represent the three agro-ecological zones (highland, midland, and lowland).

The study sites are spatially distributed across three districts of the region to capture heterogeneous data on both socioeconomic and plot level biophysical attributes. The study sites are also characterized by various climatic and topographic domains ranging from altitude differences to temperature and rainfall variations as well as cropping patterns.

Kola-tembien is topographically located with a range of 1501 to 2500 m above sea level. The estimated annual rainfall ranges from 500 to 800 mm, while mean annual

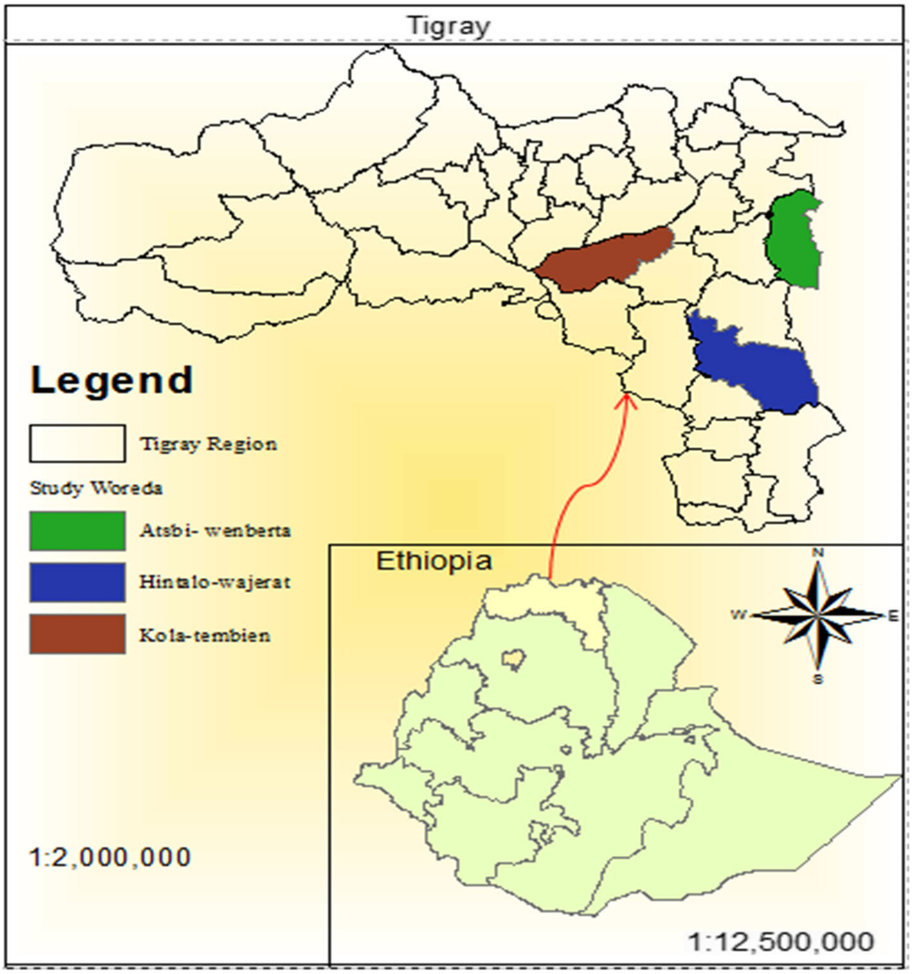

Fig. 1 Location of study sites

temperature varies between 25 and 30 °C. The wereda is administratively divided into 27 tabias. The total population of the wereda is 148,282 and the total area is estimated at 147,427 ha. On the other hand, Atsibi-wenberta is subdivided into 16 administrative tabias with a total population of 112,341. The elevation of *Atsibi-wenberta* wereda varies significantly which ranges from 918 to 3069 m above sea level. The third study site (*Hintalo-wajerat wereda*) has a total population of 153,505 with 34,360 households and an area of 2864.79 km^2. This *wereda* is situated at an altitude range of 1500 to 2540 m above sea level. In addition, the wereda is divided into 20 administrative tabias.

The farming system was observed to be a mix of livestock and crop production which is fairly similar in the three study sites. The dominant crops grown by smallholder farmers in *Kola-tembien* district, for instance, are teff, sorghum, maize, and finger-millet. In *Hintalo-wajert* district, the staple crops grown are wheat, barley, and teff. Similarly, the dominant crops grown in *Atsibi-wenberta* district are wheat, barley, and pulses. The livestock production system is also fairly similar across the three study weredas. It is mainly characterized by traditional husbandry system with small per capita cattle holding, sheep, and goat and to some extent poultry production. The production system of both crop and livestock is characterized by low input and low output which indicates the farming system has remained very traditional and subsistence.

Data and sampling procedures

The current study selected three catchment areas as treated observations and another three catchment areas as control observations using multi stage sampling techniques. In the first stage of the sampling procedure, the three districts were randomly selected using a lottery system from a list of all districts found in the region. Then after, using predefined criteria,[2] a total of three *tabias*[3], which includes one *tabia* from each selected district that best fits the criteria, were purposively chosen with the support of experts from the office of natural resource management of the study districts. Lastly, a model catchment area from each selected *tabia* was purposively selected based on the stated criteria. The list of selected tabias and catchment areas are presented in Table 1. For comparison purpose, one catchment area,[4] which is considered to be poorly conserved by SLM practices, from each *tabia* was also selected. The target population for this study was households who introduce SLM practice on their plots in the absence of any external incentive and also continues to maintain the conservation measures. Representative sample size was finally determined using Eq. 1, and respondents were selected through a lottery system of simple random sampling. The lottery system was done through the help of Microsoft Excel which enables to generate a random number from the data set of the sampling frame. The distribution of the sample size across the study sites was proportionate to their relative share of the total sampling frame (target population) as shown in Table 1.

This paper is based on a survey of 230 randomly drawn households from a set of list of household heads of three *tabias* and six catchments. The required data were collected using structured questionnaire from the selected heads of households. The study prepared two separate set of questions for the household survey (structured questionnaire) and for the key informant interviewees (checklist and few unstructured open ended questions). A structured questionnaire was designed to elicit information on demographic, socioeconomic, infrastructure, and plot level information from the households, whereas the key informant interview (KII) was designed to gather qualitative data on the challenges of maintaining conservation structures, benefits of sustainable land management practices, and institutional supports to promote SLM.

A check list was used to gather data from the key informants that include natural resource management experts, development agents, and *tabia* leaders of the study sites. The participants of the KII were development agents and community leaders from the three *tabias* included in this study who are better informed and can better describe about the sustainable land management practices in their localities. A pre-test survey was conducted prior to the actual survey in each study site to incorporate unforeseen variables and also for acclimatization purpose. Following this, training on the questionnaire and over all data collection was provided to the enumerators. The secondary data were obtained particularly from unpublished reports of the office of the natural resources management of the study sites.

$$n = \frac{p(1-p)}{\frac{e^2}{Z^2} + \frac{p(1-p)}{N}} \quad (1)$$

Where n is the sample size, N is the population size (171), Z is the confidence level at 95%, $Z = 1.96$, and P is the estimated population proportion (50%), precision level (e) = 0.06. The total representative sample size was found to be approximately 115 households and a reasonable sample size was taken from each catchment in proportion to their representation to the total target population (Table 1). In addition, 115 households who do not introduce SLM measures on their plots were randomly selected as control observations. The selected comparison catchment areas for controlling purpose (where the control observations were selected) are spatially located adjacent to the catchment areas where continued users of SLM practices reside. An attempt was also made to include catchments (for the treated observations) that had been treated at least 2 years prior to the survey with an intention that this time lag provides adequate time for households to develop the experience needed to operate and manage SLM practices and at the same time experience the benefits of the continued use of SLM practices on farmlands.

Data analysis

Both descriptive and inferential statistics method of data analysis were employed. Particularly, mean, standard deviation, *t* tests, and chi square tests were used to analyze data collected from the sample households. Binary logit and multivariate probit were deployed to analyze the drivers to the households' decision toward the continued use and choices of SLM practice by farm households respectively. Propensity score matching was also deployed to evaluate the impact of introduced SLM practices on the value of crop production. The data collected from the key informants was qualitatively analyzed using content analysis and the results are integrated with the

Table 1 Distribution of respondents by study *tabia* and catchment (districts in parentheses)

Agro-ecological zone	Selected tabia	Selected catchment	Total SLM users	Treated observation	Control observation	Total sample
Highland	*Kaal-amin* (*Atsibi-wonberta*)	*Ambelten*	55	37	37	74
Midland	*Hintalo* (*Hintalo-wajerat*)	*May-derhu*	64	43	43	86
Lowland	*Begashka* (*Kola-tembien*)	*Shimderena*	52	35	35	71
Total			171	115	115	230

empirical (quantitative approach) results as the main objective of its inclusion is to support the empirical findings using a qualitative approach.

Binary logit model

The determinant factors for the continued use of SLM practices were estimated using a binary logit regression. Following Garson (2008), which applies maximum likelihood estimation after transforming the dependent into a logit variable, the classification of households into a binary model, continued user and non-user, was done based on households' past experiences in SLM practices (Table 2). The dependent variable, which is the natural log of the odds (logit), is binary as shown in Eq. 2. Households whose farm plot/s is/are well conserved and regularly maintained with the introduced terraces and other modern conservation measures were considered as continued users in this analysis. On the other side, households who are reluctant to maintain the introduced conservation structure (previously introduced by a project assistant or mass mobilization) were labeled as non-continued users. The binary choices in this case are households that adopted and are also continuously maintaining the introduced terraces ($Y = 1$) and households that had removed/or reluctant to maintain conservation measures built in the past ($Y = 0$).

$$\ln\left(\frac{\mathrm{p}}{1-\mathrm{p}}\right) = a + bx \qquad p = \frac{e^{a+bx}}{1+e^{a+bx}} \tag{2}$$

Where P denotes the probability of the event occurring,
X_i denotes the independent variables,
e is the base of the natural logarithm, and
a and b are the parameters of the model.

A dummy variable Y was used to identify whether each sampled household is a continued user of SLM practice or not.

$Y = 1$ for the continued user and $Y = 0$ otherwise

X_i denotes for independent variables (explanatory variables that might affect the households' decision to continually use SLM techniques).

The reduced formal used in this logistic regression model is shown in Eq. 3.

$$\begin{aligned} Y &= \ln(\text{odds(event)}) \\ &= \ln(\text{prob(event/prob(nonevent))}) \\ &= \ln(\text{prob(event/[1-prob(event)]}) \\ &= b_0 + b_1X_1 + b_2X_2 + b_3X_3 \\ &\quad + \ldots. + b_nX_n + \varepsilon_i \end{aligned} \tag{3}$$

Where b_0 is the constant and Y is continued use of SLM technologies = PrY (1 = a household chooses to continually practice SLM technologies, 0 = otherwise).

$b_1 \ldots b_n$ is the estimated coefficients, and ε_i is an error term

$X_{1 \ldots} X_n$ = vectors of explanatory variables included in the model

The full list of explanatory variables included ($X_{1 \ldots} X_n$) in the binary logit and multivariate probit models along with their descriptions are presented in Table 3. It is important to note that some of the classifications regarding the households' perception towards plot level attributes could be relatively weak due to subjectivity of respondents, such as categorization of soil fertility into good, medium, and poor as well as slope (steep, medium and gentle). We suspect it can have some influence on the precision level of the results.

Multivariate probit

Following Cappellari and Jenkins (2003), the current study used a multivariate probit model to analyze the determinant factors for the choice of SLM practices using Eq. 4. The reason behind the use of multivariate probit (MVP)[5] is due to the premises that farmers use a combination of any of the SLM practices instead of relying on a single conservation practice to reduce their land degradation problems in which the SLM options can be a complement or a substitute to one another (Kassie et al. 2013; Teklewold et al. 2013).

Table 2 Classification of SLM practices implemented on farmlands

Type of SLM measures[a]	Description	Source
Physical soil and water conservation	Structures that are implemented on farm plots such as soil and stone bund, terraces and trenches	WOCAT 2005; GIZ 2014
Agroforestry practice	Growing multi-purpose trees on farm plots such as fruit trees, animal fodder, and the like	WOCAT 2005; GIZ 2014; Kirui and Mirzabaev 2015
Agronomic practice	Include activities that aim at production and conservation at a time. It includes compost and manure application and other soil fertility management practices	GIZ 2014; WOCAT 2005
Indigenous conservation	Conservation measures that are originated from the local people and that have been practiced for a long time. It includes contour plowing, crop rotation, and fallowing	WOCAT 2005; FAO 2011

[a]Physical soil and water conservation, agro-forestry, and agronomic practice are relatively standardized conservation measures that are promoted by the agricultural and natural resources management extension systems, while the indigenous conservation measures are not standardized and rely on local knowledge. This classification focuses on SLM measures that are dominantly practiced on farm plots by individual households in the study sites.

Table 3 Description of explanatory variables included in the binary logit and MVP models

Explanatory variables	Type of the variable	Expected relationship (for binary logit)	Description of the variable
Yearsh	Continuous	+	Years of schooling of the household head
Aghhd	Continuous	+/−	Age of the household head in years
Family size	Continuous	+/−	Family size of the household
HhdlF	Continuous	+	Size of labor force in the household
Sex	Binary	+/−	Sex of the household head (1 = male, 0 = female)
Plot size	Continuous	+/−	Total size of plots owned by the household in tsimad[a]
Off farm	Continuous	−	Total off and non-farm incomes of the household (ETB/year), ETB is currency of Ethiopia
TotVAST	Continuous	+	Total value of assets owned by the household in ETB
Cattlholding	Continuous	−	Number of heads of cattle owned in TLU
Crop yield	Continuous	+	Total crop produce in 2016/17 production year in quintal
Farm input	Continuous	+	The value of farm inputs employed by the household in 2016/17 production year in ETB
Slope	Categorical	+/−	Slope of the plot (1 = gentle, 2 = medium,3 = steep)
Soil fertility	Categorical	+	Fertility status of the soil (1 = good, 2 = medium, 3 = poor)
Soil type	Categorical	+/−	Type of soil (1 = clay, 2 = silt, 3 = sandy)
Plot location	Continuous	−	The distance between the house and the plot of a household in Km
Agro-ecology	Categorical	+/−	Agro-ecological zone (1 = Kaal-amin (highland), 2 = Hintalo(midland), 3 = Begashka (lowland))
Position	Binary	+/−	Participation in the community administration organs (1 = yes, 0 = no)
Extension service	Continuous	−	Distance between residency and farmers training center in km
Tenure security	Binary	+	Land certification (1 = yes, 0 = no)
Credit access	Binary	+	Access to credit services (1 = yes, 0 = no)
Infonaccess	Binary	+	Access to mass media (1 = yes, 0 = no)
Irrnaccess	Binary	+	Access to irrigation facility (1 = yes, 0 = no)
Zero grazing	Binary	+	Practicing zero grazing (1 = yes, 0 = no)
Market access	Continuous	−	Distance to nearest market in km
Dependent variable in logit model	Continued use of SLM practices		1 = continued user, 0 otherwise
Dependent variable in MVP	Choice of SLM practices		Indigenous (1 = yes, 0 = no), physical (1 = yes, 0 = no), agro-forestry (1 = yes, 0 = no), agronomic conservation (1 = yes, 0 = no)

[a]*Tsimad* is a local unstandardized measurement of size of farm plots (one *tsimad* is roughly equivalent to 0.25 ha)

The current study grouped the various sustainable land management options implemented on farm plots into four major classifications. There are a number of SLM practices which make it very difficult to separately analyze the choice of farmers towards these options at a time. The details on the grouping along with their descriptions are presented in Table 2.

$$y^*_{im} = \beta_m x_{im} + \varepsilon_{im}, \quad y_{im} = 1 \text{ if } y^*_{im} > 0 \text{ and 0 otherwise} \tag{4}$$

Equation 4 is based on the assumption that a rational ith farmer has a latent variable y^*_{im} which captures unobserved preferences associated with the mth choice of SLM measures (m = the four available SLM practices used in this study); β_m is the set of parameters that reflect the impact of changes in the vector of explanatory variables x_i on the farmer's preference toward the mth SLM practices; x_{im} represents the vector of observed variables that are expected to explain each type of SLM practice; and ε_{im} represents error terms following a multivariate normal distribution, each with a mean of zero and a variance covariance matrix with values of 1 on the leading diagonal and non-zero correlations as off-diagonal elements.

Propensity score matching

The present study took a closer look at the impact of the introduced conservation practices on the value of crop production at household level since the ultimate objective of the conservation of private farm plots is to enhance its productivity. To this end, propensity score matching was used to compute the impact that the SLM measures have brought on the value of production for users compared to non-users. The study employed four matching algorisms, namely nearest neighbor, radius, kernel, and stratification to evaluate household and plot level impacts of introduced SLM practices on the value of crop production. Monetary value was used as a standard unit to measure the impact on crop yield as households cultivate more than one crop which makes it difficult to see the effect on the aggregate physical quantity of crop yield. We denote continued users of SLM practices as Y_1 and non-continued users as Y_0, whereby the impact of SLM practices is the difference in value of crop production between continued and non-continued users ($\Delta = Y_1 - Y_0$). And treatment D is a binary variable that determines if a household is a continued SLM user or not, $D = 1$ for the SLM continued user households and $D = 0$ otherwise. Then we find the average impact of the SLM practice on the value of crop production, in the jargon of propensity score matching (PSM) called average treatment effect on the treated observations.

(ATT) using Eq. 5.

$$\begin{aligned} \mathrm{ATT} &= (E(\varDelta)|p(x), D = 1) \\ &= E(y_1|p(x), D = 1) - E(y_0|p(x), D = 0) \end{aligned} \quad (5)$$

Results

Description of the respondents

The mean and percentage values of the socioeconomic and demographic characteristics of the surveyed households are presented in Table 4. The two sample t tests confirmed that a significant difference was observed in asset holding and livestock ownership measured in terms of tropical livestock unit (TLU) between continued users and non-users of SLM practices. This indicates that farmers with relatively higher ownership of asset and livestock holding tend more to adopt SLM practices than those whose ownership is relatively smaller. On the other side, the majority of sociodemographic attributes of the two groups, such as age, sex composition, level of educational attainment, family size, and land holding, show no statistically significant differences. Male-headed households accounted for about 78.3% of the total respondents, while female-headed households accounted for about 21.7% with no significant difference between SLM users and non-users ($p = 0.7$). The average family size of the surveyed households was six with no significant difference between users and non-users.

The average ages of continued user and non-user respondents were 45.5 and 44.5 years respectively while it was 45 years for the total respondents. The average total value of asset of respondents was 67,135.5 ETB with a statistically significant difference ($p < 0.010$) between the continued users and non-users of SLM practices (Table 4). About 80.1% of the total respondents were married and the remaining 19.9% were divorced, widowed, and single in aggregate. The average year of schooling was 3 years with no significant difference between the two groups. On average, the household heads of the surveyed respondents attended 3 years of schooling which indicates that majority of them can, at least, read and write. Table 4 also shows that there was a statistically significant difference ($p < 0.05$) on cattle holding between the continued users and non-users of SLM practices which is 4.7 and 3.4 in TLU respectively, while the average for the total sample was 4. This implies that households with large number of livestock holding are more willing to continually use SLM practices than those with relatively smaller cattle holdings. This might be due to the fact that some of the conservation

Table 4 Description on the profile of surveyed households

Variables	SLM users ($n = 115$) Frequency (%)	Non-SLM users ($n = 115$) Frequency (%)	Total ($n = 230$) Frequency (%)	t value/p value
Sex of the household head				
Male headed	91(79.1)	90 (77.6)	181 (78.35)	–/0.7
Female headed	24 (20.87)	26 (22.4)	50 (21.65)	–/0.7
Continues variable				
Age (average in years)	45.5	44.5	45	0.4/0.34
Average family size of households	6	6	6	0.05/0.47
Education (average years of schooling)	3	3	3	0.05/0.47
Average value of asset of households (ETB)[a]	78,483.6	55,885.2	67,135.5	1.97/0.02
Average land holding size in Tsimad	3	3	3	0.01/0.49
Average cattle holding in TLU	4.7	3.4	4	3.6/0.000

[a]Ethiopian birr, currency of Ethiopia (US$1 = 23.4 ETB as at August 2017 exchange rate)

practices introduced on farmlands such as grasses and forage trees can be a source of feed for the livestock. The socioeconomic description has also shown that the average land holding of households is roughly about three *tsimad* with no significant difference between the two groups. This also further indicates that land size has nothing to do with the decision of a household to continually use SLM practices in the study area.

SLM practices implemented on farmlands

Table 5 presents the level of participation of the respondents towards the sustainable land management practices across the study sites. In *Atsibi-wenberta wereda*, for instance, the majority of the respondents (80%) implemented physical soil and water conservation such as stone bund and terraces with small trenches, while 43% of the surveyed households use agronomic measures mainly manure application. As also evidenced in the same table, 25.5% of the respondents implemented more than one SLM practice on the same plot. However, in this *wereda*, only small proportion (2.5%) of the respondents implemented agroforestry on their farmlands. Similarly, in *Hintalo-wajerat* wereda households who introduced physical structures, agroforestry, and agronomic measures accounts for 20.2, 2, and 40.5% of the total respondents, respectively. In this *wereda*, households tend to use more than one SLM practices as compared to the other two *weredas*, i.e., 35.7% of the surveyed households implemented two or more conservation practices (Table 5). The households in *Kola-tembien* have showed much interest to implement agronomic practices such as application of manure (67% of the respondents).

The above depicted figures can give very useful insights regarding the types of SLM practices implemented in different ago-ecological zones. For instance, households in the highlands tend to practice stronger conservation measures mainly physical soil and water conservation as compared to those in the lowlands. This might be because the topography of the highlands is full of rugged terrains where acute soil erosion is evident as a result of excessive runoff. In the lowlands where the land is dominantly flat, on the other hand, agronomic conservation is the prioritized conservation approach. The result also shows that a significant proportion of the total respondents implement at least two conservation practices on a given plot, which of course is very important for augmenting farmland productivity since one conservation practice complements the other. Nonetheless, the use of agroforestry practice on farm lands by the respondents of all study sites seems to remain very low as depicted in Table 5.

Factors affecting the continued use of SLM practices

The binary logistic regression of the present study confirms that the model is fit and highly significant (Prob > $chi^2 = 0.001$). Furthermore, the Hosmer-Lemeshow test of goodness of fit also fails to reject the null hypothesis which signals that the model is fit to the data (Table 6). The results of the binary logit regression show that 10 out of the 22 variables included in the model significantly affected the continued use of SLM practices by rural households. Households' resource endowments mainly availability of labor force, land holding, crop production, and farm input utilization were found to have an influence on the continued use of SLM practices. Besides, plot level characteristics such as soil fertility status, slope of plots, and location of the plot influence the continued use of SLM practices. Particularly, the study shows that the uptake of farm inputs, plot location, and distance to agricultural extension services are the most important predictors for the continued use of SLM practices in the study sites, and their odds ratios are interpreted in the subsequent paragraphs.

The availability of labor force was found to have a significant positive influence on farmers' decision to continuously use conservation measures on private farm plots. Table 6 shows that as labor force increases by one person (adult equivalent), the odds ratio of the probability of a household to continually conserve its plots also increases by a factor of 1.2 ($p < 0.02$).

The effect of the size of farm plots owned by a household on the decision to conserve of plots was statistically significant ($p < 0.1$). An increase in the size of a farm plot by one *tsimad* results in a decrease in the likelihood

Table 5 SLM practices implemented by households on farmlands

Type of SLM practice implemented by farm households	Study weredas/districts		
	Atsibi-wenberta (% of respondents)	*Hintalo-wajerat* (% of respondents)	*Kola-tembien* (% of respondents)
Physical soil and water conservation structures (stone bund and other terraces)	80	20.2	58
Agroforestry (growing of fruit trees or other multi-purpose trees)	2.5	2	3
Agronomic measures (manure application)	43	40.5	67
Combination of any of two or more of the above SLM practices	25.5	35.7	33

Table 6 Binary logit results on determinants for the continued use of SLM practices

Explanatory variables	Dependent variable (continued use of SLM practices)		
	Odds ratio[a]	Standard error	p value
Availability of labor force	1.2	0.09	0.02
Plot size	0.77	0.11	0.08
Crop yield	1.1	0.038	0.005
Uptake of farm inputs	1	0.000	0.002
Good soil fertility status (poor as a reference)	3.204	1.6	0.024
Medium soil fertility status (poor as a reference)	2.371	0.972	0.035
Plot location	0.976	0.006	0.000
Hintalo (Begashka as a reference)	4.5	3.08	0.027
Kaal-amin (Begashka as a reference)	3.689	2.257	0.033
Distance to agricultural extension office	0.979	0.008	0.01
Constant	1.408	2.397	0.84
Model summary	Log likelihood = − 117.62	Hosmer-Lemeshow test = 0.18	Prob > $chi^2 = 0.000$

[a]Odds ratio < 1 represent negative relationship, whereas ≥ 1 represent positive relationship

of a household to continuously conserve his/her plots by a factor of 0.77 (Table 6).

The amount of modern farm input utilization, particularly fertilizers, was also positively associated with the continued use of SLM practices by self-motivated farm households. As the expenditure on farm input increases by one Ethiopian Birr (currency of Ethiopia), the odds ratio of the likelihood of farm plots to get conserved also increases by a factor of 1.0 ($p < 0.01$) as shown in Table 6. The location of plots particularly proximity of plots to the residence of the household has also an effect on the continued use of SLM practices by the rural households. Plots which are spatially located near to the residency of the owners were found to have a higher chance of getting conserved. Table 6 shows that the odds ratio in favor of conserving a plot decreases by a factor 0.976 as a result of increase in the distance between a house and a farm plot by 1 km ($p < 0.01$).

The result of this study indicates that the continuity of SLM practices varies across the study sites (agro-ecological zones). The households in *Kaal-amin* (highland) and *Hintalo* (midland) were more likely to continually use various conservation measures as compared to household in *Begashka* (lowland). The likelihood of continued use of SLM practices in *Kaal-amin* and *Hintalo* was higher by a factor of 3.68 and 4.5, respectively compared to that in *Begashka* (Table 6).

The distance between the residence of households and the office of extension service was considered as a proxy variable to analyze the association between extension service and continued use of sustainable land management practices. The binary logit result shows that the odds ratio in favor of continued use of SLM practices decreases by a factor of 0.979 as a consequence of increasing the distance between the extension office and households residency by 1 km ($p < 0.01$).

Determinants for the choices of SLM practices

The correlation regression among the dependent variables (the four SLM practices) shows that there is interdependence among the SLM practices implemented by rural households (Table 7). For instance, there is a negative correlation between indigenous conservation and the remaining three land conservation types (physical, agroforestry, and agronomic), which implies that the former one can be substituted by the latter ones. In contrast, a positive correlation was found among physical, agroforestry, and agronomic practices, which attests their complementarity (Table 7). It is also important to note that a farmer can introduce multiple SLM practices on a given plot. For this reason, the study adopted multivariate probit model and the results are presented in Table 8. The availability of labor force is shown to have a positive influence on the choice of physical conservation which is significant at 10% level of significance but not at 5% or less, whereas it was negatively associated with the use of agro-forestry practice ($p < 0.05$) (Table 8). More specifically, households with greater labor force tend to prefer more of physical soil and water

Table 7 Correlation coefficient among the four SLM practices

Types of SLM practices	Agronomic	Physical	Agroforestry	Indigenous
Agronomic	1.00			
Physical	0.5	1.00		
Agroforestry	0.18	0.3	1.00	
Indigenous	− 0.65	− 0.79	− 0.22	1.00

Table 8 Coefficient estimates of the multivariate probit model (*p* values in parentheses)

Explanatory variables	Dependent variables (choice of SLM practices)			
	Physical measures	Agroforestry	Agronomic	Indigenous
Households characteristics				
Years of schooling	− 0.043 (0.25)	− 0.055 (0.1)	− 0.0014 (0.9)	0.075 (0.1)
Labor availability	0.099 (0.07)	− 0.217 (0.02)	− 0.056 (0.5)	0.1009 (0.36)
Dummy male	− 0.185 (0.5)	0.275 (0.86)	0.673 (0.05)	− 0.972 (0.01)
Farming system-related variables				
Plot size	0.183 (0.04)	0.027 (0.75)	0.017 (0.81)	− 0.204 (0.04)
Farm input	0.00025 (0.08)	0.00032 (0.01)	0.00022 (0.08)	− 0.00035 (0.04)
Irrigation access	0.33 (0.45)	0.468 (0.1)	0.015 (0.96)	− 2.979 (0.97)
Zero-grazing	0.943 (0.000)	0.101 (0.74)	− 0.119 (0.68)	− 0.742 (0.03)
Plot level attributes and agro-ecology				
Gentle slope (steep as a reference)	− 0.426 (0.09)	0.662 (0.04)	0.700 (0.03)	− 0.472 (0.2)
Medium slope (steep as a reference)	− 0.38 (0.1)	0.398 (0.1)	0.576 (0.04)	− 0.329 (0.34)
Begashka (Hintalo as a reference)	1.747 (0.000)	0.28 (0.5)	0.16 (0.71)	− 2.463 (0.000)
Kaal-amin (Hintalo as a reference)	1.666 (0.000)	− 0.58 (0.1)	− 0.311 (0.48)	− 2.672 (0.000)
Institutional supports and infrastructure				
Extension service	− 0.008 (0.02)	− 0.00068 (0.8)	− 0.00016 (0.96)	0.011 (0.01)
Market access	0.001 (0.8)	− 0.008 (0.06)	− 0.006 (0.1)	0.003 (0.5)
Credit access	− 0.655 (0.002)	0.428 (0.09)	0.527 (0.03)	− 0.412 (0.1)
Constant	0.194 (0.85)	− 2.111 (0.06)	− 1.693 (0.08)	0.954 (0.42)
Model summary	Log likelihood = − 184.11	Likelihood ratio test Chi^2 (21) = 16.7, Prob > chi^2 = 0.000	Prob > chi^2 = 0.0011	Log likelihood = − 184.11

conservation measures such as terraces but are less interested in agroforestry practices.

The preference towards the physical conservation practice was found to be influenced by the size of farm plots operated by smallholder farmers. Table 8 shows that households who operate relatively larger plot size were more likely to practice physical conservation structures ($p < 0.05$) and less likely to practice indigenous conservation measures ($p < 0.05$).

The utilization of farm input was found to be very important in terms of explaining the choice of households towards various sustainable land management practices. It was found to positively influence the choice of smallholder farmers toward practicing physical conservation structures, agroforestry practice, and agronomic practice but with different levels of significance. Households who spend more money to acquire inputs are more likely to prefer physical conservation practices, agronomic practices ($p < 0.1$), and agroforestry practices as well ($p < 0.05$). On the other hand, households with less farm input expenditure were found to choose more of indigenous conservation measures ($p < 0.05$).

Households who practice zero grazing were found to choose physical conservation structures compared to households who practice free grazing ($p < 0.01$) as shown in Table 8. The study also finds that households with irrigation access are in favor of implementing agroforestry practice. The positive association between irrigation access and the use of agroforestry practices shows that farmers are more interested to grow multipurpose trees, which are perennial, on their plots if they have access to irrigation water.

The study explored the role of agro-ecological variations on the preferences of smallholder households towards the sustainable land management practices. For this purpose, the study sites were purposively chosen from the three agro-ecological zones (highland, midland, and lowland) not only to ensure data heterogeneity but also to predict its influence. Physical conservation measures were found to be more preferred practices ($p < 0.01$), and the indigenous conservation measures are less likely to be practiced ($p < 0.01$) in lowlands (*Kola-temben* district) than in midland. Moreover, households in highland areas (*Atsibi-wenberta* district) are more likely to prefer physical conservation measures ($p < 0.01$) and less interested in agro-forestry

($p < 0.1$) and indigenous conservation practices ($p < 0.01$) (Table 8).

Plot level characteristics, mainly including slope, soil type, and soil quality, were included in the model to explain their association with the choice towards various SLM practices by rural households. Plots that are characterized by a gentle slope were found to be treated more of by agroforestry ($p < 0.05$) and agronomic measures ($p < 0.05$) and less likely to be conserved by physical conservation structures ($p < 0.1$) as compared to plots with a steep slope (Table 8). The same can also be said for plots characterized by a medium slope as compared to plots with a steep slope except for the differences in the level of significance.

Table 8 shows that households that are located far from farmers training center are more likely to practice indigenous conservation options ($p < 0.01$) and less likely to implement physical conservation practices ($p < 0.05$). An access to credit has also an influence on farmers' decision for the choice of SLM practices as it carries positive coefficient for the use of agroforestry ($p < 0.1$) and agronomic practices ($p < 0.05$). In contrary, access to credit was found to have a negative influence on introducing physical conservation structures ($p < 0.05$) and indigenous conservation practices ($p < 0.1$).

Impact of SLM practice on crop production

The PSM result presented in Table 9 shows that the SLM practices introduced on farm plots have a significant influence on the productivity of farmlands. The annual value of crop production[6] of continued users of the SLM practices was on average higher by ETB 17199, 25,501, 23,450, and 16,457 using nearest neighbor, radius, kernel, and stratification methods respectively as compared to non-continued users. This does mean that the continued users of SLM practices achieved annual benefits of 77% to 100% higher as compared to the non-continued users of SLM practices on average.

Discussion

The empirical findings of the current study show that farmers' decision towards the continued use and the preferences to the SLM practices are influenced by various factors. The significant predictors that explain the continued use and choice of SLM practices are discussed as follows.

Availability of labor has carried a positive coefficient for the continued use of SLM practice, which indicates that households with larger family size are relatively more willing to continual use of the SLM practices. The household can, therefore, allocate enough labor force to sustain the conservation measures through carrying out maintenance work and even by introducing new conservation practice regularly. However, there are conditions that majority of the members of family size may account for larger proportion of dependents mainly children and elders. In such condition, therefore, households with larger family size but lower labor force may tend to allocate much of their time in generating daily income such as off/non-farm incomes to cover their daily subsistence instead of investing their time and labor in conservation since the benefit from the conservation of their plots are not realized immediately. The result of the current study is consistent with the findings of Wagayehu and Drake (2003) and Pender et al. (2001) who reported that in a family with a greater number of mouths to feed, much attention is given to their immediate food requirements and less attention to soil conservation activities on the farmlands.

The availability of labor force also determines the preference of households toward the SLM options. Households with larger labor force were found to choose physical conservation over the other SLM practices. The positive effect of the abundance of labor force regarding the choices in favor of physical conservation structures, particularly terraces and bunds, is probably due to the fact that physical conservation practices usually demand substantial labor force and are labor-intensive works.

This finding was substantiated by the fact that about 75% of the respondents stated that the labor-intensive nature of the soil and water conservation structures hinders its adoption and continued use. The same view was also stressed by the key informants by describing some of the SLM practices as very tiresome. However, the negative effect of labor force on the choice to agroforestry may be attributed to the less favorable environment to introduce agro-forestry practices on private plots. Farmers may refrain from implementing agroforestry over the other conservation measures such as physical and agronomic conservation practices. This is in agreement

Table 9 Impacts of SLM practices on the crop production at household level

Matching methods	Treated observations	Control observations	Average treatment effect on treated (ATT)	*t* value
Nearest neighbor	115	59	17,199	1.9**
Radius	115	115	25,501	3.4***
Kernel	115	115	23,450	3.3***
Stratification	115	115	16,457	1.65*

***, **, * denotes values significant at 1%, 5%, and 10%, respectively with the findings from different regions of Ethiopia and other developing regions (Asrat et al. 2004; Clay et al. 1998; Gebremedhin and Swinton 2003; Jara-Rojas et al. 2012; Pender and Gebremedhin 2007) who reported a positive relationship between availability of labor force and continued use of stone bunds and other terraces.

Plot size (crop field) was found to negatively influence the decision of households to the overall continued use of SLM practices. A household who operates larger size of farmland definitely need high labor and time to keep the introduced conservation measures well maintained, and also to improve the fertility status of the farmlands (for compost and manure application). These activities may demand a significant labor force and put much burden on the farm households since they are busy in different farm and other social-related activities in which such pressure may enforce them to discontinue the use of some of the sustainable land management practices. Regarding the preferences, households who possess a larger plot size were in favor of using physical conservation over the other conservation measures. The positive correlation between large plots and choosing physical conservation measures could probably be due to the reason that most of the physical SLM practices take proportionally more space on small plots and the benefit from conservation on such plots may not be enough to compensate for the decline in production due to the loss in the area devoted to conservation structures. Similar results have been reported from other regions of the country (Bekele and Drake 2003; Birhanu and Meseret 2013; Enki et al. 2001; Mengstie 2009; Tesfaye et al. 2014; Teshome 2014) in which plot size was negatively associated with the implementation of soil and water conservation structures.

Farming systems were also found to be very instrumental in determining the continued use of and preferences towards the set of SLM practices. The results of the current study give an impression that farming systems mainly the amount of farm inputs deployed and zero-grazing practice are found to be very helpful for the continued use and choices of SLM practices. The highly significant influence of farm input expenditure on the continued use signifies the complementarity of modern farm input application and other SLM practices implemented at plot level. Farm input utilization, mainly application of chemical fertilizer and improved seeds, is usually supported by soil and water conservation so as to boost crop yield. Furthermore, the positive association between zero grazing and the overall continuity of SLM practices is among the most interesting findings of this study. The zero grazing policy that has been adopted by the government of Ethiopia could directly help in promoting SLM practices since it limits the mobility of livestock in the conserved areas, which otherwise could destroy the introduced SLM practices. In line with the findings of the current study, Kassie et al. (2008) reveals that households who practice zero grazing tend to continually use SLM practice. Regarding the effect of modern farm input utilization on the choice of SLM practices, the results imply that households who spend more to acquire farm inputs are also willing to use physical structures, agronomic and agroforestry practices. This does mean that the effect of farm input utilization on the preference of the set of SLM is indifferent which also mean that the practices are equally preferred by the household.

This study shows mixed results regarding the influence of plot level characteristics both on the continued use and the choice of SLM decisions by rural households. For instance, topographic location of plots was found to have an influence on the choice regarding which type of SLM practice to deploy, but shows no significant influence on the continued use of SLM practices. The results also find that plots that are located in a flat and moderately flat topography are less likely to be conserved using physical conservation structures compared to farm lands located at a steep topography. This does mean that farm plots with gentle and medium slopes are less likely to be treated by physical conservation structures compared to plots with steep slopes. This is probably due to the reason that plots characterized by a steep slope are more vulnerable to soil erosion emanated from high speed of runoff because of the rugged terrains. In order to deter such erosion problems, farmers may prefer physical soil and water conservation structure, particularly bunds and terraces. Moreover, the relatively gentle and medium slope farm plots were found to be more likely to receive agronomic and agroforestry conservation which signals that conservation-based agriculture is practiced in fairly flat and undulating flat locations. The current results are parallel to the finding of Kassie et al. (2008) who reported that conservation-based agricultural practices are mostly implemented in plots with a moderate and a gentle slope.

The positive influence of proximity of farm plots to the residency of the owner on the continued use of SLM indicates that plots that are placed in a near distance from the residency have higher chance of frequent visit and follow-up and thereby higher chance of getting treated with the conservation structures regularly. Previous studies in this regard have reported mixed results. Amsalu and de Graaff (2007) and Kassie et al. (2009) asserted that practicing soil and water conservation measures were positively associated with the distance of plots to residency. This is consistent with the findings of the current study. In contrast, a negative association between distance of plot and adoption of SLM practices mainly agronomic conservation practices has been reported by Benin (2006), Mengstie (2009), Pender and Gebremedhin (2007), and Teklewold et al. (2013).

The influence of access to infrastructures particularly credit access, extension service, and access to irrigation facility were found to be very effective in explaining the preferences of households towards SLM practices but not for the overall continued use. The positive effect of credit access to the choice of agroforestry and agronomic practices implies that farmers tend more to allocate borrowed money to buy inputs such as improved varieties of fruit trees for agroforestry, improved seed of cereal crops, and fertilizers. Besides, the positive association between agroforestry and access to irrigation signals that most of the time perennial crops/fruit trees are grown for agroforestry purpose which needs to be supplemented by irrigation during the long dry season in the study sites. Other studies in this regard reported similar results. In Chile, for instance, access to credit positively affected the use of soil and water conservation activities (Jara-Rojas et al. 2012). Similarly, extension service has a positive influence on the continuity of SLM on individual farm plots in central Ethiopia (Moges and Taye 2017; & Bonger et al 2004), which is parallel to the results of the current study.

Looking at the productivity impact of SLM practices, the present study finds a significant variation in the value of crop production between continued and non-continued users of SLM practices. The PSM results show that the value of crop production of SLM users was 77–100% higher than that of non-continued users on average. The descriptive statistics result also substantiated this finding. The average crop yield (2016/17 production year) of SLM user households was 14 quintal/household while it was 10.5 quintal for the non-continued users on average. It was observed that the average amount of crop yield of continued users of SLM practices was 33.3% higher than that of non-continued users. Introducing more than one conservation measure on a given farm plot was also associated with a higher crop yield. For instance, it was found that the average crop yield (2016/17 production year) of households who practice multiple land conservation was 15 quintals/household, which is significantly higher than the average yield of total SLM user respondents. This does mean that the crop yield of households who practiced multiple SLM was found to be higher by 42.8% compared to the non-continued users of SLM practices. Such considerable yield increase gives the impression that the productivity effect of one conservation measure is enhanced by the use of the others, which in turn confirms the presence of complementarity among the SLM practices. The strong positive association between the amount of crop yield and continued use of SLM practices could perhaps be due to the fact that households who produce more are ready to invest on conservation of farm plots to keep the productivity as high as possible. In addition, the benefits from farmland conservation may be enough to compensate for the costs incurred in association to implementing some of the SLM practices. The result of the current study is consistent with the findings of Kassie et al. (2008) who reported a significant crop yield increment as a result of introducing soil and water conservation practices on farm plots.

Conclusion

The results of the current study confirms that the implementation of various sustainable land management practices are influenced by farming technologies deployed by rural households, agro-ecological variations, plot characteristics, and institutional supports. The findings further affirm that most of the SLM practices are complementary to one another, and practicing of two or more SLM practices in a given plot is found to be highly associated with higher value of crop production. Such complementarity highlights that the productivity effect of a given SLM practice is enhanced by the use of the others. This in turn provides an incentive for a multiple use of SLM practices on farm plots. More importantly, a considerable increase in value of crop production was observed in plots which are treated with multiple SLM practices. This may also pose a considerable incentive for rural households to conserve their plots.

The findings of this study give the impression that the implementation approaches for the SLM practices should be as diverse as the farming techniques, household attributes, and plot level features so that the SLM practices can be integrated with the day-to-day farming operations of the households. This will eventually create self-motivated individuals who can persistently conserve their farmlands even in the absence of public support for the costs of the SLM implementation.

Endnotes

[1]District and *wereda* are interchangeably used throughout the paper. District is a synonymous to what is locally known as *wereda*, the second smallest administration unit in Tigrai, Ethiopia

[2]The first criterion to select the study catchments was size of farm plots that are well treated with various SLM practices. The second criterion was experience and availability of self-motivated farmers who continues to maintain terraces on their private plots

[3]The smallest administration unit in Tigrai region in rural settings

[4]Households for control observations were randomly drawn from other three selected adjacent catchments

in which plots are poorly treated from respective study sites.

[5]To better understand the details on the nature and application of multivariate probit model, including its application on preferences of SLM practice, we suggest to see Dorfman (1996), Greene (2003), Aurier and Mejia (2014), and Cappellari and Jenkins (2003)

[6]The value of crop production was computed by multiplying the total produce of each crop by its prevailing local market price.

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Authors' contributions
HE has developed the concept, designed the study, interpreted the results, and wrote the manuscript. TN participated in the study design, data analysis, and write up. MA participated in developing the data collection tools and technically supported the data analysis and the write up. The authors read and approved the final manuscript.

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