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Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia

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A B S T R A C T

Adoption rates of soil and water conservation measures remain below the expected levels in Ethiopia despite the considerable investments in reducing land degradation and improving soil fertility. This constitutes one of the key research agendas in the country. This paper underscores the need for investigating the factors hindering or facilitating the adoption of soil and water conservation measures. The study results presented in this paper are based on cross-section data collected from 408 households in eastern Ethiopia, including field observations of 790 plots selected using a multi-stage sampling procedure. A multivariate probit model was employed to analyse the determinants of adoption of three soil and water conservation measures (stone bund, soil bund, and bench terracing) at the plot level. The study findings reveal that household, socioeconomic, and institution characteristics were the key factors that influenced the adoption of soil bund, stone bund, and bench terracing conservation measures. Furthermore, there was a significant correlation among the three soil and water conservation measures, indicating that the adoption of these measures is interrelated. In particular, the results show that there was a positive correlation between stone bunds and soil bunds. However, the correlations between bench terracing and stone bunds as well as bench terracing and soil bunds were negative (implying substitutability). These results imply that the Government and other relevant organizations that are responsible for reducing land degradation in order to increase agricultural production should support the establishment and strengthening of local institutions to facilitate the adoption of soil and water conservation measures.

1. Introduction

Land degradation is a serious problem across Sub-Saharan Africa. Sixty seven percent of the total land is degraded to some degree with levels of degradation ranging from light to very severe. In East Africa, the severity of land degradation is reported to vary from one country to another. In Ethiopia for example, 25 percent of the total land is degraded. Comparatively, the proportions of land degradation in Kenya and Tanzania is 15 and 13 percent respectively (Kirui & Mirzabaev, 2016). This implies that there is more land degradation in Ethiopia than there is in Kenya and Tanzania.

The available evidence (e.g. Pender, Gebremedhim, & Haile, 2001) indicates that losses of topsoil in Ethiopia amounts to about 42 tons per ha per annum, which is equivalent to 8 percent of the total global loss of top soil from arable lands (Greenland & Nabhan, 2001). Soil erosion in Ethiopia is at an average of nearly 10 times the rate of soil formation, with the country's rate of soil nutrient depletion being among the highest in Sub-Saharan Africa (Holden, Shiferaw, & Pender, 2005).

According to scholars (e.g. Bojö & Cassells, 1995; Sutcliffe, 1993) the cost of soil degradation due to inappropriate soil management in Ethiopia is estimated at about USD139 million annually. This cost is about 4 percent of the total GDP of the country's agricultural sector and it includes forest losses and loss of livestock capacity. It is important to note that land degradation adversely affects the productive capacity of land. According to Sonneveld (2002) on a

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simulation study results, land degradation in Ethiopia has resulted in the loss of agricultural value, which is estimated at about USD7 billion for the period between 2000 and 2010.

Land and water degradation reduce agricultural productivity and contribute immensely to food insecurity and poverty (Shibru, 2010). According to Demel (2001), the amount of grain lost due to land degradation in Ethiopia alone could feed more than 4 million people. This is particularly important because land degradation is much more severe in the highlands of Ethiopia where 85 percent of the population lives, relying on 95 percent of the total cultivated land and on 77 percent of the country's livestock population (Bewket, 2007).

One of the ways of addressing soil and water degradation and improve crop productivity is the use of improved Soil and Water Conservation (SWC) measures. The role of SWC measures in improving productivity is widely acknowledged in the literature (see Adgo et al., 2013; Kassie et al., 2008; Pender et al., 2001; Hishe, Lyimo, & Bewket, 2017; Amare et al., 2014; Abdulai & Huffman, 2014; Tenge, Sterk, & Okoba, 2011). In the recognition of this reality, the government of Ethiopia has made considerable investments in soil and water conservation (SWC) since the mid-1970s, with a purpose of not just to reducing soil loss but also improving crop yields and livelihood of the rural farmers. In particular, the central government started massive SWC campaigns in 1980s, targeting the low potential (drought prone and highly degraded) parts of the highlands. On the other hand, the Government discouraged farmers from implementing SWC measures in high potential area while encouraging the adoption of alternative improved technologies, such as the use of fertilizers and improved seeds, in order to enhance productivity per unit of cultivated area (Mekuriaw et al., 2018). As such, SWC has been considered as an important part of the agricultural extension package in the country since 1991when the Ethiopian People Republic Democratic Front (EPRDF) came to power. It should however be noted that the introduction of these measures and technologies has largely used the top-down approach with little participation of the target farmers. Consequently, these efforts have generally failed mainly due to lack of support and awareness among farmers (Haregeweyn et al., 2015; Mekuriaw et al., 2018; Mekuriaw & Hurni, 2015; Shiferaw & Holden, 1998; Wolka, 2014).

Participatory watershed management was recognized at the national level since early 2000s under the framework of national development strategy. This framework triggered the launching of different sustainable land management programs throughout the country. Along with the national strategy, integrated SWC is implementing different mechanical and biological SWC measures (such as Bench terracing, Soil bund, Stone bund, farm forestry, and so on) in the main intervention areas. Similarly, the Government of Ethiopia is running a massive SWC campaign for two months every year in the selected areas since 2011 (Mekuriaw et al., 2018). The campaign aims at encouraging rural farming households to construct SWC structures and change their attitudes towards land degradation and SWC. From 1995 to 2014, the average labour investment in SWC per annum has being increasing in monetary terms and is currently reported to amount to more than US$ 1.2 billion per year (Adimassu, Langan, & Barron, 2018; Gebreselassie, Kirui, & Mirzabaev, 2015). This amount is much lower than the cost of land degradation (USD 4.3 billion per year). Notwithstanding all these efforts by the central government, regional government, donors, and development partners, land degradation remains a serious problem and the adoption of SWC measures is generally low.

The low rate of adoption of improved SWC measures is not only peculiar to Ethiopia; it is a common phenomenon in Sub-Saharan Africa as a whole (Asfaw & Neka, 2017; Tenge et al., 2011; Wagayehu 2003; Wolka, Mulder, & Biazin, 2018). Just as important, its underlying effects on crop productivity, income, and rural livelihoods can not to be overemphasized here. As such, we underline the need for identifying the key factors that prevent farmers from adopting the improved SWC measures, which could improve agricultural production and productivity. Previous studies which focused on this research agenda include Mekuriaw et al. (2018); Asfaw and Neka (2017); Teshome, de Graaff, and Kassie (2016); and Barungi et al. (2013); Fentiel et al., 2013; Shimeles, Janekarnkij, & Wangwacharakul, 2011; Huckett, 2010; Holden, Bekele, & Pender, 2004; Bekele & Drake, 2003. These studies used different economic models to identify and map different demographics, institutional, socio-economic factors, plot level characteristics, and agro-ecology conditions that influence the adoption of SWC measures. The findings of these studies show that the adoption of SWC measures was influenced by different aspects, including the socio-economic factors, such as sex, age, and education of the household head. Others include household assets, income and land size, livestock holding, engagement in off-farm activities, as well as access credits. On the other hand, other scholars (e.g. Asfaw & Neka, 2017; Teshome et al., 2016; Fentiel et al., 2013) found out that contact with development agents was a key influential factors.

However, most of these previous studies have assumed the adoption of SWC measures as mutually exclusive with little or no interdependency among them. This implies that farmers can choose only one SWC measure from several of mutually exclusive (independent) options to practice on their single cultivated plot. In other words, each conservation measure does not have complimentary (positive) or substitution (negative) correlation with other conservation measures. This is unrealistic because other studies have already observed that farmers can adopt more than one SWC measures on an individual plot (Amare et al., 2014; Tenge et al., 2011). We therefore argue that SWC measures are not necessarily mutually exclusive and recognize the possibility of farmers to implement more than one SWC measures simultaneously on a single plot. We also acknowledge the possibility of having some potential correlations between the adopted measures. Based on this proposition, we use the case of smallholder farmers in eastern Ethiopia to analyse the factors that jointly influence (facilitate or impede) the adoption of different SWC measures and determine whether these measures complements or substitutes.

2. Methodology

2.1. Description of the study area

This paper uses data and information gathered from a study, which was conducted in the eastern part of Ethiopia specifically in East Hararge, which is one of the zones in the regional state of Oromia. East Hararghe is located between latitudes 7°32′- 9°44′ North and longitudes 41°10′- 43°16′ East (Fig. 1). The area is characterized by rugged, dissected mountains, deep valley, plateaus, and plains, which are categorized into plateau, lowland, and transitional slope with altitudes ranging from 500 to 3405 m above the sea level (PEDO, 2012). The zone is characterized by three agro-ecological zones: the semi-arid, the semi-temperate, and the temperate tropical highlands. Temperate tropical highlands, known as *dega* constitute 11.4 percent of the total area of the zone. The temperate tropical highlands (*dega*) are located from 2300–3500 m above the sea level with annual rainfall ranging from 1200–2000 mm and an average temperature of 10 °C–15 °C. This region occupies the western and central highlands of the zone covering a total area of 2589.14 km^2. The semi-temperate (tropical rainy midlands) part or *woinadega* accounts for 26.4 percent of the total area of East Hararghe. This agro-ecological zone is found in the

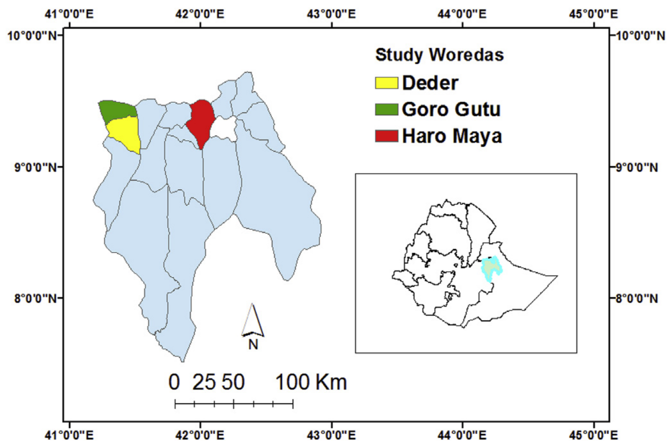

Fig. 1. Physical map of Ethiopia and east Hararghe zone.

western and central highlands with altitudes ranging from 1500 to 2300 m above the sea level. It has annual rainfall ranging from 600 mm to 2000 mm and the mean annual temperature ranging from 15 °C to 20 °C. The semi-arid (tropical dry or arid) or *kola* comprises 62.2 percent of the total area of the East Hararghe. This is characterized by altitudes that range from 500 to 1500 m above sea level, with an annual rainfall ranging from 400 to 820 mm and mean annual temperature that ranges from 20 °C to 25 °C. This region is found in the south eastern and northern parts of East Hararghe sharing borders Somali National Regional State, Bale Zone, and Dire Dawa Administration.

The farming system of East Hararghe constitutes a complex production system involving a diversity of interdependent mixed cropping and livestock keeping activities. The agro-climatic zone allows the area to produce a variety of agricultural products, including cereal crops such as sorghum, maize, wheat, and *teff*; vegetables like potatoes, onions, shallots, and cabbage; as well as perennial crops like coffee and *khat* (*Catha adulis*).

2.2. Sampling technique and data collection

The data used in this paper were gathered from a household survey conducted in the study area during August and September 2017. A multi-stage sampling procedure was used to select the study districts, *kebeles*,[1] and sample households. In the first stage, three districts (Deder, Gurugutu, and Haramaya) were selected randomly from the areas involved in the integrated SWC program. In the second stage, three *kebeles* were selected purposively from each district based on the extent of land degradation and participation in the program. Then households were stratified into two strata (adopters and non-adopters of SWC). Finally, 200 households that adopted at least one SWC measure and 208 households that did not adopt any measure were randomly selected from both strata using proportionate probability sampling based on the size of each district and *kebele* (Table 1). Moreover, data were collected on plot level leading to 790 observations (400 adopters plots and 390 non-adopters plots), numbers of plots cultivated in the 2016/17 production period.

The sample households were interviewed using a semi structured questionnaire, which was designed and pretested before the actual survey. The questionnaire covered a wide range of questions, which were intended to identify factors that influenced the adoption of SWC measures in the study area. Specifically, the questionnaire was used to solicit information on demographics, socio-economics, and institutional context of the sample households, as well as plot specific characteristics, types of SWC measures adopted, and perception of farmers about land degradation and SWC.

2.3. Methods of data analysis

There is evidence that the adoption of a specific SWC measure by smallholder farmers is not mutually exclusive or independent of other measures that are implemented on the same farm plot (Amare et al., 2014; Tenge et al., 2011). However, most economic models that have been used to analyse the adoption of these measures failed to capture the interdependence and relationship between them as well as the potential correlation between unobserved disturbances (error term). For instance, binary logit/probit models are only able to estimate the adoption of a single measure, with only two binary outcomes (Wooldridge, 2002). On the other hand, multinomial models are useful when the bivariate response models involve more than two possible outcomes. In other words, the multinomial models are useful when the outcome variables are unordered and mutually exclusive, and the farmer can choose only a single outcome from among a set of independent alternatives (Young, Valdez, & Kohn, 2009). This means that, the model should pass the *independence of irrelevant alternatives* test. However, various studies have indicated that SWC measures are not mutually exclusive; thus, one must consider the possibility for a simultaneous use of more than a single SWC measure on a single farm plot as well as the potential for interdependence between these different measures (Amare et al., 2014; Tenge et al., 2011).

In this paper, we use a multivariate probit (MVP) regression model to identify factors affecting the adoption of three SWC measures namely; stone bund, soil bund, and bench terracing using a set of demographic, institutional, socio-economic and plot characteristics. The main advantage of this model is that it allows the analysis of potential correlation between unobserved disturbances (error terms) and the correlation between the adoption of each SWC measure (Belderbos, Carree, Diederen, Lokshin, & Veugelers, 2004; Young et al., 2009). Accordingly, the correlation among the decisions to adopt different measures may be due to technological complementarities or substitutabilities (Belderbos et al., 2004; Wainainaa, Tongruksawattanab, & Qaim, 2013). In this case, estimates of simple binary logit or probit models can be biased and inefficient (Wainainaa et al., 2013). Thus, the study employed the MVP model using simulated maximum likelihood with large numbers of random draws ($R = 100$) on plot level observations.

The analysis is based on the expected utility maximization theory which suggests that individual farmer *i* will adopt a specific SWC measure on his or her farm plot if the expected utility from adoption (U_{ij}^*) is greater than the expected utility from any other alternative measures, including the business as usual (i.e. not adopting any measure) (U_{ij}), i.e. $y^*_{1i} = U_{ij}^* - U_{ij} > 0$; where, y^*_{ji} is the net benefit (latent variable) that the farmer can received from adopting *j*th measure.

In the multivariate probit model, there are multiple binary dependent variables (y_{ji}), and multiple latent variables (y^*_{ji}). However, in this study, the multivariate model consists of three binary choice equations (i.e. soil bound, stone bound, and bench terracing). Consequently, the model assumes that each binary observed variable takes a value 1 if, and only if, the continuous latent variable is greater than zero:

[1] Kebele is usually named peasant association and is the lowest administrative unit in the country.

Table 1
Sample districts, *Kebeles* and number of sample households.

Districts	*Kebeles*	Total number of households	Adopters Sample	Non- Adopters Sample	Total sample
Deder	Chafe Gurumu	1183	28	27	55
	Gaba Gudina	1377	34	30	64
	Walfaa Gabon	817	21	17	38
Gurugutu	Biftu Dirama	688	15	17	32
	Ifa Jalala	1162	29	25	54
	Mauhasa Walfaa	817	16	22	38
Haramaya	Biftu Geda	882	17	24	41
	Amuma	753	15	20	35
	Ifa Oromiya	1097	25	26	51
Total		8776	200	208	408

$$y_{ji}^{*} = X_{ji}\beta_{ji} + \upsilon_{ji} \tag{3}$$

$$y_{ji} = \begin{cases} 1 & \text{if } y_{ji}^{*} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (\mathrm{j} = \mathrm{S, A, B}) \tag{4}$$

where y_{ji} is the dependent variable; y^{*}_{ji} is a latent variable that captures the unobserved preferences associated with the choice of three SWC measures and is influenced by observed characteristics (X_{ij}) and unobserved characteristics captured by the stochastic error term (υ_{ij}); β_{1j} is a vector of parameters to be estimated. The error terms $\upsilon_{im} \quad _{m=1,2,3}$ are distributed multivariate normal with mean of 0 and a variance covariance matrix as given below with values of 1 on the leading diagonal and correlations $\rho_{kj} = \rho_{jk}$ as off-diagonal elements.

$$\begin{bmatrix} \upsilon_{1i} \\ \upsilon_{2i} \\ \upsilon_{3i} \end{bmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}\begin{pmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{pmatrix}\right] \tag{5}$$

Thus, off-diagonal elements show correlation between the different types of SWC measures. In addition, the elements also capture unobserved characteristics that affect the adoption of different SWC measures (Ahmed, Geleta, Tazeze, & Andualem, 2017; Teklewold, 2016).

3. Results and discussion

3.1. Household and socio-economic characteristics of households

The summary statistics of variables, which were hypothesized to influence the adoption of SWC and included in the MVP model, are provided in Table 2. The specification of these variables was informed by a review of relevant literature (see Ahmed et al., 2017; Asfaw & Neka, 2017; Shimeles et al., 2011; Mekuriaw et al., 2018; Holden et al., 2004; Shimeles et al., 2011; and Fentiel et al., 2013). These variables include a range of demographic, socioeconomic, institutional, and plot characteristics. The average ages of household heads for adopters and non-adopters were 39.94 and 40.43 years respectively. About 86.80 percent of the heads of the sample households were males. When disaggregated as adopters and non-adopters the male headed households constituted 91.00 and 82.70 percent respectively of the total sampled households. The average family sizes for the adopters and non-adopters were 6.24 and 6.18 respectively. Overall, the household heads in the pooled sample have attended formal education for an average of 3.65 years. However, the study results show that farmers who adopted SWC measures were relatively more educated (with an average of 4.46 years in formal education vis-à-vis only 2.88 years for non-adopters) and the difference was statistically significant at 1 percent probability level. Education was found to be among the most important variables that directly influenced the adoption of SWC measures. Other studies done elsewhere in Ethiopia (see Asfaw & Neka, 2017; Mekuriaw et al., 2018; Tesfaye, Brouwer, van der Zaag, & Negatu, 2016) also confirm that farmers who adopted SWC measures were more educated than those who did not.

The study results also reveal that the value of assets owned by farmers varied with the adopters and non-adopters owning assets worth Birr 29594.80 and 19851.70 respectively. Overall, the units of livestock owned by the sampled households averaged at 1.78 TLUs. Moreover, farmers who adopted SWC measures earned higher annual income averaging at Birr 20129.33 than the non-adopters who earned an average income of Birr 13753.03. Concerning the institutional variables, about 15.50 and 11.50 percent of the adopters and non-adopters respectively, had received credits from formal credit institutions. On average, farmers had contacted extension agents for 2.28 times per month per household. However, the adopters of SWC measures reported higher frequencies of contact with development agents than the non-adopters. This finding is in line with the findings of several other studies in Ethiopia and other places (see for example in Teshome et al., 2016; Mango, Makate, Tamene, Mponela, & Ndengu, 2017; Teferi1, Philip, & Jaleta, 2015; Bogale, Aniley, & Haile-Gabriel, 2007).

Our analysis of farm plot characteristics has considered various aspects including the average walking distance to the plot, severity of the erosion problem, soil fertility status, plot slope and plot sizes. Farmers who lived close to their farm plots had a location advantage in the sense that they saved time and energy from walking shorter distances before arriving at their plots as opposed to those who spent more time walking to their plots. Overall, the average time farmers spent to reach their farming plots was 13.29 and 14.93 min for adopters and non-adopters respectively. The average plot size for the pooled sample was 0.15 ha with adopters having relatively larger plot sizes than the non-adopters. Moreover, nearly 33.50 percent of adopters and 24.61 percent of non-adopters reported to have suffered from very severe soil erosion on their farming plots.

About 23.16, 51.90, and 24.94 percent of the sample plots had low, medium, and high soil fertility status respectively. However, the plots of farmers who adopted SWC measures were relatively less fertile than the plots of non-adopters. The low soil fertility status for the plots cultivated by farmers who adopted SWC measures might have influenced these farmers to adopt SWC measures so as to improve soil fertility, moisture content and hence, productivity of their plots. This finding is not surprising as a substantial proportion of the plots of the adopters were located along steeper slopes (38.00 percent) as opposed to that of non-adopter plots (30.77 percent). Elsewhere in north-western highlands of Ethiopia, Moges and Taye (2017) also reported a similar scenario that most of the adopters' plots were located at higher slopes than that of non-

Table 2
Description of explanatory variables.

Variables	Description	Adopters		Non-Adopters		Total Sample	
		Mean	SD	Mean	SD	Mean	SD
Sex	Dummy of sex of household head (1 = male)	0.910***	0.287	0.827	0.379	0.868	0.339
Age	Age of the household head in years	39.940	12.545	40.428	12.940	40.189	12.735
Education	Level of education in numbers of years	4.460***	3.631	2.875	3.547	3.652	3.671
Number of plots	Total numbers of plots owned	1.995	0.848	1.889	0.806	1.941	0.827
Family size	Household size	6.240	1.998	6.178	2.074	6.208	2.035
Income	Total household income in Birr	20129.330***	15036.12	13753.030	10416.14	16878.67	13263.07
Off-farm Activity	Dummy for participation in off-farm activities (Yes = 1)	0.440	0.498	0.476	0.501	0.458	0.499
Total Asset	Total value of assets in Birr	29594.798**	51561.049	19851.702	44079.070	24627.729	48081.687
Livestock (TLU)	Livestock owned (Tropical Livestock Unit)	1.939	1.825	1.627	1.957	1.780	1.898
Received credit	Dummy for receiving credits (Yes = 1)	0.155	0.363	0.115	0.320	0.135	0.342
Contact of DA	Number of contacts with DA, per month	3.035***	2.298	1.559	1.529	2.282	2.078
Distance plot	Average walking distance to farming plots in minutes	13.289	16.250	14.935	15.342	14.156	15.780
Area plot	Total area of plot in Ha	0.156	0.099	0.143	0.106	0.149	0.103

***and ** * significant at the 1 and 5 percent probability levels, respectively.

adopters. The results of Chi-square test in Table 3 also support the assertion that soil fertility status and slope were systematically associated with the adoption of SWC measures at 5 and 1 percent significant levels, respectively.

3.2. Adoption status of SWC and relationships between measures

The results of descriptive analysis summarized in Table 4 for different SWC measures implemented in the study area show that the adopters of SWC measures operated 400 plots and the non-adopters had 390 plots out of 790 plots which were covered by our study. About 93.5 percent of the adopters' plots (374 plots) were under at least one SWC measure. Specifically, the key SWC measures implemented in the study area are shown in Table 4. These include soil bund, stone bund, bench terraces, check-dam, as well as other mechanical and biological conservation measures. The most and widely applied SWC measures are the stone bunds (53.75 percent), followed by the soil bunds (50.50 percent), bench terraces (21.50 percent), and check-dams (3 percent). Others such as *fanyajuu*, cut of drain, and biological conservation are implemented only on about 4.25 percent of the adopters' plots.

Most plots (about 62 percent or 231 plots) of the adopters were entailed a single conservation measure. About 33 percent (125 plots) and 3.5 percent (13 plots) comprised two and three SWC measures respectively. Very few plots (about 0.8 percent or 3 plots) contained more than three measures. This indicates that there is simultaneity and interdependence among the adoption decisions of improved SWC technologies measures in the study area.

Table 3
Farm plot characteristics.

Characteristics	Adopters		Non-Adopters		χ^2-value	Total	
	No.	Percent	No.	Percent		No.	Percent
Level of soil erosion							
Less severe	155	38.750	179	45.897	7.948**	334	42.278
Severe	111	27.750	115	29.487		226	28.608
Very severe	134	33.500	96	24.615		230	29.114
Soil fertility status							
Low	84	21.000	99	25.385	7.659**	183	23.165
Medium	227	56.750	183	46.923		410	51.899
High	89	22.250	108	27.692		197	24.937
Plot slope							
Flat	103	25.750	147	37.692	16.660***	250	31.646
Moderate	145	36.250	123	31.538		268	33.924
Steeper	152	38.000	120	30.769		272	34.430

***and ** * significant at the 1 and 5 percent probability levels, respectively.

Table 4
Major SWC measures in the study area.

Types SWC	Number	Percent
Stone bund	215	53.75
Soil bund	202	50.50
Check-dam	12	3.00
Bench terraces	86	21.50
Other	17	4.25
Not implement	26	6.50

Furthermore, the conditional and unconditional probability of adopting the three SWC measures as presented in Table 5 indicates that the three measures were interdependent. The unconditional probability for a plot with stone bund was 27.21 percent. However, this probability of adoption increased significantly to 57.92 percent and decreased to 10.47 percent for plots with soil bund and bench terracing conservation measures respectively. The unconditional probability for plots with soil bunds was 25.56 percent and this probability increased to 54.42 percent conditional on the adoption of stone bund but decreased to 17.44 percent when farmers adopt bench terracing. This implies that there is a complementary relationship between stone bund and soil bund and substitutability between bench terracing and stone bund/soil band. One of the possible explanations for the two relationships is to do with the relative costs of implementing specific SWC measures. Though more stable, stone bunds and bench terraces are relatively more expensive and labour demanding than the soil bunds (Mishra & Rai, 2014; Rolker, 2012). Soil bunds are relatively less stable, and depending on the type of soil, they may easily become eroded. Because of high costs of implementing stone bunds and terraces, most farmers prefer to combine the two (i.e. soil bunds with stone bunds interspaced) to reinforce their SWC structures (we refer this to complementary relationship). Moreover, where stones are

Table 5
Unconditional and conditional adoption probabilities.

	Stone band (S)	Soil band(A)	Bench terracing (B)
$P(Y_k = 1)$	0.2721	0.2556	0.1088
$P(Y_k = 1 \mid Y_S = 1)$	1	0.5442	0.0419
$P(Y_k = 1 \mid Y_A = 1)$	0.5792	1	0.0743
$P(Y_k = 1 \mid Y_B = 1)$	0.1047	0.1744	1
$P(Y_k = 1 \mid Y_S = 1, Y_A = 1)$	1	1	0.0581
$P(Y_k = 1 \mid Y_S = 1, Y_B = 1)$	1	0.0246	1
$P(Y_k = 1 \mid Y_A = 1, Y_B = 1)$	0.0330	1	1

Y_k is a binary variable representing the participation status with respect to choice K
K = Stone band (S), Soil band (A), Bench terracing (B).

plenty and readily available, farmers would prefer to use stone bunds; and where stones are either scanty or not readily available, farmers would obviously go for soil band or combine soil bunds with stone bunds interspaced. It is important to note that farmer's decision on what type of SWC measure to adopt will also depend on the steepness of the slope. For example, bench terracing is more suited and preferable on steeper slopes while stone bunds and soil bunds are common in plots with less steep slopes.

3.3. Determinants for adoption of SWC measures

As noted earlier, smallholder farmers who adopted SWC in the study area implemented at least one or more conservation measures. In this paper, we only focus on three specific SWC measures: stone bund, soil bund, and bench terracing because the other conservation measures were adopted by a small number of farmers.

Table 6 presents the results of MVP model. Before interpreting the results, it is essential to determine the statistical validity of the model and interdependence of dependent variables. Our model fitted the data reasonably well [Wald Chi-squared = 274.34, P = 0.000)]. Thus, the hypothesis that all coefficients in each equation are jointly equal to zero was rejected. On the other hand, the Chi-square test verified that the adoption decisions among the three SWC measures were not mutually exclusive (independent). According to Young et al. (2009), this confirms that the coefficient estimates obtained from joint estimation are asymptotically more efficient than the coefficient estimates obtained from a single equation when the binary outcome variables are correlated. Accordingly, all the possible pairs of correlation between the error terms were significant at less than one percent probability level, supporting joint estimation. The correlation coefficients between stone bund and soil bund, stone bund and bench terracing, and soil bund and bench terracing were 56.71 percent, −47.61 percent, and −27.29 percent respectively. The positive sign indicates that there was a positive (complementarity) and interactive correlation between stone bund and soil bund, while the negative sign for bench terracing indicates substitutability and interactive correlation with stone and soil bunds.

The results of MVP model reveal that demographic, socio-economic, institutional, and plot characteristics as significantly influencing farmers' choice of adopting SWC measures. Out of the 16 hypothesized variables, 5, 4, and 9 were found to be significantly influencing the adoption of stone bund, soil bund, and bench terracing, respectively.

The adoption of stone bund and soil bund conservation measures increased with the level of education of the household head and the relationship was significant at 5 and 1 percent levels, respectively. Heads of household who attended formal education were more likely to adopt stone and soil bunds than their uneducated counterpart heads of household. This might be because better education is associated with greater access to information and awareness about the severity of soil degradation and its consequences, which, in turn, motivate them to adopt SWC measures. Moreover, educated farmers are also more likely to use appropriate SWC measures than uneducated farmers. Elsewhere in Ethiopia, scholars (e.g. Fentiel et al., 2013; Asfaw & Neka, 2017) also found education to be an important factor of accelerating the adoption of SWC measures.

The results of MVP model indicate that the adoption of stone bunds was decreasing with family size and this relationship was significant at 1 percent level. The negative relationship between family size and the adoption of stone bund is not surprising; particularly for households with a high dependency ratio (average dependence ratio was 129.24 percent). Thus, households with a large family size are less likely to choose the stone bund conservation structure than are smaller sized families. This relationship is also reported by Bekele and Drake (2003) and Shiferaw and Holden (1998) who found the adoption of SWC measures decreasing with family size.

Contact with extension agents constituted another important institutional factor that was positively influencing the decision to adopt stone bund, soil bund, and bench terracing conservation measures (P < 0.01). Farmers who have close contact with extension agents can develop awareness and understanding of the soil

Table 6
Results of multivariate probit model for choice of SWC measures.

Variables	Stone Bund			Soil Bund			Bench terracing		
	Coef.	B.Std.	Z	Coef.	B.Std. Err.	z	Coef.	B.Std. Err.	z
Sex of hh	0.3124	0.1759	1.78	0.2083	0.1661	1.25	−0.3629	0.1744	−2.08**
Age of hh	0.0018	0.0047	0.39	0.0058	0.0047	1.23	−0.0092	0.0059	−1.55
Level of education	0.0342	0.0169	2.02**	0.0439	0.0163	2.70***	0.0184	0.0200	0.92
Number of plots	0.0321	0.0678	0.47	−0.0491	0.0666	−0.74	−0.2659	0.0908	−2.93***
Family size	−0.0726	0.0278	−2.61***	−0.0201	0.0291	−0.69	0.0275	0.0306	0.90
Income	1.41e-05	5.38e-06	2.62***	9.33e-06	5.17e-06	1.80	4.36e-05	6.49e-06	6.72***
Off-farm Activities	−0.1429	0.1144	−1.25	−0.1255	0.1167	−1.08	−0.6379	0.1544	−4.13***
Total Asset	−8.45e-07	1.25e-06	−0.68	4.75e-07	1.19e-06	0.40	2.69e-07	1.30e-06	0.21
Livestock (TLU)	−0.0565	0.0301	−1.88	−0.0735	0.0323	−2.27**	−0.1691	0.0423	−4.00***
Received credit	−0.0381	0.1435	−0.27	0.0996	0.1440	0.69	0.3028	0.1560	1.94**
Contact of DA	0.1499	0.0248	6.04***	0.1568	0.0248	6.31***	0.0626	0.0300	2.09***
Distance plot	0.0004	0.0032	0.13	−0.0027	0.0033	−0.83	−0.0015	0.0041	−0.36
Erosion problem	0.0575	0.0641	0.90	0.2258	0.0641	3.52***	−0.0471	0.0840	−0.56
Plot soil fertility	−0.0383	0.0775	−0.49	0.0582	0.0757	0.77	−0.0739	0.0947	−0.78
Plot slope	0.2208	0.0628	3.52***	−0.0464	0.0666	−0.7	0.2188	0.0790	2.77***
Area plot	−0.0011	0.0664	−0.02	−0.0008	0.0663	−0.01	−0.1547	0.0748	−2.07***
_cons	−1.6584	0.3805	−4.36***	−1.8366	0.3975	−4.62***	−0.7384	0.4231	−1.75
/atrho21	0.6432	0.0784	8.21***	Multivariate probit (SML, # draws = 100)					
/atrho31	−0.5179	0.1033	−5.01***	Log pseudo likelihood = −990.2775					
/atrho32	−0.2800	0.1016	−2.76***	Number of obs = 790					
rho21	0.5671	0.0532	10.67***	Wald chi2(42) = 274.34					
rho31	−0.4761	0.0799	−5.96***	Prob > chi2 = 0.0000					
rho32	−0.2729	0.0940	−2.90***						
Joint probability (success)		0.0097							
Joint probability (failure)		0.5421							

Likelihood ratio test of rho21 = rho31 = rho32 = 0: chi2(3) = 111.149 Prob > chi2 = 0.0000.
***and ** significant at the 1 and 5 percent probability levels, respectively.

erosion problem and become encouraged to adopt improved soil conservation measures (Yirga, 2007; Bogale et al., 2007; Shimeles et al., 2011).

The adoption of stone bund and bench terracing conservation measures also increased with household income ($P < 0.01$). Farm households with high incomes were more likely to adopt SWC measures than were those with low incomes. This result is not astonishing because households with higher incomes can better afford to purchase SWC material and hire additional labour to implement the conservation measures. Furthermore, farmers with high incomes have a higher risk of bearing the capacity of testing new technologies than have those with low income.

The adoption of soil bunds increased with the perception of farmers about the severity of erosion on their farm plots ($P < 0.01$). This implies that farmers who had already perceived their plots to have soil erosion problem were more likely to adopt SWC measures than those who did not. This is because soil bunds were relatively cheaper to construct than the stone bunds and bench terraces. Farmers who perceived to have suffered from soil erosion on their plots would preferably select a cheaper measure.

The study results also indicate that the adoption of soil bunds and bench terraces decreased with the size of livestock holdings and the relationship was statistically significant at 5 and 1 percent respectively. This means that households with larger livestock holdings were less likely to adopt soil bund and bench terracing than were household with smaller livestock holdings. This is because households with larger livestock holdings focused more on livestock than on crop production. In addition, temporal yield gains through the application of manure might have replaced the fertility loss and potential productivity losses due to soil erosion, thus reducing conservation efforts. Similar findings were reported by Shimeles et al. (2011) and Fentiel et al. (2013) for rural farmers of Gursum District, and Hulet Eju Enesie District, East Gojjam Zone respectively in Ethiopia.

The likelihood of farmers to adopt bench terracing declined with an increase of plot size ($P < 0.01$). According to Bekele and Drake (2003), larger numbers of plots may imply greater degree of land fragmentation. Then the construction of SWC structures would occupy a large area of land. Large numbers of farm plots are therefore associated with reduced likelihood for farmers to implement bench terracing. Similarly, farmers cultivating larger plots were less likely to construct bench terrace for SWC. This is because large cultivated farm plots require large amounts of SWC construction materials and labour, which make it difficult for subsistence farmers to implement. Moreover, most farmers cultivating large farm plots were relatively older and lacked the labour required for constructing conservation structures.

The results of MVP model also show that farmers who participated in off-farm activities as alternative sources of income were less likely to implement bench terracing ($P < 0.01$). This may be because off-farm activities competed with agricultural production in terms of labour resources making it difficult for farmers to mobilize adequate labour for the construction of SWC measures. On the other hand, farmers may earn more returns from participating in off-farm activities rather than concentrating on on-farm activities, which include among others the construction and maintenance of SWC structures. Thus, farmers engaged in off-farm activities are less likely to choose bench terracing as conservation measure because it is a labour intensive undertaking and competes with other activities over the available capital and labour resources.

Surprisingly, the male-headed households were less likely to adopt SWC measures as opposed to the female-headed households ($P < 0.05$). This could probably suggest that female heads of households were more concerned with produce and ensuring food security for their families than was the case with their male counterparts. Female heads of households therefore felt they had the responsibility of taking actions against land degradation, which reduces crop productivity. Furthermore, the government and other partner NGOs had given female headed households the priority in enabling them construct SWC structure and providing them with other related support. This might have influenced their decision of adopting SWC measures.

The adoption of stone bunds and bench terraces as SWC measures was also significantly influenced by the slope steepness. The steeper the slope of the plot the more likely that the farmer would adopt stone bunds and bench terraces as SWC measures. The is possibly because land degradation is more prominent and severe in steeper than on flat slopes and farmers are therefore more likely to adopt SWC measures that are more stable in plots located at steeper slopes.

Finally, the adoption of bench terracing increased with an increase of access to credits from formal lending institutions ($P < 0.05$). Most subsistence farmers lacked the capital, which is needed in reinvesting in farming, including the financial resources, which are needed for the construction of SWC structures. Hence, access to credit was vital for farmers to make timely purchase of agricultural inputs and invest in SWC structures.

4. Conclusions

This paper investigates the determinants of the adoption of improved SWC measures using the primary data collected from eastern Ethiopia. A sample of 790 plots, 400 belonging to adopters of SWC, and 390 plots operated by non-adopters were used. The findings show that at least one type of SWC measures was implemented on 374 plots (equivalent to 93.50 percent of the adopters' plots). Of these, the most widely and intensively used measures were stone bunds (53.75 percent), soil bunds (50.50 percent), and bench terraces (21.50 percent). Others constituted the least used measures, including the check-dam (3 percent) as well as the cut-off drains, *fanyajuu* and biological conservation, which were by practiced only on 4.25 percent of the plots of the adopters. Moreover, the conditional and unconditional probabilities of adoption decisions indicated that there were significant complementarities between stone bunds and soil bunds, as well as a substitutability relationship between bench terracing and stone bunds, and bench terracing and soil bunds. The results MVP model reveal that the adoption of bench tracing conservation measure was positively influenced by household income, farmers' contact with development agents, access to credit and the plot's slope steepness. The adoption of bench terraces was also negatively influenced by sex of the head of the household, the number of plots, the size of the plots, engagement in off-farm activities and the units of livestock owned. Similarly, the adoption of soil bunds was positively and significantly influenced by famers' contact with development agents, the level of education of the head of the household and the perception of farmers towards the intensity of the erosion problem on their plots. Equally important, the adoption of soil bunds was negatively influenced by the units of livestock owned by the household. Furthermore, the adoption of stone bunds was positively influenced by the level of education of the household head, annual income, farmer's contact with development agents and the steepness of the plot's slope, while influenced negatively by family size. Based on these findings, we recommend that efforts of addressing land degradation using SWC structures should focus on strengthening the human and institutional capacity. This should be done through enhancing farmers' education and continuous training and creation of awareness on the effects of land degradation, as well as, the importance of adopting appropriate SWC to control soil degradation and enhance farm productivity. In addition, it is imperative to create credit facilities that are tailor made to address the challenge of access to credits by smallholder farmers.

Conflict of interest

There is no conflict of interest among the authors.

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