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Adoption Decision and Sustainable Utilization of Soil Conservation Technologies: Empirical Evidence from North West Ethiopia

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Abstract

Soil is a crucial and precious natural resource that govern numerous ecological processes. However, in Ethiopia particularly in north Gondar zone, soil erosion is a severe problem and a major cause of the decline of agricultural productivity. The adoption and diffusion of soil and water conservation practices (SWC), as a way to tackle this challenge, has become an important issue in the development policy agenda in the zone. Therefore, this study was to identify factors affecting Soil conservation investments in the North Gondar zone. Data was collected through interviewed schedule, filed observation and focus group discussion. The multistage sampling technique was employed to select 206 sample households. Both descriptive and econometrics model was used to analyze the collected data. A multivariate profit (MPV) model was used to analyze the effect of demographic, socioeconomic, market, institutional and biophysical related factors on the interdependent investment decisions of SWC practices using household survey. The MPV model analysis indicates that farmers invest a combination of practices at parcel level by considering substitution and complementarity effects of the practices. The results also revealed that age of household heads, literacy status of household heads, off-farm activity, distance of farmlands from homesteads, tropical livestock unit, and access to training were influence farmers' investments in SWC practices. The overall results indicate that the identified physical, socioeconomic, and institutional factors influence promote or hinder investments in SWC practice so, policymakers should take into consideration these various factors in designing and implementing SWC policies and Programmers.

Keywords; Soil, Soil, and Water Conservation Practices, Investment, Multivariate Profit Model, Adoption

1. Introduction

Soil is a vital non-renewable natural resource which takes between 200 and 1000 years for the formation of 2.5cm fertile soil under the farming ecosystem. It is crucial and precious natural resource that govern numerous ecological processes (nutrient cycle, waste treatment, water purification, detoxification) and medium for human food production (Ochoa et al., 2016). In this 21st century, the capacity of a soil to function within the ecosystem and to interact positively with all nearby ecosystems is being looser and threatening Pulido, Helwig, Carlos, Gabriels, & Cornelis, 2017). Studies showed that accelerated soil degradation seriously affected food security and implies a decline in prosperity with an attendant reduction in ecosystem function and services. Soil degradation is old aged phenomenon on this planet (Dessalew Meseret, 2016). It started as early as the human being's history of farming. The deterioration of soil resource arises due to two major factors. The first is anthropogenic activities due to increases in human population growth in the world that led to a reduction in land availability, and a shift in conventional farming system used to be the means of replenishing soil fertility (Ajayi, Akinnifesi, Sileshi, & Chakeredza, 2007). The second reason include all-natural factors of soil degradation like climate (precipitation, temperature, wind), soil type (texture, structure, moisture, roughness, and organic matter), topography slope angle and slope length, hydrology, and geomorphology.

Even though soil degradation is a shared environmental problem for the whole world, developing countries continue to be the most vulnerable and threatened by soil degradation because of inability of their farming populations to replace lost soils and nutrients (Gashaw, Bantider, & Silassie, 2014; Haregeweyn et al., 2013; Dessalew Meseret, 2016; Yitbarek, Belliethathan, & Stringer, 2012). Moreover, mismanagement of soil resource by human activities that take place in already fragile areas lead to accelerated soil degradation (Gashaw et al., 2014; Dessalew Meseret, 2016; Tekwa, Belel, & Alhassan, 2010). If land degradation continues in the current trend, it may pose a serious threat to food production and rural livelihood in those developing nations. For instance, studies in Ethiopia reveal that soil fertility is getting low and many lands become in a position of being no efficient to support plant growth (Adugna, Abegaz, & Cerdà, 2015; Beyene, 2011; Esser & Haile, 2002; Mushir & Kedru, 2012; Thiemann, 2005). The decrease in soil fertility leads to increase in farm-level investment and made land-based living extremely difficult. All physical and economic evidence shows that reduction of land resource productivity is a serious problem in Ethiopia with the continued population growth; the problem is going to escalate in the future. Poor farmers outlook toward the problem and their inability to adopt conservation technology aggravate the problem (Adimassu, Kessler, Yirga, & Stroosnijder, 2013; Belay, 2014; Birhanu & Meseret, 2013; Desalew Meseret & Amsalu, 2017; National & State, 2013). Over the last three decades, population growth has outstripped agricultural production and income growth in Ethiopia. In the highlands, soil, the basic natural resource on which the livelihood of the majority of the population-based degraded progressively. Likewise, many authors stated that the main obstacle to sustainability of subsistence farmers is the depleted soil organic matter caused by land degradation (Adugna et al., 2015; Amsalu & Graaff, 2006; Beyene, 2011; Esser & Haile, 2002; Mushir & Kedru, 2012; Thiemann, 2005; Zegeye, 2009) This devastating problem is not uniform all over the country because the Northern and highland portions of the country found to be under severe to very severe degradation risk due to reasons like mountainous land escape, erosive rainfall, and poor soil quality.

The strategies designed in combating soil degradation and assuring environmental sustainability need to evaluate. Conventional technological and extension approach rarely considered indigenous knowledge and actual local situations. In addition, challenges that become barriers to soil conservation technologies adoption hardly studied. The influence of land quality, land fragmentation, and land tenure aspects on investment in SLM still requires some thorough investigation, Therefore, the general objective of this research work is to printout biophysical and socioeconomic factors that are bottlenecks for sustainable adoption of soil resource conservation technologies in north Gondar zone.

2. Description of The Study Sites

The study area is the North Gondar zone, which is located in the northwestern part of Amhara Region of Ethiopia. This mountainous agricultural zone is one of the most severely eroded parts of the Ethiopian highland. The study region has a very rugged mountainous topography, with an average slope of 12%, and most of the study areas are composed of gullies and ridges. The soil types of study areas predominately classified as Nitosols and Vertisols. The common land-use types of the study area are mainly agricultural (crop) land, forestland and grazing land.

2.1. Sample Size and Sampling Method

For the household survey, a total of 206 households were sampled based on a systematic sampling procedure, with kebele registers used as sampling frames. A two-stage sampling procedure was employed to select sample households. In the first stage of the sampling procedure, as mentioned earlier, the districts were selected purposely based on their specific experience with SLM activities and diverse bio-physical and socio-economic characteristics. In the second stage, farmers from each district were selected randomly from lists of all households in the districts. A total of 60, 125, and 115 farmers were selected randomly from Chilga, Tikil dngay, and Maksegnit districts, respectively.

2.2. Method of Analysis

Simple descriptive statistics as T-test and Chi-square were employed to compare a mean/association of land quality, land fragmentation and other socioeconomic variables with SWC practices. A multivariate profit (MVP) model is applied to analyze the interdependent investment decisions of the SWC practices (soil bunds, stone bund, compost/manure, and chemical fertilizer) by smallholder farmers. Investment decisions by smallholder farmer are multivariate in nature and so the appropriate modelling procedure should not be univariate, but must instead take into account the interactions and possible simultaneity of the investment decision. This is because farmers are more likely to invest in a mix of technologies than in a single technology to cope with multiple agricultural production constraints (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013).
The multivariate profit econometric model is described by a set of binary dependent variables. The model is specified as follows

$$\begin{cases} chem_j = X_1^{'}\beta_1 + \varepsilon^A \\ compos_j = X_2^{'}\beta_2 + \varepsilon^B \\ soilB_j = X_3^{'}\beta_3 + \varepsilon^C \\ stonB_j = X_4^{1}\beta_4 + \varepsilon^d \end{cases} \quad (1)$$

$$\begin{pmatrix} \varepsilon^A \\ \varepsilon^B \\ \varepsilon^C \\ \varepsilon^d \end{pmatrix} \ldots\ldots N \left[\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \begin{pmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 \end{pmatrix} \right] \quad (2)$$

$$E\left(\varepsilon / X\right) = 0 \quad (3)$$

$$Var(\varepsilon / X) = 1$$

$$Cov(\varepsilon / X) = \rho$$

Where soil, stone , compos$_t$ and chem$_o$, binary variables taking value 1 when farmer j selects an soil bunds, stone bund, compost/manure, and chemical fertilizer respectively, and 0 otherwise; $\mathbf{x_1}$ to $\mathbf{x_4}$ are vectors of independent variables determining the respective SWC practices variables; **β**' s are vectors of simulated maximum likelihood (SML) parameters to be estimated; ε^A to ε^d are correlated disturbances in a seemingly unrelated multivariate profit model;

and 's ρ are tetrachoric correlations between endogenous variables.

3. Results and Discussion

3.1. Household Characteristics of Investing and Non-Investing Households

Definitions and summary statistics of the variables used in the econometric analysis are given in Table 3. Farmers in the study area used both modern and traditional conservation methods. The most widely used soil conservation technologies were soil bund, stone bund, compost, and inorganic fertilizer. Results showed that 82.04% of the sampled smallholder farmers had adopted compost/manure, 87.81 % of the sampled smallholder farmers had adopted chemical fertilizer, 89.81 % of the sampled smallholder farmers had adopted stone bund , and also 82.04 % of the sampled smallholder farmers had adopted stone bund soil bund soil and water conservation practices at the time of the survey. Table 3 showed that unconditional mean analysis of the socio-economic and institutional factors determining the decisions of SWC adoption. The T-test analysis showed that the significant differences among adopters and non-adopters. In terms of age, results showed that compost and soil bund adopters were significantly older than non-adopters.

variables	compost /manure		t-/z-/χ^2 statistics	chemical/fertilizer		t-/z-/χ^2 statistics	stone bund		t-/z-/χ^2 statistics	soil bund		t-/z-/χ^2 statistics	overall (mean)
	Yes =169	No =37		Yes(186)	No (20)		Yes(185)	No (21)		Yes(169)	No(37)		
Age of household	49.8	43.7	-2.99***	48.6	49.7	0.4	49.06	46	-1.1	49.6	44.8	-2.33**	48.75
Family size	6.2	6.4	0.33	6.3	6.2	-0.18	6.25	6.80	1.00	6.3	6.3	0.10	6.31
Tropical livestock unit	9.36	5.56	-2.3**	8.7	9.7	1.58	8.1	9.8	0.52	5.2	5.7	0.20	24.32
Total farm size	1.7	1.0	-3.9***	1.61	1.43	-0.85	1.66	1	-3.04***	1.7	0.9	-4.58***	1.59
Distance to nearest development center	2.4	1.7	-2.04**	4.64	4.8	0.18	2.39	2.15	-0.52	2.42	2.18	-0.62	2.36
Distance to farm land from homer	4.73	4.34	-0.49	2.41	1.98	-0.9	4.64	4.80	0.16	4.4	5.7	1.71*	4.6
Number of plots	2.7	2.91	0.49	2.9	1.89	-2.7***	2.99	1.6	-3.33***	2.6	3.2	1.80*	2.79

Table 1: Mean of household characteristics of investing and non-investing households

**, **, and * are significant at 1%, 5%, and 10% significant levels, respectively. Source: Authors" Computation, 2018;

Table 2: Proportion of households of investing and non-investing households

Variables	Category	compost/manure		χ^2 statistics	chemical/fertilizer		χ^2 statistics	stone bund		χ^2 statistics	soil bund		χ^2 statistics	Overall (%)
		No	Yes		No	Yes		No	Yes		No	Yes		
Literacy status of HH	Literate	14.08	69.9	1.05	4.37	79.61	0.28	8.74	75.24	0.05	14.56	69.42	0.28	83.98
	Illiterate	3.88	12.14		0.49	15.53		1.46	14.5		3.40	12.62		16.02
participation in in/formal institution	Yes	11.65	54.37	0.03	2.91	63.11	0.16	5.34	60.68	1.93	13.11	52.9	0.97	66.02
	No	6.31	27.67		1.94	32.04		4.85	29.13		4.85	29.13		33.98
Access to credit	Yes	8.25	46.12	1.28	2.43	51.94	0.08	4.37	50.00	1.24	9.71	44.66	0.018	54.37
	No	9.71	35.92		2.43	43.20		5.83	39.81		8.25	37.36		45.63
Off/non income	Yes	9.71	40.78	1.28	2.43	48.06	0.05	5.34	45.15	0.14	10.68	39.81	1.60	50.49
	No	8.25	40.78		2.43	46.60		4.85	44.17		7.28	41.75		49.03
ownership of iron roof	Yes	17.48	80.10	0.01	4.85	92.72	0.26	10.19	87.3	0.56	17.96	79.61	1.12	2.43
	No	0.49	1.94		0.00	2.43		0.00	2.43		0.00	2.43		97.57
ownership of tools	Yes	9.71	40.78	0.42	4.37	89.81	0.33	8.74	85.44	3.05^{*}	15.05	79.13	8.87^{***}	94.17
	No	8.25	40.78		0.49	5.34		1.46	4.37		2.91	2.91		5.83
Perception of soil depth	Shallow	0.97	8.25	2.95	0.49	8.74	0.54	0.00	9.22	3.85	0.49	8.74	3.92	9.71
	Medium	11.17	38.83		2.91	47.09		6.80	43.20		11.17	38.83		50.00

	Depth	5.83	34.47		1.46	38.83		3.40	36.89		6.31	33.98		40.29
Perception of soil fertility	fertile	10.19	49.51	0.16	1.94	57.77	1.69	4.85	54.85	142	10.68	49.03	0.012	59.71
	Infertile	7.77	32.52		2.91	37.38		5.34	34.95		7.28	33.01		40.29
Perception of soil type	Red	6.80	37.86	0.84	1.94	42.72	0.09	4.37	40.29	0.03	5.34	39.32	4.06^{*}	44.66
	Black	11.17	44.17		2.91	52.43		5.83	49.51		12.62	42.72		55.34
SWC training	Yes	15.05	72.33	0.52	4.37	83.01	0.06	8.25	79.13	0.87	16.02	71.36	0.13	87.38
	No	2.91	9.71		0.49	12.14		1.94	10.68		1.94	10.68		12.62
SWC Program	Yes	7.28	65.05	22.7^{***}	3.88	68.45	0.30	6.80	65.53	0.37	5.83	66.50	35.87^{***}	87.38
	No	10.68	16.99		0.97	26.70		3.40	24.27		12.14	15.53		12.62

***, **, * are significant at 1%, 5%, and 10% significant levels, respectively; Source: Authors Computation, 2018.

3.2. Determinants of investment decisions in Soil conservation technologies

The results of the multivariate profit model are presented in Table 5. The regressions are estimated at the farm household level. The likelihood ratio test (chi 2(3) = 60.64, p-value < 0.0001) for independence between the disturbances is strongly rejected, implying correlated binary responses between different SWC practices and supporting the use of an MVP model. Moreover, the likelihood ratio test in the model (ρ 21 = ρ 31 = ρ 41 = ρ 32 = ρ 42 = ρ 43 = 00) is significant at 1%. Therefore, the null hypothesis that all the ρ (Rho) values are jointly equal to 0 is rejected, indicating the goodness-of-fit of the model or implying that the decisions to invest SWC practices are interdependent. Hence, the use of multivariate profit model is justified to determine factors influencing sustainable utilization of soil conservation measures. Further, there are differences in investment decision behavior among farmers, which are reflected in the likelihood ratio statistics.

The ρ values (ρij) indicate the degree of correlation between SWC practices investment decisions. The ρ 21 (correlation between the investment decisions of compost and fertilizer, ρ31 (correlation between compost and stone bund investment decisions), ρ41 (correlation between the investment decisions of compost and soil bund) and ρ32 (correlation between the investment decisions of soil bund and stone bund) are positively and statistically significant at the 1% significance level (Table 3). The study reveals that compost/manure and fertilizer are substituting each other in the farming system of the study areas. Similarly, stone bunds and soil bund are substituting each other in the farming system of the study areas.

The marginal success probability for each equation (SWC investment decision) is reported below. The simulated maximum likelihood (SML) estimation result showed that the probability that farmers invest in compost/manure, chemical fertilizer, soil, and stone bund SWC technologies were 81, 89, 81, and 88%, respectively. Chemical fertilizer was the most common SWC used by the sample households. It was used as a single technology on 89% of sample households. This is good evidence because farmers were interested in investing fertilizer as SWC practices. If farmers invest all four SWC practices, their joint probabilities of investing these SWC technologies would be only 68 %. It was likely for farmers to invest all four market channels SWC practices simultaneously. This was justified either by the fact that simultaneous invest of all SWC practices was affordable for the smallholder's farmers, or that all four SWC practices were simultaneously accessible in the study areas. However, their joint probability of not investing all four SWC practices was 2 %, implying that the households were more unlikely to fail. The finding was also consistent with (Teklewold, Kassie, & Shiferaw, 2013)and (Firew, n.d.)

Table 3: Results of a multivariate profit analysis of investments in SWC practice.

Coefficients (investment decisions equations)				
	compost/manure (1)	chemical (2)	stone bund (3)	soil bund (4)
Age of household	0.03***	-0.007	0.01	0.02***
Literacy status	0.43	-0.83*	0.15	0.32
Family size	-0.06	0.03	-0.04	0.006
Tropical livestock unit	0.01**	-0.02**	-0.02*	-0.01
Total farm size	0.58***	0.18	0.65***	0.79
Distance to nearest development center	0.14	0.11	0.04	-0.14*
Distance to farm land from home	0.01	-0.01	-0.02	-0.04*
Access to credit	0.21	0.19	0.25	0.38
participation in in/formal institution	-0.02	0.24	0.28	-0.01
Off/non income	-0.10	0.19	-0.04	-0.42*
Access to training on SWC	0.12**	-0.46	0.24	-0.18
Constant	-1.00	2.06**	0.39	-0.04
Predicted probability	0.81	0.89	0.88	0.81
ρ 21			-0.22***	
ρ 31			0.50***	
ρ 41			0.79***	
ρ 32			0.62***	
ρ 42			0.44***	
ρ 43			-0.82***	
Number of simulations (draws)	5			
Wald chi2(39)	60.64 **			

Likelihood ratio test of independence	rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: chi2(6) = 99.32***
Joint probability (success)	0.68
Joint probability (failure)	0.02

***, **, * are significant at 1%, 5%, and 10% significant levels, respectively; Source: Authors Computation, 2018

Among household characteristics, the age of the household head influenced the adoption of introduced SWC practices, which is compos/manure and soil bund positively, and it was statistically significant at 1% significance level. This result suggests that older farmers are more likely to invest in compost/manure and soil bund bunds. The result consistent with A snake et al., 2018; Seawater (2015), have verified that age of household heads had positively influenced adoption of SWC practices. Contrary to this (Teshome, 2014 reported that age of household heads was negatively correlated with investment decisions in SWC practices confirmed that younger farmers are often expected to invest more in soil conservation practices. Because they are more often educated, and they are more aware of soil erosion problem and its solution.

Access to SWC training correlated positively and significantly with the adoption of soil and water conservation practices, which is compost/manure at 5% level of significance. Farmers who have access to SWC training, the probability of adopting soil and water conservation practices, which is compost/manure will increase by 12%. This could be training is one means to create awareness about the problems of erosion and the benefits of SWC measures to motivate farmers to investment in SWC measures. These results are consistent with the findings of (Adimassu et al., 2013; Birhanu & Meseret, 2013; Posthumus, Gardebroek, & Ruben, 2010). The distance of farmland from homestead is negatively related to the decision of soil bund investment statistically significant level. This implies that households who have their farmland that are far from the homesteads have a lower probability of investing in soil bund. This revealed that less time and energy are needed for maintaining near farmlands than far away farmlands. Thus, farmers who have farmlands far from their homes are discouraged from conserving their farmlands. Similarly, reported that longer walking distance between farm lands and household residences correlated significantly and negatively to the adoption of introduced SWC practices.

The distance of the development center from home is negatively related to the decision of soil bund investment at 10% significant level. As distance of development center from home increase by 1 km, the probability of households invest in soil bund will decrease by 14 %. This implies that distance to development center was a proxy variable for access to extension service; hence, farmers who are far from development centers have got less extension service like benefiting of SWC. Households who have their farmland that are far from the homesteads have a lower probability of investing in soil bund. This revealed that less time and energy are needed for maintaining near farms than far away farmlands. Thus, farmers who have farmlands far from their homes are discouraged from conserving their farmlands. The result is consistent with (Asfaw & Neka, 2017; Desalew Meseret & Amsalu, 2017; Teshome, 2014)

The main and significant economic factors considered in this study are the area of farmland, participation in off-farm income activities, and livestock holding of the household. Economic factors can play important role in determining the adoption of SWC practices. Among the economic factors, farm size is an important variable in relation to the adoption of soil and water conservation (Table 5). Farm size had positive and significant influence on the adoption of compost/manure and stone bund terraces. As the farm size of household increases by hectare, the probability of adoption of compost used and soil bunds increases by 58% and 65%, respectively (Table). This is because large farms have land available for compost and stone bund while on small farmers all land is needed for crop production. The result consistent with Wolak & Negash, 2014) they reported that a positive relationship between the size of farmland holding and the probability of adopting soil and water conservation practices. But (Asfaw & Neka, 2017) (Adusumilli & Wang, 2018) argued against this. They confirmed that farm size is associated negatively and significantly with the adoption of introduced soil and water conservation practices

The number of Tropical Livestock Units (TLU's) is positively related to the decision of compost/manure investment and negatively related to the decision of chemical fertilizer/ stone bund. This implies that each additional unit of livestock increases the probability of compost used per hectare will increase by 1%, and probability of chemical fertilizer and stone bund used per hectare will decrease by 2%. The result consistent with; (Teklewold et al., 2013); (Firew, n.d.), they reported that livestock ownership positively influences the adoption of manure farming because livestock waste is the single most important source of manure for small farms in most parts of Ethiopia.

Participation in off/non-farm activity is one of the important socio-economic factors that influence farmers' decision to adopt introduced soil and water conservation practices. Participation in off/non-farm income is negatively related to the decision of soil bunds investment. This is because farmers who are involved in non/off-farm activities may encounter time and labor constraints for investing in bunds. This means there is labour competition between off/non-farm activity and SWC practices which restrain farmers from involving in implementing and maintaining conservation practices on their farmlands. This is in line with other findings (Asfaw & Neka, 2017). Contrary to this (Jim, Villano, & Fleming, 2012) reported that off/non-farm activity positively related to the decision of SWC investments.

4. Conclusions and policy implication

Sustainable soil management practices are important to increase productivity and improve food security in the northwest of Ethiopia. In this research, household-level data were used to printout biophysical and socioeconomic factors that are bottlenecks for sustainable adoption of soil resource conservation technologies in north Gondar zone using a multivariate profit model. The results revealed that there are strong complementarities and substitutability between soil conservation practices, reflecting the interdependence of soil conservation practices adoption. Studies that consider the adoption of soil conservation practices in isolation ignore important cross-technology correlation effects, and potentially generate biased estimates. The cross-technology correlation information can have important policy implications as policy changes that affect one soil conservation practices can have spillover effects on other soil conservation practices. In addition, such information helps policy-makers and development practitioners to define their strategies of promoting soil conservation practices technologies.

Most importantly, the results showed that the probability of adoption of soil conservation practices technologies are influenced by several factors Age of household, literacy status, tropical livestock unit, total farm size, distance to development center and farmland, participation in off/non-farm income activities and access to SWC training are important policy variables that have a high impact on adoption of soil conservation practices technologies. The study also revealed that the current level of farm fragmentation (total farm size and distance to farmland) are very high, and it affects soil conservation practices technologies investments. Therefore, policy measures are needed to stop the further fragmentation of cultivated land. On the other hand, farmers prefer to some extent fragmented land, with different types of parcels, to minimize agricultural production risks. Thus, land consolidation/land amalgamation/land exchange policies should be backed up by a proper crop insurance scheme. Livestock ownership clearly influences the use of manure. Although increasing the number of livestock might not be a feasible option, introducing high yield breeds and improved forage legumes can increase livestock products, including manure.

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