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Impact of Soil and Water Conservation Measures on Wheat Productivity and Farmers' Income: Evidence from Tigray, Northern Ethiopia

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Abstract: Soil and water conservation (SWC) practices are considered vital for improving agricultural productivity and farmer income in areas vulnerable to soil erosion and climate variability. Nevertheless, the impact of SWC practices on wheat productivity and income remains unclear because of the presence of selection bias in adoption decisions. Data were gathered randomly from 335 wheat farmer household heads from purposively selected Woredas of Emba Alaje and Endamehoni and Tabias of Atsela, Sesat, and Mekhan via a multistage sampling technique. This study examines the impact of SWC practices on wheat yield and farmer income in Tigray, northern Ethiopia. It utilizes the endogenous switching regression (ESR) model, which addresses potential endogeneity in the adoption process. The ESR model indicates that, compared with nonadopter farmers, farmers who adopt SWC practices significantly ($p < 0.01$) experience increases in wheat yield and income of 18.9% and 25.6%, respectively. The findings of this study show that both wheat yield and income were more significant when farmers adopted SWC measures on their croplands. However, among the characteristics that impact SWC adoption, family size and asset values had favourable effects on nonadopters' wheat productivity and income, whereas the sex of the farmer household head, education level, total annual income, and participation in farmer cooperatives had negative effects. For adopters, total annual income and the number of plots negatively impact wheat income, whereas asset values have a positive effect. Addressing these challenges can increase wheat productivity and income while also ensuring the efficiency of SWC practices in increasing farming productivity and economic resilience. This study highlights the benefits of SWC in boosting farming productivity and economic resilience. The findings offer valuable insights for policymakers promoting sustainable land management practices for sustainable farming yields in the face of environmental challenges in semiarid regions.

Keywords: Soil degradation, Soil water conservation, Wheat productivity, Impact assessment, Switching regression, Northern Ethiopia

Introduction

Wheat is an essential stable food crop in Ethiopia; it is cultivated by millions of smallholder farmers and is a key factor in achieving food self-sufficiency, increasing household income, improving nutritional value, and promoting overall economic viability (Zenbaba et al., 2025). Similarly, wheat production plays a vital role in enhancing food security and income. It is a source of livelihood for many Ethiopian farmers (Tesfay, 2023; Zenbaba et al., 2025). However, by 2050, Ethiopia's lands that are suitable for wheat cultivation could be challenged by climate variability and changes in rainfall patterns, possibly leading to shifts in suitable areas and reduced productivity (Alemayehu et al., 2024). Likewise, climate change is expected to reduce future wheat land suitability and yield potential (Feyissa & Worku, 2023). Constraints impacting wheat production and marketing systems have also contributed to decreased wheat yields (Anteneh & Asrat, 2020). Furthermore, land degradation and poor soil fertility are major factors contributing to persistently low farming yields (Derpsch et al., 2024; Tesfa & Mekuriaw, 2014). This land degradation, driven by nutrient depletion and water scarcity, presents significant challenges to sustainable agriculture worldwide (AbdelRahman, 2023; Alam, 2014; Sarvade et al., 2019; Ziadat et al., 2022).

Land degradation and soil erosion are key drivers of unsustainable crop production (Wolka et al., 2021). Unsustainable land use practices and steep slopes contribute to increased soil degradation and erosion, significantly reducing crop yields and farmer livelihoods (Htwe et al., 2015). In Ethiopia's northern and central highlands, soil erosion poses a major challenge to both high- and low-potential cereal production, rendering approximately 50% of the country's land unsuitable for farming. This challenge has led to an estimated loss of approximately 162 million US$—approximately 2% of Ethiopia's gross domestic product (GDP) from crop production, including wheat and maize. Specifically, the yield of rain-fed wheat has decreased by approximately 25% over the past 30 years, primarily due to soil degradation. This trend has contributed to a 3.8% loss in Ethiopia's GDP (Gebreselassie et al., 2016). Furthermore, soil erosion is a major cause of declining soil fertility (Mengistu et al., 2016), which significantly affects crop production (Fantahun et al., 2024; Meena et al., 2017). Moreover, climate change and human-induced activities aggravate land degradation and soil fertility depletion, posing serious challenges to food security (Gupta, 2019). Thus, land degradation impacts livelihoods, decreases income, and aggravates poverty in rural communities (Asnake, 2024).

To address land degradation problems, restoring degraded land through integrated watershed management can improve soil fertility and water availability, leading to increased crop productivity (Gebremeskel et al., 2018). The application of soil and water conservation (SWC) measures has improved soil fertility and, at the same time, reduced fertility depletion (Aleminew & Alemayehu, 2020; Asnake, 2024). The implementation of SWC practices on degraded agricultural land has promised to increase crop yields, reduce surface water flows, and reduce soil erosion and nutrient loss (Bezu & Tezera, 2019). In addition, combining water conservation techniques with other agricultural practices has improved crop productivity, income, nutrition, and overall revenue (Hamidou et al., 2020). Thus, SWC practices play a crucial role in addressing land degradation challenges, enhancing crop yields, and increasing farmer incomes (Bati & Esmael, 2023; Masha et al., 2021; Tebeje et al., 2024; Tesfayohannes et al., 2022).

Numerous recent studies have recognized the positive effects of SWC practices on reducing soil erosion, increasing crop yield, and increasing farmer income in Ethiopia and other sub-Saharan African countries. For example, a study in northern Ethiopia confirmed that SWC measures significantly improved soil fertility, crop yield, and farm household livelihoods while reducing soil erosion by 33%-44% (Addis et al., 2019). Similarly, integrated fanya juu terraces and stone-faced soil bunds consistently increase soil organic carbon and total nitrogen levels, resulting in improved soil fertility and increased crop yields (Jiru & Wegari, 2022). Moreover, land surface management practices, including soil moisture conservation methods, improved maize yields by three to four times compared with those of untreated land (Jelde et al., 2024). Sustainable land management interventions in southern Ethiopia have led to higher crop yields by mitigating soil erosion and nutrient loss (Tadesse, 2023). Interference with SWC practices reduces soil erosion rates and increases land productivity (Moges & Wondimagegn, 2025). In southern Ethiopia, integrated SWC measures were associated with a 72.9% increase in wheat grain yield compared with land that was left unconserved (Tanto & Laekemariam, 2019). The soil bunds practiced in the subhumid Ethiopian highlands increased wheat yields by 181% and provided a significant return on investment, underscoring the economic benefits of SWC interventions (Tebeje et al., 2024). Similarly, the implementation of SWC measures resulted in improved soil physicochemical properties and increased crop yields, highlighting the benefits of SWC practices in increasing agricultural yield (Fantahun et al., 2024). Overall, studies have reported improvements in soil fertility and increased crop production due to the adoption of SWC practices (Alemayehu & Fisseha, 2018; Erkossa et al., 2018; Mohammed et al., 2020; More & Madolo, 2020; Tanto & Laekemariam, 2019).

The adoption of conservation measures significantly increased crop yield and farm income, improved land productivity, increased food availability, and reduced household poverty (Abegaz et al., 2024). However, the adoption of SWC practices is complex and impacted by various socioeconomic factors, institutional factors, and environmental challenges, which can either encourage or prevent farmers from adopting these practices. For example, farmers' perceptions of erosion problems, educational level, plot size, farming experience, household labour availability, and access to extension services have been identified as key determinants of SWC adoption in eastern Ethiopia (Wordofa et al., 2020). Likewise, the importance of institutional support, policy gaps, and other socioeconomic factors influences the intensity of SWC adoption in Tigray (Etsay et al., 2024). Similarly, holding legal and formal land rights, easy access to credit facilities, and the availability of formal soil-related information are key factors for improved adoption of sustainable land management practices (Tariq et al., 2024).

Thus, considering the drivers affecting the adoption of SWC practices is vital for designing effective interventions. For example, the benefits of SWC depend on farmers' access to extension services and training (Tesfayohannes et al., 2022). A study conducted in Eastern Ethiopia identified distance from markets and off-farm employment opportunities as challenges to adoption rates (Wordofa et al., 2020). Limited access to credit, labour shortages, restricted market access, and low awareness negatively and significantly impact adoption decisions (Abegaz et al., 2024). Approximately 64% of the farmers in the Lege-Lafto watersheds of southern Wollo adopted SWC measures, with factors such as education, family labour, and institutional membership having a positive and significant effect. Conversely, involvement in off-farm activities and distance from markets negatively influence adoption rates (Yifru & Miheretu, 2022). Furthermore, the type of SWC measure and landscape position significantly influence wheat yield and economic return in the Ethiopian highlands (Tebeje et al., 2024). On the other hand, agroecological practices, specifically the adoption of certified wheat seeds and optimal site-specific fertilizer use, have been shown to improve wheat yield and economic profitability (Karanja et al., 2025). Additionally, watershed management practices and farmland slopes play key roles in determining wheat yields and farmer incomes (Andualem et al., 2025; Masha et al., 2021).

Because of these multiple determining factors, some studies present contrasting findings. For example, Abebe & Bekele (2014) concluded that SWC interventions did not significantly improve crop productivity or household income. In light of this, this study underscores the need for regular evaluation of SWC programs. Additionally, Tilahun & Gizaw (2021) identified several limiting factors, such as the inappropriateness of certain SWC measures, low adoption rates, insufficient community commitment, and inadequate extension services, all of which hinder the effectiveness of SWC efforts to reduce soil erosion and improve crop productivity. Thus, to reconcile these contrasting findings, understanding the relationship between the adoption of SWC measures and household productivity is vital (Gatbel et al., 2019). Furthermore, the impact of SWC on crop yield varies according to socioeconomic and other contextual factors (Tilahun & Belay, 2019). However, estimating the impact of SWC measures is complex, as unobservable factors may influence their effectiveness. To address this issue, this study applied the endogenous switching regression (ESR) model, which accounts for endogeneity and enables the simultaneous estimation of adoption decisions and their impacts on outcome variables.

Few studies have examined the combined effects of SWC practices on both productivity and income. However, many studies explore SWC practice adoption separately, focusing on either productivity outcomes or specific aspects of farm production. These studies may not capture the broader impacts of SWC practices on both productivity and household incomes (Bati & Esmael, 2023; Kihara et al., 2022; Ojo et al., 2021). To fill this gap, the present study used household survey data and a robust econometric model, specifically the ESR model, to concurrently assess the impacts of SWC practices on wheat productivity and farmer income. Unlike other econometric models, such as propensity score matching and Heckman selection models, the ESR model accounts for selection bias, estimates counterfactuals, and allows for separate outcome equations. Thus, the overall objective of this study was to assess the effects of SWC practices on wheat yield and income in the Tigray highlands of northern Ethiopia. Specifically, the study aimed to do the following:

(1) Comparing wheat productivity and income between adopters and nonadopters of SWC practices.
(2) To identify the factors affecting household farmers' decisions to adopt SWC practices.
(3) Evaluate the impact of SWC on wheat productivity and farmer income, controlling for selection bias.

Materials and methods

Biophysical and socioeconomic conditions of the study area

The study was conducted in Emba Alajie and Endamehoni Woredas of the Southern Zone of Tigray Regional State, Northern Ethiopia. Geographically, Emba Alajie Woreda is located at 12°58′35″ N latitude and 39°31′46″ E longitude (Fig. 1). Woreda has three agroecological zones, i.e., highlands, mid-highlands, and lowlands, with a mean yearly rainfall of 912 mm and a daily temperature range of 9°C to 23°C. It covers a total land area of 76,722 hectares (ha), of which 27,327 ha is cultivated land, 20,366.6 ha is grazing land, 2,618 ha is forest, and 26,410.4 ha is categorized under other land uses. The livelihood of Woreda farmers relies heavily on crop and livestock farming (Tesfay et al., 2014). On the other hand, Endamehoni Woreda is located at 12°44′59.99″ N latitude and 39°29′59.99″ E longitude (Fig. 1). Woreda has three climate zones, namely, lowland, temperate, and highland zones, which cover 5%, 30%, and 65%, respectively. Its daily temperature typically ranges from 12°C to 18°C, and it receives an average annual rainfall of 600¬800 mm. Furthermore, 17,992 ha of land cover is cultivated, 16,910 ha is forest, and 1,094.5 ha

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consists of bushes and shrubs. On average, most farmers own approximately 0.44 hectares of land. Renting land and livestock production are common agricultural practices in Woreda (Admasu et al., 2011).

Rain-fed cultivation, which accounts for 47% of the total land use, is the predominant form of cultivation in southern Tigray. The topographic steepness, rainfall variability, and dominance of rain-fed farming are the characteristics of Woredas, which make the region prone to soil erosion and land degradation (Zenebe et al., 2015).

With the help of Woreda and Tabia agricultural experts, this study was conducted in three "Tabias," i.e., Sesat and Atsela Tabias from Emba Alajie and Mekhan Tabia from Endamehoni Woredas. Woredas and Tabias were then chosen specifically because of their accessibility, prior involvement in SWC activities, and, more importantly, the availability of wheat-producing farmer households.

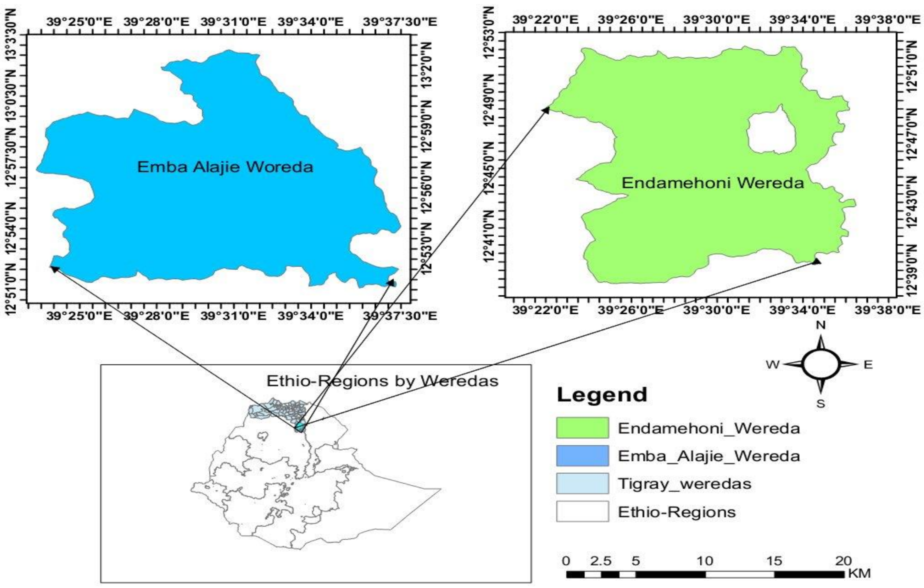

Figure 1. Location map of the study area

Sampling procedures and data collection

A multistage sampling approach was employed to choose Woredas, Tabias, and specific farmer household heads for the research. The process involved three stages. In the first stage, two Woredas, Emba Alajie and Endamehoni, were purposively selected from the SWC program intervention area and the availability of wheat farmer households in the plateaus of the southern Zone of the Tigray Regional State. SWC practice interventions were highly implemented in the Southern Zone of Tigray, specifically in those selected highland Woredas, while the adoption rate was low and not fully implemented in all rainfed croplands. In the second stage, three Tabias were purposively chosen on the basis of the criterion that these Tabias are better wheat producers in the selected woredas. Consequently, to compare farmers' wheat productivity and income among adopters and nonadopters of SWC measures, we selected those Woredas and Tabias purposively. In the third stage, wheat farmer household heads were randomly chosen from each Tabia and categorized into two groups: those who practiced SWC measures (treated group) and those who did not practice SWC measures (control group). In total, data from 335 wheat farmer household heads were sampled, with 189 wheat farmer household heads having adopted at least one SWC measure and 146 wheat farmer household heads not having adopted any SWC measures. These wheat farmer household heads were selected through a proportionate probability sampling technique in which farmer household heads were selected with a probability directly proportional to the particular measure of the population size (Table 1). This sampling technique is vital in farming surveys of farmer household heads when the units, such as tuna and adoption status, vary considerably in size, and that size is associated with the features being measured.

To gather the survey data, a structured questionnaire was developed and pretested before the actual survey. Wheat farmer household heads who adopted SWC and those who did not adopt SWC were selected for interviews via a structured questionnaire. This study focused on the drivers affecting the adoption of SWC practices at the wheat farmer household level. Data were collected on the socioeconomic status, institutional, and plot characteristics of the wheat farmers' household heads. Moreover, interviews were carried out with agricultural extension officers to identify targeted areas. The study also incorporated secondary data from both published and unpublished sources.

To analyse the drivers affecting the adoption of SWC practices, wheat farmer heads who either adopted or did not adopt SWC practices were interviewed. However, the study collected data from 350 randomly selected wheat farmer household heads to account for incomplete surveys or missing data. After inaccurate or incomplete responses were removed, the final sample consisted of 335 wheat farmer household heads, i.e., 189 adopted SWC and 146 nonadopted SWC. Sixty-one adopters and 47 nonadopters from Sesat, 60 adopters and 49 nonadopters from Atsela, and 68 adopters and 50 nonadopters from Mekhan Tabias were selected for structured questionnaire interviews (Table 1).

Table 1: Sampled woredas, tabias, and number of farmer household heads (FHHHs)

Woredas	Tabias	Total number of FHHHs	Adopters	Nonadopters	Total sample
Emba Alajie	Sesat	1709	61	47	108
	Atsela	1832	60	49	109
Endamehoni	Mekhan	2163	68	50	118
Total household heads		5704	189	146	335

Source: Woreda administration office documentation, 2022.

Data analysis techniques

The collected data were analysed via a combination of descriptive and inferential statistical methods with STATA version 14 software. Descriptive statistics, including means, frequencies, percentages, and standard deviations, were used to summarize the data. Inferential statistics, such as t tests and binary probit regression models, were employed to examine the relationships between variables. Additionally, the ESR model was applied to estimate the consistent impact of SWC practices on the livelihoods of smallholder household farmers, with a specific focus on annual wheat productivity and income. The study further compared the effects of SWC adoption on wheat productivity and farmers' household income in the study areas.

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Econometric modelling framework

Estimation with the endogenous switching regression (ESR) model

To accurately evaluate the effects of SWC practices on crop productivity and farm incomes, it is crucial to consider both visible and hidden characteristics of farmers who implement SWC measures and those who do not. Methods for impact evaluation that rely on nonexperimental data, specifically data not randomly assigned, are often unable to accurately capture these key characteristics, which in turn affect both the adoption and the outcomes. Instrumental variables can resolve unobservable differences among individuals, but they depend on the premise that any variation in outcome variables stems from the treatment itself (Ahmed et al., 2017; Geffersa et al., 2022; Shiferaw et al., 2014). Conversely, relying on regression models to evaluate the effect of SWC practices by combining data from adopters and nonadopters of SWC can be misleading since it may imply similar outcomes for both groups (Ahmed et al., 2017; Assefa et al., 2021; Ketema et al., 2021). A more effective way to overcome these limitations is the ESR model, which is frequently utilized to assess the effects of such technologies (Abdulai & Huffman, 2014; Ahmed et al., 2017; Baiyegunhi et al., 2022; Gebre et al., 2021; Jaleta et al., 2018; Marenya et al., 2020; Mengistu et al., 2018; Merga et al., 2023; Shiferaw et al., 2014). This research uses a parametric ESR model to minimize selection bias and achieve consistent outcomes by accounting for both observed and unobserved factors affecting adoption choices and outcome measures.

Farmer household heads decide whether to adopt or reject SWC practices on the basis of drivers such as socioeconomic assets, access to institutional services, and physical barriers. A rational farmer is more likely to adopt SWC practices if the expected utility from adoption (Z1) exceeds the utility from not adopting (Z0). The net utility gain from adopting SWC practices (Z* =Z1-Z0) can be modelled as a function of observable covariates (X) in a latent model in equation 1. Specifically, individual farmer i will adopt SWC measures on their land if the expected utility from adoption (YiA) is greater than that from nonadoption (YiN), meaning that YiA-YiN>0.

$$Zi = \beta Xi + vi \; where \; Zi = \begin{cases} 1 \; if \; Zi > 0 \\ 0 \; if \; Zi < 0 \end{cases} \qquad (1)$$

In this model, Zi is a latent variable representing the unobservable factors influencing a farmer’s decision to adopt SWC measures. It is determined by the observed households' socioeconomic, institutional, and plot characteristics (Xi), along with a random error term (νi) assumed to follow a normal distribution. The observed variable Zi is binary, where it equals 1 if the household adopts SWC measures and 0 if the household does not. The parameter vector β is estimated to capture the relationships among these variables. The implementation of SWC measures is expected to influence various farmer household-level outcomes, including annual wheat productivity and income. Specifically, the annual wheat productivity and income (outcome variables) are modelled as linear functions of a vector of exogenous variables (βi) and the endogenous decision to adopt SWC practices (Zi), as shown in the following equation:

$$Yi = X'\beta i + \delta Zi + \varepsilon i \qquad (2)$$

In this context, Yi represents outcome variables such as annual wheat productivity and income, whereas Zi is defined as previously described. The parameters β and δ need to be estimated, and εi is the error term. However, household farmers may self-select into adopting SWC practices rather than being randomly assigned. As a result, using ordinary least squares (OLS) regression to estimate equation (1) could lead to biased estimates. To address this bias, the ESR model is used, as it provides unbiased and consistent estimates. This is the reason why we used an ESR model rather than other models because this model is particularly effective in accounting for both observed and unobserved characteristics of farmer household heads or units. The ESR model also addresses the endogeneity of SWC adoption by addressing potential biases from both observable and unobservable factors (Lokshin & Sajaia, 2004).

The regression equation used to assess the impact of SWC practices on annual wheat productivity and income is based on an endogenous switching regime model. This model consists of two stages: the first stage involves the decision to adopt SWC practices (selection equation), whereas the second stage estimates the outcomes for both adopters and nonadopters (outcome equations). The outcomes are modelled separately for each group, adopters (denoted as 1) and nonadopters (denoted as 0), across two distinct regimes described as follows:

$$Regime\ 1: YiA = X'\beta iA + \varepsilon Ai\ if\ Zi = 1 \qquad (Adopters) \qquad (3)$$

$$Regime\ 2: YiN = X'\beta iN + \varepsilon Ni\ if\ Zi = 0 \qquad (Non-adopters) \qquad (4)$$

In this model, Yi represents the outcome variables, specifically net annual wheat yield and net annual wheat income for smallholder farmer i, for each regime, in which 1 denotes adopters of SWC measures and 0 denotes nonadopters. X^' is a vector of socioeconomic, institutional, and plot characteristics of the farmer household heads that influence the outcome variables. βiA and βiN are vectors of parameters to be estima ted, and εAi and εNi are the error terms associated with the outcome variables. In the estimation of the ESR model, the error terms v, εA, and εN (in equations (1), (3), and (4)) are assumed to follow a trivariate normal distribution with a mean vector of zero and a covariance matrix of the following form:

$$\mathrm{Cov}\ (\varepsilon A, \varepsilon N, v) \begin{pmatrix} \sigma^2 A & \sigma AN & \sigma Av \\ \sigma AN & \sigma^2 N & \sigma Nv \\ \sigma Av & \sigma Nv & \sigma^2 v \end{pmatrix} \qquad (5)$$

In this model, the variances of the outcome functions and the selection equation (1) are represented as follows: $var(\varepsilon A) = \sigma 2A$, $var(\varepsilon N) = \sigma 2N$, and $var(v) = \sigma 2v$. These correspond to the variances of the outcome equations for adopters (3) and nonadopters (4) and the selection equation (1), respectively. If YA and YN are not observed together, determining the covariance between εA and εN becomes challenging. The covariances between the error terms are given by $cov(\varepsilon A, \varepsilon N) = \sigma AN$, $cov(\varepsilon A, v) = \sigma Av$, and $cov(\varepsilon N, v) = \sigma Nv$, which represent the relationships between εAi, εNi, and vi. Additionally, the variance of the selection equation ($\sigma 2v$) is assumed to be equal to 1, as the coefficients (β) can be estimated only up to a scale factor. Overall, the estimated values of εA and εN, given the sample selection, are nonzero because the error term in equation (1) is correlated with the error terms of the outcome equations (3) and (4):

$$E(\varepsilon Ai|Zi = 1) = \sigma Av\ \frac{(\varphi(\beta Xi))}{(\Phi(\beta Xi)}\ = \sigma Av\lambda Ai \qquad (6)$$

$$E(\varepsilon Ni|Zi = 0) = \sigma Nv \frac{(\varphi(\beta Xi))}{(1 - \Phi(\beta Xi))} = \sigma Nv\lambda Ni \quad (7)$$

In this model, φ and Φ represent the standard normal probability density function (PDF) and cumulative density function (CDF), respectively. The ratios of φ and Φ, i.e., λA $== \frac{(\varphi(\beta Xi))}{(\Phi(\beta Xi))}$ $and\ \lambda N = \frac{(\varphi(\beta Xi))}{(1-\Phi(\beta Xi))}$, are the inverse Mills ratio λ (IMR), which is computed from the first-stage regression equation (1). The variables in the second-stage regression equation account for both observed and unobserved heterogeneity in the ESR estimation process (Jaleta et al., 2018). In addition, the IMR included in equations (3) and (4) corrects for selection biases caused by unobservable factors (Ahmed et al., 2017; Shiferaw et al., 2014). Thus, we have:

$$YiA = X'\beta iA + \sigma Av\lambda Ai + \delta Ai\ if\ Zi = 1 \qquad (Adopters) \quad (8)$$

$$YiN = X'\beta iN + \sigma Nv\lambda Ni + \delta Ni\ if\ Zi = 0 \qquad (Non-adopters) \quad (9)$$

In this model, the error terms δAi and δNi have conditional means of zero. To obtain consistent estimates, the full information maximum likelihood (FIML) method was applied (Greene, 2003; Lokshin & Sajaia, 2004). For appropriate identification of the endogenous selection rule, it is necessary to include at least one variable in the treatment equation that does not appear in the outcome equation. This variable serves as an exclusion restriction (criterion), which is crucial for fully estimating the model. As noted by Ahmed et al. (2017) and Shiferaw et al. (2014), ESR models rely on a strong exclusion restriction, which can be sensitive to the choice of instrumental variables. In this study, the estimation of the selection equation (1) includes two potential instruments. The first valid instrument is related to the question ‘’Is the adoption of SWC measures considered difficult due to turning Oxen?’’. To answer this question, we created a dummy variable, “difficulty turning Oxen,” which takes a value of 1 if farmers reject the adoption of SWC measures and 0 otherwise. This instrument is assumed to be significantly associated with the adoption of SWC practices. Farmer household heads who perceive difficulty turning oxen are more likely to disadopt SWC measures. This perception may lead to the rejection of SWC adoption, as farmers fear the difficulty of turning oxen when implementing practices on their croplands. However, the perception of difficulty in turning oxen is not expected to directly affect outcome variables such as annual wheat productivity and wheat income since it only indirectly influences these outcomes through the adoption of SWC practices.

The second potential instrument is the suitability of cropland for adopting SWC measures by farmer household heads. Similar to the first instrument, this is based on the question “Is your cropland suitable for practicing SWC measures?” From this, we created a dummy variable, “Cropland suitability”, which takes a value of 1 if the farmer household head responds that their cropland is suitable for SWC adoption and 0 otherwise. This variable reflects the farmer household heads’ willingness and desire to adopt SWC practices, indicating their readiness to implement these measures based on the perceived suitability of their land.

To assess the validity of the instrumental variables, we performed a probit model for equation (1) and OLS regressions for the outcome equations (3 and 4) separately. We then tested which of these variables were significantly effective in each equation. The results are presented in Appendix Table 10. The positive coefficients for the variables “Difficulty in turning Oxen” and “Cropland suitability” support the assumption that farmer household heads who perceive difficulty turning oxen and those who own cropland suitable for SWC adoption are less or more likely to adopt SWC measures. These instruments were found to significantly influence SWC adoption but had no direct effect on the outcome variables, such as annual wheat productivity and net wheat income.

On the basis of the contexts outlined above, the average treatment effect on the treated (ATT) can be calculated by comparing the expected outcomes of adopters in both actual and counterfactual scenarios. Similarly, the average treatment effect on the untreated (ATU) scenario is determined by comparing the expected outcomes of nonadopters in these two scenarios. Several studies, including those noted by Abdulai & Huffman (2014), Jaleta et al. (2018), and Shiferaw et al. (2014), provide the expected values for the mean outcomes of both adopters and nonadopters of SWC measures in both the actual and counterfactual scenarios. These expected values are expressed as follows:

Adopters who have implemented SWC measures (actual)

$$E\left[D1i \,\middle|\, X, I = 1\right] = X1\beta iA + \sigma Av\lambda 1i \tag{10}$$

Nonadopters who have not implemented SWC measures (actual)

$$E\left[D0i \,\middle|\, X, I = 0\right] = X0\beta iN + \sigma Nv\lambda 0i \tag{11}$$

If adopters had not implemented SWC measures (counterfactual)

$$E\left[D0i \,\middle|\, X, I = 1\right] = X1\beta iN + \sigma Nv\lambda 1i \tag{12}$$

If nonadopters had implemented SWC measures (counterfactual)

$$E\left[D1i \,\middle|\, X, I = 0\right] = X0\beta iA + \sigma Av\lambda 0i \tag{13}$$

Equation (10) calculates the observed outcome (a) for adopters of SWC measures, and equation (11) calculates the observed outcome (b) for nonadopters. The expected outcome (c) in equation (12) represents the counterfactual for the observed outcome (a) in equation (10). These counterfactuals express what would have happened had the farmers decided to adopt SWC measures. Similarly, Equation (13) is a counterfactual outcome (d) for the observed outcome (b) in Equation (11). This represents the scenario in which farmers decide to adopt SWC measures. Using the expected outcomes (equations 10 to 13), we drive unbiased treatment effects of the average treatment effect on the treated (ATT, which is the difference between equations 10 and 12 that is a-c), and the average treatment effect on the untreated (ATU, which is the difference between equations 13 and 11 that is d-b).

Thus, the ATT for adopters is determined by the difference between (10) and (12):

$$\begin{aligned} ATT = {} & E\left[D1i \,\middle|\, X, I = 1,\right] - E\left[D0i \,\middle|\, X, I = 1,\right] \\ & = (\beta iA - \beta iN)Xi1 + (\sigma Av - \sigma Nv)\lambda 1i \end{aligned} \tag{14}$$

Additionally, the ATU for nonadopters is determined by the difference between (13) and (11):

$$\begin{aligned} TU = {} & E\left[D1i \,\middle|\, X, I = 0,\right] - E\left[D0i \,\middle|\, X, I = 0,\right] \\ & = (\beta iA - \beta iN)Xi0 + (\sigma Av - \sigma Nv)\lambda 0i \end{aligned} \tag{15}$$

Addressing other potential endogeneity issues

The empirical specification for estimating the selection equation in the first stage of the ESR model, using probit estimation, includes several factors correlated with the adoption of SWC practices. These factors encompass personal characteristics of the household head (age and education), economic factors (annual income, livestock units, nonfarm activities, crop sharing, and rented land), institutional factors (extension services, number of contacts, received credit, tenure security, and market information), physical characteristics of the cropland (plot distance, plot area, and land suitability), and psychological perceptions (difficulty in turning oxen and collective action).

However, the adoption of SWC practices may be influenced by access to nonfarm economic activities, which creates potential endogeneity in the variable "access to nonfarm economic activities" when modelling the choice to adopt SWC measures. This endogeneity could result in biased estimates. Following Wooldridge (2015), the study addresses this issue via a two-stage control function approach. In the first stage, the model (probit) separately estimates the relationship between nonfarm economic activities and the adoption of SWC practices, using the same independent variables plus an instrument. Here, the instrument "access to nonfarm economic activity" was found to significantly affect participation in nonfarm economic activities (X^2 (1) = 2.413, p value = 0.000) but had no direct effect on the decision to adopt SWC practices (X^2 (1) = -0.088, p value = 0.647). The results are presented in Appendix Table 9. In the second stage, a probit model is used, where the variable "engagement in nonfarm economic activities" and its generalized residuals predicted from the first stage are included in the selection equation. Importantly, the instrument "access to nonfarm economic activities" is not correlated with other instruments used in the analysis, such as the difficulty in turning Oxen (Pearson's correlation = 0.134, t = 5.645, p value = 0.104) or land suitability (Pearson's correlation = -0.082, t = 2.763, p value = 0.135).

Results and discussion

Descriptive statistics of the wheat farmers

Before conducting the impact assessment, it is important to outline the descriptive statistics of the socioeconomic, institutional, and plot characteristics of the farmer household heads, as presented in Table 2. Based on the results of the study shown in Table 2, approximately 56% of the wheat farmer household heads adopted SWC practices as a strategy to curb factor-driven land degradation and increase wheat yield.

Table 2: Variable names, descriptions, units, and statistics for the variables included in this study

VARIABLES	DESCRIPTIONS	MEAN	STD. DEV.
Net Production	Total annual wheat yield – other consumptions (kg/ha/y)	228.06	67.82
Net Income	Total annual wheat income – total cost (ETB)	17638.51	5870.69
Adoption	1 if farmers practiced bunds, 0 otherwise	0.56	0.50
Sex	1 if male-headed households, 0 otherwise	0.67	0.47
Age	The age of household heads (years)	45.22	7.86
Education	Number of years of schooling of Household heads	2.95	3.56
Fsize	Household heads' family size in number	6.38	1.61
Tincome	Total annual income of household heads (ETB)	27744.05	4800.23

Asset	Total values of assets owned by household heads (ETB)	29159.02	5912.76
Livestock	Total livestock unit (TLU) holding by household heads	4.59	2.02
Extentions	1 if farmers got extension services, 0 otherwise	0.54	0.50
Contacts	Number of contacts of HH heads with agents (per year)	2.36	0.98
Rcredit	1 if household heads received credit, 0 otherwise	0.51	0.50
Parea	Own plot area in hectares	0.44	0.13
Pdistance	Plot distance from homestead in minutes	28.45	10.03
Rentedl	Number of rented lands in hectares	0.02	0.06
Csharing	Number of crops sharing land in hectares	0.15	0.13
Nplots	Total number of plots owned by HH heads (in number)	3.47	0.93
Tenure	1 if farmers feel secure in having land tenure, 0 otherwise	0.51	0.50
Difftotox	1 if SWC is difficult in turning Oxen, 0 otherwise	0.52	0.50
Non-Farm	1 if farmers are involved in nonfarm activity, 0 otherwise	0.31	0.46
Landsuitability	1 if croplands are suitable for SWC construction, 0 otherwise	0.46	0.50
Market	1 if farmers got access to market information, 0 otherwise	0.59	0.49
Membership	1 if farmers had membership with cooperatives, 0 otherwise	0 .44	0.48
Coaction	1 if farmers had collective action to control erosion, 0 otherwise	0.53	0.50
Perception	1 if farmers had perceived soil erosion on their plot, 0 otherwise	0.75	0.44
Slope	1 if farmers owned a flat slope of a plot, 0 if a steep slope	0.46	0.50
Off-Farm	1 if farmers are involved in off-farm activity, 0 otherwise	0.73	0.45
Fertilizer	1 if farmers used fertilizer, 0 otherwise	0.47	0.50

Household Demographics: The results of the descriptive statistics show that approximately 67% of the farmer households were male-headed. The average age and years of education of the farmer household heads were 45 years and 3 years, respectively. The results further show that, on average, the farmer household heads consist of 6 family members.

Institutional Factors: According to the survey results, 54% of the wheat farmer household heads frequently contacted extension agents or officers twice per year. The survey further revealed that approximately 51% and 44% of the respondents had secured land tenure and were members of farmers' cooperatives, respectively. Moreover, approximately 51% of the wheat producer household heads had reliable access to credit, which significantly contributed to their motivation to adopt SWC practices. On average, approximately 59% of the wheat-producing household heads had access to market information, whereas adopters of SWC practices had significantly greater access to market information than nonadopters did (Tables 2 and 4).

Economic factors: The statistical results revealed that the total average annual household income of farmer household heads was 27,744 Ethiopian birrs (ETB), with total average assets of 29,159 ETB. As shown in Table 4, adopter households had higher total income and asset levels than nonadopters did. Compared with nonadopters, those adopting

SWC practices had significantly higher total annual income (29936 ETB) and assets (30134 ETB).

Furthermore, farmer household heads own an average of 0.44 hectares of land and 4.59 Tropical Livestock Units (TLUs). Compared with adopters, nonadopters of SWC practices held more livestock (4.81 TLU). On average, approximately 47% of farmer household heads used fertilizer to improve soil fertility and increase wheat yield.

Surprisingly, the survey results revealed that approximately 73% of farmer household heads were involved in nonfarm economic activities. Additionally, Table 4 shows that a significant number of farmer household heads who had not adopted SWC practices were involved in income-generating activities outside farming. Nonadopter household heads also held a greater number of plots than did adopters of SWC practices. This may prevent them from adopting SWC measures, as they have alternative croplands to shift to when one becomes degraded. In addition, having more plots may be more difficult to manage effectively.

Physical (plot) characteristics: The results of the survey revealed that the average walking distance from home to plots was 28.45 minutes, and the average plot size was 0.44 hectares. The plot distance was significantly greater for nonadopters, with a mean travel time of 32.50 minutes, than for adopters, with a mean travel time of 25.24 minutes. Approximately 46% of the land owned by wheat-producing household heads was flat, which is less than the proportion characterized by steep slopes. Among the wheat-producing households, 51% of the nonadopter plots and 43% of the adopter plots were flat, indicating that the cropland of SWC practice adopters was more likely to be located on a steep slope.

Perception: On average, approximately 75% of farmer household heads perceived soil erosion on their plots. Approximately 75% of nonadopters and 74% of adopters reported observing soil erosion on their croplands. Moreover, a significant number of nonadopter farmer household heads reported that their land was not suitable for implementing SWC measures because of the difficulty of turning oxen. Approximately 54% and 68% of nonadopters reported that their land was not suitable for adopting SWC practices and said that the measures made it difficult to turn Oxen. In addition, the level of collective action to control soil erosion was greater among adopters than nonadopters of SWC practices.

Overall, adopters of SWC practices tended to be more educated, had better access to extension services and credit, and possessed higher income and asset levels. However, nonadopters had larger land holdings, more livestock, lands located farther from the homestead, and greater access to fertilizer.

Farmers' perceptions of soil fertility and depth

As shown in Table 3, conservation interventions had a positive effect on soil fertility and depth. Among the households that adopted SWC practices, 54.55% perceived a medium level of soil fertility, whereas 27.81% perceived a high level. In contrast, most nonadopters (49.32%) reported low soil fertility in their plots. Additionally, 68.98% of the SWC adopters experienced an increase in soil depth due to conservation measures. On the other hand, 68.51% of nonadopters reported a decrease in soil depth, primarily due to soil erosion. Overall, the effects of SWC on soil fertility and depth were more favourable than those on plots without conservation practices. The results of the chi-square test confirmed a significant relationship between SWC adoption and soil fertility indicators, with a 1% level of significance, indicating that SWC significantly improved both soil fertility and depth trends, resulting in increased wheat yield. This result is consistent with that of Ren et al. (2024), who reported that crop yield is significantly correlated with increased soil fertility indicators attributed to long-term conservation tillage.

The results of the net wheat productivity and its annual income for adopters and nonadopters are described in Table 4. The average net wheat productivity for SWC adopters of SWC practices is 245.19 kg/ha/year, whereas it is 206.42 kg/ha/year for nonadopters, indicating a positive correlation. Adopters also earned, on average, 19373.69 more ETB annually from wheat production than nonadopters did. This notable difference in annual crop productivity and income between adopters and nonadopters is likely attributed to improvements in soil fertility and a reduction in soil erosion resulting from SWC interventions. Consistent with this study, Tilahun & Gizaw (2021) reported that, compared with nonconserved land, SWC practices effectively reduce runoff, soil loss, and slope gradient while improving soil moisture and crop productivity.

Table 3: Household perceptions of the impact indicators of SWC practices

Variables	Perceptions	Nonadopters		x2-value	Adopters		Total sample	
		N	Percentage		N	Percentage	N	Percentage
Soil fertility	High	18	12.16		52	27.81	70	20.90
	Medium	57	38.51	40.35***	102	54.55	159	47.46
	Low	73	49.32		33	17.65	106	31.64
Soil depth trend during the last 5-25 years	Increasing	15	10.14		129	68.98	144	42.99
	Decreasing	94	63.51	123.20***	29	15.51	123	36.72
	No change	39	26.35		29	15.51	68	20.30

*Note: *** significant at the 0.01 level.*

In line with this result, households engaged in SWC practices had a higher annual crop income of 33,903 birr than nonparticipants did, 33,808.40 birr (Bati & Esmael, 2023). Overall, descriptive statistics suggest that, compared with nonadopters, farmers who adopted SWC measures experienced greater wheat yields and higher net income. However, it is difficult to conclude that SWC adoption alone leads to increased wheat yield and income at this stage. Therefore, a thorough impact assessment is necessary to determine whether the observed enhancements in yield and income are truly attributable to SWC practices while accounting for both observable and unobservable factors that influence adoption decisions and outcomes. To fully assess the impact of SWC on the outcome variables, it is important to control for both observed and unobserved factors that may influence SWC adoption decisions and the resulting outcomes. In this case, given potential selection bias, we used the difficulty of turning Oxen and land suitability as instruments to identify the causal impact of adoption on outcomes, i.e., wheat productivity and income.

Estimation of factors influencing the adoption decisions of SWC measures

As a result of the first-stage ESR binary probit estimation presented in Table 5, our probit model fits the data reasonably well (Wald chi-square (X^2) = 126.29, p = 0.000). In addition to the model fitness check, the outlier and multicollinearity tests among explanatory variables using variance inflation factors (VIFs) were performed. In this case, the tolerance values (1/VIF) and VIFs of each explanatory variable were close to 1, indicating that there was no significant correlation between the explanatory variables in this study, and the mean value of the VIF was 1.24 (Appendix Table 11). The probit model results showed that household personal characteristics and socioeconomic, institutional, and plot characteristics significantly influenced SWC adoption decisions. The binary probit model revealed that a total of 26 variables were considered in the econometric model, of which 17 variables were found to statistically significantly influence the adoption of SWC practices at the 1%, 5% and 10% probability levels. Farmers in the reference category have not implemented any type of conservation measure on their farm plots.

The age of farmers' household heads was positively and significantly associated with adopting SWC measures at the 1% probability level. Thus, older farmers had a greater probability of adopting SWC measures, indicating that older farmer household heads may be more conventional and have more experience than younger farmers. In contrast to these findings, Asfaw & Neka (2017), Dessie et al. (2023), and Janeth et al. (2019) reported an inverse relationship between age and SWC adoption, implying that SWC adoption decreased as age increased. The adoption of SWC measures increased with the increased number of years of schooling of household heads. Households with better formal education have a better perception of the benefits of SWC measures and, at the same time, impediments to adopting SWC practices (Asfaw & Neka, 2017; Bassa & Senapathy, 2022; Belachew et al., 2020; Dessie et al., 2023; Leta & Megersa, 2021; Masha & Bojago, 2023; Meseret & Amsalu, 2017; Sileshi et al., 2019). This result implies that households with a better level of education have a better understanding of the merits of SWC measures and, at the same time, the challenges of adopting SWC measures. Thus, farmer household heads with better education could be more aware of and adopt SWC.

The number of contacts with development agents, credit access, and tenure security were positively and significantly associated with the adoption of SWC practices. Farmer household heads with a greater number of contacts were more likely to be proxies for extension exposures and received more information about SWC adoption and its benefits, as well as costs. The positive coefficients suggest that for each additional contact with extension agents, the likelihood of SWC adoption increased by 53%. In line with this finding, other studies stated that farmers with a greater number of contacts with extension agents had a greater probability of adopting SWC practices (Ejegue et al., 2021; Sileshi et al., 2019; Tesfayohannes et al., 2022; Wordofa et al., 2020). Farmer household heads with better access to credit can better facilitate adoption by minimizing liquidity limitations. This finding is consistent with that of Debie (2021) and Sileshi et al. (2019), who reported a positive impact of SWC adoption. In contrast, households receive credit for purposes other than investing in SWC adoption (Belachew et al., 2020). Furthermore, farmer household heads held land certificates, which ensured a sense of ownership and could increase long-term investment in SWC adoption. Consistent with this result, Betela & Wolka (2021), Debie (2021), and Leta & Megersa (2021) reported a positive association.

Table 4: Summary statistics of the outcome and explanatory variables of adopters and nonadopters of SWC practices

VARIABLES	NONADOPTERS	ADOPTERS	DIFFERENCE
Net annual wheat yield (kg/ha/y)	206.42	245.19	38.77***
Net annual wheat income (ETB)	15446.08	19373.69	3927.61***
Sex of household head	0.66	0.68	0.03
Age of household head	44.78	45.57	0.78
Education level of household heads	2.34	3.44	1.10**
Household heads' family size	6.43	6.34	-0.10
Total income of household heads	24973.77	29936.58	4962.81***
Total value of assets of household heads	27925.93	30134.94	2209.01***
Total number of livestock units	4.81	4.41	-0.39*
Extension service	0.45	0.61	0.17***
Number of contacts	1.92	2.72	0.80***
Received credit	0.48	0.52	0.04
Plot area	0.45	0.43	-0.02
Plot distance	32.5	25.24	-7.26***
Rented land	0.02	0.03	0.01
Crop sharing	0.14	0.15	0.01
Total number of plots	3.59	3.37	-0.22**
Tenure security	0.38	0.61	0.23***
Nonfarm activity	0.39	0.25	0.14***
Market information	0.52	0.65	0.13**
Membership with cooperatives	0.40	0.47	0.07
Collective action	0.39	0.65	0.26***
Perception of soil erosion	0.75	0.74	-0.007
Slope of plots	0.51	0.43	-0.08
Off-farm activities	0.72	0.73	0.02
Use of fertilizer	0.51	0.44	-0.075
Difficulty in turning Oxen	0.68	0.39	0.30***
Land suitability	0.54	0.39	0.15***
Access to nonfarm	0.60	0.58	0.024
Number of observations	146	189	

Note: ***, **, and * indicate significance at the $p < 0.01$, 0.05, and 0.1 levels, respectively.

However, there was a negative and significant association of the total number of livestock units, large plot area, distance from home, and crop sharing with the adoption of SWC measures. This implies that farmers who hold a large number of livestock, plot and own plots far from home, and farm for crop sharing are less likely to adopt SWC measures. Farmer household heads holding large livestock reflect their economic strength and access to manure rather than SWC adoption for improving soil fertility. In line with this finding, Sileshi et al. (2019) reported a negative and significant association. Lands far from homesteads may be difficult to manage easily, which results in a lower likelihood of SWC adoption. Other studies, such as Asfaw & Neka (2017), Asfew et al. (2023), Wordofa et al. (2020), and Yifru & Miheretu (2022), also reported a significant negative association.

Table 5: Probit estimation of determinants of adoption of SWC measures

VARIABLES	COEFFICIENTS	MARGINAL EFFECTS
Intercept	-7.126(1.384) ***	
Sex	0.247(0.220)	0.097(0.087)
Age	0.058(0.017) ***	0.023(0.007) ***
Education	0.127(0.038) ***	0.050(0.015) ***
Family size	0.022(0.062)	0.009(0.024)
Annual income	0.0002(0.00003) ***	0.00007(0.00001) ***
Total assets	-0.00002(0.00002)	-7.75E-06(0.00001)
Total livestock unit	-0.093(0.051) *	-0.036(0.020) *
Extension service	0.344(0.193) *	0.134(0.075) *
Number of contacts	0.532(0.119) ***	0.208(0.046) ***
Received credit	0.605(0.171) ***	0.234(0.065) ***
Plot area	-1.610(0.921) *	-0.630(0.359) *
Plot distance	-0.039(0.010) ***	-0.015(0.004) ***
Rented land	3.669(1.578) **	1.435(0.616) **
Crop sharing	-1.695(0.875) **	-0.663(0.344) **
Total number of plots	0.052(0.106)	0.020(0.041)
Tenure security	0.792(0.214) ***	0.302(0.077) ***
Nonfarm activity	-0.538(0.377) **	-0.211(0.146) **
Market information	0.401(0.204) **	0.157(0.080) **
Membership	0.121(0.181)	0.047(0.071)
Collective action	0.490(0.205) **	0.191(0.078) **
Perception of erosion	0.014(0.222)	0.005(0.087)
Slope of plots	-0.199(0.207)	-0.078(0.081)
Off-farm activity	0.248(0.235)	0.098(0.093)
Use of fertilizer	-0.184(0.184)	-0.072(0.072)
Land suitability	-0.580(0.204) ***	-0.225(0.077) ***
Difficulty in turning Oxen	-0.928(0.218) ***	-0.350(0.075) ***
Nonfarm residuals	0.249(0.457)	
Log likelihood	-104.180	-104.180
LR Test	126.29***	
Number of observations	335	335

*Note: ***, **, and * indicate significance at the $p < 0.001$, $p < 0.05$, and $p < 0.1$ levels, respectively. Standard errors are in parentheses.*

Farmer household heads' access to market information was positively and significantly influenced by SWC adoption decisions at $p < 0.05$. Farmer household heads with better access to market information are more likely to be notified about pricing and SWC technology adoption decisions. In addition, farmer household heads' collective action to control soil erosion was significantly affected by SWC adoption decisions, implying that group efforts to reduce soil erosion may increase the likelihood of SWC adoption. Similarly, a study by Kumar et al. (2021) reported cooperative efforts in promoting land management practices.

Instrumental variables: The instrumental variables (IVs) used in this impact evaluation of SWC practices affected adoption but did not directly affect outcome variables, i.e., wheat productivity and income. The difficulty in turning Oxen is the first IV, which reflects the hardness of plots to manoeuvre, which may disincentivize and limit SWC adoption. On the other hand, land suitability is the second IV that reflects the physical appropriateness (e.g., plot size, slope, etc.) for SWC adoption. It influences adoption decisions but not outcomes directly. Both IVs are negatively affected by SWC adoption and satisfy the IV assumption, i.e., they address selection bias or identify the causal impact of SWC adoption on wheat productivity and income (outcome variables).

Impact evaluation of SWC practices: ESR results

The results regarding the impact of the adoption of SWC practices on annual wheat productivity and net annual wheat income of nonadopters and adopters are presented in Tables 6 and 7, respectively, and the estimates generally revealed the impact of demographic, socioeconomic, institutional, and plot characteristics on wheat productivity and income for nonadopters and adopters. The results from the ESR were estimated via the FIML approach, which drives both the selection and outcome equations jointly. The first stage of the estimation of ESR regressions is designated the selection equation, whereas the second-stage estimation shows the separate outcome equations of the net annual wheat productivity and income of nonadopter and adopter farmer household heads.

In terms of signs, the estimation results of the selection equations in the probit model are similar to the estimation of the selection equations in the outcome variables. However, in terms of significance, except for the plot area and rented land variables, the ESR estimation results of the selection equation are similar to those of the probit estimation. The exclusion restriction variables, land suitability and difficulty in turning Oxen are not statistically significant for the wheat productivity and income models. For this analysis, the second stage of the FIML indicates that the estimated coefficients of the correlation ƿ between household farmers' adoption of SWC and both annual net wheat productivity and income are negative but statistically significant only for nonadopters, inferring that the hypothesis of selectivity bias in both the productivity and income models may be rejected.

This finding suggests that both observed and unobserved factors influence the decision to use SWC practices and that both net annual wheat productivity and income are affected by the adoption of SWC practices. Furthermore, the ƿNA (adoption correlation coefficients) in both the net annual wheat productivity and income outcome models have a negative sign, indicating positive selection bias and inferring that households with above-average net annual wheat productivity and income are more likely to belong to farmer household heads' adoption of SWC practices. Similarly, ƿN and ƿA have the same sign, inferring that those adopters have above-average net annual wheat productivity and income, whether they are adopters or not, but they are better off being adopters, whereas nonadopters have below-average net annual wheat productivity and income, but they are better off being nonadopters.

The study provides valuable insights into the factors influencing SWC adoption and their impact on wheat yield and farmers’ income; nonetheless, cross-sectional data obtained from 335 respondents are limited in the ability to draw causal conclusions. To address this gap, a longitudinal study is vital to gain a deeper understanding of the long-term impacts of SWC on wheat yield and farmer income.

Table 6: ESR results for adoption and the impact of adoption on wheat productivity

VARIABLES	SELECTION	NET ANNUAL WHEAT PRODUCTIVITY (KG/HA/Y)	
		NONADOPTERS	ADOPTERS
Intercept	-7.665(1.545) ***	96.418(58.740)	97.899(62.540)
Sex	0.193(0.232)	-17.416(9.074) **	2.894(8.388)
Age	0.063(0.021) ***	0.108(0.828)	-0.294(0.675)
Education	0.140(0.043) ***	-3.661(1.863) **	-0.212(1.141)
Family size	0.043(0.063)	5.810(2.590) **	-0.460(2.329)
Annual income	0.000(0.000) ***	-0.001(0.001)	-0.002(0.001) *
Total asset	-0.000(0.000)	0.005(0.001) ***	0.008(0.001) ***
Total livestock unit	-0.091(0.053) *	1.148(2.068)	-0.903(1.954)
Extension services	0.348(0.206) *	7.169(8.081)	3.293(7.751)
Number of contacts	0.573(0.120) ***	-2.312(4.958)	5.065(5.064)
Received credit	0.610(0.221) ***	7.917(8.219)	2.552(7.831)
Plot area	-1.482(0.947)	-37.197(31.735)	-5.331(33.395)
Plot distance	-0.038(0.011) ***	0.509(0.413)	-0.717(0.465)
Rented land	3.040(1.930)	-82.974(70.370)	-8.358(62.853)
Crop sharing	-1.736(0.890) **	22.889(31.586)	31.898(30.293)
Total number of plots	0.030(0.125)	-6.124(4.314)	-7.447(4.588)
Tenure security	0.837(0.221) ***	-1.207(8.347)	-4.940(8.250)
Nonfarm activity	-0.472(0.415) **	6.881(8.651)	-11.969(8.575)
Market information	0.375(0.213) *	-8.874(8.478)	-2.255(8.012)
Membership	0.149(0.213)	-14.903(8.058) *	-12.659(7.836)
Collective action	0.474(0.214) **	-5.840(8.314)	-2.528(7.962)
Perception of erosion	0.079(0.241)	1.182(9.375)	11.111(8.636)
Slope of plots	-0.126(0.213)	-5.874(8.483)	-5.324(8.00)
Off-farm activity	0.269(0.249)	-8.156(9.414)	12.793(8.797)
Use of fertilizer	-0.214(0.213)	-10.736(8.152)	29.226(7.690) ***
Land suitability	-0.492(0.232) **		
Difficulty in turning oxen	-0.877(0.227) ***		
Nonfarm residual	0.258(0.481)		
σN		3.823(0.072) ***	
pN		-0.635(0.323) **	
σA			3.875(0.052) ***
pA			-0.025(0.276)
Log likelihood	-1862.053		
Number of observations	335	146	189

*Note: ***, **, and * indicate significance at the $p < 0.01$, 0.05, and 0.1 levels, respectively. Standard errors are in parentheses.*

Factors impacting wheat productivity among nonadopters and adopters of SWC practices

The outcome equation developed from the ESR model shows that the sex of farmer household heads, education level, family size, total value of assets, and membership in farmer cooperatives significantly affect the net annual wheat productivity of nonadopters. As shown in Table 7, the sex of farmer household heads negatively and significantly influenced the wheat productivity of nonadopters of SWC practices ($p < 0.05$). This could be attributed to the limited labour availability, extension services, and agricultural inputs typically associated with female-headed households, which may tend to have lower wheat productivity than male-headed households do.

The educational level of farmer household heads was negatively associated with wheat productivity. Higher educational attainment among nonadopters may be linked to a shift in labor allocation away from wheat farming, as better-educated farmer household heads might participate in or prioritize nonfarm employment. This shift can decrease the time, attention, and labor available for wheat farming. Likewise, without the benefits of SWC practices or under conditions of degraded croplands, better knowledge may not necessarily translate into better outcomes. This finding aligns with the study conducted by Yigezu and El-Shater (2021), which reported the same findings in Morocco.

The number of family members in a farmer household head's family positively and significantly affects wheat productivity among nonadopters, likely because of the availability of family labor during key farming operations. The marginal gains in wheat productivity can increase or decrease depending on the efficiency of household labour use. However, there appears to be a negative association between farmer household head membership in cooperatives and wheat productivity. Farmers who are not members of cooperatives tend to have lower wheat productivity, possibly due to limited access to input supply chains, market supply, and extension services. Cooperative membership may offer better access to farming inputs and markets, benefits that nonadopting farmer households may not utilize entirely.

On the other hand, the total annual income, value of assets, and fertilizer use by farmer household heads are the factors that significantly influence the net annual wheat productivity of adopters. The ESR model results show that total income negatively affects the wheat productivity of farmer household heads who have adopted SWC measures. Farmer household heads with higher total income tend to have less perception of the immediate benefits of SWC practices. Those with higher income often seek to engage in nonfarming activities, which can lead to a negative association between total income and wheat productivity among SWC adopters.

However, there is a positive and significant association between the total value of assets and wheat productivity among adopters of SWC practices. Farmer household heads with greater assets tend to be more economically resilient than those with fewer assets, allowing them to invest more reliably in SWC and enhancing agronomic practices to improve soil fertility and crop productivity in their croplands. Additionally, there is a positive and significant association between fertilizer use and wheat productivity. This implies that combining fertilizer use with SWC practices improves soil fertility and water-holding capacity, leading to better wheat productivity. A one-unit increase in fertilizer use increases wheat productivity by 29%, holding other factors constant.

Factors impacting wheat income among nonadopters and adopters of SWC practices

The ESR regression model reveals disparities in the factors affecting the net annual wheat incomes of adopters and nonadopters of SWC practices. In the context of annual wheat income among nonadopters of SWC practices in the highlands of Tigray, factors such as the sex of the farmer household head, education level, total annual income, asset value, membership in farmer cooperatives, and fertilizer use have been observed to negatively and significantly impact net annual wheat income. This counterintuitive result may be attributed to several causal explanations.

Compared with female-headed farmer households, male-headed households generally have better access to extension services, information, and agricultural resources, which can lead to higher wheat income. However, without SWC practices, male-headed farmer households might be more vulnerable to environmentally related shocks, resulting in potential income losses, variability, and volatility. This finding is consistent with that of Belay et al. (2022), who reported similar explanations.

Table 7: ESR results for adoption and the impact of adoption on wheat income

VARIABLES	SELECTION	NET ANNUAL WHEAT INCOME (ETB)	
		NONADOPTERS	ADOPTERS
Intercept	-7.649(1.516) ***	8215.342(4909.757) *	8896.418(5433.944)
Sex	0.194(0.231)	-1492.155(759.772) **	54.261(695.420)
Age	0.063(0.021) ***	29.126(69.291)	-28.874(56.758)
Education	0.138(0.042) ***	-284.643(156.110) *	-14.095(119.962)
Family size	0.046(0.062)	460.192(216.706) **	-174.154(193.045)
Annual income	0.000(0.000) ***	-0.201(0.107) *	-0.177(0.100) *
Total asset	-0.000(0.000)	0.504(0.071) ***	0.681(0.056) ***
Livestock	-0.089(0.053) *	-24.651(172.848)	19.640(162.488)
Extension services	0.355(0.204) *	410.535(675.479)	415.406(646.351)
Number of contacts	0.592(0.121) ***	-196.699(407.094)	297.825(435.330)
Received credit	0.614(0.220) ***	424.269(687.298)	103..791(655.961)
Plot area	-1.439(0.939)	-3912.918(2651.203)	-737.677(2768.933)
Plot distance	-0.038(0.011) ***	55.960(34.242)	-48.258(38.724)
Rented land	2.827(1.939)	-7489.497(5878.167)	-1811.755(5206.591)
Crop sharing	-1.579(0.890) *	1118.07(2639.824)	1789.015(2512.104)
Total number of plots	0.008(0.127)	-572.166(361.848)	-689.907(382.872) *
Tenure security	0.829(0.219) ***	-481.372(694.524)	-249.577(692.364)
Nonfarm	-0.483(0.412) **	432.600(722.060)	-856.745(710.822)
Market information	0.354(0.213) *	-843.032(710.262)	-167.288(665.633)
Membership	0.145(0.211)	-1255.776(676.096) *	-957.959(650.338)
Collective action	0.471(0.212) **	-619.389(692.454)	-327.273(663.007)
Perception of erosion	0.082(0.240)	613.896(783.666)	1158.421(716.723)
Slope of plots	-.0.098(0.214)	-602.081(713.591)	-203.113(663.007)
Off-farm activity	0.258(0.246)	-644.822(790.853)	934.142(729.101)
Use of fertilizer	-0.214(0.211)	-3522.248(680.146) ***	-368.796(637.057)
Land suitability	-0.459(0.231) **		
Difficulty in turning oxen	-0.826(0.225) ***		

Nonfarm residual	0.287(0.475)		
σN		8.260(0.054) ***	
ρN		-0.750(0.335) **	
σA			8.292(0.052) ***
ρA			-0.038(0.308)
Log likelihood	-3342.805		
Number of observations	335	146	189

*Note: ***, **, and * indicate significance at the p < 0.01, 0.05, and 0.1 levels, respectively. Standard errors are in parentheses.*

The survey results revealed a negative association between the education level of nonadopter household heads and their wheat income. Although better-educated farmer household heads are more likely to understand and adopt innovative agricultural technologies and improved SWC practices, leading to higher wheat yields and income, these benefits may not be fully realized in the absence of SWC practices. Without such measures, productivity gains from education may be undermined by environmentally related challenges. Additionally, farmer household heads with higher annual income are more likely to invest in agricultural inputs and technology adoption, which can result in increased wheat income. However, in the absence of SWC practices, these farmer household heads may face greater losses during droughts or other environmental stresses, which negatively affect wheat income.

Additionally, membership in cooperatives offers farmer household heads better access to information, shared resources, and collective bargaining power. However, the advantages of cooperative membership may be reduced in the absence of SWC practices and challenged by environmental factors, ultimately lowering overall yields. Similarly, nonadopters who use fertilizers achieve better wheat productivity than those who do not, leading to increased income. However, applying fertilizer to unconserved croplands may harm ecosystem services, and the long-term benefits may be jeopardized by soil degradation, resulting in decreased income over time. In line with these findings, Tesfay (2020) reported similar observations.

However, in the context of wheat income among nonadopter farmer household heads, family size has been observed to be positively and significantly associated with wheat income. Nonadopters of SWC practices tended to have larger household sizes and could offer more family labor, which is vital for intensive farming activities. This, in turn, allows for better management of wheat farming, leading to higher wheat yields and income. This explanation is supported by Zegeye et al. (2022).

In contrast, the net annual wheat income for those who adopt SWC practices is influenced primarily by their total annual income, the value of their assets, and the total amount of cropland they manage. Farmer household heads with higher annual total income might perceive fewer direct benefits from SWC practices, assuming that their current farming practices are sufficient. This perception may lead to a negative connotation between total annual income and the income gained from wheat farming among adopters. In line with this finding, Biru et al. (2020) stated that richer households were less likely to adopt SWC practices, possibly owing to a perceived lower return on investment. Additionally, the relationship between the number of land plots and wheat income under SWC practices is negative. A greater number of plots can pose management challenges for farmer household heads, requiring more labour and resources, which may reduce wheat productivity and income. Fragmented land holdings can also hinder the adoption of SWC practices, potentially reducing overall wheat income.

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Table 8: ESR estimates of ATT and ATU of SWC adoption

Outcome variables	Mean outcome		Treatment effect	Effect (%)
	Adopters	Nonadopters		
Annual wheat productivity (kg/ha/y)	245.187(51.943)	206.275(36.560)	ATT = 38.9***	18.9%
	229.450(45.112)	182.367(36.695)	ATU = 47.1***	25.8%
Net annual income (ETB)	19373.69(4254.39)	15424.82(3652.714)	ATT = 3948.9***	25.6%
	17931.59(3645.68)	13032.57(3740.22)	ATU = 4899.0***	37.6%

*Note: ATT, average treatment effect on the treated; ATU, average treatment effect on the untreated; *** significant at the $p < 0.01$ level. Standard errors are in parentheses.*

However, the total value of household assets positively affects SWC adoption outcomes, particularly wheat income. Household heads with greater asset values are better equipped to invest in SWC and other farming practices, leading to improved soil fertility, better water-holding capacity, and higher wheat yields. Similarly, Tesfayohannes et al. (2022) reported that households with better access to resources achieved higher crop income as a result of adopting SWC practices.

The ESR model calculates the average outcomes for farm households that implemented SWC practices and determines what the outcomes would have been if these households had not participated in the program. The ATT is calculated by subtracting the outcomes that participants would have experienced without treatment from the actual outcomes for individuals who received the treatment. The model also estimates counterfactual outcomes for nonparticipants ATU, reflecting what their productivity and income would have been had they adopted SWC practices.

These projections, including the ATT and ATU, are summarized in Table 8. The results of the ESR model indicate that adopters of SWC practices experienced a significant increase in their net annual wheat productivity and income. Specifically, the ATTs for net annual wheat productivity and income are 38.912 and 3948.87, respectively. The implementation of SWC practices resulted in an 18.9% increase in the log of net annual wheat productivity and a 25.6% increase in income. Conversely, if nonadopters had adopted SWC practices, their net annual wheat productivity would have increased by 25.8%, and their income would have increased by 37.6%. The observed differences in wheat yield and farmer income may be attributed to factors influencing SWC measures in the study areas.

The results of the ESR model for the ATT and ATU concerning continuous outcome variables show that adopting SWC practices leads to increases in net annual wheat productivity (245.187 kg/ha/y for ATT and 229.450 kg/ha/y for ATU) and income (19373.69 ETB for ATT and 17931.59 ETB for ATU). Research suggests that implementing SWC practices in Ethiopia can significantly increase both the agricultural productivity of wheat and the income of farmers. Consistent with existing research in Ethiopia, Bati & Esmael (2023) and Tesfayohannes et al. (2022) reported that farmers who implemented SWC practices typically achieved greater crop yields and incomes than those who did not adopt these methods.

Conclusion and recommendations

Soil and water conservation practices are strategies that improve crop productivity and income in the Tigray highlands, northern Ethiopia. However, the effects of these practices are still uncertain because of the possibility of selection bias and the fact that adoption decisions are influenced from within. This research aims to evaluate the impact of SWC practices on wheat yield and income in northern Ethiopia via an ESR model, which takes into account the endogenous nature of adoption decisions, thereby estimating the causal influence of SWC adoption on wheat yield and income, accounting for self-selection bias. The model distinguishes between individuals who adopt SWC practices and those who do not, taking into account various factors that impact adoption choices, including socioeconomic, institutional, and plot characteristics, which could otherwise distort the findings. This research centres on cross-sectional data gathered from 335 farmer household heads through a multistage sampling procedure in southern Tigray, northern Ethiopia.

The initial phase of the ESR model revealed that several factors have a statistically significant relationship with the adoption of SWCs. The factors considered include age, educational level, total income, livestock ownership, number of interactions with development agents, access to credit, plot size, proximity of the plot to the homestead, tenure security, collective action to control erosion, and plot slope. These factors either encourage farmer household heads to adopt SWC practices or prevent them from adopting these practices. Additionally, those factors affect outcomes, i.e., wheat productivity and income.

The study's findings show that implementing SWC practices leads to a substantial increase in both annual wheat yield and household income within the research area. Specifically, farmers who adopted SWC practices experienced an average 18.9% increase in wheat yield and a 25.6% increase in income compared with those who did not adopt these practices. The model validates that the positive effects are dependent not only on observable variables such as asset values, income, fertilizer use, and the quantity of plots but also on unobservable factors that enhance the outcomes.

While the adoption of SWC practices directly impacts wheat productivity and income, drivers such as the sex of farmer household heads, education level, total income, membership in farmer cooperatives, and fertilizer use also make substantial contributions to determining the income level of nonadopters. Policies aimed at addressing these drivers can increase wheat productivity and income, even in the absence of SWC adoption. Additionally, farmer household heads with higher total annual income may not prioritize SWC adoption, potentially leading to a negative effect on wheat productivity and income among adopters. In contrast, those with more assets may be able to invest in SWC measures that improve wheat productivity and income. Therefore, addressing these factors can further increase farming productivity and income.

This study indicates that increasing the adoption of sustainable SWC practices could significantly increase agricultural productivity and income in northern Ethiopia. Policymakers should prioritize factors that facilitate the adoption of SWC practices, including offering technical training, providing financial help, and enhancing access to market information. Scaling up sustainable SWC practices could be a vital approach for enhancing food security and increasing rural incomes in the area because of their benefits in terms of wheat production and income. Policies promoting SWC adoption would notably consider the factors influencing wheat productivity and income in northern Ethiopia. More research is needed to evaluate the long-term viability of these practices, i.e., soil fertility changes, their effects on other crops, their ability to mitigate drought impacts, and their environmental outcomes, and to pinpoint further obstacles to their implementation.

Limitations of the study

This study focused on one-year wheat yield and farmer income data, which may not have sufficiently captured the long-term and collective effects of SWC measures in the highlands of northern Ethiopia. This short-term setting could limit the estimation of continued crop yield gains and economic viability. Furthermore, seasonal shocks and unobserved variances in farm management, farmers' skills, and soil fertility conditions may impact the outcomes of wheat yields and farmers' income in the study area.

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Appendices

Table 9: Addressing the potential endogeneity of the nonfarm engagement variable

VARIABLES	ADOPTIONS	NONFARM ENGAGEMENT
Intercept	-7.315(1.355) ***	-0.689(1.170)
Sex	0.194(0.215)	0.495(0.209) **
Age	0.060(0.017) ***	-0.025(0.016)
Education	0.134(0.038) ***	-0.032(0.035)
Family size	0.024(0.062)	0.012(0.058)
Annual income	0.000(0.000) ***	-0.000(0.000)
Total assets	-0.000(0.000)	-0.000(0.000)
Total livestock unit	-0.094(0.053) *	-0.020(0.047)
Extension service	0.333(0.193) *	0.368(0.196) *
Number of contacts	0.523(0.118) ***	0.004(0.102)
Received credit	0.635(0.171) ***	-0.294(0.185)
Plot area	-1.668(0.900) *	0.156(0.711)
Plot distance	-0.039(0.010) ***	0.002(0.010)
Rented land	3.204(1.525) **	1.227(1.375)
Crop sharing	-1.790(0.883) **	1.087(0.680)
Total number of plots	0.355(0.104)	0.046(0.106)
Tenure security	0.798(0.208) ***	-0.282(0.193)
Market information	0.396(0.202) **	-0.222(0.191)
Membership	0.116(0.180)	0.096(0.195)
Collective action	0.475(0.203) **	-0.024(0.187)
Perception of erosion	-0.015(0.225)	0.397(0.207) **
Slope of plots	-0.208(0.204)	0.181(0.192)
Off-farm activity	0.322(0.226)	-0.193(0.196)
Use of fertilizer	-0.217(0.182)	0.075(0.185)
Land suitability	-0.623(0.196) ***	0.207(0.187)
Difficulty in turning Oxen	-0.858(0.214) ***	-0.123(0.198)
Access to nonfarm	-0.088(0.192)	2.413(0.310) ***
Log likelihood	-105.390	-131.439
Number of observations	335	335

*Note *** p < 0.01, ** p < 0.05, * p < 0.1*

Table 10: Instrumental variables checking for endogenous switching regression (ESR)

Variables	Adoptions	Wheat productivity		Wheat income	
		Nonadopters	Adopters	Nonadopters	Adopters
Intercept	-7.13(1.38) ***	108.64(59.04) *	98.90(64.28)	10061.97(4880.11) **	9498.60(5617.79) *
Sex	0.25(0.22)	-20.32(9.07) **	3.02(8.42)	-1752.72(762.03) **	81.80(697.97)
Age	0.06(0.02) ***	-0.10(0.83)	-0.25(0.69)	4.35(69.83)	-29.47(58.08)
Education	0.13(0.04) ***	-3.75(1.84) **	-0.11(1.47)	-313.52(155.45) **	-16.07(123.60)
Family size	0.02(0.06)	6.54(2.61) ***	-0.47(2.34)	538.11(218.38) **	-182.45(194.48)
Annual income	0.00(0.00) ***	-0.00(0.00) *	-0.00(0.00) *	-0.30(0.11) ***	-0.19(0.11) *
Total assets	-0.00(0.00)	0.01(0.00) ***	0.01(0.00) ***	0.50(0.07) ***	0.68(0.56) ***
Total livestock unit	-0.09(0.05) *	2.07(2.12)	-1.00(1.97)	79.25(176.75)	21.19(164.24)
Extension service	0.34(0.19) *	2.79(8.29)	3.73(7.81)	-77.76(701.09)	415.69(652.39)
Number of contacts	0.53(0.12) ***	-3.81(4.83)	4.69(5.15)	-335.49(400.00)	238.96(445.28)
Received credit	0.61(0.17) ***	8.07(8.24)	3.09(8.00)	416.91(693.27)	92.11(674.59)
Plot area	-1.61(0.92) *	-21.67(32.46)	-5.14(33.74)	-2658.75(2776.47)	-584.41(2803.02)
Plot distance	-0.04(0.01) ***	0.54(0.40)	-0.72(0.47)	55.54(34.12)	-46.53(38.97)
Rented land	3.67(1.58) **	-103.47(72.97)	-8.46(63.71)	-10313.86(6236.26) *	-2082.65(5278.69)
Crop sharing	-1.70(0.87) **	22.22(31.64)	30.66(30.61)	1232.00(2655.98)	1818.20(2538.75)
Total number of plots	0.05(0.11)	-8.16(4.39) *	-7.63(4.65)	-802.14(372.59) **	-718.51(386.78) *
Tenure security	0.79(0.21) ***	-1.10(8.47)	-5.00(8.72)	-561.17(703.55)	-337.48(739.41)
Nonfarm activity	-0.54(0.38)	3.07(8.74)	-11.28(8.85)	92.02(734.27)	-758.86(733.91)
Market information	0.40(0.20) **	-13.01(8.60)	-2.33(7.99)	-1205.32(719.35) *	-180.21(662.22)
Membership	0.12(0.18)	-14.65(8.09) *	-12.52(7.82)	-1231.47(683.36) *	-946.91(649.43)
Collective action	0.49(0.21) **	-5.11(8.43)	-2.61(8.20)	-638.81(704.70)	-389.87(683.59)
Perception of erosion	0.01(0.22)	1.93(9.40)	10.73(8.65)	631.68(791.56)	1138.81(719.10)
Slope of plots	-0.20(0.21)	-2.75(8.57)	-5.31(7.98)	-359.28(724.46)	-200.97(660.12)
Off-farm activity	0.25(0.23)	-12.87(9.65)	13.67(8.88)	-1240.02(821.37)	1002.12(735.95)
Use of fertilizer	-0.18(0.18)	-9.50(8.11)	28.46(7.79) ***	-3460.74(680.16) ***	-398.43(647.03)
Land suitability	-0.58(0.20) ***	25.08(8.57)	-5.18(8.01)	2261.40(709.52)	-254.07(670.45)
Difficulty in turning Oxen	-0.93(0.22) ***	10.30(9.87)	2.13(8.90)	1492.04(807.07)	364.03(751.59)
Nonfarm residuals	0.25(0.46)				
No. of observations	335	146	189	146	189

*Note *** p < 0.01, ** p < 0.05, * p < 0.1*

Table 11: Multicollinearity test of explanatory variables

VARIABLES	VIF	1/VIF
Age	2.20	0.455
Education	2.11	0.474
Income	1.45	0.688
Asset	1.34	0.744
Number of plots	1.25	0.799
Number of contacts	1.23	0.816
Plot area	1.20	0.832
Rented land	1.20	0.835
Sex	1.19	0.838
Plot distance	1.18	0.847
Difficulty in turning Oxen	1.18	0.848
Off-farm	1.17	0.856
Tenure security	1.16	0.858
Nonfarm activity	1.14	0.874
Collective action	1.14	0.874
Crop sharing	1.13	0.885
Slope	1.12	0.891
Farm size	1.12	0.892
Livestock holding	1.12	0.894
Market information	1.11	0.900
Use of fertilizer	1.11	0.904
Land suitability	1.10	0.908
Membership	1.09	0.916
Perception of erosion	1.09	0.917
Received credit	1.09	0.921
Extension services	1.08	0.926
Mean VIF	1.24	