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Acronyms and abbreviations

ADLI	Agricultural Development Led Industrialization
AGP	Agricultural Growth Program
ATP	Agricultural Transformation Programs
CIAT	International Center for Tropical Agriculture
CSA	Central Statistical Agency
DA	development agents
DAP	diammonium phosphate
DAWR	Department of Agriculture and Water Resources
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus group discussion
FTC	Farmers' Training Centers
GHK	Geweke–Hajivassiliou–Keane
GO	government organization
KA	Kebele administrations
LR	likelihood ratio
MFI	micro-finance institutions
NGO	nongovernment organization
NPS	nitrogen, phosphorus, and sulfur fertilizer
OLS	Ordinary least squares regression
PA	pastoral area
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
SD	standard deviation
SOC	soil organic carbon
TLU	Tropical Livestock Unit
TV	television

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Abstract

This study aimed at identifying the factors that determine the decision to adopt and the intensity of adoption of soil organic carbon (SOC)-enhancing practices using two watershed sites in Ethiopia: Yiser (Amhara region) and Azugashube (Southern region). The study used survey data collected from 379 sample households drawn from four Kebele/village administrations at each watershed site. Multivariate and ordinary least squares regressions were used to identify the factors that determine the decision to adopt the SOC-enhancing practices and the factors that determine the extent of adoption of these practices, respectively. The study classified these various practices into three classes: soil and water conservation, agronomic, and agroforestry SOC-enhancing practices. We find that the decision to adopt soil and water conservation practices is negatively related to both the decision to adopt agronomic and to adopt agroforestry SOC-enhancing practices. On the contrary, we find that the decision to adopt agronomic and agroforestry practices is complementary. The study also identified diverse agroecological, farming system, institutional, and household characteristics that determine the decision to adopt and the intensity of adoption of the three SOC-enhancing practices. Among the different variables, the study found location as a strong determinant of the type and intensity of adoption of the SOC practices.

Photo: CIAT/Georgina Smith

1. Introduction

1.1. Background of the study

Natural resource degradation has remained the primary source of the poor performance of the agricultural sector in developing countries. Natural resource degradation coupled with the increase in adverse impacts of climate change has caused the productivity of agriculture to stagnate even in the face of increased development interventions to improve its performance. Natural resource degradation not only increases farmers' discount rates (Heath and Binswanger 1996) by reducing land productivity, but it also undermines the potential impacts of increased use of productivity-enhancing agricultural technologies. Antle and Diagana (2003) identify degradation of soils through the loss of soil organic matter as the key component of many unsustainable agricultural systems.

The ruling party in Ethiopia took political power in 1991 and declared Agricultural Development Led Industrialization (ADLI) as its main development strategy, aimed at guiding all other policies and strategies. ADLI put the agricultural sector and rural society at the center of its development agenda. In addition to large programs designed to directly enhance the production and productivity of the agricultural sector and improve the welfare of rural society, the stated primary goal of most other policies and programs was also to contribute to the development of the agricultural sector and rural society. Thus, large countrywide programs such as Poverty Reduction Strategic Paper I, Plan for Accelerated and Sustained Development to End Poverty (PASDEP), Agricultural Transformation Programs (ATP), Agricultural Growth Program (AGP), Production Safety Net programs, Food Security programs, and many other small programs and projects have been implemented over the past two and half decades. Despite all these, ADLI has remained the primary development strategy for more than two decades, but the country has not progressed into industrialization. The government has claimed that the economy has been achieving rapid (two-digit) growth for successive years in the past two decades. But it is not clear whether this growth has been achieved as a result of an increase in productivity or an increase in the size of the production area. A Central Statistical Agency (CSA) report shows that there has been continuous growth in production area. For instance, the size of the crop production area between 2000 and 2010 increased by 66.2% (CSA 2010, 2000). This indicates that only a small portion of the growth was achieved due to an increase in productivity. Thus, growth in productivity was limited. But, more importantly, no perceptible change has been observed in the structure of the sector. Not only has the agricultural sector remained predominantly subsistent and its production system traditional but natural resource degradation has also increasingly become a bottleneck to growth of the sector.

However, conversion from natural vegetation to cultivated land is a well-known cause of soil organic carbon (SOC) loss (Post and Kwon 2000) as the SOC stock in the upper soil layer is highly sensitive to land-use change (FAO 2017). Depending on the climate, soil type, and historic management of the land, soils of the world's

agroecosystems (croplands, grazing lands, rangelands) are depleted of their SOC pool by 25–75%. Depletion of SOC adversely affects agricultural production in the long run by causing climate change, but it also affects agricultural production in the short run by reducing soil productivity and lowering the efficiency of added input (Lal 2011).

Land-use change per se may not reduce SOC stocks (Manna et al. 2008; Paustian et al. 2000). Instead, land-use change in agricultural production can even build the stocks if improved management practices are adopted that enhance soil quality, including the available water-holding capacity, cation exchange capacity, soil aggregation, and susceptibility to crusting and erosion (Lal 2006). Improved tillage management and cropping systems that reduce soil disturbance, increase the amount of land cover, and efficiently use production inputs (e.g., nutrients and water) are critical aspects (Follett 2001). These improved agricultural practices ensure sustainable production in the long run by enhancing SOC and, at the same time, they improve household welfare in the short run by improving agronomic productivity (Lal 2011; Pretty et al. 2006; Ringius 1999).

In view of this, developing countries have made a lot of efforts in the past to increase farmers' adoption of improved management practices. Despite these efforts and contrary to the suggested positive relationships between biological productivity and SOC stocks, evidence generally shows that farmers in developing countries continue to use extractive practices that deplete the SOC pool, degrade soil quality, and adversely affect agronomic productivity (Lal 2006). Some argue that the interlinked forces of population pressure, poverty, and environmental degradation pose a common challenge for the effectiveness of the interventions made to reverse the deterioration of soil quality (Shiferaw and Holden 1998). Population pressure, the magnitude of poverty, and the extent of environmental degradation may limit the feasible set of technologies. These factors, in general, may limit the technologies by limiting the investment capacity of households and the responsiveness of technologies, and by raising the discount rates of long-term investments in soil improvement. Hence, this may explain the limited adoption of SOC-enhancing technologies in these countries in the short run. But, these factors do not explain the adoption of SOC-enhancing technologies in the long run if they are outcomes of inappropriate policies as argued by Heath and Binswanger (1996).

In the short run, evidence shows striking differences even among poor households in the adoption of SOC-enhancing practices (Scherr 2000). Furthermore, micro-scale research evidence suggests that other socioeconomic and biophysical characteristics explain household differences in the level of adoption of SOC-enhancing technologies. Empirical evidence suggests that the set of household-specific, community-specific, and plot-specific factors determine the adoption of these technologies. Household-specific characteristics such as age, experience, education, sex of the household head, family size, and farm size (Melesse 2018; Kankwamba and Mangisoni 2015; Laxmi and Mishra 2007); community-specific characteristics such as imperfections in financial, input, and output markets, tenure security, and institutional and policy environments (Glover et al. 2013; Jack 2011; Gledhill et al. 2011); and plot-specific characteristics such as soil types and topography (Kankwamba and Mangisoni 2015; Glover et al. 2013) determine the adoption of SOC-enhancing practices.

Photo: CIAT/Georgina Smith

Other factors such as the existing farming system can also allow only a few SOC-enhancing technologies. The grazing pattern and the dominant cropping pattern can limit the feasible SOC-enhancing technologies to a few technologies or practices. For instance, if an open and free grazing system is the norm in a community, it will be difficult for the farmers to adopt many of the soil carbon-enhancing practices on their croplands such as alley cropping, grass strips, planting of agroforestry trees on cropland, and planting of improved forage grasses and trees on the common grazing lands. Maintaining soil and water conservation structures will also be costly as these will be damaged by animals. Exclusion of forests from animals will also be costly. This situation also does not incentivize farmers to leave residues on their croplands. As a result, this will leave farmers with few alternative SOC-enhancing technologies such as fallowing, crop rotation, and tillage management. The current research aims at identifying the type of SOC-enhancing practices that are being implemented by farmers in the study areas given their circumstances and identifying the factors that determine potential variations among households in the level and extent of adoption.

The primary purpose of this study is to identify household, community, and plot-level factors that determine a household's adoption of SOC-enhancing technologies in the case of two watershed areas: Yesir and Azugashube watersheds located in the Southern and Amhara regions, respectively.

We hypothesized that several household, plot-level, ecological, farming system, and institutional variables determine the level and intensity of a household's decision to adopt SOC-enhancing practices. Household socioeconomic characteristics such as education, wealth (livestock, land, number of radios held), and family size; indicators of institutional access (markets, extension, credit, and farmers' organizations); plot characteristics such as slope, fertility, soil type, and erosion problems; and farming system indicators such as crop diversification, land fragmentation, fertility management, and fertilizer application were included in the analyses. In addition, we analyzed the effects of watershed location in determining the level and intensity of the adoption of SOC-enhancing practices.

Photo: CIAT/Georgina Smith

1.2. Objectives

The overall objective of this research is to identify the factors that influence the type, level, and extent of the adoption of SOC-enhancing practices among farmers at two watershed sites.

The specific objectives are:

1. to measure the level and extent of adoption of the different SOC-enhancing practices and
2. to identify the household- and community-specific factors that explain the level and extent of adoption of SOC-enhancing practices.

1.3. Production context and land tenure

1.3.1 The production context

The agricultural production system and the activities (e.g., deforestation, burning, plowing, grazing) determine the dynamics of soil carbon (Lal and Kimble 1997). The production system at the two study sites (Azugashube and Yesir watersheds) is characterized by a mixed crop–livestock system that is common in the highland parts of Ethiopia. In the typical mixed crop–livestock production system of the country, farmers primarily produce crops but also rear a few cattle and small ruminants (sheep and goats) as a means to supply oxen power for plowing and as a source of food and to generate income. Their crop production is characterized by small-scale *subsistence* production systems in which farmers produce a crop primarily to meet the food demand of the household. The total land size for a typical household is not only small, usually less than 1 hectare, but is also highly fragmented and scattered over different parts of the rural kebele.[1] Owing to the rapidly growing population, the average land size per household has been dwindling. Compared to the Yesir watershed site, the land size is even smaller in Azugashube watershed. In a given cropping season, a household produces different types of crops on the different plots of land. Although crop production usually contributes to increasing storage of carbon in agricultural soils (DAWR 2016), the specific production context may matter.

Farmers produce livestock as an integral part of their crop production. Their livestock production is characterized by a traditional production system with low operating costs for feed and other management activities. The major source of feed is communal grazing land. In almost all mixed crop-livestock production systems, grazing lands are communally owned and farmers use the free-grazing system. The grazing system is free and open to all communities. Farmers in the area rear livestock for many purposes: to generate additional income, generate food, and carry out crop production activities. In these areas, farming activities such as plowing, threshing, and land leveling (especially for *teff* plots) are all done using cattle, donkeys, and horse/mule draft power. In addition, cattle and equines are the primary means of transportation. Most of the crop production activities in the mixed crop–livestock production system are hardly carried out without livestock power. In sum, this situation forces every household to hold at least two oxen and one donkey/horse to carry out farming activities. Livestock in the mixed crop–livestock farming system not only generate food and income but also are necessary for farming operations. Thus, each household in the area must have some livestock. But, the total number of livestock (cattle, small ruminants, and equines) that exist in each community is larger than the number that can be carried by the pasture lands. The grazing lands are not only shrinking in size but they are also becoming degraded due to overgrazing. The communal grazing lands in almost all areas cannot carry the available number of livestock.

The common grazing system is such that, except in the rainy season when crops are in the field, animals freely roam anywhere within the areas delineated for the community. The norm is that once the crops are harvested, all crop fields are open for common and free grazing. Thus, a farmer cannot let the crop residue (straw and stack) and biomass of other plants decay as it is not possible to exclude animals from grazing what is left on the plots. Since the communal grazing lands are highly degraded by overgrazing, crop fields are important grazing areas for some period after harvesting periods. Once the farmer harvests the crop and piles it, the crop fields will usually be open for free grazing. For some crops, until the harvested crop is threshed or taken home, the croplands may be closed for animal grazing. During this period, the plot owners allow their own animals to graze on the remnant biomass. After all the farmers have threshed their crop and taken the residues home, all crop fields in the area can be opened for free grazing. Thus, part of the stack harvested with the grain will be taken away from the field to use it for other purposes and the remaining surface biomass will be fed to livestock. As a result, no surface biomass returns to the soil. Even the weeds removed from crop fields during the rainy season are also taken away from the plot in order to feed the animals.

The crop residues taken away from the plots have multiple purposes: animal feed, construction, fire energy, and others. Since the crop residues produced in a given production season are not sufficient to meet the various demands of farmers, the farmers use the straw to feed only selected animals, usually oxen and lactating cows. The remaining straw is used for other purposes such as firewood and construction. Shortage of firewood is a serious problem in most areas. Thus, straw and cattle dung are important sources of fuel. In addition,

[1] *Kebele* is the lowest administrative unit that is formed by bringing several neighboring villages together and can contain around 1,000 households.

the straw of some crops is used for construction. For instance, *teff* straw is an important construction material to make "mud-bricks." In some cases, wheat straw is also used as a replacement for making mud-bricks. Similarly, maize stalk is used for the construction of fences and walls, while wheat straw is used for making local mattresses. In sum, farmers have to allocate the straw and crop residue among competitive uses. Obviously, the straw used for fire energy and construction never returns to the soil. But, even the crop residues fed to animals are unlikely to return back to the soil as the dried dung is also used for fire.

Whether the existing large number of livestock is driven by Hardin's (1968) "The Tragedy of the Commons" or is necessitated by the farming system is an empirical question. In spite of the dwindling size of the common grazing lands as a result of conversion in land use and the absence of collective rules to limit livestock number or to improve the deteriorating grazing lands, the large livestock number seems to be driven more by "The Tragedy of the Commons" than other reasons. Setting aside the source of large livestock numbers, the existing crop and livestock production systems not only erode the carbon pool in grazing lands but also limit the feasibility of implementing many of the carbon-enhancing practices. Given the existing livelihood and farming system, implementing many SOC-enhancing practices such as mulching, agro-forestry (grass strips and planting of forage trees), alley cropping, and manuring is technically infeasible and economically costly. The open grazing system is also a problem for sustaining physical soil conservation practices such as soil bunds and *fanya juu* terraces.

Shortage of firewood is another serious problem in most rural areas, and cattle dung is used as an important source of fire energy. Households dry the dung collected from livestock pens and use it as firewood. Even the cattle dung dropped on the grazing lands and crop fields is also collected by some poor farmers and sold to people around towns as it is an important source of livelihood for some poor households. Moreover, wet cattle dung is used for smoothing house floors, walls, and threshing grounds. Thus, most portions of the biomass fed to cattle will not return to the soil. In sum, almost all the surface crop biomass produced every year is taken away from the soil and never returns to it. This means that only the underground biomass remains in the soil.

Furthermore, losses are exacerbated by changes in land use. Land conversion from natural to agricultural land use often results in loss of SOC (Lal and Kimble 1997). In this regard, owing to the rapidly growing population, demand has been increasing for cropping land. As a result, there has been a conversion of natural/pasture land and forest land into agricultural land. However, the average landholding has been declining continuously in the whole country while the total size of cultivated land has increased at the community level. These land-use changes can reduce the overall soil organic carbon pool.

Similar deteriorations of the natural resource base have occurred in forest and shrub areas. Not only has there been a conversion of forest land into farmland and pasture land, but the biomass coverage of the available community forest and shrubland has also been declining through animal grazing and deforestation. Most communal areas that had been covered with endogenous forest trees and shrubs have been converted into grazing land, cropland, and settlement places. As a result, the forest coverage around the crop–livestock-producing areas has been declining over the past decades. Although some efforts have been made to maintain, protect, and develop community forests, success has remained limited. For farmers to plant trees on their cropland, the costs of protecting the seedlings from animals during the dry season are high. Thus, farmers plant trees for the production of wood only around the residential area. But, eucalyptus tree is nearly the only tree species planted around the backyard. One good culture in both study areas is that, unlike most other areas of the country, farmers maintain a few endogenous trees such as *bisana* on their cropland. They use these trees to fix nitrogen, to produce wood, and to use as shade for animals and humans.

In general, the crop production system fails to maintain or enhance soil carbon in the cropland, grazing land, and other land uses. But, some changes have occurred in recent times that have the potential to reverse these trends. One important change is the expansion of electricity in the towns and some rural areas in the past two decades. Electrification can potentially reduce the use of straw and animal dung as a source of fire energy. For this change to impact the amount of biomass that returns to the soil, the amount of straw that will be free from this should be larger than the amount of crop residue required for other competing demands: animal feed and construction purposes. To what extent such changes have affected the amount of crop residue that is returned to the soil is not clear. Furthermore, the positive impacts of such changes could be offset by the increased exploitation of the natural resource base caused by the increasing pressure.

1.3.2 Land tenure

The constitution of the country states that all lands are the property of the state and the people. With the exception of residential compounds and cropping lands, the rest of the lands are owned by the state and the people. Farmers have the right to use and transfer the residential and cropping lands that they own. But, they have no right to sell or to use the land as collateral against any obligations. In addition, their use rights are not even secured because the land can be expropriated and redistributed by the government. Such arbitrary expropriation and redistribution by the government occurred on a massive scale twice in the past. But, expropriations and redistributions also take place at the individual level under the guise of public interest, rules, and regulations.

The literature shows that an insecure property rights regime fails to incentivize farmers to invest in long-term land improvement practices. Furthermore, the restriction on the ability to use the land as collateral tends to limit farmers' ability to invest in improving the land by limiting their access to finance. The adverse effects of insecure property rights on efficiency and long-term investments in land improvement are widely documented (Ambaye 2015; Grover and Temesgen 2006; Deininger et al. 2003). Recent evidence also suggests that such property rights in the long run discourage farmers' mobility from agriculture to other sectors and hence constrain potential agricultural transformations (Emran and Shilpi 2015a, 2015b; Giles and Mu 2014). In addition, a recent study by Ali et al. (2015), using a choice experiment, found that the preference of farmers to have larger family size declines when private ownership of land is secure and distributions are made only within the household. But, apart from the effects of the type of land ownership on the production decision of households, the land property rights regime could have considerable effects on the evolution of the socioeconomic landscape of communities.

Apart from the treatment of expropriations, the socioeconomic context of communities may matter in determining the scope of the use of rights. In addition to formal rules, local norms and local socioeconomic contexts can determine the scope of use rights: the exhaustiveness and freeness of the use rights and the ability to exclude others from using the land. As described above, the specific production context in the study areas limits the farmers' rights to use the land for crops of their choice and the ability of farmers to exclude others from using the land for open grazing. This aspect of the land property rights has especially important implications for improved land management programs and SOC-enhancing technology adoption.

1.4. Adoption of carbon-enhancing technologies

Agricultural activities (e.g., deforestation, burning, plowing, intensive grazing, intensive cultivation, continuous cropping, and poor residue management) usually contribute considerably to the atmospheric pool by depleting the SOC stock (Post and Mann 1990). But, the extent of this depletion depends on the specific production system. For instance, the amount of crop residue that returns to the soil depends on the production system. The production systems in the study areas, at both the individual and community levels, are generally exploitative in that they deplete the existing SOC stock. Evidence from the literature suggests diverse SOC-enhancing practices that can increase or maintain SOC without compromising the ability to meet the growing food demand and the ability of producers to improve their livelihoods (Lal 2011) and also without impairing the ability of future generations to meet their food demand (Hobbs 2006; Schahczenski and Hill 2009).

Agricultural scientists propose diverse improved production and natural resource management practices that can increase productivity and at the same time maintain or increase SOC (e.g., Pretty et al. 2006; Lal 2006). For instance, Lal (2006) estimated the yield gains in kilograms per hectare for every 1 Mg/ha increase in SOC pool in the root zone to be 20–70 for wheat, 10–50 for rice, and 30–300 for maize. Efforts have been made for about half a century to improve the natural resource base of soil, water, and plants. The improved SOC-enhancing measures promoted and implemented in the country include construction of soil conservation structures such as soil/stone bunds, check dams, diversion canals, and interception ditches; agroforestry practices such as alley cropping, planting of trees, grass strips, and hedges; and the implementation of improved and traditional agronomic practices such as contour tillage, strip planting, manuring, mulching, crop rotation, and, recently, conservation tillage (zero or minimum tillage). In addition, efforts have been made to increase forest coverage and to improve the supply of forage through various individual-level technologies. We classify the practices that have been promoted and implemented in croplands into three categories: physical soil and water conservation, agroforestry, and improved agronomic practices.

However, agricultural scientists claim that these SOC-enhancing practices also enhance agricultural productivity. The effect of SOC enhancement on

productivity is more important especially in the tropics than in the temperate zone due to the high mineralization rate in the former (Woomer et al. 1994). The positive contribution of adopting SOC-enhancing practices to productivity is theoretically well-established. But farmers, in their decision to adopt technologies, take into account many other factors in addition to productivity. The potential productivity gain from technology is just one factor among the many that determine the adoption of a practice by farmers. Especially in mixed crop-livestock production systems, in addition to crop productivity, the effects of the practice on farming operations, livestock production, and demand for feed and firewood also enter into the household's decision to adopt.

Unfortunately, the most feasible SOC-enhancing technologies/practices also involve some costs to households. For instance, leaving crop residue in the plot can increase productivity in the subsequent production periods but can also involve some costs if the crop residue has alternative uses such as for livestock feed, fuelwood, construction material, etc. The farmer will adopt the SOC-enhancing technology if the additional gains of the technology in terms of increased productivity exceed the foregone benefits of the specific technology. The magnitude of these costs and benefits depends on the specific production context. The farmer is expected to adopt a practice by equating the marginal benefits with the marginal costs. Since the contribution of soil-enhancing technologies to productivity involves a time lag (Antle and Diagana 2003), farmers optimize by equating the discounted marginal benefits with the discounted marginal costs of the technology. The magnitudes of these discounted marginal costs and marginal benefits and the discount rate depend on the specific production context. The implication is that the willingness of farmers to invest in SOC-enhancing technologies/practices depends on the time preference of farmers. In subsistence farming communities where the sustenance of the household depends on current production, the time preference of farmers for increased production could be high. Furthermore, time preference tends to be higher if the property is insecure. The likelihood of farmers to realize future benefits depends on the likelihood that farmers secure the right to reap the fruits of the land until future time *t*. In effect, the discount rates will be higher when user rights are not secure. Furthermore, the intertemporal flow of benefits and costs matters.

Given the production contexts discussed above, leaving crop residues in plots involves a lot of costs in livestock production, fuelwood, and supply of construction materials. In the absence of a well-functioning capital market, these costs have to be borne fully, undiscounted. But, the productivity gains are not only long term but also they cannot be realized without incurring a lot of costs to protect the residues. Since farmers' plots are scattered and unfenced, crop residues could be grazed by animals and even collected by other farmers. The same is true with the use of grass strips. Unless farmers take collective actions to entirely exclude animals throughout the year, the enforcement costs for an individual farmer tend to be too high to justify the practice. On top of all of this, the sequestered carbon can be released back into the atmosphere within a short period of time if farmers revert to conventional practices (Antle and Diagana 2003). This implies that realizing future benefits requires farmers to adopt a practice on a permanent basis.

These discussions are based on the assumption that the farmers perfectly know the future benefits. Setting aside the inherent uncertainties associated with future benefits, farmers' expectations of these benefits depend on their knowledge about the effects of the improved practice on future productivity. In a situation in which farmers lack scientific knowledge about soil dynamics, they are likely to underestimate the future benefits.

Furthermore, the existing overall production and institutional contexts of the communities can encourage/discourage the adoption of one technology in favor of another. Some contexts provide individual farmers with little incentive to implement SOC-enhancing technologies. In other cases, this can even be discouraged by imposing constraints on individuals. In other words, some contexts expand the feasible set of SOC-enhancing practices while others narrow it.

These discussions show that farmers' decision to adopt SOC-enhancing technologies is a function of complex household and technical factors. While household and plot characteristics determine the type, level, and extent of adoption by farmers within a given homogeneous socioeconomic and agroecological context, differences in these contexts between communities also cause the farmers to behave differently. This means that while household and plot characteristics explain the differences in adoption among households within a community, community-level factors explain the differences in adoption between communities.

One important issue that poses a serious challenge in our analysis is that, unlike SOC-enhancing practices related to agronomic and agroforestry practices, soil and water conservation structures

have been implemented by mobilizing all farmers of the community, through a campaign and without consultation and consent of the individual farm owners. The problems of soil erosion and water loss involve a lot of externalities. The effectiveness of any soil and water conservation practice implemented on a given plot is affected by the erosion problem in upstream plots, and the action can also cause erosion problems in downstream plots. Thus, effective conservation of soil and water technically requires collective actions along the watershed. This alone may not pose a serious challenge if the implementation of the practices was made through consultation with every individual farmer and with the participation of farmers that have plots in the area. But, in practice, the structures are constructed by mobilizing all farmers in the community, including those that have no plot of land in the conservation area. Thus, practices implemented in such a manner are hardly considered as adoption.

The preceding discussion shows that farmers' knowledge of future benefits, time preference, the magnitude of costs, access to a well-functioning capital market, level of externalities, the continuity of the practice, and, more importantly, the enforcement costs all matter for farmers to adopt carbon-enhancing technologies. Thus, the question is: which of these practices were adopted by the farmers and what factors determined their adoption? Our interest is thus to measure the level and extent of adoption of the three classes of SOC-enhancing technologies and identify the factors that determine their adoption.

1.5. Conceptual framework

Natural resources (soil, water, minerals), climate (temperature, rainfall, humidity), topography, and geographic location form the biophysical environment that determines the suitable plants and animals that can thrive in an area. Access of the community to rural and urban markets (product, input, factor, and financial markets); access to technology, extension, education, health, irrigation, transportation, communication, electricity, and other services; demographic pattern; culture and religion; institutional environment (norms, rules, codes of conduct), etc., form the overall socioeconomic and institutional environment. The interplay between the sets of socioeconomic and institutional contexts and biophysical factors gives the community a unique characteristic. This, coupled with external factors, determines the farming system of the community. It determines the types, patterns, and modes of crop and livestock produced, the productivity levels, the land-use pattern, other off-farm activities, and the feasible set of technologies adopted in the various enterprises.

The overall community context gives a common opportunity and constraint to all members of the community. Households make production and consumption decisions that maximize their utility, given their resource constraints. Household characteristics such as age, education level, family size, landholding, wealth level, labor supply, livestock number, etc., determine the production and consumption pattern of the household. The level and extent of adoption of SOC-enhancing technologies is thus a function of community characteristics and household characteristics. The aggregate level and extent of adoption of the SOC-enhancing practices will in turn influence the overall community context. These relationships can be changed over time due to exogenous factors such as **climate change**.

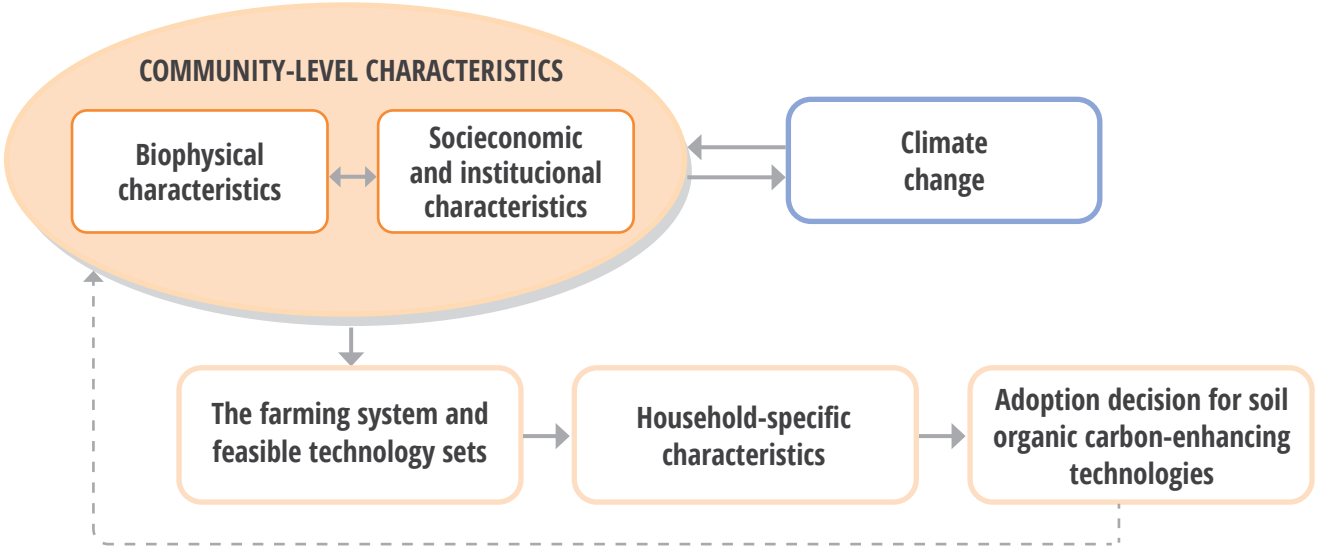

Photo: CIAT/Georgina Smith

2. The data and analytical model

2.1. About the data

This study used both primary and secondary data. Primary data were collected from 160 sample households selected from the two watershed sites. Moreover, community-level data that could give an overall picture about the overall agroecological, socioeconomic, institutional, and infrastructural aspects were also collected from district offices of the Agricultural and Natural Resource Development and village-level development agents. In addition, results of focus group discussions were used to further describe and validate the results of the household survey. Secondary data were collected from diverse sources: empirical studies, statistical abstracts, and various reports.

2.2. Sampling design

The study used data collected from households drawn from two watersheds. Yiser watershed is located in Bure Damot Woreda, Western Gojjam Administrative Zone, in Amhara region, while Azugashube watershed is located in Woreda, Kembata and Wolaita Administrative Zone, in the Southern region. The central aim of the sampling design was to obtain households that were representative of the various household groups and landscapes of the watershed. To obtain representative landscapes of the watershed, the Kebele Administrations (KAs), the lowest administrative structure, in the watershed were stratified into three zones: upper, middle, and bottom of the watersheds. Accordingly, on the upper side, two KAs from the middle and one KA from the bottom side of the watershed were randomly selected from the existing KAs in each stratum. Accordingly, households that had a plot of land within the watershed in the four selected KAs were used as the sampling frame. Using this sampling frame, in the second stage, the number of sample households in each pastoral area (PA) was allocated proportionally to the number of households in the PA. Accordingly, 161 households in the four KAs in Azugashube and 218 households in the four KAs in Yiser were drawn randomly from the PA household roster, which gave a total sample of 379 households. In order to avoid missing responses, only those households that had a plot of land in the watershed were included in the sampling. When the selected household was not accessible, it was replaced by the next household on the list. Table 1 shows the distribution of the sample households across the watersheds and KAs.

Table 1 Distribution of sample households in the two watersheds.

WOREDA/DISTRICT	KA	N	%
Azugashube	Ambercho Wasera	47	12.4
	Bondenna	46	12.1
	Bucha	23	6.1
	Gerba Findide	45	11.9
	Subtotal	*161*	*42.5*
Yiser	Gulim	51	13.5
	Jib Gedel	69	18.2
	Tengeha	44	11.6
	Wadra	54	14.2
	Subtotal	*218*	*57.5*
Grand total		**379**	**100.0**

2.3 Methods of collection

Primary data from sample households were collected through an interview using a structured questionnaire. The questionnaire focused on key household characteristics that were expected to influence the adoption of SOC-enhancing practices and included detailed questions about these various practices. A short guideline about the questions and interview procedure was prepared and given to the enumerators in hard copy. In addition, community data about the socioeconomic, institutional, infrastructural, and agroecological variables were collected at the PA level. The data were collected in one round. Six enumerators were recruited and trained at each watershed site. The enumerators were trained for one full day about the household and community questionnaire, potential difficulties they might encounter, and common mistakes committed by enumerators and the cautions they needed to take during data collection. The data were collected with Table using SurveyCTO software. The training was also given with lab exercises on the application of SurveyCTO. Close supervision was carried out using two supervisors at each watershed site. The collected data were checked by the supervisor on a daily basis and appropriate correction measures were taken on-site.

2.4. Analytical model

Descriptive statistics such as percentage, mean, standard deviation, and, more importantly, test statistics such as the t-test (for continuous variables) and chi-square test (for categorical variables) were used to gain an overall picture of the socioeconomic, biophysical, institutional, and infrastructural contexts about the sample households and the watershed. Furthermore, descriptive analyses were made for the various SOC-enhancing technologies/practices and comparisons were made between the two watershed sites.

With regard to analytical econometric models, the primary purpose was to identify the factors that explained households' decision to adopt SOC-enhancing technologies/practices and the intensity of their adoption. For convenience, we divided the SOC-enhancing technologies into three categories: (i) physical soil and water conservation, (ii) agronomic practices, and (iii) agroforestry practices.

2.4.1 Multivariate probit model

Since the different carbon-enhancing practices are not mutually exclusive, farmers can adopt one or more of the three classes of SOC-enhancing practices included in the

questionnaire. Some studies used a multivariate probit model to capture the interdependence in the adoption decisions between SOC-enhancing practices and soil and water management practices (e.g., Adusumilli and Wang 2018; Aryal et al. 2018). A multivariate probit model is an extension of the univariate probit model. Cappellari and Jenkins (2003) specified the general equation that uses a simulation method to maximum likelihood estimation as shown in Eq. 1.

$$y_{im}^{*} = \beta_m{}'X_{im} + \varepsilon_{im},\ m = 1, \ldots M$$

Eq. 1

where ε_{im}, m = 1, ..., and M are error terms distributed as multivariate normal, each with a mean of zero, and variance-covariance matrix V, where V has values of 1 on the leading diagonal and correlations $\rho_{jk}=\rho_{kj}$ as off-diagonal elements.

The observed dichotomous outcomes are as shown in Eq. 2

$$y_{im} = \begin{cases} 1, & if\ y_{im}^{*} > 0 \\ 0, & otherwise \end{cases}$$

Eq. 2

The y_{im} might represent outcomes for M different choices at the same point in time: in our case, whether an individual adopts each of M different SOC-enhancing practices.

In the trivariate probit case, the log-likelihood function for a sample of N independent observations is given by Eq. 3.

$$L = \sum_{i=1}^{N} w_i log\Phi_3(\mu_i, \Omega)$$

Eq. 3

where w_i is an optional weight for observation i = 1, ..., N, and Φ_3(.) is the trivariate standard normal distribution with arguments μ_i (Eq. 4).

$$\mu_i = (K_{i1}\beta'_1 X_{i1}, K_{i2}\beta'_2 X_{i2}, K_{i3}\beta'_3 X_{i3}$$

Eq. 4

and Ω, where with $K_{ik} = 2y_{ik} - 1$ for each i, k = 1, ..., 3. Matrix Ω has constituent elements Ω_{jk} (Eq. 5), where

$$\Omega_{21} = \Omega_{12} = K_{i1}K_{i2}, \rho_{21}$$
$$\Omega_{31} = \Omega_{13} = K_{i1}K_{i3}, \rho_{31}$$
$$\Omega_{32} = \Omega_{23} = K_{i2}K_{i3}, \rho_{32}$$

Eq. 5

Clearly, the log-likelihood function depends on the trivariate standard normal distribution function Φ_3(.). For evaluating multivariate normal distribution functions, the smooth recursive conditioning simulation method provided by Geweke–Hajivassiliou–Keane (GHK) is most popular (Cappellari and Jenkins 2003).

2.4.2 OLS regression model

The models shown in Eq. 1 to Eq. 5 are used to identify the factors that determine the adoption decisions regarding SOC-enhancing practices. But, sample households also differ in the intensity of their adoption. To identify the factors that determine the intensity of adoption, we estimate OLS regression using the area of land covered with one or more of the three SOC-enhancing practices as a dependent variable as shown in Eq 6.

$$y = \beta_k{}'X_k + u \qquad k = 1, 2, \ldots. K$$

Eq. 6

where y is the area in hectares covered with one or more of the three classes of SOC-enhancing practices; X_k represents the explanatory variables of household, plot, and community characteristics; u is the error term assumed to be normally distributed with mean μ and σ; and $\beta_k{}'$ represents vectors of the parameters to be estimated.

2.5. Description of dependent and independent variables

Dependent variables

The study classified the different SOC-enhancing practices into three categories: soil and water conservation practices, agronomic practices, and agroforestry practices. The study used a different dependent variable for each model. For the multivariate model, the dependent variable yi takes a value of 1 if the farmer adopts one or more of the ith SOC-enhancing practices and 0 otherwise. But, for the OLS regression, the study measures y in terms of the total land area covered with one or more of the three classes of SOC-enhancing practices in the 2017 production season.

Independent variables

Studies suggest the contextual nature of land degradation, SOC stock, and intervention responses to improve them. Thus, spatial, temporal, economic, environmental, and cultural contexts matter (Warren 2002). This study hypothesizes that diverse factors composing plot-level (biophysical and agroecological), household-level (institutional and farming system), and community-level (watershed) characteristics explain the probability of adoption and intensity of adoption of SOC-enhancing practices. In the absence of argument to the contrary, we assume that the same variables that determine the probability of adoption also determine the intensity of adoption of these practices.

VARIABLES ASSOCIATED WITH AGROECOLOGICAL ASPECTS

- ***Watershed dummy:*** 1 if Yesir and 0 if Azugashube.
- ***Fertile land:*** the ratio of fertile land in hectares to the total area of land operated by the farmer.
- ***Slope:*** the ratio of sloping land in hectares to the total area of land operated by the farmer.
- ***Clay:*** the ratio of land in hectares with clay soil to the total area of land operated by the farmer.
- ***Erosion:*** the ratio of land in hectares with erosion problems to the total area of land operated by the farmer.

VARIABLES ASSOCIATED WITH THE FARMING SYSTEM

- ***Crop diversification:*** the number of crop types grown by the farmer during the production season.
- ***Land fragmentation:*** the total time it takes for the farmer to reach all the plots.
- ***Fertilizer:*** the amount of fertilizer in kilograms divided by the total area.
- ***Residue:*** measures the proportion of residue that was left in the plot expressed in terms of percent.

SOCIOECONOMIC CHARACTERISTICS

- ***Family size:*** the number of people that live in the household.
- ***Area:*** total area of land in hectares operated by the farmer during the production season.
- ***TLU:*** Total Livestock Units derived using the conversion factor presented (see Appendix).
- ***Education:*** the sum of grade levels attained by household members who participate in farming activities.
- ***Radio:*** 1 if the household owns a radio and 0 otherwise.

ACCESS TO INSTITUTIONS

- ***Rural market:*** the distance in walking minutes from the farmer's home.
- ***Extension:*** 1 if the household has had access to extension and 0 otherwise.
- ***Credit:*** 1 if the household has had access to credit and 0 otherwise.
- ***Farm-org:*** 1 if the household was a member of a farmers' organization and 0 otherwise.

Photo: CIAT/Georgina Smith

3. Discussion of results

This part presents and discusses the results of the descriptive and economic analyses. The first subsection describes the overall socioeconomic characteristics of the sample households and the adoption of the various SOC-enhancing practices in detail. The next subsection presents and discusses the results of the econometric analyses.

3.1. Description of socioeconomic characteristics of sample households

From the total sample of 379 households, 89.5% and 93.2% of the sample households are males in Yiser and Azugashube, respectively (Table 2). The small proportions of female sample households reflect the reality that, except for a few, most households are headed by a male and there is no significant difference between the two watershed sites. With regard to education level, 56.9% and 70.2% of the sample households are literate in Yiser and Azugashube, respectively. The evidence suggests that literacy is higher in Azugashube than in Yiser and the difference is significant at 1%. Similarly, 81.2% of the household heads participate in labor activity in Yiser and almost all household heads (98.8%) participate in labor activity in Azugashube and the difference is significant at the 1% level.

Table 2 Demographic characteristics of sample household heads at the two sites.

INDICATORS	DUMMY	YISER		AZUGASHUBE		TOTAL		Chi-2
		N	%	N	%	N	%	
Sex	Males	195	89.5	150	93.2	345	91.0	1.57
	Females	23	10.6	11	6.8	34	9.0	
Literacy	Literate	124	56.9	113	70.2	237	62.5	7.00***
	Illiterate	94	43.1	48	29.8	142	37.5	
Labor participation	Yes	177	81.2	159	98.8	336	88.7	28.41***
	No	41	18.8	2	1.2	43	11.4	

With regard to other demographic and socioeconomic characteristics of the sample households, the descriptive results show significant differences between the two watershed sites in almost all household characteristics except age. As shown in Table 3, the mean age of households at both sites is around the age of 45 years and no evidence of age difference was found between the two sites. But, significant differences were found at the 1% level for all the rest of the household characteristics (see details in Table 3). The average family size of the sample households in Yiser and Azugashube is 8.0 and 10.6, respectively, and the difference is statistically significant at the 1% level. Similarly, the level of participation of household members in labor activities is 2.7 and 5.2, respectively.

The extent of education attendance and the education level of sample households in Azugashube is better in terms of both the number of educated household members and the aggregate grade level attained by the family. While on average 6.1 household members gained some education in Azugashube, this was only 3.8 members in Yiser. The average aggregate grade level achieved by the household members as a whole was 29.2 years in Azugashube while it was only 10.5 years in Yiser. Although the family size of sample households in Azugashube is higher than in Yiser by 2.6 members on average, the aggregate grade of the households in Azugashube is about three times higher than in Yiser. This means that sample households in Azugashube allow children to continue their education to higher grade levels.

Table 3 Mean comparison of household characteristics between the two sites.

HOUSEHOLD ATTRIBUTES	GROUP	OBS	MEAN	STD. ERR.	STD. DEV.	T-RATIO
Age of household head	Yiser	218	44.8	0.8	11.9	-1.36
	Azugashube	161	46.4	0.9	11.0	
Family size	Yiser	218	8.0	0.2	3.3	-7.28***
	Azugashube	161	10.6	0.3	3.7	
Labor participation of hh members	Yiser	218	2.7	0.1	1.8	-12.63***
	Azugashube	161	5.2	0.2	2.1	
Number of educated hh members	Yiser	218	3.8	0.1	1.9	-11.04***
	Azugashube	161	6.1	0.2	2.1	
Education level of the family in terms of aggregate grade level	Yiser	218	10.5	0.8	11.5	-12.89***
	Azugashube	161	29.2	1.3	16.7	

hh stands for households

Measuring the wealth status of households in rural areas is a difficult task. Although nearly all the sample households in Yiser watershed live in houses roofed with iron sheets, only about half of the sample households (49%) live in such types of houses in Azugashube (Table 4). The remaining 51% of the sample households live in houses roofed with grass. In the past, almost all rural households lived in houses made of grass cover. But they gradually moved to houses made of iron sheets. Ownership of houses made of iron sheets was used as an important indicator of wealth in the past. But it becomes a common asset in some areas as all farmers replace their grass-roofed house with iron sheet. This is especially true in Yiser watershed. Some also question whether the move from a grass-roofed to iron sheet-roofed house is a response to the scarcity of the grass or a deliberate action to improve their house. In the sense of the former, the transition from houses roofed with grass to iron sheet can indicate a deterioration of the natural resource base. Thus, if it was not due to scarcity, the change would be favorable for SOC accumulation by reducing the demand for grass. Sample households' ownership of a TV set is almost nil at both watershed sites. On the other hand, sample households' ownership of a sofa set is significantly (at the 1% level) higher in Azugashube (19%) than in Yiser, although the vast majority of the sample households at both sites do not have a sofa set.

In contrast, about half of the sample households own a radio, with 55% of the sample households in Azugashube owning a radio vis-à-vis 41% in Yiser.

With regard to ownership of a toilet, a majority of the sample households in both watersheds own one. This was not the case some decades ago in Ethiopia. Sample households' ownership of a water pump, motorcycle, and horse cart is considerably low at both sites. Although this shows the general low wealth status of the population, it will not be used as a useful explanatory variable as there is no significant difference among the sample households at both sites. Finally, with the exception of a few, a majority of the sample households at both sites own at least one mobile phone although a significant difference exists between the two sites. Except in the ownership of iron sheet-roofed houses, the wealth status of sample households in Azugashube is higher than in Yiser. This may thus indicate that the complete transition from grass-roofed houses to iron sheet-roofed houses in Yiser is more as a response to the scarcity of grass than to improvements in wealth status of the households.

Table 4 Descriptive statistics of wealth indicators.

VARIABLE		YISER		AZUGASHUBE		TOTAL		Chi-2
		N (218)	%	N (161)	%	N (379)	%	
Iron sheet	Yes	217	99.5	79	49.1	296	78.1	138.5***
	No	1	0.5	82	50.9	83	21.9	
TV	Yes	1	0.5	2	1.2	3	0.8	0.7
	No	217	99.5	159	98.8	376	99.2	
Sofa set	Yes	1	0.5	30	18.6	31	8.2	40.9***
	No	217	99.5	131	81.4	348	91.8	
Radio	Yes	89	40.8	89	55.3	178	47.0	7.5***
	No	129	59.2	72	44.7	201	53.0	
Toilet	Yes	206	94.5	158	98.1	364	96.0	3.2*
	No	12	5.5	3	1.9	15	4.0	
Motor pump	Yes	15	6.9	9	5.6	24	6.3	0.2
	No	203	93.1	152	94.4	355	93.7	
Motorcycle	Yes	1	0.5	4	2.5	5	1.3	2.9*
	No	217	99.5	157	97.5	374	98.7	
Horse cart	Yes	18	8.7	8	5.0	26	6.9	1.9
	No	200	91.3	153	95.0	353	93.1	
Mobile phone	>=3	22	10.1	56	34.8	78	20.6	13.3***
	2	48	22.0	44	27.3	92	24.3	
	1	96	44.0	46	28.6	142	37.5	
	0	52	23.9	15	9.3	67	17.6	

In addition to households' holdings of household furniture, their land and livestock holdings are perhaps more important indicators of wealth. As described in Table 5, the average livestock holding in Yiser was 3.7 measured in Total Livestock Units (TLUs) and it was 2.9 TLUs in Azugashube, and the difference was found to be statistically significant at the 1% level. Similarly, the average total land operated by sample households in Yiser and Azugashube was found to be 1.3 and 0.8 ha, respectively. The sample households not only differ significantly in terms of the total size of land they operated, they also differ in the proportion of land acquired through such informal land transactions as sharecropping, hiring, and borrowing as 30% and 10% of the land in Yiser and Azugashube was acquired through these means, respectively.

Table 5 Descriptive statistics of land and livestock holdings of sample households

HOUSEHOLD ATTRIBUTES	GROUP	OBS	MEAN	STD. ERR.	STD. DEV.	T-RATIO
Livestock holdings in TLUs	Yiser	218	3.7	0.2	2.8	3.30***
	Azugashube	161	2.9	0.1	1.4	
Total iron sheet of the house	Yiser	218	79.9	4.0	59.0	6.13***
	Azugashube	161	44.5	4.0	50.2	
Total land in hectares	Yiser	218	1.3	0.1	1.1	4.98***
	Azugashube	161	0.8	0.0	0.5	
Ratio of land not owned	Yiser	217	0.3	0.0	0.5	4.69***
	Azugashube	161	0.1	0.0	0.2	

The membership of households in a farmer organization is higher (63%) in Azugashube than in Yiser (54%) and the difference is significant at the 1% level (Table 6). For access to credit and extension services, sample households in Yiser have higher access (42% and 82%, respectively) than in Azugashube (9% and 67%, respectively), and, in both cases, the differences are significant at the 1% level. This might be because not only the regional state of Amhara provides extensive input credits to farmers, but also the Amhara Credit and Saving Institution is the largest MFI in the country in terms of outreach and number of beneficiaries. The government is also committed to allocating from three to four extension agents in each KA composed of crop and animal production, natural resources, and veterinary experts. Moreover, the government established a large number of Farmers' Training Centers (FTCs) in rural areas. In contrast, the Southern region, where Azugashube watershed is located, is weaker in delivering these services. The proportion of sample households with access to multiple sources (DA, FTC, GOs, and NGOs) is also larger in Yiser than in Azugashube. But, in absolute terms, access to extension services is generally good as more than half of the sample households at both sites have access to services.

Photo: CIAT/Georgina Smith

Table 6 Description of sample households' access to services.

VARIABLE		YISER		AZUGASHUBE		TOTAL		Chi-2
		N	%	N	%	N	%	
Membership in farmers' organization	Yes	137	62.8	66	41.0	203	53.6	7.30***
	No	81	37.2	95	59.0	176	46.4	
Access to credit	Yes	91	41.7	14	8.7	105	27.7	50.5***
	No	127	58.3	147	91.3	274	72.3	
Access to extension service	Yes	179	82.1	111	68.9	290	76.5	8.9***
	No	39	17.9	50	31.1	89	23.5	

Land fragmentation

Land fragmentation has a bearing on the performance of agricultural and natural conservation activities, although fragmentation may allow households to have land of different quality and hence enable them to diversify production. But it also poses a great challenge for farming and other operations. This is especially true when the land is scattered over wide areas. When the livestock grazing system is open, this makes undertaking timely farming operations difficult and protecting implemented SOC practices from cattle encroachment is also difficult and costly. In such contexts, protecting physical soil and water conservation structures such as bunds requires fencing, and activities such as the planting of grasses, trees, and mulching may require more than fencing the plots. In this regard, the average number of plots of sample households in Yiser and Azugashube was found to be 5.6 and 3.1, respectively (Table 7). Not only the level of fragmentation is significantly higher in Yiser than in Azugashube but also the plots are significantly more scattered in Yiser than in Azugashube as it takes 147.5 and 20.8 minutes for a farmer to reach all plots, respectively. Similarly, the extent of crop diversification was found to be 4.2 and 3.0 in Yiser and Azugashube, respectively. However, these contexts adversely affect the overall implementation of SOC-enhancing practices. This poses great challenges, particularly for implementing SOC-enhancing practices related to increasing the surface biomass of the plots. For these reasons, we expect that the implementation of agroforestry and some agronomic SOC-enhancing practices will be especially less attractive or costlier in Yiser than in Azugashube.

Table 7 Descriptive statistics of indicators of land fragmentation.

HOUSEHOLD ATTRIBUTES	GROUP	OBS	MEAN	STD. ERR.	STD. DEV.	T-RATIO
Number of plots	Yiser	218	5.6	0.17	2.55	11.48***
	Azugashube	161	3.1	0.10	1.24	
Total distance to plots in minutes	Yiser	218	147.5	12.6	185.7	8.61***
	Azugashube	161	20.8	1.6	20.8	
Crop diversification in terms of number of crop types	Yiser	218	4.2	0.1	1.6	8.00***
	Azugashube	161	3.0	0.1	1.1	

Implementation of SOC practices

An important objective of the sustainable management of soil resources is to increase the SOC pool by increasing the passive fraction. Soil surface management, soil water conservation and management, and soil fertility regulation are all important aspects of carbon sequestration in soil. The survey results show that different types of SOC-enhancing practices were implemented at both sites. We divided all SOC-enhancing practices into three classes: physical soil and water conservation, agronomic practices, and agroforestry practices. We found high differences in the number of farmers who implemented the different types of SOC-enhancing practices between the two sites. The results show that the number of households that implemented physical soil and water conservation activities is more or less large at both sites but the frequency of adoption is higher in Yiser than in Azugashube (Table 8). Although stone/soil bunds are implemented more or less equally at both sites, other types of soil and water conservation structures such as the construction of *fanya juu*, check dams, diversion canals, and interception ditches are implemented only in Yiser. One of the limitations of these practices is that they are largely implemented through heavy pressure by the development agents and by mobilizing all farmers. They are also implemented through a campaign and sometimes without the willingness of the plot owner. Hence, not only the quality of the structures is mostly poor, but the farmers also rarely own the structures and protect and maintain them. The poor quality of the structures, their construction through government imposition, and the high costs of protecting the structures against livestock encroachment coupled with insecure property rights on land often make these structures less sustainable than others.

With regard to agronomic practices, they are mostly implemented only in Yiser watershed. On the contrary, the implementation of agroforestry practices is almost nonexistent at both sites, except for the high adoption rate of grass strips observed in Azugashube. The low adoption rate of agroforestry practices is mainly due to the open grazing system discussed earlier.

Important SOC-enhancing practices such as mulching, minimum or zero tillage, and strip cropping are almost nonexistent at both survey sites. Despite conservation tillage being recognized as an important instrument for increasing SOC content of the surface layer, it has not been adopted at both sites.

One interesting traditional practice that was common in Yiser was traditional manuring called *"degele." Degele* is a cooperative strategy among neighboring farmers to fertilize their cropping land. Farmers bring all their animals together and make a temporary barn on the cropland and let the animals stay the night there. On the next day, they shift the barn to the next quarter until the crop plot of the member is fully covered with the dung of the animals. After the cropland is fully covered with dung, they shift the barn to another member's cropland and do the same thing. In this way, they cover the croplands of group members that are located not too far from the village. With this strategy, farmers do not need to transport the manure, but they can allow all the animal wastes to fertilize the land. This was an excellent cooperative strategy to fertilize their croplands with manure. Sadly, the farmers reported that they have now abandoned this strategy for many reasons: the scarcity of dung, declining numbers of livestock holdings, and, more importantly, the security problem. Farmers now keep their animals at home. Some farmers still fertilize their cropland using manure by transporting the dry or wet dung: either by scattering the dry dung or by burying the wet dung inside a pit.

Table 8 Participation level in the different SOC-enhancing technologies between the two sites.

SOC-ENHANCING ACTIVITIES	YISER		AZUGASHUBE		BOTH	
	N (218)	%	N (161)	%	N (379)	%
Physical soil and water conservation activities						
Soil/stone bunds	58	26.5	41	25.5	99	35.4
Terrace	109	49.8	31	19.3	140	50.0
Fanya juu terrace	43	19.6	-	-	43	15.4
Check dam	12	5.5	-	-	12	4.3

SOC-ENHANCING ACTIVITIES	YISER		AZUGASHUBE		BOTH	
	N (218)	%	N (161)	%	N (379)	%
Diversion canal	59	26.9	1	0.6	60	21.4
Interception ditch	14	6.4	-	-	14	5.0
Agronomic SOC-enhancing practices						
Contour	115	52.5	5	3.1	120	42.9
Minimum or zero tillage	3	1.4	4	2.5	7	2.5
Crop rotation	115	52.5	1	0.6	116	41.4
Strip cropping	1	0.5	-	-	1	0.4
Mulching	8	3.7	-	-	8	2.9
Manuring	62	28.3	-	-	62	22.1
Agroforestry SOC-enhancing practices						
Agroforestry	5	2.3	-	-	5	1.8
Grass strip	3	1.4	71	44.1	74	26.4
Alley cropping	5	2.3	-	-	5	1.8
Hedge	1	0.5	-	-	1	0.4
Others	2	0.9	3	1.9	5	1.8

Integration of the various SOC practices

As described in Table 9, of the total of nine types of SOC-enhancing practices, a majority of the sample households (64%) implemented one or two types of SOC-enhancing practices, of which about half implemented only one type of practice. The remaining 34.3% and 1.3% of the sample households implemented three to five and six to nine types of SOC-enhancing practices, respectively. The difference in the distribution between the two watershed sites was significant at the 1% level.

Table 9 Distribution of implementation of the types of SOC-enhancing practices.

FREQUENCY OF FARMERS WHO IMPLEMENTED	YISER		AZUGASHUBE		TOTAL		PEARSON Chi-2
	N	%	N	%	N	%	
One or two types of SOC practices	98	45.0	146	90.7	244	64.4	
Three to five types of SOC practices	115	52.8	15	9.3	130	34.3	84.71***
More than six types of SOC practices	5	2.3	0	0.0	5	1.3	
Total	218	100.0	161	100	379	100	

The extent of implementation of SOC practices

The survey results show that farmers implemented these SOC-enhancing activities in their different plots. Thus, farmers differ in the extent of their implementation, although the frequencies of the number of plots in which one or more types of SOC practices are implemented are higher among sample farmers in Yiser than in Azugashube (Table 10).

Table 10 Distribution of households in terms of the number of plots in which they implemented SOC practices.

NUMBER OF PLOTS	YISER		AZUGASHUBE		TOTAL	
	N (218)	%	N (161)	%	N (379)	%
At least one plot	9	4.1	61	37.9	70	18.5
Two or three plots	69	31.7	89	55.3	158	41.7
Four or five plots	86	39.5	10	6.2	96	25.3
Six plots or more	54	24.8	1	0.6	55	14.5

As mentioned above, the decline in the traditional manuring system pushed farmers to use inorganic fertilizer. As shown in Table 11, on average, sample farmers in Yiser and Azugashube were found to use 560 kg and 202 kg of a combination of DAP, urea, and, recently, NPS fertilizer, respectively. The extent of fertilizer use between the two sites was found to be significant at the 1% level. With respect to the proportion of crop residue left in the plot, the results show that about 23% of the surface biomass is left in the plot at both sites. The remaining 77% is removed from the crop field and used for many purposes discussed earlier. But, due to the open grazing system discussed earlier, except for crops whose residues are not fed to animals such as maize stock, most portions of the residues that were left on the cropland during harvesting are browsed by animals. Thus, the proportion of crop residue that ultimately goes back to the soil is much lower than 23%.

Table 11 Descriptive statistics of fertilizer use and proportion of residue left in the field.

HOUSEHOLD ATTRIBUTES	GROUP	OBS	MEAN	STD. ERR.	STD. DEV.	T-RATIO
Fertilizer	Yiser	218	559.9	29.5	435.1	9.83***
	Azugashube	161	202.4	14.1	178.7	
Proportion of residue left in the plot	Yiser	218	23.6	1.9	27.9	0.09
	Azugashube	161	23.3	1.2	15.7	

A majority of the farmers in Yiser use crop residues for multiple purposes such as cooking, feed, and construction purposes, with a small segment of the farmers using it for fertility improvements (Table 12). In contrast, sample farmers in Azugashube frequently use the residues for construction and feed with about 40 using it for cooking and fertility management. In each case, the differences between the two sites are strongly significant.

Table 12 Uses of crop residue for different purposes between the two sites.

RESIDUE USE	YISER		AZUGASHUBE		Chi-2
	N	%	N	%	
Cooking	179	82	68	42	64.86***
Feed	175	80	106	66	10.07***
Construction	160	73	152	94	28.10***
Fertility	42	19	69	43	24.89***

Finally, Table 13 shows the extent of implementation of the three categories of SOC-enhancing practices among sample households at the two sites. The results show that the frequency of implementation (in terms of the number of plots) of soil and water conservation and agronomic practices was found to be larger in Yiser than in Azugashube. On the contrary, the frequency of implementation of agroforestry practices was higher in Azugashube than in Yiser. The differences between the two sites in all three cases were highly significant because the physical soil and water conservation, agronomic, and agroforestry SOC practices were used in 3.90, 3.19, and 0.78 plots in Yiser. The corresponding figure was 1.10, 0.07, and 1.14 plots in Azugashube. Similarly, the extent of implementation (in terms of the percentage) of land covered with the three SOC-enhancing practices between the two sites was also highly significant. This is because households in Yiser covered 32%, 25%, and 1% of their land with physical soil and water conservation, agronomic, and agroforestry SOC practices, respectively, while the corresponding numbers for sample households in Azugashube were 22%, 3%, and 19%.

Table 13 Extent of implementation of the three categories of SOC practices among sample households.

PARAMETER	TYPES OF SOC PRACTICES	GROUP	OBS	MEAN	STD. ERR.	STD. DEV.	T-RATIO
Number of plots under	Physical soil and water conservation SOC practices	Yiser	218	3.90	0.22	3.31	10.27***
		Azugashube	161	1.10	0.09	1.16	
	Agronomic SOC practices	Yiser	218	3.19	0.23	3.45	11.43***
		Azugashube	161	0.07	0.02	0.31	
	Agroforestry SOC practices	Yiser	218	0.78	0.09	1.39	-2.82***
		Azugashube	161	1.14	0.08	1.04	
Area covered	Physical soil and water conservation SOC practices	Yiser	218	0.32	0.03	0.38	3.04***
		Azugashube	161	0.22	0.02	0.22	
	Agronomic SOC practices	Yiser	218	0.25	0.02	0.30	8.79***
		Azugashube	161	0.03	0.01	0.14	
	Agroforestry SOC practices	Yiser	218	0.01	0.00	0.06	-11.10***
		Azugashube	161	0.19	0.02	0.24	

Description of dependent and independent variables

The following section describes the dependent and independent variables used in the econometric analyses. Table 14 describes the categorical dependent and independent variables. The study classified the different SOC-enhancing practices into three categories: soil and water conservation practices, agronomic practices, and agroforestry practices. From the total of 379 sample households, 80.7%, 38.3%, and 49.1% have adopted at least one practice from the three SOC-enhancing practices, respectively.

Ownership of a radio apparatus is taken as a measure of a household's access to information. From the total sample, 47.0% of the sample households own a radio. The corresponding figures for access to extension and credit are 76.5% and 27.7%, respectively. Finally, 53.6% of the sample households are members of farm organizations.

Table 14 Descriptive statistics of categorical variables.

DEPENDENT AND INDEPENDENT VARIABLES		N	%
Adoption of soil and water conservation SOC practices	No	73	19.3
	Yes	306	80.7
Adoption of agronomic SOC practices	No	234	61.7
	Yes	145	38.3
Adoption of agroforestry SOC practices	No	193	50.9
	Yes	186	49.1
Radio ownership	No	201	53.0
	Yes	178	47.0
Extension contact	No	89	23.5
	Yes	290	76.5
Credit access	No	274	72.3
	Yes	105	27.7
Membership in farm organization	No	176	46.4
	Yes	203	53.6

From the total land farmers operated in the production season, sample households on average covered 57.0% of their land with one or more of the SOC-enhancing practices (Table 15). In terms of agroecological aspects, on average, 77%, 26%, 31%, and 25% of a farmer's land is fertile, clay soil, sloping, and erosion-prone. In terms of crop diversification, a farmer on average has grown 3.7 crop types. As a measure of land fragmentation, on average, a farmer has to walk for 93.7 minutes in order to reach all of his/her plots. The average fertilizer application in the study area was found to be 419.62 kg/ha. For residue management, farmers reported that on average they leave 23% of the residue in the field. Farmers in the study area have a large family size in that on average they have 9.09 members. The average land size in the area is 1.08 hectare. The livestock holding in terms of Total Livestock Units reported was 3.31. In terms of education level, the grade levels of all household members, including the household head, were added as most family members participate in farming activities. Accordingly, on average, the education level of the household was found to be equivalent to the completion of grade 18.44. Finally, on average, a household travels 39.6 minutes to reach the nearest market.

Table 15 Descriptive statistics of continuous dependent and independent variables.

VARIABLES	MEAN	SD	MIN	MAX
Dependent variable				
Proportion of land covered with SOC practices	0.57	0.28	0	1
Agroecological variables				
Proportion of fertile land	0.77	0.27	0	1
Proportion of clay land	0.26	0.38	0	1
Proportion of sloping land	0.31	0.43	0	1
Proportion of land with erosion problems	0.25	0.36	0	1
Farming system				
Crop diversification by number of crop types	3.66	1.52	1	11
Land fragmentation in terms of distance to all plots	93.70	154.61	1	1470
Fertilizer rate (kg/ha)	419.62	296.33	0	2000
Residue proportion left on the land in percentage	23.19	23.98	0	100
Family size	9.09	3.72	2	23
Land area in hectares	1.08	0.95	0	8
Livestock ownership (TLU)	3.31	2.35	0	14
Education at the household level, sum of grades by the family	18.44	16.74	0	82
Distance from the market in walking minutes	39.60	29.65	1	180

3.2 Econometric analysis

3.2.1 Determinants of level of adoption

The study used two models to identify the factors that explain the level and extent of adoption of SOC-enhancing practices. We identify the factors that affect the probability of adoption of the three categories of SOC-enhancing practices using a multivariate probit model. Using the same explanatory variables, we also identify the factors that affect the extent of adoption of the three practices using OLS regression. We divided the explanatory variables into four categories: agroecological characteristics of the plots (watershed sites and plot characteristics such as fertility, slope, soil type, and perceived erosion problems), farming system-related variables (number of crops, land fragmentation, fertilizer use, and residue management), household socioeconomic characteristics (livestock holdings, family size, education, and landholding), and institutional access (access to rural markets, credit, social organization, and extension).

The decisions to adopt alternative SOC-enhancing practices are mutually exclusive and, instead, they are interdependent (Adusumilli and Wang 2018). We thus expect interdependence in adoption decisions between the pair of each class of SOC-enhancing practices. Following Aryal et al. (2018) and Adusumilli and Wang (2018), the study used a multivariate probit model to capture possible interdependence between the adoption decision combinations of the three classes of SOC-enhancing practices: physical soil and water conservation, agronomic, and agroforestry. The maximum-likelihood estimates of the multivariate probit models with associated standard errors for the joint decisions of soil and water conservation and agronomic, agronomic and agroforestry, and soil and water conservation and agroforestry SOC-enhancing practices are given in Table 16.

From the estimation results, the null hypothesis that all the parameter estimates are simultaneously equal to zero is strongly rejected at the 1% level of significance. In addition, the null hypothesis that all rho (ρ_{jk})

coefficients are simultaneously equal to zero (rho21 = rho31 = rho32 = 0) is strongly rejected at the 1% level. This means that the disturbance terms between the possible combinations of adoption decisions for the three SOC-enhancing practices are not independent. This indicates that the multivariate probit model is more appropriate than the standard univariate probit model. The coefficient ρ_{21}, which measures the interdependence between the adoption decisions of soil and water conservation and agronomic SOC-enhancing practices, was found to be negative and significant at the 5% level. This means that it is not likely for a farmer who adopted soil and water conservation SOC-enhancing practices to also adopt agronomic practices and vice versa. Similarly, from the strongly significant (1% level) negative coefficient of ρ_{31}, it is highly unlikely that a farmer who adopts soil and water conservation will also adopt agroforestry practices. On the contrary, from the positive coefficient of ρ_{32}, it can be inferred that the likelihood that a farmer who adopted agronomic SOC-enhancing practices will also adopt agroforestry practices is strongly significant at the 1% level.

Table 16 Estimation results of a multivariate probit model.

VARIABLES	PHYSICAL SOIL AND WATER SOC-ENHANCING PRACTICES			AGRONOMIC SOC-ENHANCING PRACTICES			AGROFORESTRY SOC-ENHANCING PRACTICES		
	Coef.	Std. err.	z	Coef.	Std. err.	z	Coef.	Std. err.	z
Agroecological aspects									
Watershed dummy	-0.43	0.18	-2.37***	-1.35	0.22	-6.19***	0.10	0.17	0.59
Fertility	0.18	0.30	0.61	-0.12	0.32	-0.38	-0.31	0.28	-1.13
Slope	0.51	0.30	1.67*	0.37	0.30	1.24	0.49	0.28	1.76*
Clay	0.36	0.23	1.52	0.47	0.20	2.35**	0.85	0.20	4.20***
Erosion	-0.08	0.30	-0.25	-0.13	0.28	-0.46	0.03	0.27	0.10
Farming system									
Crop diversification	0.10	0.07	1.49	0.24	0.06	3.76***	0.11	0.06	1.94**
Land fragmentation	0.00	0.00	-0.73	0.00	0.00	-1.57	-0.01	0.00	-4.19***
Fertilizer	0.00	0.00	1.96**	0.00	0.00	2.60***	0.00	0.00	-2.04**
Residue	-0.01	0.00	-2.40**	0.00	0.00	1.28	0.00	0.00	0.52
Socioeconomic status									
Family size	-0.02	0.03	-0.72	0.00	0.03	-0.03	0.04	0.02	1.46
Area	0.66	0.21	3.06***	0.16	0.14	1.14	0.20	0.13	1.53
TLU	-0.09	0.05	-1.79*	-0.03	0.04	-0.61	0.01	0.04	0.30
Educ. level	0.01	0.01	1.33	0.01	0.01	1.04	0.00	0.01	0.60
Radio	0.59	0.18	3.24***	-0.13	0.17	-0.76	-0.04	0.16	-0.26
Access to institutions									
Rural market	0.00	0.00	-0.71	0.01	0.00	3.08***	-0.01	0.00	-3.40***
Extension	0.36	0.21	1.76*	-0.44	0.22	-2.00**	-0.05	0.20	-0.25
Credit	0.10	0.22	0.47	0.12	0.19	0.66	0.13	0.19	0.71
Farm organization	0.14	0.20	0.72	-0.20	0.20	-1.00	-0.37	0.18	-2.11**

VARIABLES	PHYSICAL SOIL AND WATER SOC-ENHANCING PRACTICES			AGRONOMIC SOC-ENHANCING PRACTICES			AGROFORESTRY SOC-ENHANCING PRACTICES		
	Coef.	Std. err.	z	Coef.	Std. err.	z	Coef.	Std. err.	z
rho21	-0.23	0.11	-1.99**						
rho31	-0.42	0.09	-4.48***						
rho32	0.47	0.09	5.1***						
LR test of rho21 = rho31 = rho32 = 0			31.83***						
Log-likelihood			-476.21						
Wald Chi-2 (54)			355.53***						

Consistent with Aryal et al. (2018), the study found that a combination of household, plot, and institutional and climatic factors determines the adoption of the different SOC practices. In the physical soil and water conservation enhancement practices equation, 8 variables out of 18 were significant (3 variables at 1% level, 2 variables at 5% level, and 3 variables at 10% level). Land area operated, slope, fertilizer, extension, and radio ownership have a positive and significant effect on the likelihood of adopting soil and water conservation practices. On the contrary, watershed site, residue proportion, and livestock ownership have significant and negative effects on the likelihood of adopting soil and water conservation practices. Farmers that operate larger land area, have more proportion of sloping land, have a radio, use more fertilizer, and have extension contact are more likely to adopt soil conservation practices. On the contrary, farmers located at the Azugashube watershed site that left more proportion of residue in their plots and that own more livestock will be less likely to adopt soil and water conservation practices. Surprisingly, none of the aggregate plot characteristics, except slope, were found to be significant in explaining farmers' adoption of soil conservation practices. These results are conditional on the adoption of the other two SOC-enhancing practices.

In the agronomic SOC-enhancing practices, six variables were significant (4 at 1% level and 2 at 5% level). The proportion of land with clay soil type, crop diversification, fertilizer application, and access to a rural market have positive and significant effects on the adoption of agronomic SOC-enhancing practices. On the contrary, watershed site and extension contact have negative effects on the adoption of these agronomic practices conditional on the adoption of the other two SOC-enhancing practices. No evidence was found on the effects of other variables considered in the analysis on the adoption of agronomic practices.

In the agroforestry SOC-enhancing practices, seven variables were significant (3 variables at 1% level, 3 variables at 5% level, and 1 variable at 10% level). The proportion of sloping land, proportion of land with clay soil type, and crop diversification have positive effects on the adoption of agroforestry practices, whereas land fragmentation, amount of fertilizer, rural market, and membership in a farm organization have negative effects. Unlike the others, watershed site was to have an insignificant effect. Farmers that have a large proportion of sloping and clay land, that have grown more diverse crops, that have less fragmented land, that use lower fertilizer rates, that are near rural markets, and that are not members of farm organizations are more likely to adopt agroforestry practices. The negative effects of access to extension services on the adoption of agronomic practices and membership in farmers' organizations on the adoption of agroforestry practices, respectively, are hard to explain and they are contrary to the theory.

The dummy variable watershed site was found to be strongly significant in the adoption of soil and water conservation and agronomic practices, implying that community characteristics strongly explain the likelihood of adoption of the different types of SOC-enhancing practices. Many studies found similar results (Aryal et al. 2018; Shiferaw and Holden 1998). The reason could be that the location captures differences in all other factors that are not captured by the rest of the explanatory variables. The strongly significant positive coefficients of the watershed site in the regressions of soil and water conservation and agronomic SOC-enhancing practices show that households in Yiser watershed are more likely to adopt these practices than those in Azugashube. No evidence was found on the effect of location on the adoption of agroforestry practices.

3.2.2 Determinants of the intensity of adoption

The above results show the likelihood of farmers to adopt one or more of the SOC-enhancing practices. But, the analyses were made in terms of whether the farmer implemented one or more of the practices or not regardless of the size of the land they were implemented on. It is therefore essential to assess the roles of these same explanatory variables in determining the magnitude of the adoption of the practices.

Table 17 OLS regression estimation results of implementation of all SOC-enhancing practices.

EXPLANATORY VARIABLES	COEF.	STD. ERR.	T
Dependent variable: the ratio of land covered with SOC practice			
Agroecological aspects			
Watershed dummy	0.14	0.03	4.75***
Fertility	0.25	0.05	4.93***
Clay	0.22	0.05	4.46***
Slope	0.12	0.03	3.50***
Erosion	-0.07	0.05	-1.53
Farming system			
Crop diversification	-0.02	0.01	-2.13***
Land fragmentation	0.00	0.00	-2.65***
Fertilizer	0.00	0.00	3.86***
Residue	0.00	0.00	-1.31
Socioeconomic status			
Family size	0.01	0.00	1.86*
Area	-0.01	0.02	-0.65
TLU	-0.01	0.01	-0.94
Educ. level	0.00	0.00	-2.05**
Radio	0.04	0.03	1.39
Access to institutions			
Rural market	0.00	0.00	3.05***
Extension	0.09	0.04	2.66***
Credit	0.05	0.03	1.49
Farm organization	-0.05	0.03	-1.65*
Number of observations	=		379
F (18, 361)	=		107.9***
Adj. R-squared	=		0.84

We measure the intensity of adoption in terms of the ratio of the area of land covered by one or more of the SOC practices to the total land operated by the farmer during the 2017 production season. Since all sample households implemented at least one of these practices, we have continuous values for the dependent variable. We thus fit the OLS regression model to identify variables that explain the intensity of adoption. With an adjusted R-squared value of 0.84, the model fits the data well. Moreover, the null hypothesis that the coefficients of all explanatory variables are simultaneously equal to zero is strongly rejected at the 1% level. The OLS estimation result is presented in Table 17.

The results show that 12 variables out of 18 significantly determine the intensity of implementation of SOC-enhancing practices expressed in terms of the ratio of land area covered with one or more SOC-enhancing practices from the three classes to the total land operated by the sample household. Watershed site, fertility, clay, slope, fertilizer, family size, rural market, and extension were found to significantly and positively determine the intensity of adoption at the 1% level (except family size, which was significant at a marginal level of 10%). When controlling all other variables, the intensity of implementation of SOC-enhancing practices was significantly higher in Yiser than in Azugashube.

With regard to plot characteristics, the intensity of adoption of those farmers with a higher ratio of fertile, sloping, and clay lands was found to be significantly higher. Although the significantly positive relationship between the intensity of implementation of SOC practices and the ratios of sloping lands and clay lands was consistent with our prior expectations, its relationship with the ratio of fertile lands was contrary to our prior expectations. This indicates that farmers prefer to prioritize maintaining the fertility of fertile lands rather than improving the fertility of less fertile lands.

The fertilizer application rate was also found to increase the intensity of adoption of SOC-enhancing practices.

The results also suggest a positive effect of family size on the intensity of implementation of SOC-enhancing practices. Contrary to our expectations, the results showed positive and significant relationships between distances to rural markets and the intensity of adoption. Those farmers located far from rural markets were found to have a higher intensity of implementation than those located near rural markets. Access to extension service was also found to significantly and positively determine the intensity of adoption of SOC-enhancing practices. On the contrary, the results also suggest a negative relationship between membership in farmers' organizations and the intensity of implementation of SOC-enhancing practices.

For farming system-related variables, land fragmentation, crop diversification, and education levels were found to significantly determine the intensity of adoption of SOC-enhancing practices negatively. When controlling access to extension service, the effects of education level, measured by the total grade level achieved by all those household members who participate in farming activities, in determining the intensity of implementation of SOC-enhancing practices were found to be negative at the 5% significance level.

Finally, the results found no evidence on the effects of perceived exposure to erosion problems, land area, TLU, residue, and credit on the intensity of implementation of SOC-enhancing practices. Consistent with the results of the multivariate probit model, no evidence was found on the role of perceived erosion problems in determining the intensity of implementation of SOC-enhancing practices. The important implication of these results is that farmers implemented SOC-enhancing practices not to reduce erosion problems but to meet other objectives.

Photo: CIAT/Georgina Smith

Conclusions

This study aimed to identify the determinants of the level and intensity of adoption of SOC-enhancing practices in the case of two watershed sites in Ethiopia: Yiser and Azugashube. The descriptive results reveal that the two watershed sites are significantly different in almost every aspect: socioeconomic, biophysical, farming system, and institutional. Moreover, the two sites were found to be significantly different in the level and intensity of adoption of SOC-enhancing practices. Significant differences were also found between the two sites in the adoption of the three classes of SOC-enhancing practices. This indicates that, compared to the Azugashube watershed site, households in Yiser are more likely to adopt soil and water conservation and agronomic SOC-enhancing practices.

We assume that the decisions to adopt the three classes of SOC-enhancing practices are not mutually exclusive. In order to capture the potential interdependences between the adoption decisions of the three classes of practices, the study specified a multivariate probit model. The multivariate estimation reveals that interdependence exists between the decisions to adopt the three SOC-enhancing practices. The results revealed that the decision to adopt soil and water conservation is negatively related to the decision to adopt both agronomic and agroforestry SOC-enhancing practices. But, the interdependence between the decisions to adopt agronomic and agroforestry practices is positive and significant at the 1% level. That means that although the adoption of agroforestry SOC-enhancing practices is complementary with the adoption of agronomic practices, the adoption of soil and water conservation practices is competitive with the adoption of both agronomic and agroforestry practices.

The OLS regression estimated to identify the factors that determine the intensity of adoption found 12 variables out of 18 to significantly determine the intensity of implementation of SOC-enhancing practices expressed in terms of the ratio of land area covered with one or more among the 14 practices classified under the three classes to the total land operated by the sample household. Compared to the results of the probability of adoption, many explanatory variables were found to determine the intensity of adoption of SOC-enhancing practices in general. Watershed site, fertility, clay, slope, fertilizer, family size, rural market, and extension were found to significantly and positively determine the intensity of adoption at the 1% level (except family size, which was significant at a marginal level of 10%). When controlling all other variables, the intensity of implementation of SOC-enhancing practices was significantly higher in Yiser than in Azugashube. The implication is that encouraging

farmers to intensify their adoption requires more efforts than encouraging them to adopt one or more of the SOC-enhancing practices.

Finally, in an attempt to check the motive for the adoption of SOC practices, we included the ratio of land exposed to soil erosion problems. In all the regressions, this variable was found to be consistently insignificant in determining both the probability to adopt and the intensity of adoption of SOC-enhancing practices. This implies that the adoption of these practices is not driven by the perceived threat of soil loss through erosion but by other factors. This result is not surprising in the case of soil and water conservation practices as they are implemented through a community-level campaign and by involving all farmers in the community and without consultation with individual owners of plots. But, the results are surprising when it comes to the adoption of agronomic and agroforestry practices that are implemented individually.

References

Adusumilli N; Want H. 2018. Analysis of soil management and water conservation practices adoption among crop and pasture farmers in humid-south of the United States. *International Soil and Water Conservation Research* 6:79–86.

Ali DA; Deininger K; Kemper N. 2015. Pronatal property rights over land and fertility outcomes: Evidence from a natural experiment in Ethiopia. World Bank, Policy Research Working Paper 7419.

Ambaye DW. 2015. Land rights and expropriation in Ethiopia. Doctoral Thesis accepted by the Royal Institute of Technology (KTH), Stockholm, Sweden.

Antle JM; Diagana B. 2003. Creating incentives for the adoption of sustainable agricultural practices in developing countries: The role of soil carbon sequestration. *American Journal of Agricultural Economics* 85(5):1178–1184.

Aryal JP; Rahut DB; Maharjan S; Erenstein O. 2018. Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India. *Natural Resources Forum* 42:141-158.

Cappellari L; Jenkins SP. 2003. Multivariate probit regression using simulated maximum likelihood. *The Stata Journal* 3(3):278–294.

CSA (Central Statistical Agency). 2000. Report on Area and Production of Crops (Private Peasant Holdings, Meher Season): Agricultural Sample Survey 1999/2000. Ethiopian Central Statistical Agency, Volume I, Statistical Bulletin 227.

CSA (Central Statistical Agency), 2010. Report on Area and Production of Crops (Private Peasant Holdings, Meher Season): Agricultural Sample Survey 2009/2010. Ethiopian Central Statistical Agency, Volume I, Statistical Bulletin 446.

DAWR (Department of Agriculture and Water Resources). 2016. *Boosting farm productivity: Improved soils and reduced greenhouse gas emissions.* Department of Agriculture and Water Resources, Canberra, March. CC BY 4.0.

Deininger K; Jin S; Adenw B; Gebre-Selassie S; Demeke M. 2003. Market and non-market transfers of land in Ethiopia: Implications for efficiency, equity, and non-farm development. World Bank. Washington, DC.

Emran MS; Shilpi F. 2015a. Land market restrictions, women's labor force participation, and wages in a rural economy. World Bank, Policy Research Working Paper 7524.

Emran MS; Shilpi F. 2015b. Do land market restrictions hinder structural change in a rural economy? Evidence from Sri Lanka. World Bank, Policy Research Working Paper 7525.

FAO (Food and Agriculture Organization of the United Nations). 2017. Global symposium on soil organic carbon: Unlocking the potential of mitigating and adapting to a changing climate. 21-23 March 2017. FAO, Rome, Italy.

Follett RF. 2001. Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research* 61:77-92.

Giles J; Mu R. 2014. Village political economy, land tenure insecurity, and the rural to urban migration decision: Evidence from China. World Bank, Policy Research Working Paper 7080.

Gledhill R; Herweijer C; Hamza-Goodacre D; Grant J; Webb C; Steege J. 2011. Agricultural carbon markets: Opportunities and challenges for sub-Saharan Africa. Sustainability and Climate Change, PwC LLP, UK.

Glover EK; Ahmed HB; Glover MK. 2013. Analysis of socio-economic conditions influencing adoption of agroforestry practices. *International Journal of Agriculture and Forestry* 3(4):178-184.

Grover DK; Temesgen A. 2006. Enhancing land-use-efficiency through appropriate land policies in Ethiopia. Poster paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, 12-18 August 2006.

Hardin G. 1968. The tragedy of the commons. *Science*, New Series 162(3859):1243-1248.

Heath J; Binswanger H. 1996. Natural resource degradation effects of poverty and population growth are largely policy-induced: The case of Colombia. *Environment and Development Economics* 1:65–84.

Hobbs PR. 2006. Conservation agriculture: What is it and why is it important for future sustainable food production? Paper Presented at International Workshop on Increasing Wheat Yield Potential, CIMMYT, Obregón, Mexico, 20-24 March 2006.

Jack BK. 2011. Constraints on the adoption of agricultural technologies in developing countries. White paper, Agricultural Technology Adoption Initiative, J-PAL (MIT) and CEGA (UC Berkeley).

Kankwamba H; Mangisoni JH. 2015. Are sustainable agricultural practices improving output and incomes of smallholder farmers in Malawi? Contributed paper presented at the 29th International Conference of Agricultural Economists, 8-14 August 2015, Milan, Italy.

Lal R. 2006. Enhancing crop yields in developing countries through the restoration of the soil organic carbon pool in agricultural lands. *Land Degradation & Development* 17:197–209.

Lal R. 2011. Sequestering carbon in soils of agro-ecosystems. *Food Policy* 36:S33-S39.

Lal R; Kimble JM. 1997. Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems* 49:243–253.

Laxmi V; Mishra V. 2007. Factors affecting the adoption of resource conservation technology: Case of zero-tillage in rice-wheat farming systems. *Indian Journal of Agricultural Economics* 62(1):126-138.

Manna MC; Wani SP; Rego TJ; Sahrawat KL; Bhattacharyya T; Ramesh V; Bandyopadhyay KK; Rupa TR;Singh P; Pathak P; Padmaja KV. 2008. Influence of different land-use management on soil biological properties and other C fractions under semi-arid benchmark soils of India. Global Theme on Agro-ecosystems Report no. 41. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Melesse B. 2018. A review on factors affecting adoption of agricultural new technologies in Ethiopia. *Journal of Agricultural Sciences and Food Research* 9:226.

Paustian K; Six J; Elliott ET; Hunt HW. 2000. Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry* 48:147–163.

Post WM; Kwon KC. 2000. Soil carbon sequestration and land-use change: Processes and potential. *Global Change Biology* 6:317–328.

Post WM; Mann LK. 1990. Changes in soil organic carbon and nitrogen as a result of cultivation. In: Bouwman AE. (ed.), *Soils and the greenhouse effect,* Wiley & Sons, Chichester, U.K.

Pretty JN; Noble AD; Bossio D; Dixon J; Hine RE; Penning de Vries FWT; Morison JIL. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental Science Technology* 40(4):1114–1119.

Ringius L. 1999. Soil carbon sequestration and the CDM opportunities and challenges for Africa. Center for International Climate and Environmental Research – Oslo (CICERO) Report.

Schahczenski J; Hill H. 2009. Agriculture, Climate Change and Carbon Sequestration. NCAT, National Sustainable Agriculture Information Service, 1-800-346-9140, www.attra.ncat.org

Scherr SJ. 2000. A downward spiral? Research evidence on the relationship between poverty and natural resource degradation. *Food Policy* 25:479–498.

Shiferaw B; Holden ST. 1998. Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: A case study in Andit Tid, North Shewa. *Agricultural Economics* 18:233-247.

Warren A. 2002. Land degradation is contextual. *Land Degradation and Development* 13:449–459. DOI: 10.1002/ldr.532

Woomer PL; Martin A; Albrecht A; Resck DVS; Scharpenseal HW. 1994. The importance and management of soil organic matter in the tropics. In: Woomer PL; Swift MJ. (eds.). *The biological management of tropical soil fertility,* Wiley & Sons, Chichester, UK: 47–80.

Appendix. Conversion of livestock number into TLU

LIVESTOCK TYPES	TLU EQUIVALENT
Cattle: mature female, bulls, and oxen	1.00
Calves	0.75
Goats and sheep	0.40
Heifers 1-2 years	0.10
Donkeys	0.50
Camels	1.00
Horses and mules	0.80

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