Determinants of small-scale farmers' perception to soil erosion and their adoption of land management practices in north-western Ethiopia

(エチオピア北西部における小規模農家の土壌侵食に対する認識
および土地管理策の選択に関する決定要因)

Gebresilasie Zerihun Nigussie

The United Graduate School of Agricultural Sciences
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A dissertation submitted to

The United Graduate School of Agricultural Sciences, Tottori University
In partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Gebresilasie Zerihun Nigussie

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank and praise the Almighty God, for all his blessings and for giving me the patience and strength throughout the study period.

I give special gratitude to Japanese Government for providing this study opportunity through its Monbukagakusho: MEXT Scholarship program. I am also thankful to the International Platform for Dryland Research and Education (IPDRE) of the Tottori University for offering an overseas travel grants to my study sites in Ethiopia. This study was supported by JSPS KAKENHI Grant Number JP25257417.

My heartfelt appreciation goes to my principal supervisor Prof. Atsushi Tsunekawa for his unreserved comments, guidance and encouragement in the whole process of my study. His support of my travels to the study sites was deeply appreciated. I would also like to extend my sincere gratitude to Dr Nigussie Hargeweyn, Dr Enyew Adgo, Dr Dagnachew Aklog and Dr Derege Tsegaye for their overall guidance, encouragement, comments, logistic and other supports during the whole study period. I am also thankful to my co-supervisor, Prof. Makoto Nohmi, for his guidance and valuable comments.

I owe much thanks to Prof. Dr Steffen Abele, you were the one around when I was looking for professional discussion. I enjoyed working with you and learned a lot. I wholeheartedly thank you for that!

My deepest thanks go to Emako Tomemori and Yuki Miyata for willingly assisting on different administrative issues, translation, handling my study travel cases and other administrative routines.

I would also like to thank my colleagues in Tottori University (Kindye Ebabu, Mesenbet Yibeltal, Dagnenet Sultan, Ayele Fenta, Fantahun Aklog, Misganaw Teshager, Shunsuke Imai, Tana Qian, and others) for the wonderful and memorable time we spent together.

I am also very grateful for the whole Ethiopian community in Tottori for making me feel home during Ethiopian holidays.

I would also like to extend my appreciation to Anteneh Wubet, Getachew Dagnew, Bantesew Muluye, Solomon Gezahegn, Fentahun Ferede and Achameleh Kassie for sharing the hurdles of my field works with no hesitation. Thank you guys for being around when I was looking for your help. In addition, the support I received from data enumerators is immense and it deserves real thankfulness to all of them.

I appreciate the support of farmers, experts and local administrators who have participated in interviews, group discussions and questionnaire surveys. You have devoted your precious time with no incentive at all. I wholeheartedly thank you all.

I am fully indebted to my loving wife, Simret Kassahun, for taking all family responsibilities alone, for her unreserved love and encouragement throughout my study period, and for her patience while I was away from home. Thank you for being part of life. I should also extend a warm bunch of love to my beloved son, Mikias. You are the source of my strength and a sign of bright future all the way through. May God bless you both!

Last but not least, I would like to extend my sincere gratitude to my mother, Yalemwork Abate. Thinking of your prayer is serving me as a leaping spring all in my way. May God give you more age and health! I would also like to thank my brothers and sisters for their encouragement and love.

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ACRONYMS AND ABBREVIATIONS

°C	Degree Celsius
ETB	Ethiopian Birr (currency)
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System
GTP	Growth and Transformation Plan
ha	hectare
m a.s.l.	meter above sea level
m b.s.l.	meter below sea level
ME	Marginal Effect
MEA	Millennium Ecosystem Assessment
MERET	Managing Environmental Resources to Enable Transition to more sustainable livelihoods
Mg	Megagram
mm	millimeter
MT	Metric Ton
MVP	Multivariate Probit
OLM	Ordered Logit Model
PASDEP	Plan for Accelerated Sustainable Development to Eradicate Poverty
PPOM	Partial Proportional Odds Model
PR	Poisson Regression
PSNP	Productive Safety Net Programs
RUSLE	Revised Universal Soil Loss Equation
SD	Standard Deviation
SDC	Swiss Agency for Development and Cooperation
SE	Standard Error
SLM	Sustainable Land Management
SLMP	Sustainable Land Management Programme
SPSS	Statistical Package for the Social Sciences
SSA	sub-Saharan Africa
SWC	Soil and Water Conservation

TLU	Tropical Livestock Unit
USD	United States Dollar
USLE	Universal Soil Loss Equation
WFP	World Food Programme
WLRC	Water and Land Resource Centre

Chapter 1

Introduction

Chapter 1. Introduction

1.1 Setting the context

Ethiopia is a mountainous country in the East Africa Horn region with topographic features dominated by rugged terrains, deep gorges and associated lowland plains, and it is bisected plateau by the Great Rift Valley—the northwestern and the southeastern highlands. Geographically, it lies between latitudes 3°24′N and 14°53′N and longitudes 32°42′E and 48°12′E (see Figure 1), neighboring with Sudan and South Sudan to the west, with Eritrea to the north, with Djibouti and Somalia to the east and with Kenya to the south. It has a surface area of 1.127 million km^2. According to the World Bank estimate, as of 2015 a population of more than 99 million people (over 99 people per square km) inhabits the country, growing at a rate of about 2.5% per annum, of which 80% reside in rural areas (World Bank, 2017). This makes the country the second populous nation in Africa next to Nigeria (Hermans-Neumann *et al.*, 2017; World Bank, 2017).

Ethiopia is one of the poorest countries of the world with per capita income of USD 590 for year 2015 (World Bank, 2017). Climatic conditions within the country are quite diverse due to topographic-induced variations, ranging from semi-arid to humid and warm (i.e., tropical monsoon climate), and altitude ranges from 125 m b.s.l. at Danakil Depression to 4,620 m a.s.l. at Ras Dashen Mountain, the highest point in the country (Taddese, 2001). The annual rainfall contrasts from as low as 100 mm $year^{-1}$ in the northeast lowlands of Afar region to as high as 2,500 mm $year^{-1}$ in the southwest highlands with high variation across the country (Hermans-Neumann *et al.*, 2017). The relative favorable conditions of the Ethiopian highlands, which represent areas exceeding 1,500 m a.s.l. and mean annual temperature of 20 °C or less, have attracted humans to make a living through farming for long time (Sonneveld & Keyzer, 2003).

To date, as elsewhere in SSA, the agriculture sector in Ethiopia is central to the economy in terms of income, employment and generation of export revenue. Although showing a slight decline over the years, it accounts about 41% of the country's total GDP, close to 81% of its total employment (World Bank, 2017), and approximately 70% of its total export earnings (FAO, 2014). Except in the lowland and pastoral areas, agriculture in the country is characterized by subsistence mixed farming system where crop cultivation and livestock husbandry form important components.

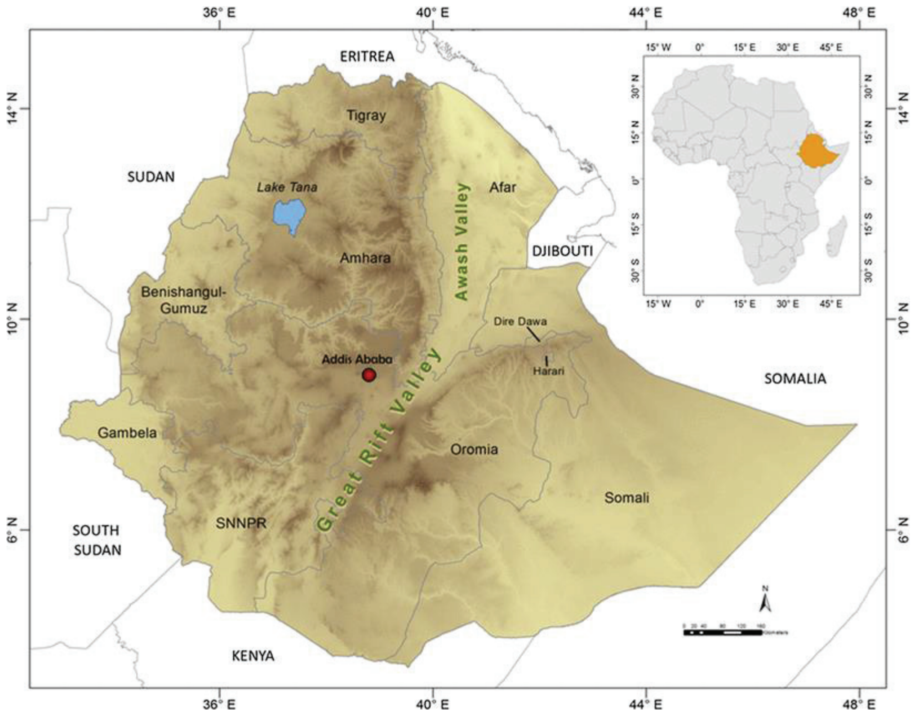

Figure 1: Location map of Ethiopia (Source: Hermans-Neumann et al., 2017)

Among the sub-sectors of agriculture, crop production is a major contributor to GDP accounting for approximately 29% in 2005/2006 (Alemayehu *et al.*, 2011). Smallholder agriculture contributes the lion's share (about 95%) of agricultural outputs, occupying more than 96% of the total agricultural cropland in the country (Alemayehu *et al.*, 2011). Agriculture is also the main source of fuel energy for cooking and heating. Wood biomass and agricultural residues constitute about 90% of the national household energy consumption (Berhanu *et al.*, 2017). The sector is predominantly rain-fed, low input, low output subsistence agriculture, so highly sensitive to changes and variability in the climate and other environmental problems. Cereal production occupies the major share of agricultural production (more than 73%) in the country, of which teff, maize, sorghum and wheat are the most important crops grown. Teff constitutes around one-fifth of the total smallholder agricultural land, followed by maize (17%), sorghum (12%) and wheat (11%) (Alemayehu *et al.*, 2011). Smallholder farmers also grow pulses, oilseeds, vegetables, root crops, fruits and cash crops.

The country has been witnessing an increase in agricultural production. However, it is asserted that much of the increase has resulted from land expansion rather than increase in productivity (Alemayehu *et al.*, 2011). For instance, World Bank (2017) shows that between 2000 and 2014, the average annual total cereal production, was 14.3 million MT (ranging from 8 million MT in 2000 to 23.6 million MT in 2014) whereas the average harvested area was 8.8 million ha of land (ranging from 7.2 million ha in 2000 to 10.2 million ha in 2014). Owing to the low agricultural productivity and production systems, the sector has been unable to produce sufficient quantities to feed the country's rapidly increasing population during the last three decades (Kassa & Alemu, 2017). This imbalance, among others, puts the country amongst large recipients of emergency food aid and commercial food importer (Gelan, 2007; Kassa & Alemu, 2017). Much of the country's agricultural production is concentrated in the highland domains—areas where there exist acute land shortages, rapid population growth, and high demand for increased food production (Sonneveld & Keyzer, 2003). Average land holding size is low and declining over time. On average, the per capita land holdings in Ethiopian highlands fell from 0.5 ha in the 1960s to only 0.2 ha by 2008 (Spielman *et al.*, 2011). Highlands comprise nearly 43% of the country's total land mass, 88% of the human population, and 75% of the country's livestock (Keyzer & Sonneveld, 2001). As a consequence, overexploitation of the land resources in the highlands over a long period has resulted in severe soil degradation. One of the most challenging impacts of which is falling or unchanging yields of major food staple crops in the country. For example, while the area under grains expanded on average by 3.4% during 2004/05–2008/09 (Bachewe, 2012), the per hectare grain production remained flat at 1.4 tons—one of the lowest worldwide (Alemayehu *et al.*, 2011).

Being the cornerstone of the Ethiopian economy and the fact that about 30% of the population live below the poverty line (World Bank, 2017), agriculture is placed at the center of the growth and poverty reduction strategies in the most recent five-year development plans. All of the plans and strategies have recognized soil degradation as an important detriment to development of the agriculture sector. For instance, the PASDEP (2006–2010) aimed to significantly accelerate growth through commercialization of agriculture, promotion of the private sector and scaling-up of efforts to foster sustainable development. Land and watershed management activities were featured among the most important investment areas to boost agriculture production (Schmidt & Tadesse, 2014). Likewise, the GTP (GTP I, 2010–2015; GTP II, 2016–2020) maintained its focus on agricultural productivity, research and natural resources management. It outlined the importance of promoting agroecology based SLM to combat land degradation (Schmidt & Tadesse, 2014). Despite the fact that policies and strategies are important in achieving economic development, sustained growth in the agriculture sector relies on how land resource is managed by small-scale farmers. Efforts are needed to understand the behavior of farm managers towards adoption of various land management practices so as to achieve their sustained use across the landscape.

1.2 Problem in focus

In Ethiopia, land degradation is mainly the outcome of historical development of agriculture and human settlement in highland areas: due to its favorable climatic conditions, political factor and fertile soil (Hurni, 1993; Sonneveld, 2002). Land degradation particularly through soil erosion and soil nutrient depletion have been a major threat to the environment in Ethiopia, and to the sustainable development of agriculture, where the majority of rural livelihoods is dependent. Many parts of the country—especially the highlands—have been witnessing severe soil erosion and nutrient depletion phenomena due to intensive cultivation, forest clearing and other natural problems, such as rugged topography and intensive rainfall. While assessments of land degradation extent and severity vary significantly across the country, depending on the methods and scales under consideration, existing statistics provides sufficient testimonies for the severity of the problem. That is, it occurs at varying rates and with varying degrees of severity in different locations. Estimates show that half of the Ethiopian highlands (about 27 million ha) are significantly eroded, around 25% (about 14 million ha) are seriously eroded, and 4% have been irreversibly lost so that they could not support further cultivation (FAO, 1986; Yesuf *et al.*, 2005). Furthermore, according to Haregeweyn *et al.* (2017) around 39% of the Upper Blue Nile Basin, for instance, is estimated to suffer from severe to very severe soil erosion problem.

As estimates from a national-scale study indicate, annual gross soil loss all over the country reaches about 1.5 billion Mg (Hurni, 1993), out of which the Upper Blue Nile Basin is estimated to contribute 131 million Mg of fertile soil (Betrie *et al.*, 2011). The rates of soil loss estimate in the country ranges between 42 to 300 Mg ha^{-1} year^{-1}, mainly depending on slope gradient, rainfall intensities and land-use types (Gebreselassie et al., 2016). The mean annual rate of soil erosion on cultivated land in the country, according to Hurni (1993), is estimated at 42 Mg ha^{-1} year^{-1}, which is equivalent to a soil depth loss of 4 mm year^{-1}. In the extreme cases, in highland areas the rates of soil loss reach as high as 200 to 300 Mg ha^{-1} year^{-1} (Hurni, 1993). More specifically, higher rates of soil loss have been observed in the north-western highland watersheds such as Angeni (110 Mg ha^{-1} year^{-1}) (Herweg & Ludi, 1999), Chemoga (102 Mg ha^{-1} year^{-1}) (Bewket & Teferi, 2009) and Koga (265 Mg ha^{-1} year^{-1}) (Gelagay & Minale, 2016). Accordingly, almost all of the soil loss figures being reported from the region are far exceeding the often-slow soil formation rate (i.e., 12.5 Mg ha^{-1} $year^{-1}$) (Hagos *et al.*, 2011). Similarly, estimate on soil nutrient depletion from the Ethiopian highlands has indicated a rate of 122, 13 and 82 kg ha^{-1} $year^{-1}$ of nitrogen, phosphorus and potassium, respectively; out of which 70%, 80% and 63% respectively of the nutrient outflows are contributed by soil erosion (Haileslassie *et al.*, 2005).

All the aforementioned estimates suggest that the rate of soil degradation in Ethiopian highlands is not acceptable. And much of the soil degradation takes place from cultivated lands and its effects are easily reflected in the agricultural sector. As a result, the overall economy of Ethiopia is estimated to lose about USD 106 million annually (Bojö & Cassells, 1995), and the study of Sonneveld (2002) extends this estimate to an annual loss of USD 1 billion. Furthermore, a more recent estimate of Gebreselassie *et al.* (2016) puts the annual cost of land degradation to about USD 4.3 billion. Annually, because of soil erosion the economy loses about 1.5 million MT of grain yield that could have added to the country's food basket (Taddese, 2001). Generally, the loss is reported to represent 2–6.75% of the agricultural GDP, and an annual reduction of about 2% in national grain yield (Yesuf et al., 2005). Under a stationary scenario, Sonneveld & Keyzer (2003) predicted that the agricultural production potential of the land would be reduced by 30% due to soil erosion by the year 2030. Estimates on the cost of action to rehabilitate lands being degraded between 2001 and 2009 due to land use and land cover change is found to equal about USD 54 billion over three decades, whereas if nothing is done (cost of inaction), the subsequent losses may equal almost USD 228 billion (Gebreselassie *et al.*, 2016). The above illustrations partly show the extent to which soil erosion is a contributing feature in the country's declining agricultural productivity, persistent food insecurity and rural poverty, and it also suggests that improvement can only be possible through the enhancement of the degraded land resource base.

1.3 Past efforts to mitigate the problem

In the highlands of Ethiopia, land degradation has been and remains among the most severe problems that constrains agricultural productivity and food security (Hurni, 1993; Bewket, 2007). Soil erosion and nutrient depletion are the most important forms of land degradation in the Ethiopian highlands (Hurni, 1993; Sonneveld & Keyzer, 2003; Haileslassie *et al.*, 2005; Amsalu & de Graaff, 2007; Hurni *et al.*, 2015). Among others, unsustainable farming practices, high human and livestock pressure, deforestation, and lack of appropriate land policy have been pointed out in literature as the main contributory factors to soil erosion in Ethiopian highlands (Osman & Sauerborn, 2001; Tamene & Vlek, 2008; Gebreselassie *et al.*, 2016).

Despite the alarmingly increasing land degradation in the Ethiopian highlands, the issue of soil conservation had been curiously neglected prior to 1974—the year of overwhelming famine in northern Ethiopia (Shiferaw & Holden, 1998; Amsalu & de Graaff, 2007; Teshome *et al.*, 2016). Recognizing the importance of SWC and afforestation in improving the country's food security situation in general and the productivity of subsistence agriculture in particular, the government of Ethiopia, with the support gained from various international and bilateral agencies, has been implementing different large-scale projects. For instance, the WFP (1973–2002) has been among the first to provide such support (Harrison, 2002; Haregeweyn *et al.*, 2015). The early phase of WFP intervention has taken the form of emergency food assistance in famine affected areas. In the early 1980s, the support has evolved into the 'food-for-work' programme—farmers provide their labour in implementing various mechanical conservation measures (e.g., stone bunds, soil bunds) in cultivated fields and the afforestation of hillsides, and in return they receive grain and edible oil—and employment generation schemes (Harrison, 2002; Amsalu & de Graaff, 2007). For example, during the period of 1975 to 1989, terraces were built on 1,188,000 ha, and a land of about 310,000 ha was vegetated (Assefa & Hans-Rudolf, 2016).

Later on, similar large-scale interventions have been pursued across the country with the support of multiple international agencies (e.g., FAO, European community, World Bank, GIZ), including the MERET (2003–2015), PSNP (2005–present), community mobilization through free-labor days (1998–present), and the SLMP (2008–2018) (Haregeweyn *et al.*, 2015). However, the majority of physical SWC works have been either partially or entirely removed by farmers themselves (Shiferaw & Holden, 1998; Bewket, 2007). Besides, small-scale farmers' in the highlands of Ethiopia have been observed resorting between different land use systems and implementing various land management practices for long time to protect their land from soil erosion, including drainage ditches, waterways, bunds, agroforestry, manuring and cut-off drains (Osman & Sauerborn, 2001; Taddese, 2001; Monsieurs *et al.*, 2015; Engdayehu *et al.*, 2016). However, in spite of the rapidly growing awareness about the beneficial effects of implementing these practices among small-scale farmers', their investment is limited or do not coincide with the extent of the soil erosion problem (Teklewold *et al.*, 2013). In addition, it seems that farmers' needs and SWC wisdom have attracted far lesser attention in consecutively introduced land management intervention programmes, which may be serving as a disincentive for wider expansion. As a consequence, soil erosion remains a widespread phenomenon across the highlands of Ethiopia in general and the Upper Blue Nile Basin in particular, which is the subject of this study. This in turn seems to imply that the initiatives had little or low success in stimulating wider adoption and sustained use of introduced land management practices among small-scale farmers (Bewket, 2007; Adimassu *et al.*, 2012), which in turn entails the need to understanding of factors that determine farmers' investments in and sustained use of SLM practices.

1.4 The objectives of the study

The main objective of this study is to develop an empirical model that links perceptions of farm level soil erosion problem with adoption of various land management options among small-scale farmers in Ethiopia. The specific objective to be perused under this study include:

- Investigate how farmers perceive the severity of soil erosion and to explore the principal determinants of variations.
- Determine the underlying factors that are posited to affect the adoption of SLM technologies.
- Assess the motivations of farmers to establish agroforestry, the respective determinants and the context in which tree planting has expanded.
- Analyze policy implications and come up with relevant policy implications.

1.5 Concepts and definitions

Land degradation reduces the capability of land to satisfy a particular use to humans (Blaikie & Brookfield, 1987). It covers any process that reduces land productivity, assuming other factors such as technology, management and weather remain same (Bojö & Cassells, 1995). On the other hand, soil degradation is a specific subsection of land degradation which has significant bearing on agricultural production. It is 'a process that describes human-induced phenomena which lower the current and/or future capacity of the soil to support human life' (Lal, 1988; Oldeman *et al.*, 1991). More broadly, it can also be defined as a loss or a fall in soil's life-support functions or sustainable production, in agricultural sense (Lal *et al.*, 1989). Such degradation occurs when the soil resource is overexploited beyond its capability/suitability, which is a widespread phenomenon in the developing world (Lal, 1988). It is generally a complex and long-term process that undermines soil quality, and hence its productivity potential.

Soil erosion is defined as the washing away of soil by water, and/or the blowing away of soil particles by wind and depositing elsewhere. It can occur naturally in the physical environment, but human interference significantly accelerate this natural process (Blaikie & Brookfield, 1987), which is mainly the case in SSA. Soil erosion involves both on-site and off-site effects (Ledermann *et al.*, 2010; Erkossa *et al.*, 2015). The onsite effect of soil erosion is related to yield loss, which is often related to nutrient loss with runoff and sediment (Erkossa *et al.*, 2015), higher fertilizer application rates, and stone accumulations on the field, thus increasing farm production costs; whereas its offsite effects include water pollution, sedimentation and siltation of rivers, lakes, dams and waterways and disruption of wildlife ecology (Lal, 1998; Ledermann et al., 2010). And SWC stands for any sets of measures that are aimed at maintaining or enhancing the production capacity of the soil through preventing or reducing of erosion, conserving of soil moisture and maintaining or improving of soil fertility. And so, it generally involves the use of various biological (e.g., agroforestry, grass strip, cover crop), physical (e.g., *fanya juu*[1], soil bund, stone bund, terrace) and agronomic measures (e.g., minimum tillage, mulching, manuring) to offset the effects of soil degradation.

The economic assessments of SWC often poses a substantial analytical challenge, and (Erenstein, 1999) differentiates two schools in this regard: (1) the evaluation school is aimed to quantify the on-site and off-site economic effects and the present and future values of implementing SWC measures. That is, it assesses the trade-offs involved in the decision to implement SWC measures, and (2) the adoption school is meant to provide explanation behind the divergent behaviors of economic actors towards investing in SWC measures. This study follow the latter approach, and adoption is defined as the in-field implementation of—or investment decision on—a set of SWC technologies by a farm household. The extent of farm households' response to in-field soil erosion, among others, depends on their perceptions of the problem. The addition of individual farmer perceptions toward soil erosion in a farmer behavior model is believed to add to our empirical understanding of farmer behavior. This is believed to establish a link between perceived soil erosion and the farmer's on-farm adoption of SWC measures. Here, perception is explained by individual's attitudinal differences toward the severity and likelihood of the consequences of soil erosion.

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[1] A bund that consists of constructing embankments along a slope by digging out ditches following contour lines and depositing the soil uphill to form a ridge to block soil movements. Originally, it is a Swahili word meaning to "throw soil uphill".

1.6 Theoretical framework of adoption

Researchers have long studied the processes by which farm households adopt new practices and innovations. Several paradigms can be distinguished across literature regarding this issue. For instance, Adesina & Zinnah (1993) define three main paradigms, namely the economic constraint paradigm, the innovation-diffusion-adoption paradigm, and the adopter perception paradigm.

Economic constraints paradigm: Upadhyay *et al.* (2003) further subdivides the economic constraint paradigm into the income paradigm and the utility maximisation paradigm. Under the income paradigm, there are some economists who assume that individuals strive for profit maximisation. This implies that when an innovation or new technology results in higher profits, farm households 'automatically' adopt the technology. This idea is consistent with the neoclassical economic theory. The main strength of this version of the paradigm—profit maximization—lies in considering the role of changes in income that motivates or inhibits innovation (Upadhyay *et al.*, 2003). Generally, it assumes that resource endowments are asymmetrically distributed and this conditions the observed pattern of adoption of technological innovation (Adesina & Zinnah, 1993). The possible economic constraints (or incentives) can be:

- Endowments of natural resource: an increasing scarcity of resources (e.g. fertile land) leads to higher shadow prices for the resource, motivating farm households to adopt a resource conserving technology (e.g., soil and water conservation). As a result, early adopters of the technology are those resource constrained farm households (Foltz, 2003).
- Capital scarcity: lack of own capital or no access to credit entails the difficulty that farm households have to undertake long term investments, and thus farmers with better access to capital will be in the forefront to adopt the technology (Foltz, 2003).
- Learning costs: technologies will diffuse fastest in areas where the learning costs are low. When information about a technology is readily available and can be evaluated by potential adopters, being rational profit maximizers, they can act easily upon it (Shampine, 1998; Foltz, 2003).
- Risk attitude: risk aversion behavior delays adoption i.e., farmers do not invest in uncertain technologies or technologies that potentially create higher variance in output (Feder *et al.*, 1985; Foltz, 2003; Yesuf & Bluffstone, 2009).

However, this paradigm fails to recognize heterogeneity among farmers' preferences, and thus unable to justify why some profitable technologies remain not adopted (Upadhyay et al., 2003). For instance, small-scale farm households often opt for tolerable profits (also called satisfying behavior or preference for self-sufficiency), not for maximum profit. There are authors (e.g., Fairweather & Keating, 1994) who argue that though profit maximization objective is clear, it fails to recognize the complexity of farm households' goals. Farm households often have objectives other than profit maximization, and thus economic objectives are only part of a set of objectives. The various set of objectives, including risk spreading, leisure, social reward, social status, social network, consumption, profit, environmental protection, etc., can therefore congregate in the term utility. As a result, most economic analysis of adoption decision is deeply entrenched in utility considerations (i.e., utility maximization) in explaining farm households' behaviour. Thus, this paradigm states that farm households will adopt a new technology if its utility exceeds the utility of the traditional technology.

Innovation-diffusion-adoption paradigm: The diffusion paradigm is based on the innovation-diffusion theory of Rogers (1983). In his pioneer work, he defined the adoption process as 'the mental process an individual passes from first hearing about an innovation to final adoption'. According to this paradigm, given the appropriateness of the innovation, exposure to information about the innovation is the key factor determining adoption decisions. As the knowledge is spread over time, the new technology is adopted on a larger scale. The diffusion theory made an important contribution to the adoption studies.

The innovation-diffusion-adoption paradigm conceptualizes adoption as a multi-stage decision process. Adoption is seen as a process of collecting information, revising opinions/attitudes and reassessing decisions – in other words, a dynamic learning process (Feder et al., 1985). Existing literature recognizes that adoption behaviour of farm households is complex and requires a blend of the income, utility and diffusion paradigms (Upadhyay et al., 2003). Any adoption decision is preceded by an information acquisition period which is also called an awareness or learning period (Dimara & Skuras, 2003). As a result, knowledge generation and distribution mechanisms (e.g., extension, training) are important factors in the adoption process of an innovation as the decision whether to adopt or not can be seen as a 'risky choice' problem. In such a case, the farm household is unsure whether he/she will be better off or not by adopting the innovation (Foltz, 2003; Marra et al., 2003), i.e., how the new technology or innovation will affect the production and/or profit. The likelihood of making a correct decision clearly depends on the decision maker's knowledge of the relevant parameters. Over time, when actual yields and profit are realised with the innovation, more knowledge is gained on the new technology (Feder et al., 1985), and the innovation is perceived as less risky (Marra et al., 2003). Thus, the model assumes that making people aware of new ideas will lead to attitude formation, which will be conducive for acceptance and ultimately adoption.

Adopter perception paradigm: The adopter perception paradigm states that perceptions of the adopting farm households are important in influencing adoption decisions (Adesina & Zinnah, 1993). In case of SWC, innovations are often more of environment than profit oriented. Attitude and perception play an important role in the decision-making to adopt environmental technologies besides economic considerations (Ervin & Ervin, 1982; Norris & Batie, 1987; Gould et al., 1989). To fully explain adoption behavior of farm households, any model of the adoption process must include attitudes, motivations and perception. Before taking any concrete action, farmers often make internal trade-off analysis, weighing the personal advantages and disadvantages related to the conservation decision. This analysis in turn is determined by human values, which often differ from person to person. For instance, farm households that are ‘environmental’ oriented sooner adopt a SWC technology than their ‘profit’ oriented counterparts. According to Lynne et al. (1988), favorable attitudes towards SWC increase the levels of effort or investment.

Ervin & Ervin (1982) conceptualized the decision-making process towards SWC innovations as a three-stage model. The first stage is the recognition that there is an erosion problem. Farm households are believed to have a general awareness of existing and potential soil degradation problems (Smit & Smithers, 1992). This perception is conditioned by personal factors (human capital) as well as bio-physical factors of the land (physical capital) and institutional factors (awareness raising). Here the dependent variable is perception, measured on a scale. The second stage is the decision to adopt, whether to implement the SWC practices or not, measured as the number of interrelated land management practices. Besides the factors influencing the perception, also economic considerations start to play a role. In the final stage, the SWC effort (a function of the extent of individual practices on the farmland) is determined. The aforesaid factors influence conservation effort as well, but in a different way than they influence the decision to use a SWC technology (Ervin & Ervin, 1982).

1.7 Conceptual model for the study

In view of the foregoing discussion and following the work of Ervin & Ervin (1982), this study takes SWC adoption behavior as a sequential decision-making process where the physical environment, together with social, economic and institutional factors are accountable. Firstly, the farm household recognizes the existence of the soil erosion problem, secondly, the farm household decides whether or not to apply SWC practices, and finally he decides on the level of adoption in terms of its intensity or area under SWC technologies is determined. The advantage of dividing the adoption process into these three stages is that it gives a chance to dealing with each of them as a separate subsequent stage in the adoption process (Mbaga-Semgalawe & Folmer, 2000). As a result, they are analyzed independently to examine factors explaining each of them. On the basis of the conceptual models discussed above and other relevant literature, a conceptual model graphically illustrated below was developed to guide the study (see Figure 2). Thus, it is postulated that household's perception of the soil erosion problem, decision to use soil conservation measures and level of investment devoted to soil conservation are influenced by household's characteristics, economic, physical and institutional factors.

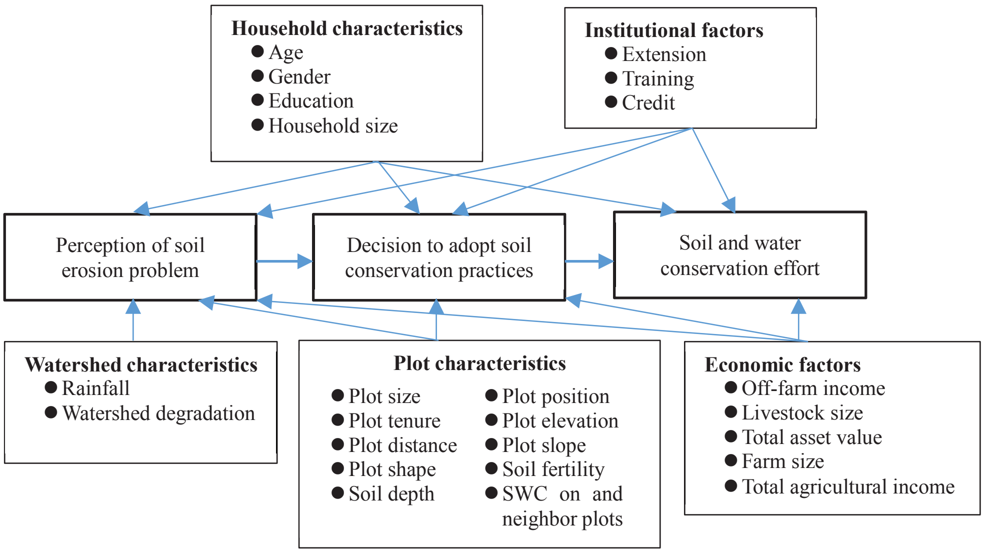

Figure 2: Decision-making process for soil and water conservation practices (Adapted from Ervin & Ervin (1982))

1.8 The structure of the thesis

The thesis is organized into five chapters. This chapter (Chapter 1) is devoted to providing background information regarding soil erosion problem and SWC activities in Ethiopia. This is to help readers to understand the extent of the problem and lay the ground to the rest of the chapters. In addition, it is composed of the objectives and conceptual framework of the study. Following the present chapter 1, chapter 2 presents the estimated empirical model for examining the factors that condition small-scale farmers' perceptions of the soil erosion problem. Chapter 3 is concerned with the analysis of small-scale farmers' adoption behavior of multiple SLM technologies in north-western Ethiopia. Chapter 4 provides the motivations behind successful expansion of agroforestry trees (i.e., *Acacia decurrens*) on degraded cultivated lands in contrast to other land management options. Moreover, it presents an estimated empirical model for explaining factors that determine farmers' investment decision in agroforestry practices. The last chapter, Chapter 5, presents the main synthesis of the thesis.

Chapter 2

Farmers’ perception about soil erosion in Ethiopia

Land Degradation and Development 28(2): 401–411, 2017.

Chapter 2. Farmers' perception about soil erosion in Ethiopia

2.1 Background

Soils have played significant roles in the earth's life-support system through the provision of a multitude of essential ecosystem services (i.e. provisioning, regulating, cultural, and supporting services) to humans and the environment (Keesstra *et al.*, 2016; Schwilch *et al.*, 2016). Nonetheless, most human interferences for pursuing economic benefits contribute to rapid and extensive degradation of soils over the past half a century (Haileslassie *et al.*, 2005; Brevik *et al.*, 2015), and consequently jeopardize their ability to provide services to society (MEA, 2005).

Soil degradation is a major threat to development in most economies of the world (Erkossa *et al.*, 2015; Taguas *et al.*, 2015; Keesstra *et al.*, 2016). About 15% of land worldwide is degraded, of which 16% is in Africa (Lal, 2003; Bai *et al.*, 2008). Soil degradation induced by water erosion in SSA is of concern mainly because of its consequences for subsistence agriculture, from which about 75% of the population derives their livelihoods (Erkossa *et al.*, 2015; Tully *et al.*, 2015). Among the SSA countries, Ethiopia has a high level of soil erosion (Mekonnen *et al.*, 2015; Gessesse *et al.*, 2016). Continued soil erosion seriously threatens peoples' livelihoods, especially in drought-prone highland parts of the country, where arable land is a very scarce resource. Over the past several decades, government and international agencies have been trying to support better land use and promote SWC technologies to halt soil erosion and improve peoples' livelihoods (Tesfaye *et al.*, 2014; Haregeweyn *et al.*, 2015; Gessesse *et al.*, 2016). Reports (Bewket & Sterk, 2002; Tesfaye *et al.*, 2014), however, have indicated a relatively low level of success in this respect across the wider landscape. Soil erosion rates as high as 42 Mg ha^{-1} year^{-1} have been reported on cultivated lands across the country (Bewket & Sterk, 2003; Tesfaye *et al.*, 2014; Haregeweyn *et al.*, 2015), and recent estimates by Hurni *et al.* (2015) indicated rates of 20 Mg ha^{-1} year^{-1} on currently cultivated lands and 33 Mg ha^{-1} year^{-1} on formerly cultivated degraded lands. Similarly, soil erosion has been a serious problem in the Upper Blue Nile Basin. Gelagay & Minale (2016) stated a soil erosion rate of 47 Mg ha^{-1} year^{-1} in the Koga watershed, and Bewket & Teferi (2009) reported a rate of 93 Mg ha^{-1} year^{-1} in the Chemoga watershed. In one of our study sites, Guder watershed, Kindye (2016) measured a soil loss rate of 71.8 Mg ha^{-1} year^{-1} on cultivated land.

The USLE, RUSLE and expert judgement based qualitative response models are the most widely used models to predict soil loss and identify erosion hotspots (Tamene & Vlek, 2008; Sonneveld *et al.*, 2011). These models make use of qualitative and quantitative data to estimate the magnitude and spatial distribution of soil erosion (Sonneveld *et al.*, 2011). In data–sparse (i.e. agricultural, geological and hydrological data) regions like Ethiopia, where estimations of soil loss are highly driven by empirical models (Bewket & Teferi, 2009; Gelagay & Minale, 2016; Haregeweyn *et al.*, 2017), however, their application is worrisome. Moreover, these models do not incorporate the observations of farmers who experience the phenomenon on a daily basis (Boardman, 2006) either as part of model input parameters complementing expert knowledge (e.g. assignments of weight scores, and crop cover, management practice and soil erodibility factor values) or means for validating results obtained. Furthermore, these approaches do not acknowledge the importance of local knowledge in perceiving the extent of the erosion problem.

A growing body of literature (Tegene, 1992; Shiferaw & Holden, 1998; Bewket & Sterk, 2002; Tefera & Sterk, 2010; Assefa & Hans-Rudolf, 2016) has demonstrated farmers' considerable knowledge in categorizing their land according to their soil erosion severity. Likewise, it is often highlighted that farmers' environmental behaviors (i.e. land management decisions) depend on their own perceptions of conditions in their environment (Shiferaw & Holden, 1998; Assefa & Hans-Rudolf, 2016; Keshavarz & Karami, 2016). Conversely, SWC intervention plans in the country to date have not considering but often rather ignoring such abilities of local farmers' (Snyder *et al.*, 2014; Assefa & Hans-Rudolf, 2016), and take them as mere labor contributors as a result (Bewket & Sterk, 2002; Abebe & Sewnet, 2014; Haregeweyn *et al.*, 2015). This results in locally undifferentiated SWC measures and little acceptance of the same by farmers, possibly explaining the little success in the past decades (Tegene, 1992; Snyder *et al.*, 2014; Tesfaye *et al.*, 2014; Assefa & Hans-Rudolf, 2016). If it can be shown that farmers can perceive soil erosion, for example, there can be a good reason to change the top–down dominated strategic and operational SWC planning process into a relatively interactive and participatory process.

The objectives of the paper are: i) to determine whether farmers are apt to perceive soil erosion patterns, and ii) to examine which factors influence farmer's ability to perceive soil erosion. Hence, I aimed to investigate factors that influence farmers' perception of soil erosion severity by examining the case of farmers in the Upper Blue Nile Basin, Ethiopia. I also compared our findings with theoretical predictions and empirical findings to determine whether farmers correctly perceive soil erosion as well as introduce appropriate measures.

2.2 Materials and methods

2.2.1 Study sites

The study was undertaken in three watersheds (see Figure 3): the Guder and Aba Gerima watersheds from the Fagita Lekoma (10°57′ to 11°11′ N, 36°40′ to 37°05′ E) and Bahir Dar Zuria (11°25′ to 11°55′ N, 37°04′ to 37°39′ E) districts, respectively, of Amhara Region, and the Dibatie watershed from the Dibatie district (10°01′ to 10°53′ N, 36°04′ to 36°26′ E) of the Benishangul Gumuz Region. These watersheds are part of the north-western highlands of the Upper Blue Nile Basin, Ethiopia. The watersheds are selected purposively because of their specific SWC experience, states of soil erosion, their ability to capture bio-physical and socio-economic heterogeneity, and represent higher, medium and lower elevation watersheds within the highlands of the basin. They thus provide a most suitable environment for the empirical study, as maximum potential factors affecting and determining farmers' soil erosion perception can be found.

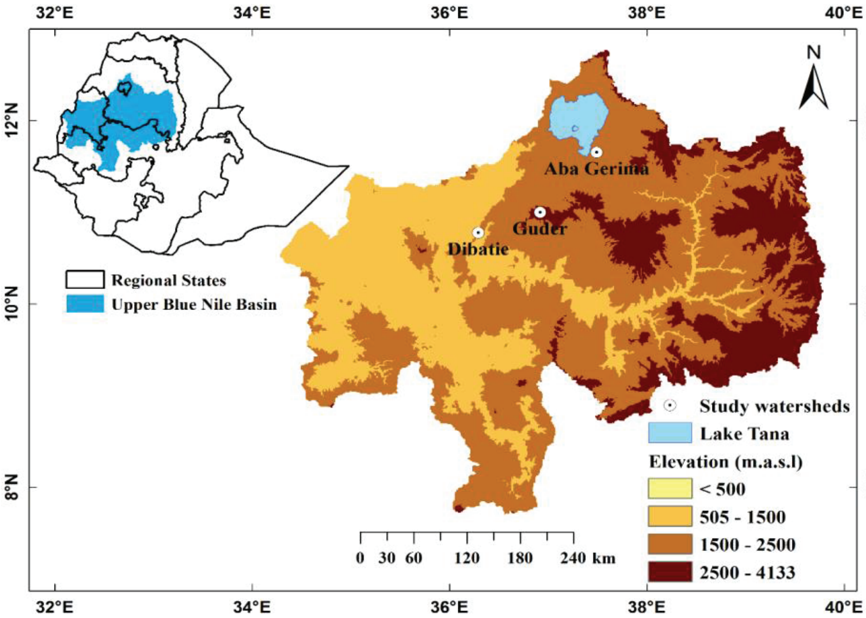

Figure 3: Location of the study sites

Beside the traditional SWC technologies (e.g., traditional stone bund, drainage ditch, agroforestry, etc.) practiced by farmers, various improved SWC technologies (e.g., soil bund, *fanya juu*, stone-faced soil bund, trench, etc.) are implemented. Each area has participated in the national government's regular extension programs and other public-based SWC interventions, but the areas' experiences with other externally funded programs has varied a great deal. The Aba Gerima watershed is part of the SDC funded WLRC project since 2011.

The Guder watershed has received support from the World Bank under the SLMP since 2008. The Dibatie watershed is not under any external support for SWC projects. Although it may need further study, I hypothesize that there is a better perception of soil erosion severity in sites where these projects are active. Agriculture in the watersheds is dominated by subsistence mixed crop–livestock farming systems (Table 1).

Table 1: Bio-physical characteristics of the study sites

Feature (unit)	Aba Gerima watershed	Guder watershed	Dibatie watershed
Location	11° 39′ 59″N 37° 29′ 24.4″E	11° 00′ 31.66″N 36° 55′ 56.68″E	10° 46′ 12.28″N 36° 16′ 38.98″E
Altitude (m a.s.l.)	1922–2250	1800–2900	1479–1709
Temperature (°C)	13–27	9.4–25	25–32
Annual rainfall (mm)	895–2037	1951–3424	850–1200
Rainfall pattern	Unimodal	Unimodal	Unimodal
Agro-ecological zone	Humid subtropical	Moist subtropical	Tropical hot humid
Total area (ha)	719	742.5	700
Soil type	Nitosols, Leptosols	Acrisols, Nitosols	Vertisols, Nitosols
Dominant crop	Teff, finger millet, wheat, maize, khat	Barley, teff, wheat, potatoes	Finger millet, teff, maize, ground nut
Dominant livestock	Cattle, sheep, goats and donkeys	Cattle, sheep, donkeys and horses	Cattle, sheep, goats and donkeys
Major land use types (ha)	Cultivated land (399.7), degraded bushland (123.5), grazing land (97.6), degraded land (5.5)	Cultivated land (297), degraded bushland (119), forest (72), grazing land (99), plantation (155)	Cultivated land (343), degraded bushland (117), degraded land (40.4), grazing land (136.8)
Soil erosion severity[a]	Moderate	Very severe	Slight
SWC-related projects	WLRC	SLMP	None
SWC activities	High	Medium	Low

Sources: Achamyeleh, 2015; Kindye, 2016; Nigussie *et al.*, 2016; Own surveys.

Note: Teff (*Eragrostis tef*); finger millet (*Eleusine coracana*); wheat (*Triticum aestivum*); maize (*Zea mays*); ground nut (*Arachis hypogaea*). Plantation includes eucalyptus and Acacia decurrens.

[a] Slight = 5–15 Mg ha^{-1} $year^{-1}$; Moderate = 15–30 Mg ha^{-1} $year^{-1}$; Very severe = >50 Mg ha^{-1} $year^{-1}$ (Haregeweyn *et al.*, 2017).

2.2.2 Data type, sampling and analysis

The data used in this study came from detailed household and plot surveys of 300 farm households and 1010 plots operated by the respondents in three watersheds of the Upper Blue Nile Basin. The survey was conducted in February and March 2015. A two-stage cluster sampling procedure, involving a combination of purposeful and random sampling, was used to select sample respondents. In the first stage, I purposely selected three watersheds based on the characteristics described in the section on the study sites above. In the second stage, 100 households were selected from each watershed, for a total of 300. Respondents were selected using systematic random sampling techniques on lists of households obtained from the respective local agricultural offices.

The household survey was conducted using semi-structured questionnaires and covered detailed information at the household, plot and watershed levels. A pre-survey test was also conducted in each watershed to customize instruments to local conditions. The plot survey covered specific plot-level information (i.e. plot elevation and slope) using a checklist. Plot elevation was measured by using GPS (GPSMAP 62st, Garmin) and slope was measured with a clinometer (PM-5/360 PC Clinometer, Suunto). Rainfall data was obtained from weather stations. To match with the period that farmers were asked to consider in their judgment of soil erosion severity, I took ten years monthly rainfall data. The data were input into SPSS statistical software (ver. 23.0, IBM, Armonk, NY, USA) and analyzed with a combination of descriptive and econometric methods.

2.3 Empirical model

The determinants of farmers' perceptions of plot-level soil erosion severity can be analyzed using qualitative response statistical models. In a case where a dependent variable takes graduated discrete-ordinal values, for example, when respondents are asked to rate their plot-level severity of soil erosion on a scale that takes several different values. In this type of case, I can assume that the probability of a farmer perceiving a specified level of soil erosion severity is the probability that the perception function falls in a range around the respective value, given that random disturbances in the perception function follow a logistic probability distribution.

In our case, farmers were asked to respond to two questions: i) whether they identified soil erosion as a problem on each of their plots since the last 10 years for owned plots, or since the time that they have started farming for rented in ones, and ii) the extent of the problem (severity level). They evaluated them on a limited scale: "very low", "low", "medium", "high" or "very high". Often, these types of evaluations are converted into a numeric score, in this case, from 1 (very low) to 5 (very high). For convenience, many researchers treat these scores as continuous variables, calculate the mean score and compare those means using standard statistical tools. Unfortunately, this type of analysis is based on assumptions that are hard to justify. One such assumption is that the numeric distance between scores has a specific meaning, for example, that two scores of 3 (medium) would have the same value as a score of 2 (low) and a score of 4 (high), even though this cannot necessarily be presumed from what the farmers actually said. Farmers' evaluations fell into different categories, which are clearly ordered but are not measured on an interval scale. Therefore, these scores should be treated and analyzed as ordered categorical responses, leading to the use of ordered-response models. In such models, it is assumed that scores represent ordered segments. In our case, respondents scored a level of soil erosion severity in a given plot in a particular ordered category, driven by a latent, unobserved variable y^*, which represents the farmer's ordering of the plot-level severity of soil erosion. Instead of this latent variable y^*, I observed y, a variable that falls into one of j ordered categories, in our case from 1 (very low) to 5 (very high).

Given that the outcome categories of the dependent variable appear to be ordered in terms of perceived soil erosion severity, a typical approach would be to use the standard OLM (Weisburd & Britt, 2014). The results from this type model are only valid, however, if the proportional odds assumption (i.e. parameter estimates are constant across the severity scores) is met (Williams, 2006; Weisburd & Britt, 2014). Therefore, after I fitted the standard OLM, I also conducted a formal test (the Brant test) on that assumption to reveal whether it had been violated by any subset of variables. If the assumption was found to be violated, a generalized OLM was used to express the probability of perceived soil erosion severity j by a farmer for a given plot such that:

$$\mathrm{p}(y_i > j) = \frac{\exp(\alpha_j - X_i'\beta_j)}{1 + \exp(\alpha_j - X_i'\beta_j)}, j = 1, 2, 3, 4$$

where X_i is a $(m \times 1)$ vector containing the values of perceived soil erosion severity i on the full set of m explanatory variables, β_j is a $(m \times 1)$ vector of regression coefficients, and α_j represents the cut-off point for the j^{th} cumulative logit.

However, this model relaxes the proportional odds assumption for all independent variables, which is not always correct. Because this assumption may be violated by only a few variables, however, a PPOM can be employed, in which one or more βs differ across equations and others can be the same for all equations. A gamma parameterization of the PPOM with logit function can be specified as:

$$p(y_i > j) = \frac{\exp[\alpha_j - (X_i'\beta_j + T_i'\gamma_j)]}{1 + \exp[(\alpha_j - (X_i'\beta_j + T_i'\gamma_j))]}$$

where T' is a $(n \times 1)$ vector $(n \leq m)$ containing the values of perceived soil erosion severity i on the subset of the m predictor variables for which the proportional odds assumption was not fulfilled. γ_j is a $(n \times 1)$ vector of regression coefficients associated with the n covariate in T', so that $T'\gamma_j$ is the increment associated with the j^{th} cumulative logit. In the model, each explanatory variable has one β coefficient, and $k - 2\gamma$ coefficients, where k is the number of alternatives (in our case, $k = 5$). There are $k - 1\alpha$ coefficients reflecting cut-off points. The overall contribution of these variables on different perceived categories of soil erosion severity can be computed by adding the gamma coefficients of the respective equation and the beta coefficients.

In this study, parameters of the OLM and PPOM were estimated by the maximum likelihood procedure in Stata software (ver. 14.1, StataCorp, College Station, TX, USA). The PPOM was fitted with a user-written Stata routine gologit2 gamma parametrization alternative (Williams, 2006). Interpreting the coefficients of intermediate categories requires caution because the direction of the effect is not always determined by the sign of the estimate (Weisburd & Britt, 2014). Marginal effects (measures of the impacts of the variables on the probability of each soil erosion severity level) were considered in the interpretation of the variables. For continuous variables, the partial derivative was calculated numerically; for dummy variables, the difference was computed.

Variables considered

Based on economic theory and previous empirical research of soil erosion (Gould *et al.*, 1989; Tegene, 1992; Shiferaw & Holden, 1998; Tefera & Sterk, 2010; Tesfaye *et al.*, 2014; Haregeweyn *et al.*, 2015; Teshome *et al.*, 2016), explanatory variables included socio-economic, demographic and institutional variables (age, gender, level of education, extension contact, number of livestock owned and number of days participating in public SWC works); plot-specific variables (plot size, plot tenure, plot distance to residence, plot shape, plot soil depth, plot position in the watershed, presence of SWC technology in neighboring plots, whether plot received public SWC improvements, and plot elevation and slope); and village-level factors (June rainfall, July rainfall and perception of watershed-level soil erosion). Definitions of the selected variables, hypotheses of the direction of their influence and their descriptive statistical measures are presented in Table 2.

2.4 Results

Plots in our sample were small, with an average size of 0.41 ha (Table 2). Household heads had an average of 1.26 years of schooling, and the average age was 47.6 years. About 86% of households were male-headed, with about 3.24 available adult equivalent laborers and 5.11 tropical livestock units. Most of the plots were owner operated, and on many plots and neighboring plots SWC technologies (traditional and improved) had been installed. Household members participated in public SWC works an average of 13 days per year, and more than half of the respondents perceived that the watersheds had been degraded through water erosion.

Table 2: Summary statistics and description of the variables used in the analysis

Variable (unit of measurement)	H_0 sign	Mean	SD
Age of the household head (Years)	+	47.64	11.58
Gender of the household head (1 = male, 0 = female)	+	0.86	0.34
Education level of the household head (years)	+	1.26	2.17
Frequency of extension contacts per annum (no. of contacts)	+	2.94	2.72
Household size (adult equivalent)	+	3.24	1.37
No. days household participated in public SWC (days)	+	13.43	9.13
Livestock size owned by the household (TLU)	+	5.11	2.73
Plot size (ha)	+	0.41	0.49
Plot ownership/tenure (1 = own, 0 = rent)	–	0.83	0.38
Plot distance to residence (minutes of walking)	+	24.74	13.44
Plot is convex shaped (1 = yes, 0 = no)	+	0.30	0.46
Farmer reports plot has shallow soil depth (1 = yes, 0 = no)	+	0.36	0.48
Position of plot in watershed, upper part (1 = yes, 0 = no)	+	0.32	0.47
Position of the plot in watershed, lower part (1 = yes, 0 = no)	–	0.30	0.46
Neighboring plots have SWC measures (1 = yes, 0 = no)	–	0.44	0.50
Plot received public SWC improvements (1 = yes, 0 = no)	–	0.34	0.47
Plot elevation (m a.s.l.)	+	2059.72	431.36
Plot slope (%)	+	11.16	7.77
June rainfall, average (mm)	+	210.58	30.54
July rainfall, average (mm)	–	348.29	47.64
Watershed perceived as being degraded (1 = yes, 0 = no)	+	0.51	0.50

Note: H_0 sign shows the *a priori* hypothesized direction of influence.

Farmers' perceptions of soil erosion severity

Farmers had varied perceptions regarding the extent of soil erosion on their plots (
Table 3). The differences in the percentages of farmers' judged plot-level soil erosion severity were significantly different among the three study sites ($p < 0.01$). In particular, a significant difference ($p < 0.01$) was observed among those plots perceived with "medium" to "high" soil erosion severity levels.

Table 3: Farmers' plot-level perceptions of soil erosion severity

Perceived	Watershed				
soil erosion	Aba Gerima	Guder	Dibatie	Total	Sig. (χ^2)
Very low	60 (12.74)	44 (11.99)	21 (12.21)	155 (15.35)	0.1
Low	133 (28.24)	86 (23.43)	35 (20.35)	305 (30.2)	3.8
Medium	155 (32.91)	92 (25.07)	79 (45.93)	336 (33.27)	15.9***
High	104 (22.08)	122 (33.24)	24 (13.95)	179 (17.72)	20.1***
Very high	19 (4.03)	23 (6.27)	13 (7.56)	35 (3.47)	3.6

Note: Figures are counts. Values in parentheses are percentages of the column total.
***$p < 0.01$.

Model results

Although I present parameter estimates of both the OLM and PPOM in Table 4 for comparison, our discussion is limited to the PPOM output. This model had one beta coefficient for each variable, three gamma coefficients for variables violating the proportional odds assumption, and four alpha coefficients reflecting the cut-off points. Because there are five perceived soil erosion severity levels, I have four equations. Altogether, the model estimated 21 coefficients: 21 in the first equation (beta) and five each in the remaining three equations. The coefficients that are omitted in the last three equations (i.e. gamma_2, gamma_3 and gamma_4) are identical to those in the first equation.

Table 4: Model estimation results for perceived soil erosion severity

	Model 1: OLM		Model 2: PPOM	
Variables	Coef.	SE	Coef.	SE
Beta				
Age of the household head	–0.0062	0.0058	–0.0073	0.0059
Gender of the household head	0.1975	0.1837	0.1868	0.1858
Education level of the household head	–0.2787***	0.0906	–0.31292***	0.0944
Frequency of extension contacts per annum	0.0872***	0.0244	0.0987***	0.0254
Household size, adult equivalent	0.0824*	0.0490	0.0695	0.0501
No. days household participated in public SWC	–0.0159	0.0086	–0.0056	0.0128
Livestock size owned by household	–0.0442*	0.0235	–0.0449*	0.0239
Plot size	0.1825*	0.0932	0.1799*	0.0948
Plot ownership/tenure	–0.0649	0.1838	–0.0665	0.1889
Plot distance to residence	0.3361***	0.1181	0.3795***	0.1215
Plot is convex shaped	1.8473***	0.1504	1.8368***	0.1532
Farmer reports plot has shallow soil depth	0.1594	0.1335	–0.7418***	0.1983
Position of plot, upper watershed	0.8398***	0.1489	0.8799***	0.1532
Position of plot, lower watershed	–0.4653***	0.1469	–0.4915***	0.1523
Neighboring plots have SWC measures	0.1279	0.1937	0.1127	0.2025
Plot received public SWC improvements	–0.0019	0.2125	0.0176	0.2215
Plot elevation	0.0016***	0.0004	0.0015***	0.0004
Plot slope	0.0039	0.0083	–0.0218**	0.0110
June rainfall	0.0801***	0.0236	0.0274	0.0268
July rainfall	–0.0570***	0.0159	–0.0244	0.0177
Watershed perceived as being degraded	–0.1307	0.1175	–0.1557	0.1203
Gamma_2				
No. days household participated in public SWC	—		0.0062	0.0116
Farmer reports plot has shallow soil depth	—		0.8707***	0.1860
Plot slope	—		0.0319***	0.0107
June rainfall	—		0.0385**	0.0164
July rainfall	—		–0.0261**	0.0103
Gamma_3				
No. days household participated in public SWC	—		–0.0396***	0.0149
Farmer reports plot has shallow soil depth	—		1.6356***	0.2399
Plot slope	—		0.0459***	0.0145
June rainfall	—		0.0701***	0.0209
July rainfall	—		–0.0397***	0.0133
Gamma_4				
No. days household participated in public SWC	—		–0.0502**	0.0255
Farmer reports plot has shallow soil depth	—		1.4642***	0.4071
Plot slope	—		0.0565**	0.0219
June rainfall	—		0.2430***	0.0518
July rainfall	—		–0.1561***	0.0329
Alpha				
Constant 1	–0.1796	0.8665	0.5200	1.0727
Constant 2	1.6335	0.8663	–1.0581	0.9308
Constant 3	3.5986	0.8741	–4.8715	0.9972
Constant 4	5.9870	0.8990	–3.5115	1.3229
Number of observations	1010		1010	
Log likelihood	–1282.00		–1220.47	
AIC	2614.00		2520.94	
LR(df)	341.9(21)		464.9(36)	

Note: — indicates data not applicable. $^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

The first equation is similar to a binary logistic regression model where the dependent variable is recoded as “very low” severity versus the other categories. The second equation is similar to the first one, but the dependent variable is recoded as “very low” severity +

“low” severity versus the others. For the third equation, the dependent variable is recoded as “very low” + “low” + “medium” severity versus “high” + “very high” severity. For the fourth equation, the dependent variable is recoded as the lowest four levels versus “very high” severity. The estimations for the PPOM with logit function are presented in Table 4, and the marginal effects are shown in Table 5.

The proportional odds assumption for each variable included in the model was tested using a series of Wald tests to see whether the variable’s coefficients differed across equations. Number of days that a household participated in public SWC activities ($p < 0.001$), farmer’s perception of a shallow soil depth ($p < 0.001$), plot slope ($p < 0.01$), June rainfall ($p < 0.001$) and July rainfall ($p < 0.001$) were found to be violating the proportional odds assumption. The gamma_2 and beta coefficients for the shallow soil depth variable were (0.8707) and (–0.7418), respectively. I added these two values to obtain the coefficient of this same variable in the second equation (0.1289). Likewise, I added the gamma_3 and gamma_4 coefficients with their corresponding beta coefficients to obtain the effect of this same variable in the third and fourth equations, respectively. Similarly, the effect of the other variables that did not satisfy the proportional odds assumption in various perceived soil erosion severity categories was different. Their respective parameter estimates in the second, third and fourth equations were computed in a similar manner as was used for the shallow soil depth variable.

Household characteristics

Household characteristics (demographic, institutional and economic) such as education level of the household head, number of extension contacts, number of livestock units and number of days of participation in public SWC were identified as significant factors that affect the likelihood of a farmer perceiving a certain level of soil erosion severity (Table 4 and Table 5). Farmers with more education were less likely to perceive severe soil erosion in their plots as compared with less educated farmers (coef. = –0.31292, $p < 0.01$), with other factors held constant. Similarly, farmers with more livestock were less likely to perceive soil erosion as severe as compared to those with fewer livestock units (coef. = –0.0449, $p < 0.1$). The effect of increased frequency of contact with extension agents was as initially expected. Farmers with more frequent contact with extension agents were more likely to perceive severe soil erosion in their plots as compared with those who had fewer extension contacts (coef. = 0.0987, $p < 0.01$). However, greater participation in public SWC initiatives was not found to enhance the probability of farmers perceiving “high” and “very high” levels of soil erosion.

Table 5: Marginal effects and standard errors for different perceived soil erosion severity levels

Variable	Erosion Status									
	Very low = 1		Low = 2		Medium = 3		High = 4		Very high = 5	
	ME	SE	ME	SE	ME	SE	ME	SE	ME	SE
Age of the household head	0.0008	0.0007	0.0006	0.0009	–0.0005	0.0004	–0.0007	0.0005	–0.0002	0.0002
Gender of the household head	–0.0211	0.0210	–0.0144	0.0235	0.0131	0.0122	0.0167	0.0167	0.0058	0.0058
Education level of the household head	0.0354***	0.0107	0.0242	0.0269	–0.0219**	0.0088	–0.0281***	0.0087	–0.0097***	0.0033
Frequency of extension contacts per annum	–0.0112***	0.0029	–0.0076	0.0087	0.0069***	0.0026	0.0089***	0.0023	0.0031***	0.0009
Household size, adult equivalent	–0.0079	0.0057	–0.0054	0.0073	0.0049	0.0039	0.0062	0.0045	0.0022	0.0016
No. days household participated in public SWC	0.0006	0.0015	–0.0008	0.0017	0.0056***	0.0016	–0.0037***	0.0013	–0.0017**	0.0007
Livestock owned by the household	0.0051*	0.0027	0.0035	0.0048	–0.0031*	0.0017	–0.0040*	0.0021	–0.0014*	0.0008
Plot size	–0.0203*	0.0107	–0.0139	0.0192	0.0126	0.0079	0.0161*	0.0085	0.0056*	0.0030
Plot ownership/tenure	0.0075	0.0214	0.0051	0.0158	–0.0046	0.0132	–0.0059	0.0169	–0.0021	0.0058
Plot distance to residence	–0.0429***	0.0138	–0.0293	0.0349	0.0265**	0.0119	0.0340***	0.0111	0.0117***	0.0041
Plot is convex shaped	–0.2077***	0.0198	–0.1419	0.1619	0.1283***	0.0358	0.1647***	0.0145	0.0567***	0.0092
Farmer reports plot has shallow soil depth	0.0839***	0.0219	–0.1084	0.0776	–0.0832***	0.0281	0.0854***	0.0203	0.0223*	0.0117
Position of plot in watershed, upper part	–0.0995***	0.0179	–0.0679	0.0786	0.0615***	0.0188	0.0789***	0.0139	0.0272***	0.0059
Position of plot in watershed, lower part	0.0556***	0.0173	0.0379	0.0451	–0.0343**	0.0148	–0.0441***	0.0141	–0.0152***	0.0052
Neighboring plots have SWC measures	–0.0127	0.0229	–0.0087	0.0178	0.0079	0.0144	0.0101	0.0181	0.0035	0.0063
Plot received public SWC improvements	–0.0019	0.0251	–0.0014	0.0174	0.0012	0.0155	0.0016	0.0199	0.0005	0.0068
Plot elevation	–0.0002***	0.0001	–0.0001	0.0001	0.0001**	0.0000	0.0001***	0.0000	0.0001***	0.0000
Plot slope	0.0025**	0.0012	–0.0044	0.0027	–0.0009	0.0019	0.0018	0.0014	0.0011*	0.0006
June rainfall	–0.0031	0.0030	–0.0094***	0.0034	0.0008	0.0033	0.0034	0.0029	0.0083***	0.0019
July rainfall	0.0028	0.0020	0.0069***	0.0026	–0.0019	0.0022	–0.0022	0.0019	–0.0056***	0.0013
Watershed perceived as being degraded	0.0176	0.0136	0.0120	0.0166	–0.0109	0.0079	–0.0139	0.0108	–0.0048	0.0038

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Plot characteristics

Of the 11 plot-level factors included in the model, eight were found to significantly affect farmers' perceptions (Tables 4 and 5). Greater plot size (coef. = 0.1799, $p < 0.1$) and distance from the residence (coef. = 0.3795, $p < 0.01$) raised the likelihood of farmers perceiving a higher level of soil erosion severity, as did having a convex shape (coef. = 1.8368, $p < 0.01$), being in the uplands (coef. = 0.8799, $p < 0.01$) and higher elevation (coef. = 0.0015, $p < 0.01$). Conversely, farmers in lowland areas (coef. = –0.4915, $p < 0.01$) were more likely to perceive a lower level of soil erosion severity. The probabilities of perceiving "high" and "very high" soil erosion severity levels were higher for farmers who possessed plots with shallow soil depth, holding other factors constant. The results obtained on plot slope were mixed. Farmers who owned steeply sloped plots were more likely to perceive the two extreme erosion severity levels (i.e. very low and very high).

Watershed characteristics

June and July rainfall distributions were found to have a significant effect on farmers' perceived level of soil erosion severity (Tables 4 and 5). June rainfall amount was more likely to form a "very high" perceived soil erosion level (marginal effect = 0.0083, $p < 0.01$) on farmers, whereas July rainfall amount was less likely to have that perception (marginal effect = –0.0056, $p < 0.01$). However, the opposite held true for plots that were perceived to have a "low" level of soil erosion severity.

2.5 Discussion

This study assessed potential predictors associated with farmers' plot-level perception of soil erosion severity by using PPOM. Of these factors, level of education of the household head, frequency of contact with an extension agent, number of days that household members participated in public SWC works, number of livestock owned by the household, plot size, distance to residence, plot shape, reported soil depth, position in the watershed (i.e. upstream or downstream), elevation and slope, and June and July rainfall distributions were found to be significant. This section provides a discussion regarding the effect of these factors. However, given our findings, I must be cognizant of a risk that by having many confounding factors, e.g. watersheds with high, middle and lowland location as well as diverging previous exposure to SWC projects, causality of observed significant effects may remain speculative.

Yet still, significance shows that there is a number of possible factors affecting farmers' soil erosion perception.

Formal education is generally believed to be important to complement indigenous knowledge and to enhance the ability of farmers to process new information. However, our findings demonstrated that the level of education attained by household heads was less likely to help farmers in perceiving the risk of soil erosion severity in their plots, which is not in agreement with the findings of previous studies (Ervin & Ervin, 1982; Asrat *et al.*, 2004). A possible explanation is that the curriculum in the existing formal primary education system in this area does not adequately emphasize environmental issues and instead focuses on basic literacy and numeracy skills (Dalelo, 2011); educated farmers have implemented better SWC measures (Asrat *et al.*, 2004), as a consequence experience lower erosion risk; or it may be rooted in the generally low level of school enrollment in the study area. This explanation is in accordance with that of Bekalo & Bangay (2002), who argued that the formal education sector is not well suited to deliver a meaningful program that identifies the symptoms of soil erosion and proposes alternatives towards more SLM practices. Similarly, greater household participation in public SWC initiatives was not found to enhance the probability that farmers would perceive higher levels of soil erosion. A possible explanation for this may be that the top-down nature of government-led initiatives often overlook local conditions and community views (Snyder *et al.*, 2014).

Livestock pressure has been blamed as a major contributing factor to severe soil erosion in the highlands of Ethiopia. Several studies (Mwendera & Saleem, 1997; Taddese *et al.*, 2002; Alemayehu *et al.*, 2013) have reported that vegetation cover decreases and soil compaction increases with increasing grazing pressure, which leads to lower infiltration rates, increased runoff and soil loss. In contrast, our results showed that, with other factors held constant, farmers with a greater number of livestock were associated with lower perceived levels of soil erosion. The farmers' reported perceptions could stem from their fear of the current government's approach of banning free grazing to reduce damage on installed SWC technologies by livestock. Alternatively, it may be a result of the farmers' belief that livestock contribute to land fertility improvement rather than degrade the environment (Bewket & Sterk, 2002; Kassie *et al.*, 2009); or wealthy farmers with more livestock may have applied more SWC measures (Kassie *et al.*, 2009; Abebe & Sewnet, 2014) and face lower erosion risk as a result. Furthermore, Tesfaye *et al.* (2014) asserted that farmers with more livestock are less likely to introduce improved SWC technologies on their croplands because the technologies compete for land that could otherwise be used for food or feed production. These factors may suggest the importance of bundling enhanced community awareness activities (Tesfaye *et al.*, 2014) with the introduction of better performing multipurpose livestock breeds (Benin *et al.*, 2003), which in the medium to long term may help to reduce both herd size and pressure on land resources.

The number of contacts that farmers had with agricultural extension agents was found to positively and significantly ($p < 0.01$) affect farmers' perception of soil erosion severity. This is likely true because greater contact with extension agents enables farmers access to knowledge-intensive information related to land and SLM options (Kassie *et al.*, 2009; Matouš *et al.*, 2013), which gives them the opportunity to mix indigenous knowledge with modern technology and methods. Furthermore, Tesfaye *et al.* (2014) reported that farmers with more contacts with extension agents are also more likely to maintain SWC structures because it allows them to access technical support and information about SLM technologies.

Slope was found to have a positive significant effect ($p < 0.1$) on the "very high" severity level, implying that farmers with plots in steeply sloped areas are more likely to perceive the impact of plot gradient on severity of soil erosion. This finding is in agreement with that of Teshome *et al.* (2016), who found a positive relationship between slope and soil erosion severity. The shape of the plot in terms of slope was also significant. I found that convex (hill-shaped) plots were perceived to lose more soil, presumably because the symptoms of erosion are more prevalent in these types of plots.

Plot size and soil depth were also important factors. The larger the field the higher is the likelihood of witnessing rills, surface runoff, sediment deposition and redeposition by farmers (Bewket & Sterk, 2003). Larger parcel size may create a positive incentive for small-scale farmers to invest in SWC technologies (Tesfaye *et al.*, 2014; Teshome *et al.*, 2016). This is presumably true in subsistence agriculture because farmers assume that SWC technologies compete for space on small plots, which reduces productivity in the short run, thereby increasing farmers' reluctance to apply countermeasures (Tesfaye *et al.*, 2014). Farmers were very likely to perceive severe soil erosion in plots with shallow soil depth. Although farmers may need a relatively long time to witness a significant decline in soil depth due to erosion, they are generally more aware of a decline in rooting depth in eroded farmlands and of exposed subsoil materials (Tegene, 1992). If farmers observe these conditions, especially in shallow soils as in our study, it may partly influence their decisions to apply SWC technologies. However, Kassie *et al.* (2009) reported that farmers preferred to treat such plots with fertilizer rather than use SWC technologies.

Distant plots were perceived to be more prone to soil erosion, probably because the farther the plot is from the farmer's residence, the less attention it receives and the likelihood of severe soil erosion increases. This explanation is consistent with the results of Teshome *et al.* (2016) and Tefera & Sterk (2010), who found that more distant plots received less care as compared to nearby plots. Moreover, Mwendera & Saleem (1997) reported that plots receiving less care were very likely to become eroded due to soil nutrient depletion, particularly organic matter content, and increased soil loss through water erosion.

Differences in elevation within and between watersheds affected farmers' perceptions of soil erosion severity. Farmers in the Aba Gerima and Guder watersheds perceived higher levels of soil erosion than farmers in the Dibatie watershed. Plot elevation, which was closely associated with within and between watershed differences, had a significant positive effect ($p < 0.01$) on farmers' perceived level of soil erosion severity. Tamene & Vlek (2008) found that, in higher elevations with rugged topographies, higher rates of runoff and greater rainfall energy contribute to detaching and transporting soil particles.

I found that the upstream areas were more likely to be perceived to be affected by soil erosion, whereas the downstream farmlands were less likely to be perceived in that manner. These results conform with those of Bewket & Sterk (2003) and Tefera & Sterk (2010), who reported that the perceived severity of soil erosion was site specific, that is, relatively higher in upstream areas and lower in downstream fields.

Farmers' perceptions of soil erosion also showed intra-seasonal variation; they perceived high levels of soil erosion in June and relatively lower ones in July. This result is consistent with that of Bewket & Sterk (2003), who found that high levels of soil erosion occur in June. A plausible explanation for this is that seedbed preparation is accompanied with frequent tillage in the highland and midland watersheds, as many as 10 tillings for teff, which loosens the soil and increases its vulnerability to soil erosion in June. The lower level of perceived soil erosion in July corresponds a period of increased crop cover.

2.6 Conclusions

I found that farmers' perception of soil erosion severity corresponded well with expectations of soil erosion due to site-specific factors, such as plot shape, soil depth, plot position on hills and exposure to rainfall during the cropping season. Given this correspondence with both theoretical predictions and empirical findings from previous scientific studies, I conclude that farmers' expertise is apt to assess soil erosion situations, which suggests the importance of using participatory approaches when working to reduce soil erosion. Moreover, interaction with extension service agents increased the likelihood that farmers would perceive soil erosion problems. Despite their expected importance, level of education and number of livestock owned were not found to be significant indicators in farmers' perceptions of severe soil erosion. This situation could be addressed by introducing environmental issues in the earlier years of the school curriculum as well as by SLM oriented adult education. A better understanding of the relationship between soil erosion and livestock may require detailed community-level discussions and a closer assessment of the potential linkages between livestock wealth and land conditions.

Chapter 3

Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia

Land Use Policy 67(2017): 57–64, 2017.

Chapter 3. Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia

3.1 Background

Land degradation in the form of soil erosion and nutrient depletion is increasingly prevalent across the globe; in particular, it poses a real threat to livelihoods in SSA (Tully *et al.*, 2015). More than half of the SSA population depends on subsistence agriculture, which is jeopardized by extreme weather events such as heavy rainfall and drought (Cordingley *et al.*, 2015). In addition, rapid population growth has also resulted in shrinking and increasingly fragmented cultivated lands as well as expansion of cultivated lands to vulnerable hillsides, which has further contributed to a high level of land degradation, low productivity, and greater poverty (Teklewold *et al.*, 2013). Despite the government's and non-governmental organizations' efforts to increase agricultural productivity and tackle these problems through the promotion of various measures, adoption remains [s]low by small-scale farmers (Cordingley *et al.*, 2015).

Ethiopia is no exception to these realities. Its agricultural sector has failed to make significant soil erosion control and nutrient replenishment investments (Adimassu *et al.*, 2012; Teklewold *et al.*, 2013; Teshome *et al.*, 2016). As a result, soil loss and nutrient depletion continue to be a severe issue in this country, particularly in the highlands, with soil loss averaging 20 Mg ha^{-1} year^{-1} on currently cultivated lands and 33 Mg ha^{-1} year^{-1} on formerly cultivated degraded lands (Hurni *et al.*, 2015), and nutrient depletion averaging 122 kg N ha^{-1} year^{-1}, 13 kg P ha^{-1} year^{-1}, and 82 kg K ha^{-1} year^{-1} in cultivated lands (Haileslassie *et al.*, 2005). Likewise, soil erosion has been a serious problem in the Upper Blue Nile Basin. Bewket & Teferi (2009) reported a soil erosion rate of 93 Mg ha^{-1} year^{-1} in the Chemoga watershed and Gelagay & Minale (2016) reported a rate of 47 Mg ha^{-1} year^{-1} in the Koga watershed. The estimated annual cost of land degradation amounts to 2.0–6.8% of the country's agricultural GDP (Yesuf *et al.*, 2005), which contributes to food insecurity and further aggravates the effects of the recurrent droughts (Adgo *et al.*, 2013; SLMP, 2013). SLM investments are considered to be mandatory to address these problems and have been promoted and implemented across different parts of the country (MoARD, 2010; Adgo *et al.*, 2013; SLMP, 2013; Teshome *et al.*, 2016).

Evidence suggests that adoption of SLM practices by small-scale farmers varies with respect to a range of social, economic, institutional, and biophysical factors (Mamo & Ayele, 2003; Asrat *et al.*, 2004; Adimassu *et al.*, 2012; Teklewold *et al.*, 2013; Haregeweyn *et al.*, 2015; Teshome *et al.*, 2016). More specifically, Teshome *et al.* (2016) and Mbaga-Semgalawe & Folmer (2000) found that a high perceived erosion risk promotes farmers' adoption of SLM technologies; and Cary & Wilkinson (1997) and Amsalu & de Graaff (2007) reported that perceptions of reduced profitability from using SLM technologies deter their adoption. Moreover, different demand- and supply-side restraints have been identified that affect the adoption of SLM technologies, including endowments of physical and human capital (Gebremedhin & Swinton, 2003; Marenya & Barrett, 2007; Teklewold *et al.*, 2013; Teshome *et al.*, 2016); tenure insecurity (Gebremedhin & Swinton, 2003); and access to off-farm opportunities (Holden *et al.*, 2004), agricultural extension services (Paudel & Thapa, 2004), and credit (Tiwari *et al.*, 2008). Most of the studies (e.g., Mamo & Ayele, 2003; Amsalu & de Graaff, 2007; Pender & Gebremedhin, 2008), however, did not adequately consider the possibility of farmers applying a mix of SLM technologies to solve the problem of soil degradation. That is, they did not account for the interdependent and simultaneous characteristics of the SLM practices. As a result, they treated the use of various practices as separate decisions, whereas, Teklewold *et al.* (2013) affirmed that farmers often simultaneously pursue a number of SLM technologies in their plots, suggesting the importance of considering such issues in any analysis of farmer decision-making. Consequently, our study aimed to contribute to the existing literature through addressing this gap by objectively analyzing the underlying factors that affect the adoption of SLM measures by using a multivariate adoption framework. The results should help improve policymakers' understanding of small-scale farmers' technology adoption behaviors and thereby enable them to introduce appropriate policy measures and interventions to further enhance adoption of SLM technologies.

3.2 Materials and Methods

3.2.1 Study sites

The study was undertaken in three watersheds (see Figure 4): the Aba Gerima and Guder watersheds in the Bahir Dar Zuria (11°25′ to 11°55′ N, 37°04′ to 37°39′ E) and Fagita Lekoma (10°57′ to 11°11′ N, 36°40′ to 37°05′ E) Districts, respectively, of the Amhara Region and the Dibatie watershed from the Dibatie District (10°01′ to 10°53′ N, 36°04′ to 36°26′ E) of the Benishangul Gumuz Region, Ethiopia.

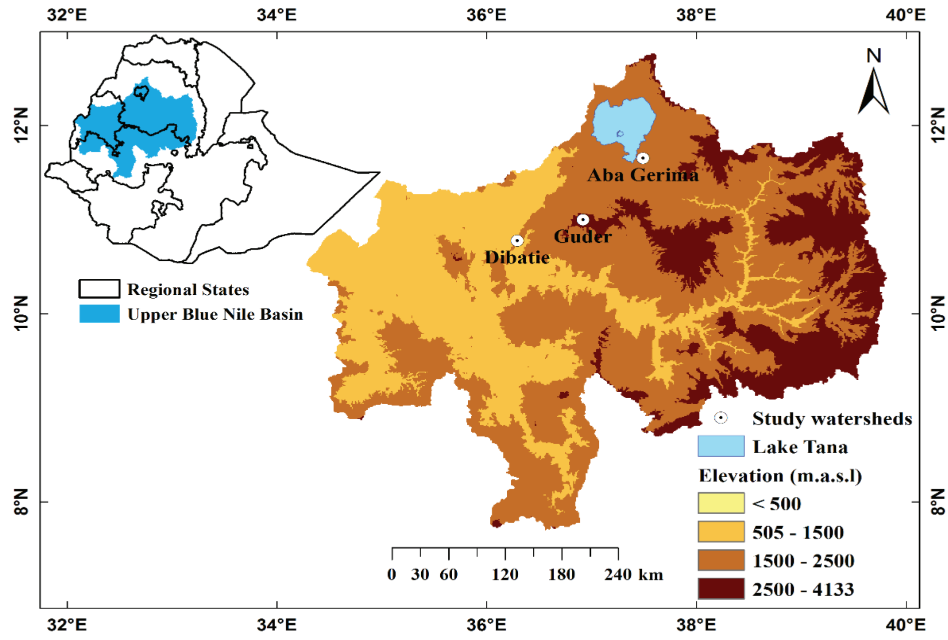

Figure 4: Location of the study sites

These watersheds are part of the north-western highlands of the Upper Blue Nile Basin, Ethiopia. They vary a great deal in their SLM experiences. Each area has participated in the national government’s regular extension programs and other campaign-based SWC programs, but the areas’ experiences with other externally funded programs has varied a great deal. The Aba Gerima watershed is part of a larger program funded by the SDC’s WLRC project. It has been serving as an experimental watershed for integrated water and land resources management since 2011. Physical and biological SWC measures were extensively implemented in the watershed with the support of the WLRC project. The Guder watershed has received support from the World Bank under the SLMP since 2008 (SLMP, 2013). Physical and biological SWC technologies were introduced in the watershed during this period, but not to the extent they were in the Aba Gerima area. During the same period, the Dibatie watershed received no external support for SWC projects. As compared to the other two watersheds, few physical SWC structures were introduced in Dibatie, primarily through the regular government extension program and campaign-based SWC interventions. Agriculture in the watersheds is dominated by subsistence mixed crop–livestock farming systems (Table 6).

Table 6: Biophysical characteristics of the study sites

Feature (unit)	Aba Gerima watershed	Guder watershed	Dibatie watershed
Altitude (m a.s.l.)	1922–2250	1800–2900	1479–1709
Temperature (°C)	13–27	9.4–25	25–32
Annual rainfall (mm)	895–2037	1951–3424	850–1200
Agro-ecological zone	Humid subtropical	Moist subtropical	Tropical hot humid
Total area (ha)	719	765	700
Soil type	Nitosols, Leptosols	Acrisols, Nitosols	Vertisols, Nitosols
Dominant crop	Teff, finger millet, wheat, maize, khat	Barley, teff, wheat, potatoes, *Acacia decurrens*	Finger millet, teff, maize, ground nuts
Dominant livestock	Cattle, sheep, goats, donkeys	Cattle, sheep, donkeys, horses	Cattle, sheep, goats, donkeys
SLM-related projects	WLRC	SLMP	None

Source: Achamyeleh (2015); Kindye (2016); Haregeweyn *et al.* (2017); Haregeweyn *et al.* (2017); Own surveys.

3.2.2. Sampling procedure, data, and data analysis

The data used in this study came from detailed household and plot surveys of 300 farm households and 1010 farm plots operated by the respondents in three watersheds of the Upper Blue Nile Basin, Ethiopia. The survey was conducted in February and March 2015. A two-stage cluster sampling procedure, involving a combination of purposeful and random sampling, was used to select sample respondents. In the first stage, I purposely selected three watersheds to represent the upper, middle, and lower parts of the basin: the Guder watershed, from the highlands; the Aba Gerima watershed, from the middle-elevation land; and the Dibatie watershed, from the lowlands. In the second stage, 100 households were selected from each watershed, for a total of 300. Respondents were selected using systematic random sampling techniques based on lists of households obtained from the respective local agricultural offices.

The household survey was conducted using semi-structured questionnaires and covered detailed household and plot-level information. A pre-test survey was also conducted in each watershed to customize instruments to local conditions. The household survey included a series of close-ended questions focusing on respondents' socio-economic, demographic, institutional and plot characteristics, and perceptions about soil erosion severity, fertility and profitability of SLM technologies. Along with the quantitative information, qualitative data were collated to elucidate farmers' reasons for investing and/or not investing in the respective SLM technologies on their plots. Specifically, I sought farmers' general explanation on their plot-level SLM investment behavior to help interpret quantitative results, including: (i) which segment of the community (e.g., young vs. old, literate vs. illiterate, male vs. female, wealthy vs. poor, labor endowed vs. less labor endowed) is applying the respective SLM measures and why, (ii) who is the main player (i.e., intra-household responsibility) in undertaking the various activities (e.g., digging, excavating, compacting, transporting) involved in implementing the respective SLM measures, and (iii) which type of plots (e.g., fertility condition, distance from residence, position in the landscape) are receiving the respective SLM measures and for what reason.

The plot survey covered specific plot-level information (e.g., plot slope, land use, position in the watershed, and existing SLM technologies on the plot and neighboring plots) using a checklist. Plot slope was measured with a clinometer (PM–5/360 PC Clinometer, Suunto). The data were input into the SPSS software (ver. 23, IBM, Armonk, NY, USA) and analyzed with a combination of descriptive and econometric analyses. Parameters of the MVP model were estimated with a user-written Stata routine (*mvprobit*) that employed the Geweke–Hajivassiliou–Keane smooth recursive conditioning simulator procedure (Cappellari & Jenkins, 2003). Parameters of the PR model were estimated by the maximum-likelihood procedure. The Stata software (ver. 14.1, StataCorp LP, College Station, TX, USA) was used in the model estimates.

3.2.3 Empirical models

Farmers' decisions on the adoption of land management technologies are not univariate decisions; rather, they have interdependent and simultaneous characteristics (Dorfman, 1996). That is, farmers apply a mix of technologies (see Figure 5) to solve their land problems (Kassie *et al.*, 2013; Teklewold *et al.*, 2013). Because of this nature, a multivariate modeling framework is needed to account for the interdependent and possibly simultaneous characteristics of their decisions (Greene, 2003). Consequently, a MVP model was used to assess farmers' decisions to adopt SLM measures. In this type of model, the choice of SLM measures related to each of the technologies corresponds to a dichotomous choice (*yes*/*no*) equation, and the choices are modeled jointly while accounting for the correlation among error terms (Kassie *et al.*, 2013). Model estimates from such specifications are superior to those from univariate specifications when the error correlations are significantly different from zero (Marra *et al.*, 2015). Otherwise, the two modeling frameworks lead to similar results (Marra *et al.*, 2015). Following Cappellari & Jenkins (2003), I constructed a system of simultaneous probit models for SLM measures as follows:

$$y_{im}^{*} = \beta_m' x_{im} + \epsilon_{im}$$
$$y_{im} = 1 \; if \; y_{im}^{*} > 0 \text{ and } 0 \; \text{ otherwise}$$

where y_{im}^{*} captures unobserved preferences of the i^{th} farmer on the m^{th} SLM measure (m = 1, 2, …, 8 available technologies in this study); β_m' is the set of parameters that reflect the impact of changes in the vector of explanatory variables x_i on the farmer's preference towards the m^{th} SLM measure; x_{im} represents the vector of observed variables that are expected to explain each type of SLM practice; and ϵ_{im} represents error terms following a multivariate normal distribution, each with a mean of zero and a variance–covariance matrix with values of 1 on the leading diagonal and non-zero correlations as off–diagonal elements.

In the second analysis, I employed a PR model. Ramirez & Shultz (2000) noted that this type of model is important in assessing factors that influence farmers' decisions to adopt SLM measures in developing countries. This seems plausible because the adoption of SLM technologies in developing countries is seldom a smooth or even process; rather, it is usually a stepwise and partial process, whereby farmers use none, some, or all of the measures. This is a typical case of event counting that necessitates the use of a PR model to estimate the number of SLM measures executed in a plot. Following Ramirez & Shultz (2000), the PR model on the dependent variable (y_i), which was constructed as the sum of the binary responses of the SLM measures implemented in a plot by the i^{th} farmer, was specified as:

$$\ln E(y_i) = \beta x_i + \epsilon_i$$

where $E(y_i)$ is the expected value of the dependent variable for the i^{th} farmer, β is the set of parameters that reflects the impact of changes in the vector of explanatory variables x_i, x_i is a vector of observed variables, and ϵ_i represents error terms.

Explanatory variables considered

The choice of the hypothesized explanatory variables was based on economic theory and empirical works on SLM technology adoption decisions (e.g., Kessler, 2006; Marenya & Barrett, 2007; Pender & Gebremedhin, 2008; Kassie *et al.*, 2013; Teklewold *et al.*, 2013;

Teshome *et al.*, 2016). The explanatory variables included in the model were socio-economic variables (age, gender, level of education, extension contact, SLM-related training, household size, off-farm income, amount of credit received, livestock size, and total asset value), and plot-specific variables (plot size, ownership, distance to residence, depth, position in the watershed, presence of SLM technologies in neighboring plots, presence of publically sponsored SLM technologies, slope, perceived fertility, perceived profitability of SLM technology, land use, and perceived soil erosion severity). Definitions of the selected variables, their hypothesized direction of influence, and descriptive statistical measures are presented in Table 7.

3.3 Results

Socio-economic, demographic, and plot characteristics

Descriptive statistics of the variables included in the models are presented in Table 7. The average age of the respondents was 47.64 years, and the average schooling was 1.26 years. About 86% of household heads were male, and the average available on-farm labor force was about three adult person equivalents. The average plot size was 0.41 ha, and farmers owned about 5 TLU of livestock and had an average total estimated asset value (excluding land and livestock) of ETB 18,500 (USD 925 at an exchange rate of USD 1 ≈ ETB 20). They had an average off-farm income and credit of ETB 8,800 ETB (USD 440 USD) and ETB 3,800 ETB (USD 190), respectively. Respondents received extension services and SLM-related training an average of about three times per year each.

Most of the plots were owned by the households that cultivate them, and most (76%) were used to cultivate annual crops. More than two-thirds of the plots are in the upper and middle sections of the watersheds, and 43% and 36% of all plots were perceived to have moderately deep and shallow soil, respectively. About 30% and 59% of the plots were considered to have poor and moderate soil fertility, respectively. Less than half of the neighboring plots had any SLM technologies implemented and 34% of the plots had received publically sponsored SLM treatments. The majority of the plots were perceived to be in a moderately to very severely eroded state.

Table 7: Summary statistics and description of selected variables used in the analysis

Variable description (coding/units)	Variable name	Expected sign	Mean	SD
Age of the household head (years)	Age	±	47.64	11.58
Gender of the household head (1 = male, 0 = female)	Gender	±	0.86	0.34
Education level of the household head (years)	Education	±	1.26	2.17
Frequency of extension contacts per annum (no. of contacts)	Extension	+	2.94	2.72
Household received SLM-related training (no. of training days per annum)	Training	+	2.71	1.36
Household size (adult equivalent)	Household size	+	3.24	1.37
Off-farm income received by the household per annum (in ′000 ETB)	Off-farm income	+	8.80	6.00
Amount of credit received by the household per annum (in ′000 ETB)	Credit	+	3.80	1.80
Livestock size owned by the household (TLU)	Livestock	+	5.11	2.73
Total asset value owned by the household (in ′000 ETB)	Asset	+	18.50	14.90
Plot size (ha)	Plot size	+	0.41	0.49
Plot ownership or tenure (1 = own, 0 = rented)	Plot ownership	–	0.83	0.38
Plot distance to residence (minutes of walking)	Plot distance	+	24.74	13.44
Farmer reports plot has a moderate soil depth (1 = yes, 0 = no)	Moderate depth	+	0.43	0.50
Farmer reports plot has a shallow soil depth (1 = yes, 0 = no)	Shallow depth	+	0.36	0.48
Position of plot in watershed landscape, upper part (1 = yes, 0 = no)	Upstream	+	0.32	0.47
Position of plot in watershed landscape, middle part (1 = yes, 0 = no)	Midstream	+	0.39	0.49
Neighboring plots have SLM measures (1 = yes, 0 = no)	SWC in neighbor plots	–	0.44	0.50
Plot received public SLM improvements (1 = yes, 0 = no)	Public SWC	–	0.34	0.47
Plot slope (%)	Plot slope	+	11.16	7.77
Farmer reports poor soil fertility (1 = yes, 0 = no)	Poor fertility	+	0.30	0.46
Farmer reports moderate soil fertility (1 = yes, 0 = no)	Moderate fertility	–	0.59	0.49
Farmer reports SLM technologies are not profitable (1 = yes, 0 = no)	SWC not profitable	+	0.48	0.50
Plot land use type (1 = cropland, 0 = non-cropland)	Land use	+	0.76	0.43
Farmers perceived level of soil erosion severity (1 = very low, …, 5 = very high)	Soil erosion severity	+	3.63	1.06

Note: ± indicates mixed result expectation.

Farmer-implemented SLM measures

The number of plots that received one or more of the SLM measures varied across the study sites (Figure 5). Aba Gerima watershed plots received the most SLM measures followed by the Guder and Dibatie watershed plots. Of the surveyed technologies, agroforestry and drainage channels were the most widely applied measures, followed by application of inorganic fertilizers and manure.

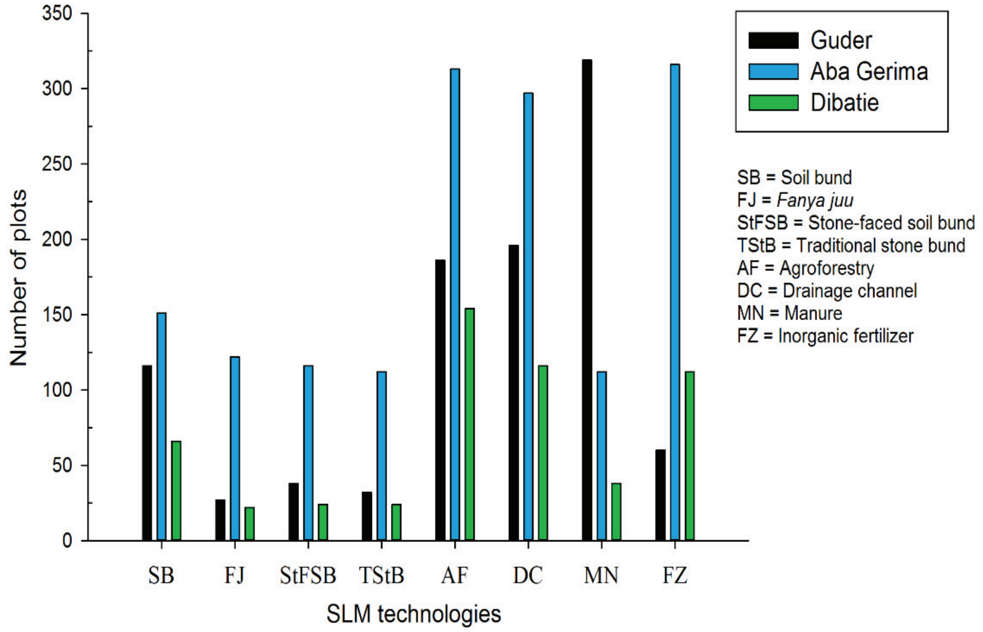

Figure 5: SLM technologies implemented by the farmers

Model results

The empirical results obtained from the MVP (Model I) and PR (Model II) models are presented in Table 8. These regression models were estimated at the plot level, and it is evident from both sets of results that most of the exogenous factors are important in explaining the plot-level adoption of SLM measures. The pairwise correlations between the error terms (ρ) in the MVP model were statistically significant ($p < 0.1$) for 16 of 28 combinations of the eight SLM measures (result not shown). This may indicate the complementarity and substitutability characteristics of the SLM measures under consideration. These results justify our decision to deploy the MVP rather than eight independently estimated probit equations.

Age of the household head was important in explaining the adoption of manure ($p < 0.01$), *fanya juu* ($p < 0.1$), traditional stone bunds ($p < 0.01$), and inorganic fertilizer ($p < 0.01$) technologies, as well as the total number of SLM measures applied ($p < 0.01$). More specifically, households headed by older farmers' were more likely to apply manure in their farmlands while less likely to implement the other technologies, besides they applied less number of SLM technologies. Male gender of the household head was shown to negatively affect adoption of manure application ($p < 0.05$), whereas the use of inorganic fertilizer ($p <$

0.05) was positively affected. The education level of the household head negatively influenced the adoption of *fanya juu* ($p < 0.01$), stone-faced soil bunds ($p < 0.05$), traditional stone bunds ($p < 0.1$), and inorganic fertilizer ($p < 0.01$) technologies; whereas, it had a positive effect on the use of manure ($p < 0.01$). Households headed by those who attained higher levels of education were more likely to apply manure, whereas they were less likely to invest in the other technologies.

Frequency of extension contacts had a significant negative effect on the adoption of traditional stone bund ($p < 0.05$), agroforestry ($p < 0.05$), and drainage channel ($p < 0.05$) technologies, as well as on the total number of SLM technologies implemented ($p < 0.1$). This means those households with more number of extension contacts had less likelihood of adopting stone bund, agroforestry and drainage channel; and also less number of SLM technologies. In contrast, households in which at least one member received SLM-related training were more likely to apply manure ($p < 0.01$), whereas those that had more on-farm laborers were more likely to apply inorganic fertilizer ($p < 0.05$).

Off-farm income negatively affected adoption of *fanya juu* ($p < 0.05$), stone-faced soil bund ($p < 0.05$), traditional stone bund ($p < 0.05$), and fertilizer ($p < 0.01$) technologies as well as the total number of SLM technologies implemented ($p < 0.1$); in contrast, it positively affected construction of drainage channels ($p < 0.1$) and application of manure ($p < 0.05$). The result suggests that households access to higher off-farm incomes were more likely to discourage the application of the former technologies, while more likely to encourage investment in the latter ones. In addition, an increment in the amount of credit received and the total number of livestock owned by households were found to significantly enhance manure application ($p < 0.1$) and *fanya juu* construction ($p < 0.1$), respectively. Furthermore, households with higher total asset values were more likely to use traditional stone bunds ($p < 0.05$) and implement a greater number of SLM measures ($p < 0.01$), but they were less likely to construct *fanya juu* ($p < 0.1$).

Plot size had a negative influence on the adoption of *fanya juu* ($p < 0.01$), stone-faced soil bund ($p < 0.01$), traditional stone bund ($p < 0.1$), and manure ($p < 0.01$) technologies; in contrast, it had a positive influence on the adoption of agroforestry ($p < 0.01$) and the application of inorganic fertilizer ($p < 0.01$). This means that an increase in the plot size significantly reduced the likelihood of farmers' investment in the former SLM technologies, whereas increasing the likelihood of their investment in the latter ones. Plot tenure positively affected the adoption of traditional stone bund ($p < 0.05$) and manure ($p < 0.1$) technologies as well as the total number of SLM measures applied ($p < 0.1$); it negatively affected the use of agroforestry measures ($p < 0.1$). Owner operated plots were more likely to receive traditional stone bund and manure, as well as more number of SLM technologies than rented ones; and less likely to integrate agroforestry. Plots perceived to have moderately deep soil were less likely to receive traditional stone bunds ($p < 0.01$) and inorganic fertilizer ($p < 0.05$), but they were more likely to be treated with manure ($p < 0.05$). However, plots that were perceived to be shallow were more likely to use stone-faced soil bunds ($p < 0.05$). Both upstream and midstream plots were more likely to receive inorganic fertilizer applications ($p < 0.01$) and less likely to be treated with manure ($p < 0.01$).

Plots where public SLM activities had been conducted were more likely to receive soil bund ($p < 0.01$), *fanya juu* ($p < 0.01$), traditional stone bund ($p < 0.01$), and agroforestry ($p < 0.01$) technologies as well as to have a greater total number of SLM measures implemented ($p < 0.01$) in addition to the ones constructed through public SLM initiatives. Plots with moderate perceived fertility were more likely to be treated with manure ($p < 0.1$). Farmers who perceived that applying SLM measures would not be profitable were less likely to implement soil bund ($p < 0.01$), stone-faced soil bund ($p < 0.01$), drainage channel ($p < 0.1$), and inorganic fertilizer ($p < 0.05$) technologies, but they were more likely to construct traditional stone bunds ($p < 0.01$) and apply manure ($p < 0.1$). Croplands were more likely to receive stone-faced soil bund ($p < 0.01$), traditional stone bund ($p < 0.01$), drainage channel ($p < 0.01$), and inorganic fertilizer ($p < 0.01$) technologies as well as a greater total number of SLM measures ($p < 0.01$). Plots that were perceived as having more severe erosion were more likely to use stone-faced soil bund ($p < 0.05$), traditional stone bund ($p < 0.05$), drainage channel ($p < 0.05$), and inorganic fertilizer ($p < 0.05$) technologies as well as a higher total number of SLM measures ($p < 0.01$).

Table 8: MVP model and PR model results for the type and number of SLM technologies, respectively

Variables	Model I MVP								Model II PR
	SB	*FJ*	StFSB	TStB	AF	DC	MN	FZ	No. of SLM techs
Age	–0.007	–0.090	–0.057	–0.224	–0.065	–0.033	0.204	–0.177	–0.035
	(0.053)	(0.052)*	(0.076)	(0.085)***	(0.059)	(0.069)	(0.061)***	(0.059)***	(0.013)***
Gender	0.069	0.024	0.072	–0.235	–0.016	0.082	–0.354	0.442	0.022
	(0.128)	(0.147)	(0.266)	(0.199)	(0.182)	(0.149)	(0.179)**	(0.172)**	(0.040)
Education	0.072	–0.184	–0.250	–0.155	–0.004	0.026	0.220	–0.146	–0.010
	(0.046)	(0.058)***	(0.098)**	(0.092)*	(0.067)	(0.061)	(0.055)***	(0.055)***	(0.015)
Extension	–0.017	0.025	0.111	–0.192	–0.171	–0.150	0.056	0.070	–0.024
	(0.051)	(0.049)	(0.079)	(0.075)**	(0.064)***	(0.075)**	(0.066)	(0.053)	(0.012)*
Training	–0.013	0.015	–0.039	0.061	–0.032	0.087	0.154	0.001	0.018
	(0.049)	(0.056)	(0.076)	(0.075)	(0.060)	(0.067)	(0.053)***	(0.054)	(0.013)
Household size	0.033	0.054	–0.048	0.019	0.032	–0.058	–0.021	0.124	0.013
	(0.054)	(0.055)	(0.080)	(0.089)	(0.067)	(0.081)	(0.062)	(0.056)**	(0.016)
Off-farm income	–0.047	–0.145	–0.189	–0.205	–0.066	0.115	0.146	–0.155	–0.022
	(0.048)	(0.058)**	(0.084)**	(0.096)**	(0.063)	(0.060)*	(0.058)**	(0.048)***	(0.012)*
Credit	–0.032	0.020	0.015	–0.094	–0.037	0.033	0.080	–0.051	–0.005
	(0.047)	(0.052)	(0.071)	(0.067)	(0.053)	(0.058)	(0.048)*	(0.048)	(0.011)
Livestock	–0.051	0.098	0.080	0.020	0.062	0.009	–0.084	0.021	0.008
	(0.045)	(0.051)*	(0.093)	(0.074)	(0.057)	(0.061)	(0.070)	(0.073)	(0.012)
Asset	–0.038	–0.118	0.026	0.222	0.087	0.109	0.002	0.046	0.036
	(0.052)	(0.060)*	(0.086)	(0.090)**	(0.063)	(0.072)	(0.059)	(0.053)	(0.013)***
Plot size	0.028	–0.270	–0.350	–0.164	0.354	0.024	–0.475	0.155	–0.011
	(0.054)	(0.098)***	(0.097)***	(0.093)*	(0.087)***	(0.055)	(0.062)***	(0.052)***	(0.012)
Plot ownership	0.067	0.173	0.128	0.432	–0.276	0.156	0.241	–0.043	0.053
	(0.132)	(0.167)	(0.209)	(0.195)**	(0.156)*	(0.152)	(0.145)*	(0.125)	(0.029)*
Plot distance	0.157	–0.064	–0.110	0.079	0.009	–0.031	0.037	–0.078	–0.002
	(0.049)***	(0.055)	(0.054)**	(0.062)	(0.049)	(0.053)	(0.046)	(0.047)*	(0.011)
Moderate depth	0.016	0.086	–0.166	–0.388	–0.062	0.083	0.177	–0.186	–0.024
	(0.092)	(0.119)	(0.107)	(0.112)***	(0.097)	(0.087)	(0.089)**	(0.092)**	(0.022)
Shallow depth	0.155	–0.139	0.261	–0.302	–0.082	0.013	–0.080	–0.017	–0.018
	(0.107)	(0.125)	(0.126)**	(0.124)**	(0.105)	(0.118)	(0.102)	(0.090)	(0.024)
Upstream	–0.232	0.373	0.129	–0.028	–0.019	0.008	–0.418	0.361	0.006
	(0.115)**	(0.133)***	(0.166)	(0.157)	(0.126)	(0.163)	(0.111)***	(0.118)***	(0.030)
Midstream	–0.012	–0.073	0.115	–0.310	0.091	0.082	–0.319	0.225	0.003
	(0.109)	(0.136)	(0.180)	(0.146)**	(0.113)	(0.138)	(0.109)***	(0.105)**	(0.028)
SLM in neighboring plots	–0.233	–0.571	0.099	–0.333	–0.408	0.085	0.225	–0.092	–0.077
	(0.183)	(0.246)**	(0.193)	(0.246)	(0.141)***	(0.140)	(0.147)	(0.148)	(0.035)**
Public SLM	0.806	1.034	–0.049	0.808	0.478	–0.107	–0.259	0.043	0.209
	(0.211)***	(0.266)***	(0.219)	(0.279)***	(0.154)***	(0.170)	(0.169)	(0.171)	(0.038)***
Plot slope	0.018	–0.090	0.071	–0.191	0.042	–0.068	0.025	–0.002	–0.013
	(0.044)	(0.056)	(0.055)	(0.054)***	(0.047)	(0.046)	(0.044)	(0.047)	(0.010)
Poor fertility	0.057	–0.194	–0.197	0.164	–0.053	–0.341	0.176	–0.184	–0.040
	(0.182)	(0.193)	(0.221)	(0.200)	(0.188)	(0.209)	(0.192)	(0.206)	(0.046)
Moderate fertility	0.004	–0.137	0.027	–0.206	–0.045	–0.186	0.302	–0.251	–0.029
	(0.148)	(0.172)	(0.199)	(0.161)	(0.173)	(0.169)	(0.175)*	(0.179)	(0.040)
SLM not profitable	–1.243	0.308	–0.648	0.746	0.037	–0.169	0.356	–0.232	–0.114
	(0.117)***	(0.125)**	(0.153)***	(0.173)***	(0.094)	(0.101)*	(0.108)***	(0.093)**	(0.024)***
Land use	0.034	–0.065	0.625	0.618	–0.540	1.365	–0.512	1.053	0.257
	(0.111)	(0.125)	(0.151)***	(0.154)***	(0.119)***	(0.148)***	(0.099)***	(0.109)***	(0.031)***
Soil erosion severity	–0.023	–0.013	0.182	0.173	0.069	0.124	–0.080	0.109	0.041
	(0.056)	(0.053)	(0.081)**	(0.076)**	(0.056)	(0.059)**	(0.052)	(0.049)**	(0.013)***
Constant	–0.373	–1.679	–1.906	–2.194	1.157	–0.748	0.017	–1.002	0.822
	(0.263)	(0.337)***	(0.423)***	(0.387)***	(0.340)***	(0.303)**	(0.289)	(0.265)***	(0.078)***
Wald chi^2 (df)	7595.59								327.99
	(200)								(25)
Prob > chi^2	0.0000								0.0000
N	1010								1010

* p<0.1; ** p<0.05; *** p<0.01.

Likelihood-ratio test of overall error terms correlation:$\rho_{21} = \rho_{31} = \rho_{41} = \rho_{51} = \rho_{61} = \rho_{71} = \rho_{81} = \rho_{32} = \rho_{42} = \rho_{52} = \rho_{62} = \rho_{72} = \rho_{82} = \rho_{43} = \rho_{53} = \rho_{63} = \rho_{73} = \rho_{83} = \rho_{54} = \rho_{64} = \rho_{74} = \rho_{84} = \rho_{65} = \rho_{75} = \rho_{85} = \rho_{76} = \rho_{86} = \rho_{87} = 0$: chi^2(28) = 599.642, Prob > chi^2 = 0.0000.

3.4 Discussion

In our study area, farmers' decisions to implement one or more SLM technologies were influenced by various exogenous factors. For example, the negative effect of the age of the household head on the adoption of *fanya juu*, traditional stone bunds, and inorganic fertilizers is related to the inability to provide sufficient labor or the relatively shorter planning horizon of the land manager (i.e., the household head). Young farmers, who are physically fitter or stronger and have longer planning horizons (i.e., they are less risk averse), are more likely to apply these technologies than older farmers, which is in agreement with the findings of Ndiritu *et al.* (2014). The positive effect of age on manure application is also related to the more risk-averse behavior of older land managers. This is plausible because older farmers have gained experience with traditional technologies and are more convinced of their productivity-enhancing attributes as compared to more labor-intensive and newly introduced technologies. On the other hand, older farmers, according to the qualitative statements in the interviews, often lack the financial means to purchase inorganic fertilizer. Nevertheless, this result contrasts with the finding of Abdulai *et al.* (2011) who argued that, if not resource-constrained, younger farmers are more likely to invest in manure application than older ones because they are in a better position to justify returns from investments whose benefits are realized over time. In any case, these results clarify the need for SLM extension programs that go beyond the traditional premise that all watershed inhabitants have similar attitudes toward technologies so that extension staff can include age-disaggregated components.

As anticipated, gender showed mixed results. The significant negative effect of male gender on manuring implies that female-headed households were more likely to apply organic fertilizer than their male counterparts, in contrast with the findings of Pender & Gebremedhin (2008); the opposite held true for applying inorganic fertilizers. The latter result is plausible in subsistence agriculture systems in which female farmers often lack the resources to buy external inputs, so they usually resort to the application of manure in their fields, which is possibly similar to the conditions faced by older farmers. Similarly, education level of the household head showed mixed results as I expected. It is generally believed that a higher level of educational achievement will aid farmers in comprehending the dynamics and benefits of SLM measures. However, our findings contradicted this general contention in terms of the adoption of *fanya juu*, stone-faced soil bund, traditional stone bund, and inorganic fertilizer technologies. Plausible explanations for these findings, according to informants, are that the generally low level of educational achievement among farmers in this area, inadequate emphasis given to environmental issues in the curricula of lower grades, or that farmers opt to participate in off-farm activities. The explanation in the middle part was in agreement with Dalelo (2011), who found that the existing primary level curriculum guides in the country provide lesser opportunity to integrate environmental issues, and the latter explanation was supported by the variable amount of off-farm income in our study. In the case of manure application, I found that education and receipt of SLM training by household members did help them to understand the importance of manure to soil fertility, or otherwise its lower competition to land managers' labor promoted its application. The latter holds true because mostly female and young household members collect, carry, and apply manure to farmlands. Likewise, farmers with more livestock and more on-farm labor were more likely to apply manure, in line with the findings of Kassie *et al.* (2013) and Teklewold *et al.* (2013). The results also revealed that wealthier farmers were more likely to construct traditional stone bunds and implement more SLM measures overall, as derived from the qualitative interviews, reflecting their greater ability to hire off-farm labor; nonetheless, they were less likely to adopt *fanya juu*, suggesting a need for greater awareness creation through wealth-disaggregated extension targeting. Furthermore, plot size was found to exert a significant negative effect on the adoption of *fanya juu*, stone-faced soil bund, and traditional stone bund technologies, contrary to our expectations, which, according to informants, is related to a lack of awareness about such technologies, space competition for scarce land, and the higher labor inputs required for their construction. A positive effect on the adoption of agroforestry and inorganic fertilizer was observed for plot size. The agroforestry result is similar to that of Marenya & Barrett (2007). This is most likely true because the opportunity costs facing households engaging in agroforestry are relatively lower as the amount of land allocated to it increases, thus they can realize economies of scale. This is not a surprise in the Guder and Aba Gerima watersheds where *Acacia decurrens* and *Chata edulis*, respectively, serve as important cash crops.

Plot tenure was found to facilitate investment in traditional stone bunds, application of manure, and a greater total number of SLM measures implemented. This finding is consistent with the studies of Abdulai *et al.* (2011), Gao *et al.* (2012), and Teklewold *et al.* (2013), who reported that owner-operated plots are more likely to receive manure applications with increased tenure security. This explanation suggests that secure tenure allows owner operators to accept delayed benefits from such investments; conversely, it becomes a disincentive for lessors to obligate sharecroppers to implement SLM measures. However, the inverse relationship with agroforestry is related to the better performance of rental markets in transferring land use to cash crop cultivation (e.g., *A. decurrens* and *C. edulis*) in the highland areas. On the other hand, plots perceived to be moderately deep and fertile, respectively, were more likely to be treated with manure rather than inorganic fertilizers, which is related to the farmers' preference to apply inorganic fertilizers rather than manure to more fertile land to gain immediate higher returns on investment. This is in stark contrast with the result of Gao *et al.* (2012), who found that highly fertile plots tended to receive more manure than plots with poor or moderate fertility. Plots perceived to have shallow soil were more likely to receive stone-faced soil bunds in areas where stone was easily accessible. Upstream and midstream plots were more likely to receive inorganic fertilizer treatments rather than manure applications. The main reason for these results, according to information from the qualitative sections of the interviews, is the distance of the plots from the residence or the bulky nature of manure with respect to transport to these positions in the landscape. This latter point is also very much related to on-farm labor availability. An equally important explanation is that plots in such landscapes are considered to be more liable to the negative impacts of runoff than the downstream ones, and therefore are less interesting for the application of long term SLM measures like manure.

Surprisingly, plots that received SLM measures through public initiatives were more likely to receive additional measures from the land managers, highlighting the importance of collective intervention in the adoption of SLM technologies. Furthermore, farmers who perceived more severe soil erosion problems and believed in the profitability of SLM measures were more likely to use structural measures and apply inorganic fertilizers. These results imply that both of these perceptions are important in farmers' land management investment decisions, which is in line with the findings of Asrat *et al.* (2004), Teshome *et al.* (2016), and Kessler (2006), who found that farmers are eager to see short-term impacts and prioritize the use of their limited resources. Farmers who perceived the adoption of SLM measures as unprofitable may instead apply manure until such time that they are able to foresee that the associated benefits outweigh costs of implementing other SLM technologies. Consequently, intervention programs must first focus on erosion hotspot areas to create opportunities for farmers to eventually learn to evaluate the additional benefits and costs of SLM measures by themselves.

3.5 Conclusions

In SSA, farming is characterized by severe soil loss as a result of water erosion and [s]low adoption of SLM measures. Our analyses provide an understanding of farmers' plot-level technology adoption decisions by simultaneously examining SLM technology adoption and farm and household characteristics. Our results indicated that farmers' adoption of SLM measures depends on a number of plot characteristics, including soil fertility, soil depth, watershed position, and tenure. Therefore, policymakers should emphasize areas with poor fertility and shallow soil in midstream and upstream plots as well as re-evaluate land-transfer agreements to ensure that farmlands receive necessary conservation measures. For example, government agencies should allow land transfers for a longer period of time and provide incentives for land conversion to agroforestry uses.

Technology adoption decisions by small-scale farmers were found to depend on age, gender, education, livestock number, and wealth. It is also clear that farmers are orientated towards economically rational decisions concerning SLM measures. As a consequence, policy efforts to promote SLM technologies should vary depending on local socio-economic and plot conditions by promoting the use of the most appropriate technologies for specific farm and household characteristics. For example, intervention supports of physical measures should be prioritized for lands owned by older farmers; whereas, the use of manure treatments should be promoted to younger and male-headed farm households. The latter group could become better informed through education, training, and asset-building intervention programs. Female-headed farm households, however, have stated to benefit more from loan supports for the application of inorganic fertilizers on their croplands. Once households see the benefits of adopting a given SLM measure, it may be possible to persuade them to try additional measures.

The adoption of SLM measures was also affected by the receipt of SLM measures through publically sponsored initiatives, perceived soil erosion severity, and perceived profitability of the SLM measures. Farmers should be encouraged to willingly participate in public SLM initiatives to ensure the enhanced adoption of additional measures. At the same time, farmers' indigenous knowledge of detecting soil erosion severity should be enhanced by providing training and integrating complementary enterprises (e.g., fodder production) to enable farmers to reap immediate additional benefits from implementing SLM measures.

Above all, our findings imply that SLM recommendations, strategies, and measures should not be based on "one size fits all" and "across the board" solutions, let alone the idea that there is one "silver bullet" to solve soil degradation problems. Instead, SLM strategies have to be specifically adapted to specific farmers’ groups and be as diverse as those groups and the regions they live in.

Chapter 4

Factors affecting small-scale farmers' land allocation and tree density decisions in an *Acacia decurrens*-based agroforestry system in north-western Ethiopia

Small-scale Forestry 16(2): 219–233, 2017.

Chapter 4. Factors affecting small-scale farmers’ land allocation and tree density decisions in an *Acacia decurrens*-based agroforestry system in north-western Ethiopia

4.1 Background

Low investments in sustainable short- and long-term land management practices are a major concern in the Ethiopian highlands (Bewket, 2007; Adimassu *et al.*, 2012); especially the north-western highlands of the Upper Blue Nile basin, an area that suffers from ongoing soil degradation and drought (Bewket & Sterk, 2003; Bewket, 2007). Among the soil degradation processes in this area, soil erosion and nutrient depletion present significant challenges to agricultural productivity and food security. These processes, coupled with population increases, constrain productivity and livelihood options and exacerbate deforestation, pushing agriculture to marginal areas like steep slopes (Jagger & Pender, 2003; Bewket, 2007), increasing soil erosion, thereby further harming subsistence farming in the region.

To curb this situation, since the early 1970s the government of Ethiopia has introduced various land management technologies (Bewket, 2007; Adimassu *et al.*, 2012). Emphasis has been placed on SWC measures on cultivated lands, as well as area-closure, reforestation and afforestation of degraded communal hillsides (Bewket, 2007; GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH), 2015). However, their widespread adoption and adaptation by small-scale farmers in the wider landscape remain low (Bewket, 2007; Adimassu *et al.*, 2012; Sisay & Mekonnen, 2013). In this context, new land use practices, that bring about an economic benefit for the farmers and at the same time contribute to SWC, for instance agroforestry, could significantly improve the sustainable use of natural resources and assist as a key natural resource management strategy in achieving the millennium development goals (Garrity, 2004).

Research findings show investment in tree planting could reduce the prevailing poverty (Garrity, 2004; Jagger *et al.*, 2005), supply firewood (Jenbere *et al.*, 2012) and improve degraded ecosystems (Sisay & Mekonnen, 2013). Recognizing such roles, government and non-government organizations are promoting exotic multipurpose tree species for small-scale farmers (Mekoya *et al.*, 2008; Sisay & Mekonnen, 2013). However, these interventions have been based on a simplistic view that all farmers should plant more trees without consideration of their resource constraints or of the socio-economic incentives for growing trees (Admassie). Reasons for the limited success include inappropriate tree species, lack of consideration of growers’ objectives and socio-economic conditions, a limited pool of species, low multipurpose value of species, and land and labor constraints of the target groups (e.g. Mekoya *et al.*, 2008; Reubens *et al.*, 2011; Sisay & Mekonnen, 2013). Besides eucalyptus species (mainly *Eucalyptus camaldulensis* Dehnh. and *Eucalyptus globulus* Labill.) that have successfully expanded across the northern and north-western highlands (Jagger & Pender, 2003; Abiyu *et al.*, 2016), *Acacia decurrens* (J.C. Wendl.) Willd. was introduced into the central highlands of Ethiopia in the early 1990s for short-rotation forestry (Sawyer, 1993) to counter urban firewood shortages arising from deforestation (Pohjonen & Pukkala, 1990). Around the same time, *A. decurrens* was introduced into state-owned plantations of the north-western highlands (Achamyeleh, 2015). Very recently the species has also been recommended for large-scale watershed rehabilitation in the country (GIZ, 2016).

Except for a few tree screening trials in the central highlands of Ethiopia (e.g. Mekonnen *et al.*, 2006; Tesfaye *et al.*, 2015), there is, to our knowledge, no study on the socio-economic aspects of establishing *A. decurrens* plantations. Recent plantings of *A. decurrens* on degraded cultivated lands for short-rotation agroforestry have earned positive feedback for their ability to prevent soil erosion (Reubens *et al.*, 2011; Kindye, 2016), improve soil fertility (Reubens *et al.*, 2011; Achamyeleh, 2015) and enhance water quality (Reubens *et al.*, 2011). Assessing the motivations of farmers to establish plantations, the respective determinants and the context in which tree planting has expanded is important to better understand the mechanisms underlying potential SLM schemes of small-scale farmers in Ethiopia. This will help to further expand the technology to areas with similar socio-economic and ecological conditions and to establish farmer-oriented agroforestry strategies within the wider landscape. The study also provides a basis for understanding, more generally, the uptake of new livelihood strategies by small-scale farmers. The hypothesis for this study is that a host of economic and environmental incentives and of farm and farmer characteristics explain the expansion of *A. decurrens*-based agroforestry systems (i.e., joint production of forestry and agricultural crops) in the Amhara region of Ethiopia.

4.2 Materials and Methods

4.2.1 Study site

The study was undertaken in Fagita Lekoma district, Awi Zone, Ethiopia (10°57′23″ to 11°11′21″N, 36°40′01″ to 37°05′21″E; 1800–2900 m a.s.l.) (see Figure 6). The district has a total population of 146,848 people, of which about 90% live in rural areas, and the population density is 224.7 people per km^2 (CSA, 2016). The mean annual rainfall is 2,434.6

mm, and the mean annual minimum and maximum temperatures are 9.4 and 25 °C (Achamyeleh, 2015). The district is part of the moist subtropical agro-ecological zone of the north-western highlands of Ethiopia. Farmers in the district practise mixed subsistence cropping–livestock farming systems. The major crops are barley (*Hordeum vulgare* L.), teff (*Eragrostis tef* Zucc.), wheat (*Triticum aestivum* L.) and potato (*Solanum tuberosum* L.). The predominant soil type is Acrisols (FAO, 1984). The topography is rugged and undulating (Achamyeleh, 2015).

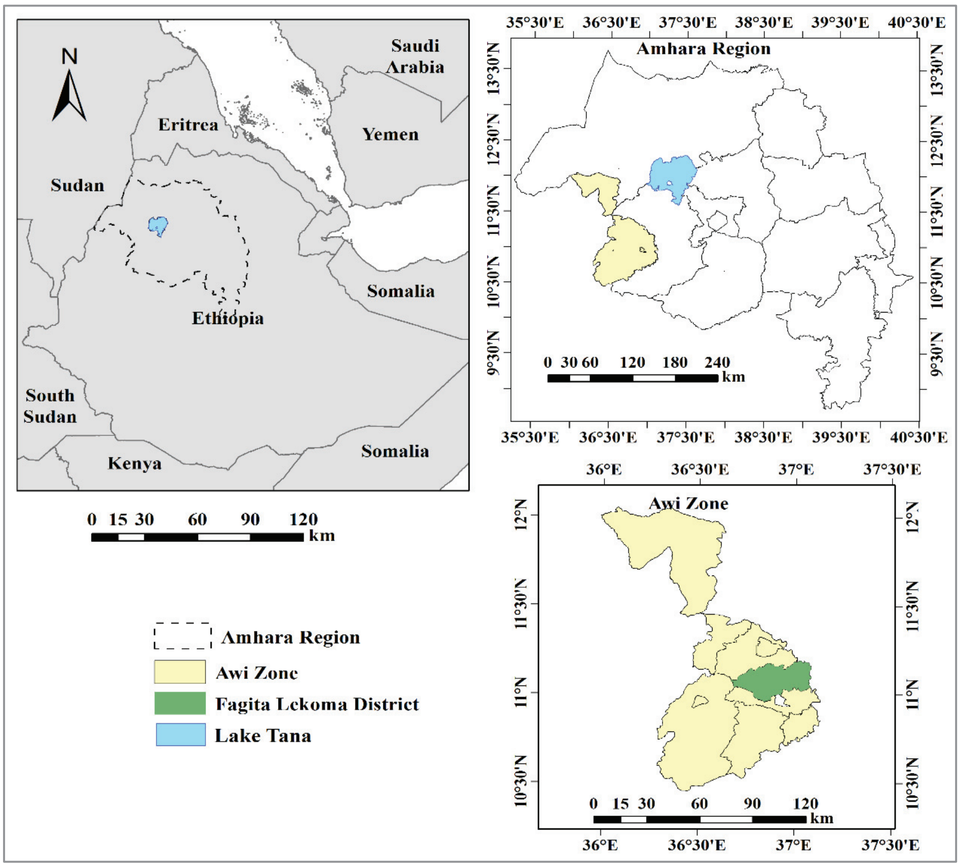

Figure 6: Map of the study area

4.2.2 Data collection and analysis

Prior to the formal survey, farmers, development agents and district experts were interviewed and field observation was undertaken to gain information for designing the main survey. The main survey data were collected from 200 randomly selected small-scale farmers in six randomly selected villages. Following random selection of the villages, a list of all households was compiled from local agricultural offices. Subsequently, I selected respondent households following systematic random procedure. A total of 200 respondents were drawn from the six villages, in proportion to the total number of households in each village. The study unit was the household and the data were collected through a face-to-face interview using structured questionnaires. Through the interviews, I sought to acquire information about socio-economic characteristics, institutional conditions and agroforestry practices. The interviews were conducted in October and November 2015.

The data were entered into SPSS statistical software (v. 23, IBM, Armonk, NY, USA) and were analysed by a combination of descriptive and econometric analyses. Chi-square test was used to assess association of farmer and farm related attributes between groups (*A. decurrens* grower vs. non-grower). The t-test was applied to assess mean differences in planted trees density between male- and female-headed households, and in farmer and farm related attributes between growing and non-growing households. A Tobit regression model was used to model the effects of explanatory variables on farmers' decisions to allocate land to planting *A. decurrens* and determine planting density, as these decisions could either be zero or take on some positive values. Prior to running the Tobit model, the data were assessed for multicollinearity. I employed the variance inflation factors to diagnose this problem and detected no problem. Parameters of the Tobit model were estimated by the maximum likelihood method in Stata software (v. 14, StataCorp, College Station, TX, USA).

4.3 Conceptual and analytical frameworks

Most studies of the adoption of agroforestry technologies tend to assess the conceptual underpinnings of the uptake of new or improved technologies. Following Holmes & Adamowicz (2003), I hypothesized that farmers' decisions on land allocation to *A. decurrens* woodlots and planting densities follow the theory of random utility maximization in light of their objectives, production possibilities and constraints, in which the utility derivable from these decisions depends on a vector of farm and farmer attributes. As utilities are random, a farmer will allocate a larger share of land and will plant trees more densely if the expected utility from doing so exceeds the expected utility from not doing so, all other factors being constant. Farmers' utility from such woodlot management is to be derived from expected future net benefit (benefits minus costs) streams. In our study, such benefits are the ones mentioned under 'farmers' motivations for planting *A. decurrens*'. In this paper, land allocation refers to the proportion of land devoted to woodlots, while tree density refers to the total number of tree seedlings planted on a given plot of land.

Literature on the diffusion of innovation theory uses different econometric models to analyse small-scale farmers' decisions on the uptake of agroforestry technology (Mercer, 2004; Choudhury & Goswami, 2013). Typically, most studies used probit or logit techniques, treating the decision to adopt as binary (Mercer, 2004). However, this does not take into account the strength of decisions. For example, a farmer may allocate a smaller or larger share of his or her farm to trees, and plant a lower or higher density of trees. And farmers might make these decisions simultaneously or independently. To address these issues, I used a Tobit regression model, following Rajasekharan & Veeraputhran (2002). Using a left-censored limit of zero, the Tobit model can easily be expressed as:

$$y_i^* = x_i\beta + \varepsilon_i, i = 1, 2, 3, \dots, n$$
$$y_i = y_i^* \; if \; y_i^* > 0$$
$$y_i = 0 \; if \; y_i^* \leq 0$$

where y_i is the dependent variable for the i^{th} observation (the proportion of land allocated for *A. decurrens* plantation and the number of trees planted in a plot of land operated by the i^{th} farmer), y_i^* is the underlying latent dependent variable, x_i is a vector of independent variables, ε_i is the disturbance term (assumed to be independently and normally distributed with zero mean and constant variance), and n is the number of observations.

Values of the estimated coefficients from a Tobit model do not directly give the marginal effects of the independent variables on the dependent variable, but their signs show the direction of relationships (Gujarati, 2012). By extending McDonald & Moffitt (1980)'s decomposition of the Tobit model, I calculated (1) changes in the mean of the latent dependent variable, β; (2) changes in the probability of being uncensored, $\partial \Pr(y>0/x)/\partial x$; (3) changes in expected values of the dependent variable conditional on being uncensored, $\partial E[y/x, y>0]/\partial x$; and (4) changes in the conditional expected value of the latent dependent variable, $\partial E[y^*/y>0]/\partial x$.

4.4 Results and discussion

Farmers' motivations for planting A. decurrens and characteristics of taungya practice

I obtained results from 162 plantation growers with an average of 0.56 ha (SD 0.233 ha, range 0.125–1.0 ha) of land dedicated to *A. decurrens*. (The other 38 respondents were non-growers.) The farmers planted an average of 16,276 trees ha^{-1}. The mean density of planting differed significantly between male-headed and female-headed households (14,703 vs 5,493 trees ha^{-1}, $P < 0.01$). Of the growers, about 68% primarily sourced their tree seedlings from their own nurseries, about 24% purchased from other farmers, and the rest of them obtained seedlings from government nursery.

The growers' main motivation for planting *A. decurrens* is to generate additional cash income (mean score = 6.82), mainly through converting the wood into charcoal (Table 9). Those who lacked sufficient financing and labor for making charcoal sold their wood to charcoal makers. The growers planted the trees in a *taungya* system, which allowed them to produce food crops (teff, wheat and barley) during the establishment phase and later grass hay to support their livestock. This helped them to secure extra income from complementary effects between the trees and crops, raising income, productivity and land-use efficiency. On average, a mean income of 76,604.94 ETB (~3596 USD) over a period of four years is reported by growers from charcoal sales. Similarly, based on a financial analysis, Achamyeleh (2015) reported a net present value of 127,128.75 ETB ha^{-1} (~5,968 USD ha^{-1}) from *A. decurrens* plantations, which was about quintuple as high compared with the gains from traditional monocultures (teff, wheat and barley).

Table 9: Motivations to plant *A. decurrens*

Score rank	Motivation	Proportion of farmers that mentioned as primary (%)	Mean score[a]	SD
1	To generate additional cash income from charcoal	84.6	6.82	0.48
2	To improve soil fertility of cultivated land	75.3	6.01	0.59
3	For soil and water conservation	52.5	4.16	1.36
4	As source of firewood	38.3	3.56	1.37
5	As source of construction material	23.5	3.36	1.02
6	As source of animal feed	16.7	2.41	1.12
7	To serve as farm boundary	9.3	1.80	1.22

[a] The expected mean score of the ranked items was computed as 4.00.

Note: Any item with a mean value ≥4.00 was regarded as main motivation to planting *A. decurrens*, while the ones <4.00 were regarded as minor.

The next most important motivations to engage in *A. decurrens* plantations are to improve the soil fertility of degraded farmland (mean score = 6.01) and to control soil erosion (4.16). Almost all growers felt that these abilities of *A. decurrens* were valuable. Of those growers, 81.5% preferred to plant on plots with low soil fertility, and the rest plant on plots with medium soil fertility. Growers preferred to plant seedlings in June and July to provide sufficient moisture and to manage them together with the intercrop. After they harvested their trees (usually after 4 years), 88% of growers planted teff, 57% barley, 72% wheat and 35% potato. Those who made charcoal did so on the same land so as to use the biochar by-product to improve soil fertility; Kassie *et al.* (2013), for example, showed that soils amended with biochar produced a higher maize yield. Thus, in addition to its income generation role, growers used the woodlots to reclaim cultivated land. This strategy is feasible in a region where 82% (Table 10) of the households possess marginal plots owing to continuous cultivation, soil acidity (Achamyeleh, 2015) and lack of money to buy fertilizer. This stands in contrast to Ndayambaje *et al.* (2013), who reported that environmental issues were not important determinants of growing farm woodlots in developing countries.

The sites where *A. decurrens* was planted have evolved over time in the study area. According to key informants, the tree was originally introduced for roadside planting. Witnessing its fast growth and compatibility with annual crops, coupled with promotion by extension agents, farmers began planting it along plot boundaries for firewood and fencing. Very recently, the emergence of attractive regional charcoal markets and the need for soil fertility improvement have led to its wider expansion into woodlot plantations on cultivated land.

Characteristics of respondents

A typical household in the study consisted of 3.37 working labor (Table 10). Around 84% of all households (93% of *A. decurrens* grower households) were male-headed. The mean age of the household heads was 45 years, and they had an average of 2.5 years of schooling. Growers were younger and better educated than non-growers. Households owned an average of 1.31 ha of land and 7.2 TLU. Growers had more than twice as much land and nearly three times as many livestock as non-growers. Growers received significantly more annual agricultural sale income (9,503 ETB) and credit (3,047 ETB) than non-growers (3,073 and 448 ETB, respectively). In addition, growers had better access to land resource management training and extension services. Therefore, households with low resource endowments are less likely to establish and integrate *A. decurrens* plantations, as much as they might want to.

Table 10: Summary statistics of the variables used in the Tobit analysis

Variable (coding/units)		Expected sign	Growers (n = 162)	Non-growers (n = 38)	Mean (SD)	Sig. (t/χ^2)
Sex of household head (1 male, 0 female)	Male	+	0.93	0.45		51.16***
	Female		0.07	0.55		
Age of household head (years)		–	44.3	49.1	45.2 (9.87)	–2.79***
Educational level of household head (years)		+	2.85	0.84	2.47 (2.89)	3.98***
Household available labor (man-equivalent)		+	3.58	2.47	3.37 (1.24)	5.30***
Total livestock owned by household (tropical livestock units)		+	8.21	2.92	7.20 (3.91)	8.87***
Land farmed by household (ha)		+	1.45	0.69	1.31 (0.55)	8.96***
Number of land resource management classes received per year		+	1.34	0.45	1.17 (0.98)	5.41***
Number of visits by extension agents per year		+	2.59	0.92	2.27 (1.65)	6.09***
Household access to credit (1 yes, 0 no)	Yes	+	0.91	0.24		83.52***
	No		0.09	0.76		
Credit received (ETB)			3047	448	2553 (2360)	6.76***
Distance of plot from main road (walking minutes)		–	21.4	31.5	23.3 (11.1)	–5.39***
Off-farm and non-farm income (ETB)		+	5379	4766	5263 (5433)	0.63
Household possession of marginal land (1 yes, 0 no)	Yes	+	0.82	0.11		73.07***
	No		0.18	0.89		
Total household cash income from sale of agricultural outputs (ETB)		+	9503	3073	8281 (6203)	6.28***

$^{***}P< 0.01$. 1 USD ≈ 21.3 ETB (Ethiopian birr).

Determinants of proportion of land allocated to and number of A. decurrens trees planted

I developed models of the determinants of the proportion of land allocated to tree planting (model I) and the number of *A. decurrens* trees planted (model II). Overall, the models fitted the data well (Table 11).

Table 11: Results of the Tobit model of farmers' decisions on land allocation and tree density

	Model I: Allocation of land to *A. decurrens*				Model II: Tree planting density			
Variable	β	$\partial Pr(y>0/x)/\partial x$	$\partial E[y/x, y>0]/\partial x$	$\partial E[y^*/y>0]/\partial x$	β	$\partial Pr(y>0/x)/\partial x$	$\partial E[y/x, y>0]/\partial x$	$\partial E[y^*/y>0]/\partial x$
Age of household head	−0.007 (3.76)***	−0.005 (−3.60)***	−0.005 (−3.79)***	−0.006 (−3.80)***	−117.154 (2.88)***	−0.002 (−2.81)***	−102.486 (−2.89)***	−106.5217 (−2.89)***
Sex of household head	0.087 (1.90)*	0.072 (1.64)	0.064 (2.00)**	0.075 (1.94)*	3 802.242 (3.56)***	0.067 (3.20)***	3 289.838 (3.63)***	3 457.68 (3.59)***
Educational level of household head	−0.003 (0.67)	−0.002 (−0.67)	−0.003 (−0.67)	−0.003 (−0.67)	−42.252 (0.35)	−0.001 (−0.35)	−36.962 (−0.35)	−38.417 (−0.35)
Household available labor	0.018 (1.25)	0.013 (1.26)	0.014 (1.26)	0.016 (1.26)	324.241 (0.94)	0.005 (0.94)	283.645 (0.94)	294.814 (0.94)
Total livestock owned by household	−0.002 (0.33)	−0.001 (−0.33)	−0.001 (−0.33)	−0.001 (−0.33)	110.086 (0.93)	0.002 (0.93)	96.303 (0.93)	100.095 (0.93)
Cultivated land operated by household	0.363 (2.92)***	0.257 (2.93)***	0.282 (2.94)***	0.318 (2.95)***	13 099.062 (4.45)***	0.200 (4.83)***	11 459.030 (4.49)***	11 910.22 (4.51)***
Cultivated land operated by household squared	−0.097 (2.31)**	−0.069 (−2.33)**	−0.076 (−2.32)**	−0.085 (−2.33)**	−3 745.310 (3.75)***	−0.057 (−4.03)***	−3 276.389 (−3.77)***	−3 405.395 (−3.78)***
Number of land resource management classes per year	0.019 (1.07)	0.013 (1.07)	0.015 (1.07)	0.017 (1.07)	642.392 (1.55)	0.010 (1.52)	561.963 (1.55)	584.090 (1.55)
Number of visits by extension agents per year	−0.000 (0.00)	0.000 (−0.00)	0.000 (−0.00)	0.000 (0.00)	−147.812 (0.58)	−0.002 (−0.58)	−129.306 (−0.58)	−134.3971 (−0.58)
Household access to credit	0.061 (1.34)	0.047 (1.21)	0.046 (1.37)	0.053 (1.35)	4 584.222 (4.34)***	0.071 (3.75)***	4 033.491 (4.39)***	4 236.333 (4.32)***
Distance of plot from main road	0.001 (1.78)*	0.001 (1.75)*	0.001 (1.78)*	0.001 (1.78)*	11.783 (0.80)	0.000 (0.80)	10.307 (0.80)	10.713 (0.80)
Off-farm and non-farm income	0.000 (0.67)	0.000 (0.67)	0.000 (0.67)	0.000 (0.67)	0.033 (0.54)	0.000 (0.54)	0.029 (0.54)	0.030 (0.54)
Household possession of marginal land	0.142 (4.29)***	0.116 (3.44)***	0.106 (4.51)***	0.125 (4.37)***	5 367.470 (6.98)***	0.079 (5.90)***	4 767.925 (7.03)***	4 997.526 (6.94)***
Total household cash income from sale of agricultural outputs	0.000 (0.23)	0.000 (0.23)	0.000 (0.23)	0.000 (0.23)	0.064 (0.93)	0.000 (0.93)	0.056 (0.93)	0.058 (0.93)
Constant	−0.082 (0.70)				−6 110.713 (2.21)**			
Sigma	0.179 (17.22)***				4 185.234 (17.17)***			
Number of observations	200				200			
Log likelihood	21.52				−1610.76			
Model chi-squared	117.50***				247.00***			

$^{*}P < 0.1$, $^{**}P < 0.05$, $^{***}P < 0.01$. Parentheses show *t*-statistics. β = change in mean of latent dependent variable; $\partial Pr(y>0/x)/\partial x$= change in probability of being uncensored; $\partial E[y/x, y>0]/\partial x$ is change in expected value of dependent variable conditional on being uncensored; $\partial E[y^*/y>0]/\partial x$ is change in conditional expected value of latent dependent variable, y^*.

As anticipated, the sex of the household head positively influenced land allocated to planting ($P < 0.1$) and tree density ($P < 0.01$). On many small-scale farms, men have less difficulty in obtaining labor and have more access to and control of resources than do women (Doss & Morris, 2001). Moreover, men’s better position within society gives them better access to technical and market information. These advantages give them greater capacity to plant *A. decurrens*. Asfaw & Admassie (2004) asserted that male-headed households are more likely to learn about new technologies than are female-headed households. Likewise, Ayele (2009) indicated that female-headed households are less likely to grow large number of trees than are male-headed households. Thus, our finding is consistent with the view that male-headed households have better incentives and opportunities to allocate more land to *A. decurrens* and to plant at a higher density to maximize their gains.

Interestingly, the age of the household head was significant ($P < 0.01$). In agreement with the expected negative sign (Table 10), age had a negative influence on land allocation and number of trees planted. Younger farmers are more likely to favor those decisions. This difference could be attributed to the fact that younger farmers are physically more capable of managing woodlots and have longer planning horizons (lower discount rates), and are thus less risk-averse. Moreover, their switching costs are lower than those of older farmers because if they are faced with a food shortfall, they might more easily resort to other livelihood options, for example seeking off-farm income. Conversely, older farmers may not be able to provide the labor needed for planting and charcoal burning. Keil *et al.* (2005) found, the intensity of adoption of leguminous trees to improve fallow land decreases with increasing age of the household head.

The size of the farm, which is the farmers’ main resource, had a positive and significant effect on both decisions ($P < 0.01$). Other things being equal, farmers with more land are more likely to allocate a larger proportion to *A. decurrens* at a higher planting density to maximize their gain from charcoal production. Similarly, Abiyu *et al.* (2016), Jenbere *et al.* (2012) and Ndayambaje *et al.* (2013) found that farmers with larger farms were more likely to expand their investment in agroforestry. In addition, Nyaga *et al.* (2015) and Ayele (2009) reported that farmers with better resource endowments are likely to allocate more land for growing more trees on the homestead than those who had fewer resources. They are able to do this because they have more flexibility owing to their better land endowment and can store surplus food to manage the risk of crop failure, or are less constrained in food production to meet immediate household requirements (Sood & Mitchell, 2009). Moreover, the square of this same variable had significant effects on land allocation ($P < 0.05$) and tree density ($P < 0.01$). Its negative sign indicates a maximum area beyond which farmers reduce the proportion of land allocated to tree planting and tree density, even on a large farm. This inverted U-shaped relationship (with the proportion of land allocated to *A. decurrens* and tree density first rising and then falling with increasing farm size) is likely due to the fact that with increasing acreage, woodlots reach their limits, be it through scarcity of labor or other production resources or through market limits (markets cannot absorb, at least locally, increasing products, or that transport costs to markets increase with larger amounts of products).

In the absence of surplus household income and accumulated savings, credit plays an important role in small-scale farm household land use decisions and technology choices. As anticipated, access to credit had a positive, significant effect on tree density ($P < 0.01$). Having access to credit can alleviate constraints of liquidity and working capital on farmers' decisions to plant trees. This finding suggests that households with access to credit are more likely to plant *A. decurrens* more densely than those without access. Moreover, households with financial constraints tended to sell the plantation stands instead of making charcoal. Exploiting the full profit potential of an *A. decurrens* plantation requires larger cash outlays than cereal production because of the investments in seedlings and the plantation establishment, costs of operation and maintenance throughout the plantation period, as well as the opportunity cost of shifting from cultivation of crops with short cash flow cycles to a relatively longer one. Hence, as most small-scale farmers have insufficient savings, increased access to credit may encourage them to invest in an *A. decurrens*-based *taungya* system.

I expected the distance of a woodlot from a main road (and hence markets for charcoal), a proxy for plot accessibility, to discourage land allocation to woodlots; in contrast, distance from main roads encouraged woodlot planting at a level approaching significance ($P < 0.1$). This result is counterintuitive because farmers pay ETB 2–5 (≈ USD 0.09–0.23) per sack to transport the charcoal to the market, depending on the distance, which constitutes an additional cost in charcoal marketing. This finding also contradicts von Thünen's theory of the isolated state (Diogo *et al.*, 2015), which posits that the farm product that achieves the highest return will outbid others in the competition for location to reduce transport costs. An explanation for this would be that woodlots are still less intensive in terms of costs, and their transport cost intensity is lower than for example perishable or high value food crops. This would then be in accordance with von Thünen, as his model proposes less intensive systems in remoter areas or circles. However, to finally determine this, a comparison of the profitability of annual food crops versus woodlots has to be done.

The effect of land quality in terms of soil fertility was interesting. Household possession of marginal land positively affected both land allocation and tree density ($P < 0.01$). Long-term soil fertility decline affected farmers' decisions to plant *A. decurrens* on a plot of land (Achamyeleh, 2015). Those households with less-fertile land have more incentive to allocate more land to *A. decurrens*, presumably because returns from cereals on less-fertile land are lower than returns from *A. decurrens*. This is an important soil fertility management strategy given the low level of inorganic fertilizer use in the study area.

4.5 Conclusions

Households are more likely to plant *A. decurrens*, and at greater density, if they have larger farms, marginal land, less accessible plots, access to credit, a male head of household and a younger head of household. The most important motivations for planting *A. decurrens* are additional income, soil fertility improvement, and the need for SWC. Although common supply-driven extension activities often treat rural households as though they are homogeneous in their uptake of new technologies, they are in fact heterogeneous (Elias *et al.*, 2016). This explains why access to extension had no influence on land allocation to *A. decurrens* planting and tree density. A more diversified extension approach with appropriate targeting could encourage more farmers to adopt an *A. decurrens*-based *taungya* system. As farmers are more willing to plant *A. decurrens* on marginal lands, farm-level factors should be considered in extension programs. Female-headed households are likely to allocate less land to *A. decurrens* and to plant less densely, probably because of socio-economic and cultural disadvantages in access to information, labor, markets and technical support. Therefore, an extension approach that considers gender as an important targeting variable would contribute significantly towards closing the gender gaps in technology. Understanding the role of this factor will require further in-depth analysis.

Land use and livelihoods are undergoing rapid change in the study area as a consequence of the expansion of *A. decurrens* plantations. If carefully managed, this change has the potential to contribute to sustainable rural livelihoods. The importance of lower plot accessibility, access to credit and farm size in our model indicates that in the absence of public intervention, small-scale farmers may face constraints that exclude them from reaping the full benefits of new technologies. Hence, as more farmers become aware of market opportunities and expand their *A. decurrens* plantations for charcoaling, the importance of road access is likely to become more significant. Improving village-to-village road access should be considered a high priority for the development of the agroforestry market system, as well as a general poverty-reduction strategy. Upgrading local roads is needed to make distant marginal *A. decurrens* plots more profitable. In addition, the importance of access to credit in influencing land allocation and tree density shows the need for improving rural credit systems. Government and non-government organizations have to play an active role in rural development through the provision of tailor-made financial assistance to resource-constrained farmers. This could cover the cash gap between planting and harvesting, when no income is generated.

In general, there is an increasing tendency in the spread of *A. decurrens* woodlots in the north-western Ethiopia. For further dissemination of such agroforestry based land management practices across the region, the extension programs should play a proactive role in introducing technologies with multipurpose values (e.g. generate income, reclaim degraded lands, provide renewable energy, etc.), and tailoring outreach efforts to assist farmers access to institutional support. Moreover there is a need for further study on the optimal level of land that farmers should allocate to plantations as well as the corresponding planting densities, given their resource constraints and mixed cropping systems.

Chapter 5

General conclusions

Chapter 5. General conclusions

Herein study, I found that farmers have their own way of interacting with their immediate environment (i.e., farmlands) through which they develop their perceptions of the problems (e.g., awareness of ongoing soil erosion), and so influences individual conservation behavior. Although farmers have good understanding of the soil erosion problem in their farmlands, it is not fully translated into their investment decisions. Consideration of explanatory variables on their farm- and farmer-levels, institutional factors and the factors beyond is crucial to understanding their adoption behaviors and, ultimately, for understanding the conditions and causes of soil damage.

Subsequently, I found that farmer perceptions regarding soil erosion, technology use and investment decisions are often context specific, both concerning the specific site (e.g., soil fertility, soil depth, watershed position) in which the practice are implemented and in regards to the circumstance (e.g., perceptions of soil erosion severity, perceived technology profitability, age, gender, education, livestock number, wealth, farm size, plot distance, credit, tenure) in which the farmers' lives are engrained. So as to expedite the limited investment on SWC measures, focus should be given on assisting farmers (e.g., training, extension, adult education) to align their soil erosion perceptions with scientific knowledge that outlines the hazards of soil loss, and also programmes targeting soil erosion should provide a room to integrate local farmers expertise and assist them through introducing complementary enterprises (e.g., fodder) that could enable to acquire immediate benefits. It is also suggested that agroforestry programmes (e.g., *Acacia decurrens*) focus on areas with degraded cultivated lands and hillsides (e.g., Guder watershed). Moreover, such programmes should give attention to the enabling environment (e.g., gender-based extension, credit, road) that would arouse and maintain interests of farmers toward such land management practices and enable its widespread disseminations to similar areas across the region.

In this study, I have inquired farmers' to reflect their perceptions of the soil erosion problem on their operational farm plots. However, it would have been more logical to make a comparison between these perceptions and their corresponding measured and/or empirically estimated soil erosion severity levels. In this regard, I suggest a research work that would extend the findings of the current study. Another important aspect that has not been dealt with and need consideration in future research concerning factors affecting farmers' perceptions about soil erosion problem in such a wider basin is the importance of incorporating area dummy variables so as to capture differences across sites. In addition, although attention has been given to select representative study sites in the Upper Blue Nile Basin, considering the basin’s diversity, the findings of the study should not be extrapolated to other highland areas, or if so it should be with care.

Although adoption of SLM practices by farming households is a dynamic decision process, the findings of this study is based on a cross-sectional data analysis. As a result, this limitation of the study may restrict the validity of the results obtained for long time.

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SUMMARY

Soil degradation—mainly through water erosion—represents a significant livelihood challenge in the highlands of the north-western Ethiopia. Annual soil erosion rates as high as 42 Mg ha^{-1} and more have been reported on cultivated lands. Over the last four decades, the government of Ethiopia with the support of several international and bilateral agencies have been promoting various types of land management technologies (e.g., soil bund, *fanya juu*, stone-faced soil bund, application of inorganic fertilizer) to control soil erosion and improve rural livelihoods. In spite of the multiple technologies being promoted in the country, small-scale farmers' investment remains unsatisfactory, or it is limited to traditional techniques (e.g., traditional stone bund, agroforestry, drainage channel, application of manure).

It is found that, there exist a widespread perceptions of the on-going soil erosion problem among small-scale farmers' in the Upper Blue Nile Basin, Ethiopia. Yet these perceptions are only marginally translated into stimulating a sustained use and widespread uptake of sustainable land management (SLM) technologies. This is due to the fact that investment decisions (i.e., 'to use and not to use', and 'how much to use') of farmers on such technical solutions are mainly directed and conditioned by a series of factors—institutional, socio-economic, and biophysical. In order to develop appropriate SLM strategies for the study region, there is a need to investigate farmers' perceptions of soil erosion severity and examine their corresponding actions to alleviate its perceived effects. This will be helpful to identify and design effective SLM programmes and support services. As a result, the study is aimed at examining small-scale farmers' attitude towards soil erosion and their adoption of land management practices in the north-western Ethiopia. Specifically, the objectives of this study are threefold: (1) to investigate how farmers perceive the severity of soil erosion and to explore the principal determinants of variations, (2) to analyze the underlying factors that affect the adoption of SLM technologies, and (3) to assess the motivations of farmers to establish agroforestry, the respective determinants and the context in which tree planting has expanded. This study comprises five chapters.

Chapter 1 presents the introductory section of this study. It sets out an overview of the background for the study, focusing on physical features, climate, economy, population, crop sector, farm size, policy, and the soil erosion problem and the country's experience in soil conservation activities. Subsequently, it presents the study objectives, concepts and definitions, theoretical and conceptual frameworks, and outline of the thesis.

Chapter 2 investigates how smallholder farmers perceive the severity of soil erosion in the Upper Blue Nile Basin, Ethiopia. The analysis is based on a detailed survey of 300 households and 1,010 plots operated by these households in three watersheds. Descriptive statistics and a partial proportional odds model were applied to analyze factors that affected farmers' perceived soil erosion severity at the plot-level. Results showed that variables such as plot distance from the residence, plot shape and position on hill slopes affected farmers' perceptions of soil erosion severity, as well as the amount of rainfall during the growing season. Farmer interaction with extension service agents also affected farmers' perception of soil erosion severity. Despite their expected importance, education and number of livestock owned had no effect on the farmers' perception of soil erosion. The results indicate that farmers' perceptions generally match empirical and theoretical findings on soil erosion determinants; thus, farmers should be considered as important partners not only to counter soil erosion, but also to obtain local expertise on soil erosion severity and restoration of degraded land.

Chapter 3 analyzes the underlying factors that affect the adoption of SLM technologies in the Upper Blue Nile Basin. A detailed survey of 300 households and 1010 farm plots was conducted. Data were analyzed by using both descriptive and econometric analyses. Results show that farmers' adoption of interrelated SLM measures depended on a number of socio-economic and farm-related factors in combination with the characteristics of the technologies themselves. For example, plot size and the availability of labor, as well as the gender of the household head, affected which SLM technologies were adopted by certain types of households. The adoption of SLM measures depended on the adaptive economic capacity of the farmers, which can be quite diverse even within a small region and can differ from the adoption potential in other regions. Our results suggest that SLM policies and programmes have to be individually designed for specific target groups within specific regions, which in turn means that "one size fits all" and "across the board" strategies—which are quite common in the field of SLM—should be abandoned by development agencies and policymakers.

Chapter 4 examines why and which factors determine the decisions of small-scale farmers to grow short-rotation woodlots on their land as an additional source of livelihood and as a land management option. Data used in this study were collected from a survey of 200 randomly selected households in the region. A Tobit regression model was used to determine predictor variables for farmers' decisions to allocate land to planting *Acacia decurrens* (J.C. Wendl.) Willd. and at what density trees are planted on the respective plots.

The most important motivations for planting *A. decurrens* were income, soil fertility management, and soil and water conservation. Having a male head of household, long distance to markets and plots being on marginal land, among other factors, increased the allocation of land to *A. decurrens* woodlots. Having a male head of household, access to credit and plots being on marginal land, among other factors, increased tree planting density. Age had a negative effect on both allocation of land to woodlots and tree density, whereas farm size had an inverted U-shaped relationship with both decisions. These results suggest that wider expansion of *A. decurrens*-based plantation systems could be achieved through improving extension, credit access and road infrastructure to connect small-scale farmers to markets and finance.

Chapter 5 provides a general synthesis of the whole thesis, including conclusions, policy implications, limitations of the study, and avenues for further research.

The findings of this study showed that small-scale farmers' perceived soil erosion severity and adoption of SLM technologies were conditioned by a number of socio-economic, biophysical, institutional and farm related factors in combination with the characteristics of the technologies themselves. These findings allow deriving policy recommendations to enhance voluntary uptake of SLM technologies by small-scale farmers. Thus, SLM programmes and support services should give attention to "participatory" approach to ascertain farmers' attitudes about soil erosion and their preferences of counter measures. This will in turn allow them to capitalize on localized knowledge and design policies and strategies that promote restoration of degraded lands.

学位論文概要

土壌の劣化、とくに降雨による土壌侵食（水食）は、エチオピア北西部の高地で暮らす人々にとって、生計を脅かす重要な問題となっている。この地域の耕作地では 42 Mg/ha 以上の年間土壌侵食速度が報告されている。過去 40 年にわたり、エチオピア政府はいくつかの国際機関および二国間の援助を得て、土壌侵食を制御し、農村の生計を向上させるための様々な種類の土地管理技術（例えば、ソイルバンド、ファニャジュ、ストーンバンド等）を導入してきた。エチオピアでは複数の技術が奨励されてきたが、小規模農家による投資は不十分であり、伝統的な技術（例えば、伝統的なストーンバンド、アグロフォレストリ、排水路、堆肥の施用等）に限られている。

エチオピアの青ナイル川上流域においては小規模農家は進行中の土壌侵食問題を広く認識していることが知られている。しかし、これらの認識は、持続可能な土地管理（Sustainable Land Management: SLM）技術の持続的な利用と広範な適用にはほとんどむすびついていない。これは、そのような技術的解決策に関する農業従事者の投資意思決定（すなわち、「使用するか否か」、「どの程度使用か」）は、主として制度的、社会経済的、および生物物理学的要因により方向付けられ、条件付けられているためである。研究対象地域における適切な SLM 戦略を策定するためには、土壌侵食の重大さに対する農民の認識を調査し、土壌侵食の影響を軽減するための対処行動を調べる必要がある。これは、効果的な SLM プログラムと支援サービスを特定し、設計するのに役立つ。そこで本研究はエチオピア北西部における小規模農家の土壌侵食に対する認識と土地管理策の選択に関する決定要因を明らかにすることを目的とした。具体的には、①農家の土壌侵食に関する認識およびその決定要因の解明、②SLM 技術の採用に影響する要因の分析、③ 生計向上の重要な手段となっているアグロフォレストリを導入するにあたっての農家の動機と決定要因の解明という三つの課題に取り組んだ。本論文は以下の 5 章から構成されている。

第 1 章は、本研究の紹介部分である。気候、経済、人口、耕作、農場の大きさ、政策、土壌侵食問題、土壌保全活動における国の経験に焦点を当てて、研究の背景を概説する。その後、研究目的、概念と定義、理論的および概念的枠組み、および論文の概要を提示する。

第 2 章では、小規模農家がエチオピアの青ナイル川上流域における土壌侵食の深刻さをどのように認識しているかを明らかにした。農家の土壌侵食に関する認識およびその決定要因の解明するために青ナイル川上流域に位置する三つの小流域に暮らす 300 世帯の小規模農家を対象とした聞き取り調査および 1010 の農地プロットに関する実地調査を行った。記述統計と部分比例オッズモデルを適用して、プロットレベルでの農家の土壌侵食に関する認識に影響を与える要因を分析した。結果は、生育期の降雨量に加えて、居住地からプロットまでの距離、プロットの形状および斜面上の位置などの変数が、農家の土壌侵食の重大性に関する認識に影響

を与えていた。また農民の農業普及員とのやりとりもまた農家の土壌侵食の認識に影響を与えた。予想に反して、教育歴や所有されている家畜の数は、農家の土壌侵食の認識に影響を与えていなかった。農家の認識は、土壌侵食の決定要因に関する経験的および理論的な知見と概ね一致しており、土壌侵食と劣化土地の回復に関する土地に根ざした専門知識を得るうえで農民は重要なパートナーとみなすことができる。

第3章では、SLM技術の採用に影響する要因の分析するために、上述した農家および農地を対象にさらに調査を行い、記述統計および計量経済的手法を用いてデータを分析した。結果は、農家のSLM技術の採用は、技術自体の特性に加えて、社会経済的要因および農業関連の要因に依存することが示された。例えば農地プロットの大きさと労働供給可能性、世帯主の性別などが採用されるSLM技術に影響を与えた。どのようなSLM技術が選択されるかは、小さな地域内であっても非常に多様であり、農業従事者の経済的適応能力によって、地域ごとに異なるSLM技術が採用されていた。この結果は、地域によって、またターゲットグループによって異なるSLMの方針とプログラムを個別に設計する必要があることを示している。すなわちSLM技術の普及にあたっては、一般的で画一的な手法や一律的な戦略は効果的ではないと考えられた。

第4章では、アグロフォレストリを導入するにあたっての農家の動機と決定要因を解明するため、200世帯を対象に聞き取り調査を行った。トービット回帰モデルを用いて、農家がアカシア・デカレンス（*Acacia decurrens*）を植えるためにどの程度の土地を割り当てるか、またどの程度の栽植密度で植林するかの決定に関わる要因を分析した。*A. decurrens*植栽の主要な重要な動機は、収入、土壌肥沃度管理、および土壌・水保全であった。家長が男性の世帯、市場への距離が遠いこと、および限界地などの条件では、*A. decurrens*圃場への土地配分がより多かった。男性が家長の世帯、金融へのアクセスがあること、限界地といった条件では栽植密度が高かった。世帯主の年齢は植林地への土地配分と栽植密度の両方と負の関係があったが、農地面積は両者と逆U字型の関係にあった。これらの結果は、農業技術指導や、小口融資、道路整備などを通じて小規模農家の市場へのアクセスや資金調達を容易にすることが*A. decurrens*植林の普及につながる可能性を示唆している。

第5章では、結論、政策的な意義、研究の限界、今後の研究課題など、論文全体を総合的にまとめた。

この研究の結果は、小規模農家の土壌侵食の重大さに関する認識とSLM技術の採用が、技術自体の特性に加えて、さまざまな社会経済的、生物物理学的、制度的、および農場関連の要因によって条件付けられていることを示した。これらの知見から、小規模農家による自主的なSLM技術の採用を促進するための政策提言を導き出すことが可能となる。以上のことから、SLMプログラムと支援サービスは、農民の土壌侵食に対する態度と対策の選択を確認する「参加型」アプローチに留意すべきである。これにより、劣化した土地の回復を促進するうえで、住民の持つ在来知識を活用し、政策と戦略を設計することが可能となる。

LIST OF PUBLICATIONS

Zerihun Nigussie, Atsushi Tsunekawa, Nigussie Haregeweyn, Enyew Adgo, Makoto Nohmi, Mitsuru Tsubo, Dagnachew Aklog, Derege Tsegaye Meshesha, Steffen Abele. 2017. Farmers' perception about soil erosion in Ethiopia. Land Degradation & Development 28(2): 401–411. (Published, this article covers **Chapter 2**)

Zerihun Nigussie, Atsushi Tsunekawa, Nigussie Haregeweyn, Enyew Adgo, Makoto Nohmi, Mitsuru Tsubo, Dagnachew Aklog, Derege Tsegaye Meshesha, Steffen Abele. 2017. Factors affecting small-scale farmers' land allocation and tree density decisions in an *Acacia decurrens*-based *taungya* System in Fagita Lekoma District, north-western Ethiopia. Small-scale Forestry 16(2): 219–233. (Published, this article covers **Chapter 3**)

Zerihun Nigussie, Atsushi Tsunekawa, Nigussie Haregeweyn, Enyew Adgo, Makoto Nohmi, Mitsuru Tsubo, Dagnachew Aklog, Derege Tsegaye Meshesha, Steffen Abele. 2017. Factors influencing small-scale farmers' adoption of sustainable land management technologies in north-western Ethiopia. Land Use Policy 67(2017): 57–64. (Published Online, this article covers **Chapter 4**)