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SOIL FERTILITY MANAGEMENT IN THE ANNUAL-PERENNIAL CROPPING SYSTEM OF ARSAMMA WATERSHED, SOUTHWESTERN ETHIOPIAN HIGHLANDS

BY

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Soil Fertility Management in the Annual-Perennial Cropping System of Arsamma Watershed, Southwestern Ethiopian Highlands

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This is to certify that the thesis prepared by Dereje Guteta, entitled: ***Soil Fertility Management in the Annual-Perennial Cropping System of Arsamma Watershed, Southwestern Ethiopian Highlands*** and presented in fulfillment of the requirements for the Degree of Doctor of Philosophy in Geography and Environmental Management (Specialization in Environment and Natural Resources Management) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Acronyms

ADB	African Development Bank
ADLI	Agriculture Development Led Industrialization
AEALHH	Adult Equivalent Agricultural Labor of a Household Head
AGHH	Age of a Household Head
Av. P	Available Phosphorus
AVFARDIS	Average Farm Distance
BD	Bulk Density
BFED	Bureau of Finance and Economic Development
BS	Base Saturation
C: N	Carbon to Nitrogen Ratio
CA	Conservation Agriculture
Ca^{2+}	Exchangeable Calcium
CEC	Cation Exchange Capacity
CRS	Creative Research Systems
CRSO	Council of the Regional State of Oromia
CSA	Central Statistical Agency
DAP	Di-Ammonium Phosphate
DEM	Digital Elevation Model
EATA	Ethiopian Agricultural Transformation Agency
EDI	Expected Direction of Influence
EDUCLHH	Education Level of a Household Head
EMA	Ethiopian Mapping Agency
EPA	Environment Protection Authority
FAO	Food and Agriculture Organization
FLS	Farmland Size
FLSWCFA	Farmland Size with Chemical Fertilizer Application
FLSWCR	Farmland Size with Crop Rotation
FLSWOFA	Farmland Size with Organic Fertilizer Application
FLSWSB	Farmland Size with Soil Bund
FTR	Farmer Training
GDP	Gross Domestic Product
GENHH	Gender of a Household Head
GIS	Geographic Information System
GPS	Global Positioning System
ICF	International Classification for Functioning
IFPRI	International Food Policy Research Institute
ISFM	Integrated Soil Fertility Management

IUSS	International Union of Soil Sciences
K^+	Exchangeable Potassium
LIVS	Livestock Size
Mg^{2+}	Exchangeable Magnesium
MSL	Mean Sea Level
N^+	Exchangeable Sodium
NAEI	National Agricultural Extension Intervention
NGO	Non-Governmental Organization
NFPLT	Number of Farm Plots
NUPIE	National Urban Planning Institute of Ethiopia
OFFARE	Off-farm Income
OM	Organic Matter
ONRS	Oromia National Regional State
PADETS	Participatory Demonstration and Training System
PAGEX	Participation in Agricultural Extension
pH	Soil pH
PPDO	Physical Planning Department of Oromia
PTCMCHFA	Perception towards Continuous Mono-Chemical Fertilizer Application
SD	Standard Deviation
SE	Standard Error
SLUF	Sustainable Land Use Forum
SPSS	Statistical Package for Social Sciences
TLU	Tropical Livestock Unit
TN	Total Nitrogen
TOTFS	Total Farm Size
TP	Total Porosity
USAID	United States Agency for International Development
WB	World Bank
YCHFERAP	Year of Chemical Fertilizer Application

Abbreviations

E	East
Ha	Hectare
I'e.	That is
KM	Kilometer
M	Meter
N	North

Abstract

The specific objectives of this study were to assess dynamics of selected physico-chemical soil properties under different land use types, examine the nexus between smallholder farmers' resource endowment and soil fertility management, identify determinants of Integrated Soil Fertility Management (ISFM) adoption, examine factors influencing agroforestry upscaling and agroforestry-based spatial land use integration (inter-plot organic fertilizer transfer and inter-plot income flow) and assess farmers' perception of soil fertility change and their preferences for soil fertility management techniques in Arsamma Watershed, Southwestern Ethiopian Highlands. Forty-two composite soil samples and 42 core samples were collected from forestland, multistory canopy coffee farm, coffee monoculture and annual cropland. The samples from the annual cropland were sub-stratified based on farmers' resource endowment. The socioeconomic data were collected from 136 randomly selected households. Two way ANOVA and Tukey's post hoc tests were used to assess soil properties under different land use types. One way ANOVA and multiple regression models were employed to examine the nexus between smallholder farmers' resource endowment and soil fertility management. Factors driving adoption of ISFM were characterized by a binary logistic regression model. Contingency tables, chi-square, phi and Cramer's V were used to examine factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow. Farmers' perception of soil fertility change and their preferences for soil fertility management techniques were assessed by descriptive statistics. Decreasing tendencies of soil organic matter, total nitrogen and the exchangeable base content were observed, sequentially, in forestland, multistory canopy coffee farm, coffee monoculture and annual cropland. Next to forest soils, soils of the multistory canopy coffee farm contained high organic matter, total nitrogen and exchangeable bases content. The soils were found to be strongly acidic (pH < 5.5) regardless of land use types. Decreasing tendencies of soil nutrient content and increasing patterns of soil acidity and soil compaction were observed, sequentially, in farmlands owned by the rich, medium and poor households. Farmland size and number of livestock explained about 61% of the variability in organic matter content of the soil. About 56% of total variation in crop yield area was explained by farmland size and livestock number, and 5.2 quintals of yield gap by area was observed between rich and poor households. Use of ISFM, agroforestry and agroforestry-based spatial land use integration was influenced by complex sets of factors. Farmland size, farmer training, participation in agricultural extension, duration of chemical fertilizer application and farmers' perception toward continuous use of mono-chemical fertilizer were the statistically significant predictors of ISFM adoption. Scaling up of agroforestry and agroforestry-based spatial land use integration were mainly influenced by access to seedling, farmers' production orientation, farmland size and farmers' wealth status. The rate of soil fertility decline and the rate of the occurrence of the contributory factors were found land use specific. Increasing fertilizer requirement of croplands and decreasing yield per unit of land were the main indicators of soil fertility decline in annual and perennial cropland, respectively. Farmers' priorities for soil fertility management techniques were land use specific. ISFM and agroforestry were their top preferences, respectively, for annual and perennial cropland. Promotion of ISFM, scaling up of the traditional coffee farm to coffee-based improved agroforestry, working towards certification of shade grown and/or organic coffee that may help the farmers to obtain premium prices from international coffee market and/ or carbon trade, application of organic fertilizers, promotion of rural electrification and energy saving stoves can alleviate the problem of soil fertility decline resulting from land use change and agroecosystem transformation. The poor farmers need to be emphatically focused on soil fertility management planning, and hence provision of credit services without tightened precondition, subsidizing chemical fertilizers, and promotion of off-farm livelihood strategies are the way out. Action-based farmer training and agricultural extension services can enhance adoption of ISFM. Agroforestry and agroforestry based symbiotic and mutually synergistic spatial land use integration can be scaled up through the promotion of agroforestry-centered diversified small-scale agricultural commercialization, tree-crop-livestock integration, and multi-purpose tree species supply. Farmers' knowledge of below-ground processes of soil degradation need to be cultivated; and ISFM for annual cropland and agroforestry for the perennial cropland need to be a top priority of soil fertility management planning in Arsamma watershed.

Chapter 1

General Introduction

Ethiopia is located in the Horn of Africa. It extends from 3-15 degrees North and 33-48 degrees East with a total area of 1.1 million km^2 (CSA & ICF International, 2012). The relief of the country ranges from 110 m below mean sea level at the Affar Depression to 4,620 m above mean sea level at Ras Dashen Mountain (Alemayehu, 2006), resulting in a vertical elevation difference of 4.73 km between the lowland and the apex point. High variation in soil properties across the country is partly attributed to these high altitudinal differences (Abreha et al., 2012).

With a projected total population of 94,351,001 in 2017 (CSA, 2013), Ethiopia is currently the second most populated country in Africa, after Nigeria (WB, 2015). Based on the current annual population growth rate of 2.6%, the total population of the country is expected to reach 165 million by 2050, and this will make it the tenth most populated country in the world (USAID, 2014). Agriculture is the mainstay of this overwhelming population, employing about 85% of the population and generating about 43% of Gross Domestic Product (GDP) in 2013 (ADB, 2014). However, per capita landholding size is very small and shrinking from time to time. The national average landholding size was just 0.95 ha/household during 2013/14 (CSA, 2014), and the number of households who owned less than 0.1 ha grew from 7.3% in 2009 to 9.1% in 2014 (CSA, 2010; 2014). As a result, land use/land cover change, over cultivation, farming of fragile steep slopes and soil fertility decline are critical environmental challenges associating with the shrinking farmland size in the highlands of the country (Engdawork, 2012; Mahmud et al., 2005).

Soil fertility depletion

Soil fertility decline is the major environmental challenge that threatens agricultural productivity and the livelihoods of millions of rural households in Ethiopia (Mitiku et al., 2007). The projected soil fertility decline by Mahmud et al. (2005) indicates that about

106,000 km^2 (9.6% of the total area of the country) was not able to sustain arable cropping in 2010. Stoorvogel et al. (1993) estimated that about 41 kg of N, 6 kg of P and 26 kg of K is lost per hectare per year from Ethiopian highlands. On top of this, approximately 41% of the total farmland of the country is acidic, of which nearly one-third faces the problem of aluminum toxicity (EATA, 2013). The direct cost of this soil fertility depletion was estimated to be 3-7% of agricultural GDP (Berry et al., 2003). Even though the extent of this problem varies spatially depending on variation in geology, relief, ecology, rainfall, land use, soil types and population density (Adugnaw, 2014), the problem is exceptionally severe in the highlands of the country, where 88% of human and 77% of the total livestock population is concentrated (Teklu, 2005).

The severity of the problem is partly attributed to topographic and climatic variables (Wood, 1993). But, it has been severely intensified by anthropogenic factors, such as land use/land cover change, overgrazing, over cultivation, farming of fragile steep slopes and inappropriate soil management practices (Adugnaw, 2014). Due to the strong association that exists between land use and soil properties, land use change from natural ecosystem to agricultural landscape is one of the major human induced factors that threatens soil nutrient content in Ethiopia (Tsehaye & Mohammed, 2013; Woldeamlak, 2003). This intimate soil-land use interaction is directly reflected through the impacts of vegetation which acts both as independent and dependent variable in its interaction with soil properties (Jenny, 1994).

Complex sets of socioeconomic, institutional and technological variables that hinder adoption of sustainable soil fertility management technologies are also underlying causes of soil fertility decline (Bekele & Holden, 2000). Among others, rural poverty, which is believed to trap small-scale Ethiopian farmers in vicious circles of poverty and soil fertility depletion, is thought to be the major socioeconomic factor that threatens sustainable soil fertility management, soil health and agricultural yield in the country (Assemu & Shigdaf, 2014; Edwards, 2010).

Soil fertility management interventions

Various mechanical and biological soil conservation programs were launched since 1970s to address the problem of soil fertility decline in Ethiopia (Tesfa & Tripathi, 2015). These programs mainly focused on arresting soil erosion by using structural soil conservation measures without sufficiently considering the underlying causes of soil nutrient depletion, socio-economic factors, and the tangible benefits to poor farmers (FAO, 2003). Farmers' priorities for various soil fertility management techniques were given less attention as the programs were mostly designed by a top-down approach (Betru, 2002). Hence, soil conservation strategies that were oriented towards physical structure could not adequately address the problem of soil fertility decline and agricultural yield stagnation in the country (Gerishu & Mvena, 2011).

A number of efforts were also made to improve soil fertility and agricultural productivity under the framework of national economic development strategy of the country, known as Agriculture Development Led Industrialization, that has been underway since the mid 1990s (Kassa, 2003). The Participatory Demonstration and Training Extension System (PADETS) and the National Agricultural Extension Intervention (NAEI) programs are major examples of this (Spielman et al., 2011). These programs mainly aimed to improve chemical fertilizer supply and extension services to smallholder farmers in order to promote agricultural production and productivity (Kassa, 2003). The focus on chemical fertilizer alone, however, increased grain yield by only 10%, although chemical fertilizer application was increased five times; this is because the country faces complex sets of soil fertility problems that require strategies that go beyond the application of chemical fertilizers (IFPRI, 2010). For instance, Spielman et al. (2011) calculated chemical fertilizer to economic yield cost ratios from 1992 to 2008 to estimate the profitability of chemical fertilizer in Ethiopia. Taking an economic yield to chemical fertilizer cost ratio threshold value of 2, beyond which application of chemical fertilizer is assumed to be profitable, the average value declined from 3.74 to 1.91 for *teff (Eragrostis tef)* and from 4.24 to 2.18 for maize from 1992 to 2008 across the country. The same study also showed that the value declined from 3.84 to 1.83 for maize in the Wellega region of

Ethiopia (which also encloses the study catchment). This implies that soil fertility management and ensuring food security through sole dependence on mono-chemical fertilizer technology faces severe challenges across the country in general and in regions facing soil acidity problems in particular.

The recent paradigm shift in soil fertility management intervention indicates that Integrated Soil Fertility Management (ISFM) is one of the eco-friendly, cost effective and adaptive soil fertility management techniques that enables smallholder farmers to overcome the many limitations of the various soil fertility management techniques used in Sub-Saharan Africa (Sanginga & Woomer, 2009; Vanlauwe et al., 2014). However, the promotion of ISFM as part of NAEIP in Ethiopia is sluggish and lacks proper implementation and wider dissemination (IFPRI, 2010).

Agroforestry is widely considered to be the most holistic, economically feasible and environmentally sustainable soil fertility management option available, enabling the many limitations of various soil fertility management strategies to be addressed (Ajayi et al., 2008; Kang & Akinnifesib, 2000). It is also thought to be an irreplaceable option for soil fertility management in the highly dissected topography and increasingly fragmented land units due to population pressures in the Ethiopian highlands (Badege & Abdu, 2003). However, without due scientific experimentation, wider adoption and/or adaption in the country, indigenous agroforestry perpetuates only by the traditional practices of smallholder farmers (Tesfaye et al., 2006).

In order to promote wider adoption and/or adaption of these soil fertility management techniques, an understanding of farmers' knowledge of soil fertility change and their preferences for various soil fertility management techniques were found to play an important role in facilitating communication among farmers, researchers, development agents and policy makers (Barrios et al., 2006; Maro et al., 2013). A number of previous soil fertility management interventions were found to be less sustainable than biophysical measures would suggest, partly due to little valuation of farmers' preferences for the various soil fertility management techniques (Zenebe et al., 2003).

In a nutshell, while land use change from natural ecosystem to agricultural land use is one of the major human induced factors that influences soil fertility status at a micro watershed level, complex sets of socioeconomic, institutional, technological, farmland characteristics and other variables hinder adoption of the various soil fertility management techniques; in the case of this study, ISFM, agroforestry, chemical fertilizers, organic fertilizers, crop rotations and soil bunds are the underlying factors that determine soil fertility management practices and then soil fertility status. A conceptual framework that shows implications of land use, topography and farmers' resource endowment on soil fertility status, and factors influencing soil fertility management practices in the study catchment, which are also thoroughly discussed throughout this thesis, are schematically presented in Figure 1.1.

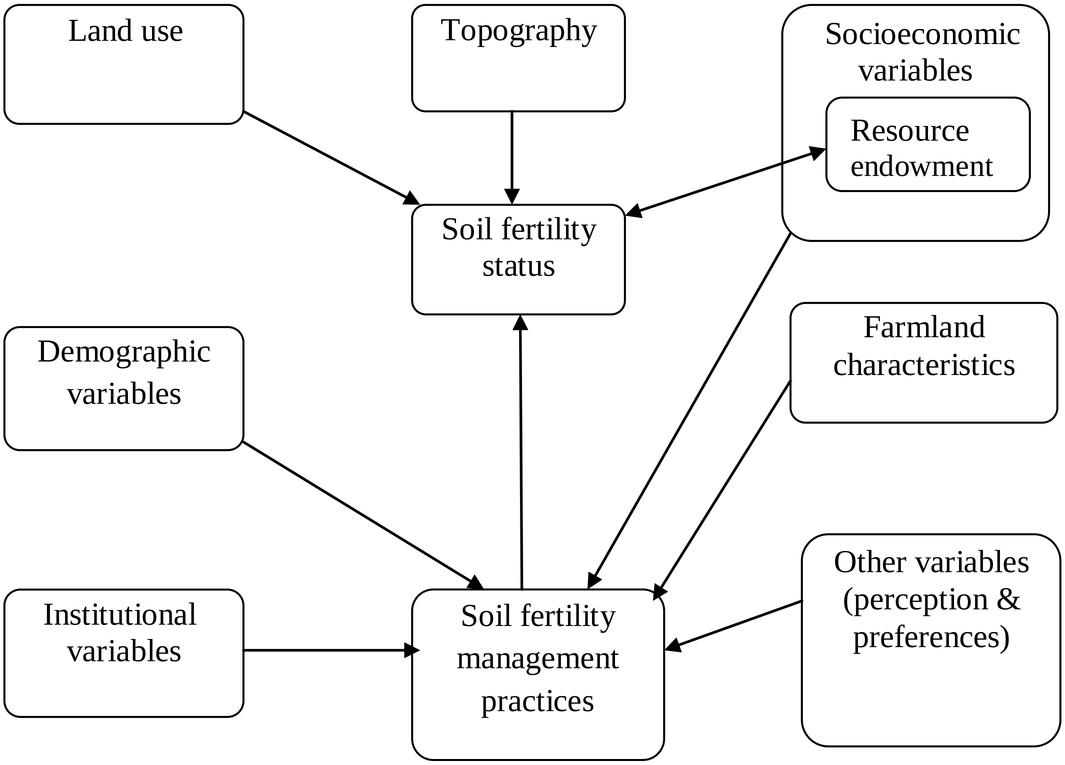

Figure 1.1. Schematic presentation of the effects of land use, topography and farmers' resource endowment on soil nutrient content, and factors influencing smallholder farmers' soil fertility management practices.

The study site: Arsamma watershed

Arsamma watershed is located in western part of Oromia National Regional State at about 475 km West of Addis Ababa, the capital of Ethiopia. It extends from 9°05’-9°12’ N and 35°40’-35°50’ E and covers a total area of 115.4 km^2 (Figure 1.2).

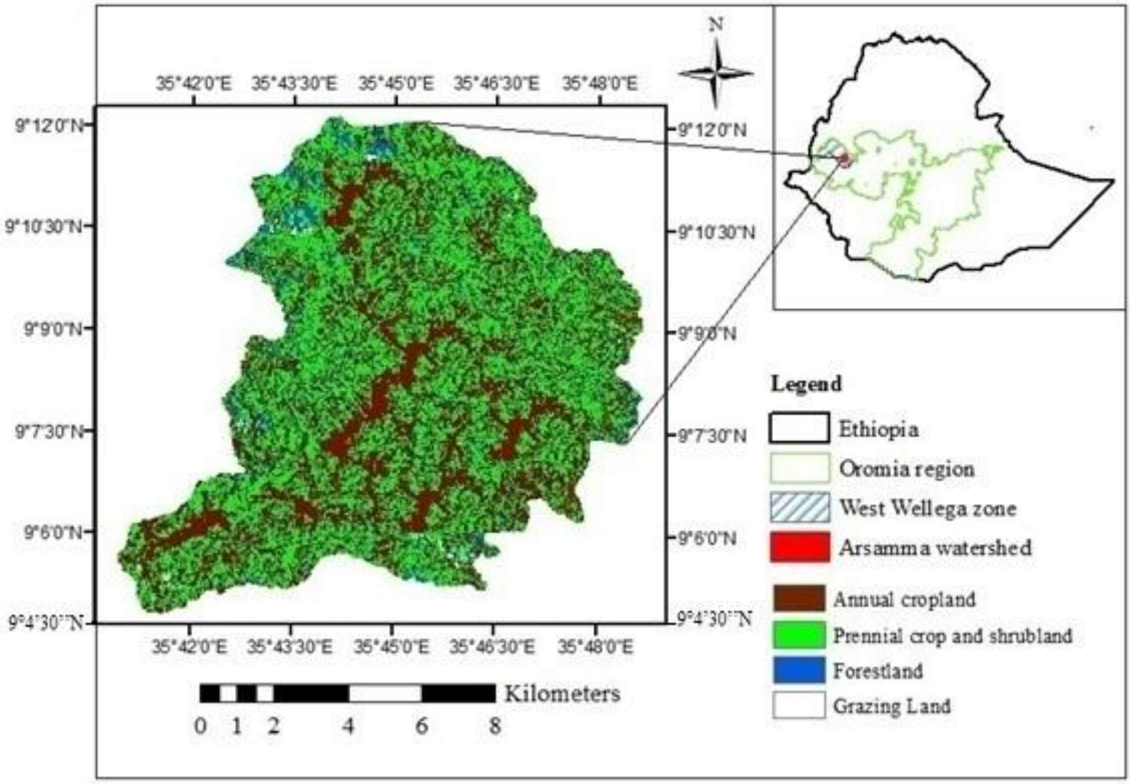

Figure 1.2. Land use types in Arsamma watershed (computed from TM 2011, path 168 and row 057 by using Erdas Imagine 9.2 and Arc GIS 10).

The watershed extends from 1,500 to 1,900 m above msl (EMA, 1983). Slope gradients that range from 0-15%, 16-30% and > 30% cover about 33%, 43% and 24% of the total area of the study catchment, respectively (Figure 1.3). This means that nearly a quarter of the catchment is characterized at least by steep slope gradients (FAO, 2006). The upstream site is steeper than the downstream site (Figure 1.3). This high topographic dissection, combined with the torrential rainfall of the area (Figure 1.4), is one of the major causes of soil fertility decline and wide prevalence of acidic soils in the region

(Mesfin, 2007). Nitosol of the dystric group is a dominant soil type in the study catchment and in its adjacent (EMA, 1988). The dystric sub-group of a soil is characterized by poor base saturation and lower pH value, and is generally considered as less fertile (Landon, 1991).

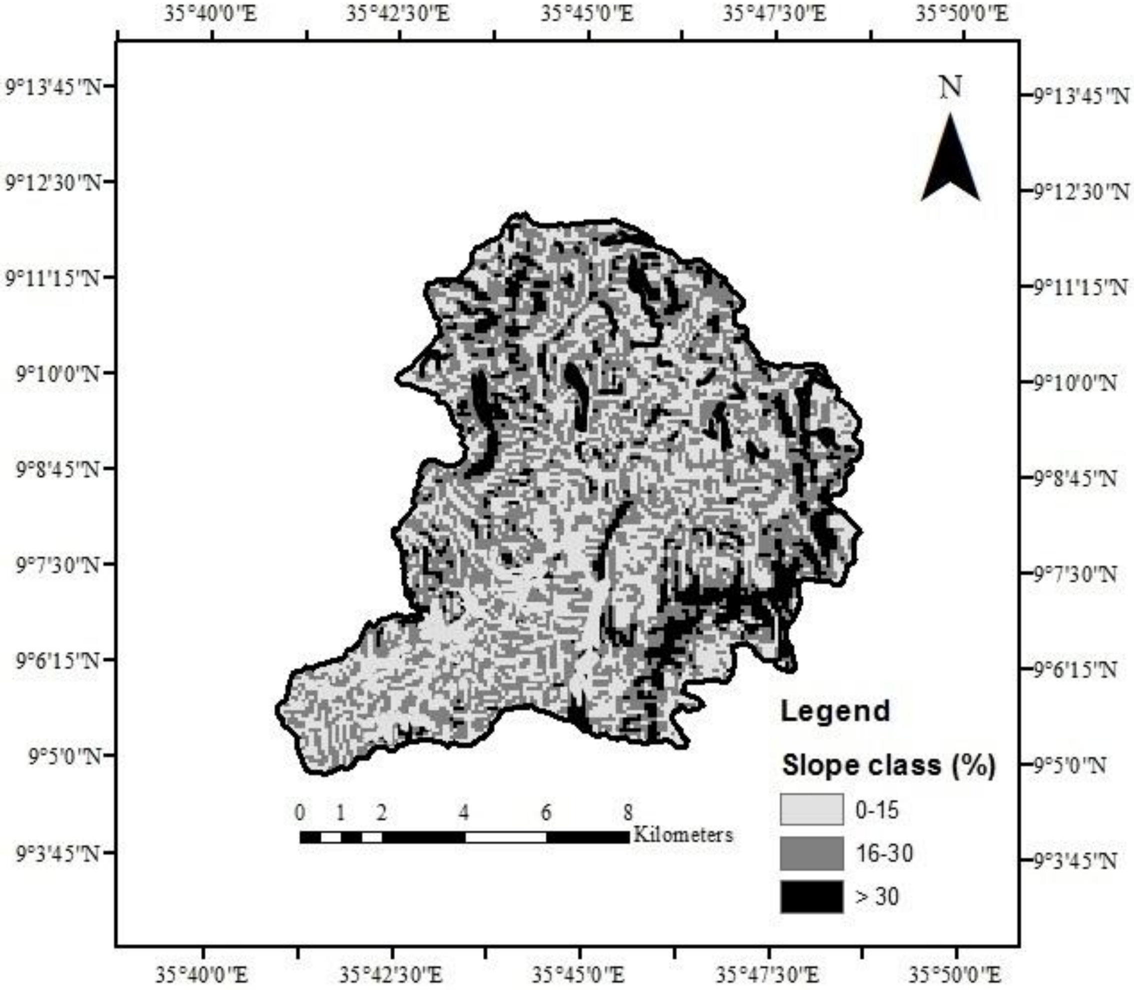

Figure 1.3. Slope gradients in Arsamma watershed (generated from DEM using Arc GIS 10).

Arsamma watershed falls under the influence of equatorial westerly winds that blow from the Gulf of Guinea to most parts of Eastern African Highlands (CRSO, 2000). This region is characterized by warm-temperate humid climate having distinct dry months in winter and a long rainy period in summer (BFED, 2013). The annual rainfall recorded from 1981 to 2010 shows that the average rainfall amount exceeds 1,900 mm per year. The rainfall pattern is unimodal with a long summer season and a short dry season. More than 78% of the total annual rainfall is concentrated in months extending from June to September. The watershed is characterized by a mean annual temperature of 20°C and a mean monthly temperature ranging from 17.8°C in August to 22.5°C in March. The periods of low mean monthly temperature coincide with the periods of high rainfall amount (Figure 1.4, Appendix 4).

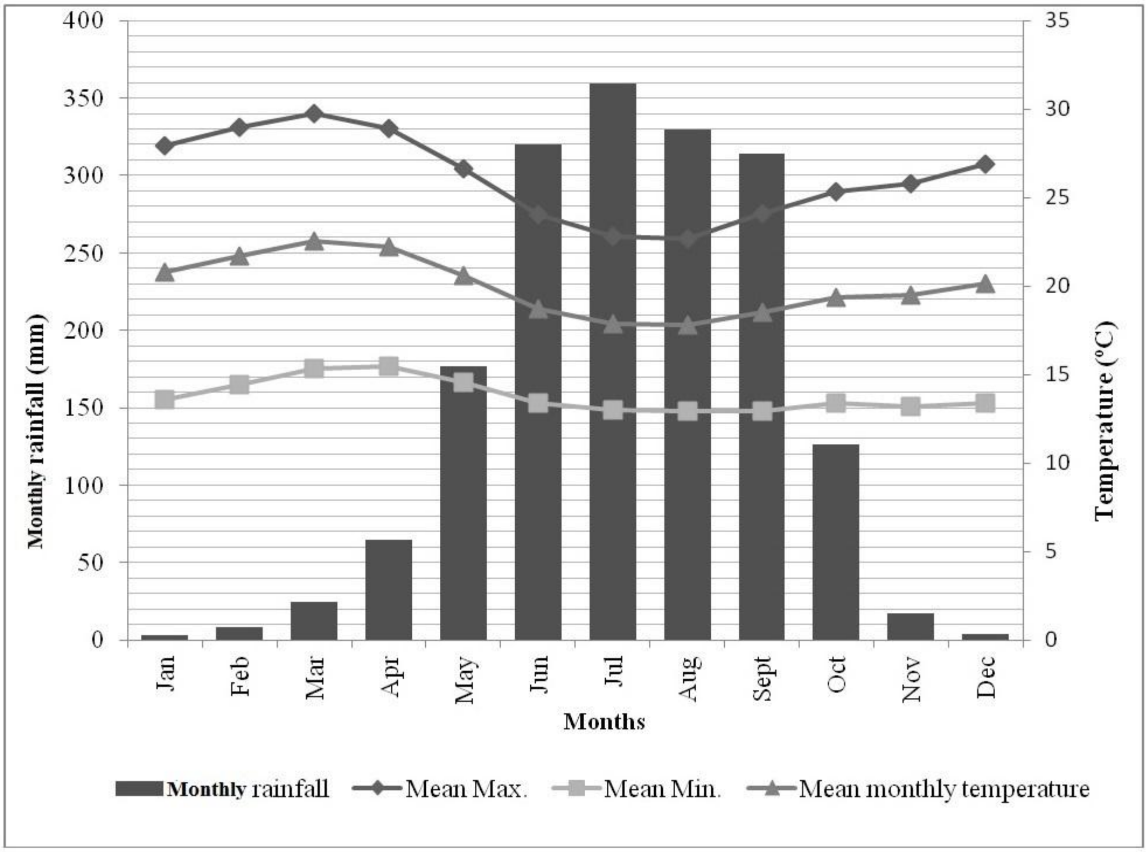

Figure 1.4. Rainfall and temperature records in Arsamma watershed (National Meteorological Agency, results for Gimbi Meteorological Station).

About 48%, 34%, 8% and 10% of the study catchment were covered by, respectively, perennial crops and shrubland, annual cropland, grazing land and forestland during 2011 (Figure 1.2). Both annual and perennial crops are grown side by side having some form of spatially delineated boundaries. Coffee (*Coffea arabica* L.) is a single most important perennial cash crop. The coffee farm appeared to be undergoing a gradual tendency of transition from multistory canopy coffee farm to pure standing coffee monoculture in some areas of the watershed (Appendix 6). As a result, the multistory canopy coffee farm, which can be a shelter for fertile soils and biodiversities, has been in a gradual tendency of transition. The evolution of pure standing coffee monoculture at the expense of forests and multistory canopy coffee farms, together with the dissected and torrential rainfall of the area, is believed to have detrimental effects on the overall fertility of the soil. In addition, it was observed during the preliminary survey that the declining per capita landholding size and increasing pressure on agricultural land were the major threats to soil fertility management in the study catchment. Hence, this study aimed to evaluate soil fertility management in the annual-perennial cropping pattern of the Arsamma watershed.

General objective

The general objective of this research was to evaluate soil fertility changes and soil fertility management practices, and then to evaluate the potential for scaling up ISFM adoption, agroforestry-based spatial land use integration and land use specific soil fertility management practices in the Arsamma Watershed, Southwestern Ethiopian Highlands.

Specific objectives

The specific objectives were:

- to assess dynamics of selected physico-chemical soil properties under different land use types,
- to examine the link between smallholder farmers’ resource endowment and soil fertility management, soil properties and crop yield performance,
- to identify determinants of ISFM adoption under annual cropping systems,

- to examine factors influencing agroforestry upscaling and agroforestry-based spatial land use integration (inter-plot organic fertilizer transfer and inter-plot income flow) for soil fertility management,
- to assess farmers' perception of soil fertility change and their preferences for soil fertility management techniques for annual and perennial croplands in Arsamma Watershed, Southwestern Ethiopian Highlands.

Research questions

Based on the above specific objectives, the following research questions were addressed during the course of this study.

- What do soil nutrient contents look like under forestland, multistory canopy coffee farm, coffee monoculture and annual cropland?
- Is there any connection between farmers' resource endowment and soil fertility management practices, soil properties and crop yield performance?
- What are the key determinants of ISFM adoption under annual cropland?
- What factors influence agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow?
- How do farmers perceive soil fertility changes in annual and perennial cropland? Which soil fertility management techniques are prioritized for annual and perennial cropland management?

Rationale

Soil fertility management requires a top priority in Sub-Saharan Africa (including Ethiopia) as a large proportion of the population in the region is dependent on agriculture (Scoones, 2001). However, our knowledge of soil fertility management is insufficient to support the hundreds of millions of smallholder farmers who make their life directly or indirectly from soil (Sanginga & Woomer, 2009; Von, 2012). Broad generalizations and inferences from various soil fertility management studies conducted elsewhere to a specific spatial context is ambiguous due to the complexity of agro-ecological settings, land use types and socioeconomic conditions in Ethiopia (Anley et al., 2007). In addition, ISFM (Vanlauwe et al., 2014) and agroforestry (Franzel et al., 2002), which are among the key concerns of this study, are very diverse and adapted to local conditions. This means that studies on adoption and/or adaptation of these soil fertility management techniques yield actionable findings only within the biophysical and socioeconomic context under which these soil fertility management techniques are practiced. While a study of soil fertility management either in annual or perennial cropland has been undertaken to some extent, a study of soil fertility management, both in annual and perennial cropland in a single watershed has been overlooked. Therefore, this study was set to assess soil fertility management practices in the specific annual-perennial cropping system of the Arsamma Watershed, Southwestern Ethiopian Highlands.

The Arsamma watershed was selected for the following three key reasons. Firstly, although Southwestern Ethiopian Highland is thought to have high potential for annual and perennial crop production (Wood, 1993), the region is highly fragile and susceptible to high risks of soil degradation due to high topographic dissection, torrential rainfall and increasing population pressures (Bezuayehu et al., 2002). Secondly, the annual and the coffee-based perennial cropland appear to require different approaches of soil fertility management interventions. Lastly, no previous study has been conducted on soil fertility management practices in the study catchment or in adjacent areas. Therefore, this study aimed to indicate the need for land use specific and sustainable soil fertility management interventions in the Arsamma watershed.

Scope of the study

The spatial dimension of this study was delimited to the Arsamma watershed, which covers an area of 115.4 km^2, and its conceptual dimension was delimited to soil fertility management in annual-perennial cropping pattern.

Soil properties are influenced by complex sets of geologic, topographic, climatic, time and human induced variables (Jenny, 1994). However, this study was limited to variation in selected soil properties due to land use and topographic variables for the top 20 cm soil depth. From a number of soil fertility management techniques, only application of ISFM, agroforestry and agroforestry-based spatial land use integration, chemical fertilizer, organic fertilizer, crop rotation and soil bunds were given due attention.

Thesis outline

This paper contains seven chapters. Following the general introduction, which is presented in chapter one, chapter two deals with dynamics of selected soil properties as influenced by land use. Impacts of forests, multistory canopy coffee, coffee monoculture and annual crops on soil properties are discussed in this chapter. The third chapter discusses the connection of smallholder farmers' resource endowment with soil fertility management, soil properties and crop yield performance. The impacts of farmers' resource endowment, which are specifically described through the effects of farmland size and livestock numbers on soil nutrient content, application of various soil fertility management techniques and crop yield performance are presented in this chapter.

The fourth chapter deals with adoption of ISFM under annual cropping systems. Demographic, socioeconomic, institutional, farm characteristics and other farm-related variables that determine adoption of ISFM are discussed in this chapter. In chapter five, factors influencing scaling up of agroforestry and agroforestry-based spatial land use integration for soil fertility management are presented. This chapter tries to envisage the potential with respect to all stakeholders for scaling up the traditional coffee-based agroforestry and agroforestry-based spatial land use linking in order to promote sustainable and land use specific soil fertility management practices.

Chapter six presents farmers' views on soil fertility change and their preferences for various soil fertility management techniques for different land use types so as to address the problem of soil fertility decline. Physical, chemical and biological indicators from which the farmers infer soil fertility change are discussed in this chapter. This chapter also presents farmers' preferred options from the available soil fertility management techniques both for annual and perennial cropland. Chapter seven summarizes and concludes the paper.

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Chapter 2

Dynamics of Selected Soil Properties under Four Land Use Types in Arsamma Watershed, Southwestern Ethiopian Highlands

Abstract

Land use change from natural ecosystem to agricultural land, and the subsequent soil fertility decline is one of the critical environmental challenges in the Highlands of Ethiopia. This study was designed to assess dynamics of selected physico-chemical soils properties under different land use types in the Arsamma Watershed, Southwestern Ethiopian Highlands. Forty-two soil samples were collected from forestland, multistory canopy coffee farm, coffee monoculture and annual cropland. Two way ANOVA, Tukey’s post hoc test and Pearson’s correlation were used to analyze the data. Forest soil contained significantly ($p < 0.05$) higher silt, organic matter, total nitrogen, exchangeable calcium and exchangeable magnesium content than annual cropland. Soil pH value in annual cropland was significantly ($p < 0.01$) lower than that of forestland. Decreasing trends of organic matter, total nitrogen and exchangeable bases content were observed following the decreasing density of soil cover. All the soils of the study catchment were strongly acidic regardless of land use. Application of Integrated Soil Fertility Management and calcium carbonate to annual cropland, and scaling up of the traditional coffee farm to coffee-based improved agroforestry, working towards certification as shade grown coffee and application of organic fertilizers to coffee soil, can alleviate the problem of soil fertility decline resulting from land use change from natural forest to agricultural land.

Key words: soil fertility; land use; multistory canopy

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Introduction

Soil fertility decline is one of the major environmental problems threatening the livelihoods of millions of farm households in rural Ethiopia (Mitiku et al., 2007; Swift & Shepherd, 2007). The problem is exceptionally severe in the highlands of the country where the majority of the human and livestock population is concentrated (Teklu, 2005). The problem is exacerbated by rapid population growth, which is rising by 2.6% per annum, and a small farm size (0.96 hectare/household); these problems have intensified pressure on agricultural lands (CSA, 2011a; CSA & ICF International, 2012).

Soil nutrient content is influenced by complex sets of human and natural factors (Cannone et al., 2008; Fantaw, 2007). Due to the strong interactions existing between land use and soil properties, land use change from natural ecosystem to agricultural land use is a major human induced factor that threatens soil nutrient content (Agoume & Birang, 2009; Jin et al., 2011; Ogeh & Ogwurike, 2006). This intimate association is reflected through the effects of vegetation which acts both as independent and dependent variable in influencing soil properties, and through the effects of net primary production, 90% of which returns to the soil system in the form of organic matter (Jenny, 1994).

Knowledge of the interactions existing between land use and soil properties is invaluable to address the problems of soil degradation resulting from land use change and agro-ecosystem transformation (Yao, 2010). Prediction of agricultural production and productivity, and site specific land management plans gives meaningful results through proper understanding of the existing interactions between soil and land uses (FAO, 2008). A good understanding of soil-land use interactions is a key to sustainable land use.

Various studies have been conducted on soil-land use interactions. Agoume and Birang (2009) reported significant variation of sand, silt and clay fractions in soils of different land use types. Cho et al. (2004) observed different soil quality indices in forestland, cultivated land and fallow land. Guo and Gifford (2002) reported reduction of organic carbon content by 59% due to land use change from forest to cropland. Reduction in the soil quality index by 44% was also noted by Islam and Weil (2000) due to land use change from forest to cultivated land. In Cote d'Ivoire, natural forest, multi-tree species plantation, teak plantation, cocoa plantation and mixed crop fields significantly varied in their organic matter contents and soil pH values (Yao, 2010). Variations in abundance and diversity of soil microorganisms were also noted in soils of different land use types in the Taita Taveta region of Kenya (Wachira et al., 2009). These effects of land use were found to be more marked on chemical and biological properties of soil than on physical soil characteristics (Schipper & Sparling, 2000).

Soil properties also vary within the same land use type due to variation in types and intensity of soil management (Cox et al., 2002; Dang, 2007; Jin et al., 2011). Soils fertilized using organic fertilizers are characterized by larger carbon pools, faster humification rates, greater nitrogen contents and better efficiency of organic matter turnover than soils fertilized by inorganic fertilizers (Canali et al., 2012).

Various studies (for example, Aklilu, 2006; Amare et al., 2005; Assefa et al., 2016; Fantaw et al., 2015; Fantaw et al., 2007; Mulugeta & Stahr, 2010; Teshome et al., 2013; Tilahun & Assefa, 2009; Tsehaye & Mohammed, 2013; Woldeamlak, 2003) have been conducted on soil land-use interactions in the Ethiopian highlands. Amare et al. (2005) observed spatial variations of soil fertility levels in the mixed farming system of Ethiopia. Fantaw et al. (2015) found a significant variation of soil organic carbon content due to land use, soil depth and the land use-soil depth interactions in the Central Rift Valley area of Ethiopia. Tilahun and Assefa (2009) observed significant variation of soil nutrient content in cultivated land, fallow land, forestland and grassland of Bale highlands. In South Gonder, Mulugeta and Stahr (2010) reported statistically significant variation of soil organic matter, total nitrogen and available phosphorus contents between conserved and non-conserved soils of similar land use types. Soil pH, organic carbon and total nitrogen contents varied significantly across soils of natural vegetation, tree plantation, cropland and grazing land in the Central Highlands of Ethiopia (Aklilu, 2006). Woldeamlak (2003) noted lower exchangeable bases, and higher sand contents in soils of cultivated fields, grazing land and eucalyptus plantations as compared to soils of natural forests in the Blue Nile Basin of Ethiopia. Differences in particle size distribution, field capacity, permanent wilting point, soil organic matter, total nitrogen, exchangeable base content, and soil pH value were also observed across soils of natural forest, cultivated land, grassland and plantation forest in Northern Highlands of Ethiopia (Tsehaye & Mohammed, 2013). Teshome et al. (2013) reported that soil organic matter content of cultivated land was significantly lower than forest and grazing lands in Western Ethiopia. Total nitrogen content under grazing and native forest was found to be significantly higher than that of cropland in the Bale Mountains of the South-eastern Ethiopian Highlands (Fantaw et al., 2007). Assefa et al. (2016) reported higher soil organic carbon stocks in soils of shrub and forest lands than in soils of cultivated and grazing lands in the landscape of the Upper Blue Nile Basin of Ethiopia.

Yet, further study on soil-land use interactions is needed for three major reasons. Firstly, the association between soil nutrient content and land use type is mainly location dependent, and makes broader generalization difficult (Minasny & Hartemink, 2011). This means that very broad generalization of studies conducted elsewhere to the complex agro-biodiversity and agro-ecosystem of the Ethiopian Highlands may give ambiguous results. Secondly, implications of similar land use types but that consist of different plant compositions, such as multistory canopy coffee farm and coffee monoculture (as is the case of this study), were not adequately addressed by previous studies.

Thirdly, the land use pattern of the study catchment was characterized as annual and coffee-based perennial cropping complex, which mainly evolved through conversion and/or modification of natural forests. It was observed during the preliminary survey that the coffee farm was undergoing a gradual tendency of transition from multistory canopy coffee farm to pure standing coffee monoculture in some areas of the watershed (Appendix 6). This transition was not because of agricultural intensification, but due to the lack of adequate management practices for coffee plantations. In some cases, the farmers remove big tree species so as to facilitate hoeing and also to allow sunlight to reach the coffee plant. Big tree species are also removed to protect crops from arboreal wildlife. Due to such interference, the natural re-generation capacity of the tree species remaining in the coffee farmland is weakened. Some trees are dried up due to old age or destroyed by wind, while others are used up for timber and firewood. Hence, the multistory canopy coffee farm, which is generally believed to be a ‘refuge’ for fertile soils and biodiversity (Perfecto et al., 1996), has been gradually deteriorating. The evolution of pure standing coffee monoculture at the expense of the natural forest and the multistory canopy coffee farm, together with the dissected topography and torrential rainfall of the study catchment, was believed to have detrimental effects on the overall nutrient content of the soil. Therefore, this study was designed to assess dynamics of selected physico-chemical soil properties under different land use types in Arsamma Watershed, Southwestern Ethiopian Highlands.

Background of the study area

The Arsamma watershed is located in western part of Oromia National Regional State of Ethiopia between 9°05’-9°12’ N, and 35°40’-35°50’ E. It is situated in West Wellega Administrative Zone at about 25 km Southwest of Gimbi town, the capital of West Wellega Zone. The watershed covers an area of 115.4 km^2 (Figure 2.1), within an altitude ranging from 1,500 to 1,900 m above mean sea level (EMA, 1983).

The watershed is a part of the western physiographic unit of Oromia National Regional State. This physiographic region is a segment of the extensive Afro-Arabian plateau, which is mainly of volcanic origin and known for its high topographic dissection (PPDO, 1997). The catchment falls under the influence of equatorial westerly winds that blow from the Gulf of Guinea to most parts of Eastern African highlands (CRSO, 2000). The region is characterized by a warm-temperate humid climate of distinct dry months in winter and a long rainy period in summer. It receives heavy mean annual rainfall exceeding 1,900 mm, most of which is concentrated in few months of a year. The mean monthly temperature of the region varies from 16-20°C (CSA, 2011b).

The Arsamma catchment is one of the head basins of Birbir River. The Birbir basin is a major sub-basin in the Baro drainage system (NUPIE, 2000). Based on the available small scale soil map of Ethiopia with the scale of 1: 1,000,000, dystric nitosol is a single dominant soil types in the study catchment (Figure 2.1). Soils of the dystric group are always poor in base saturation, lower in pH value and generally considered as less fertile than eutric and humic nitosols (Landon, 1991; Schaetzl & Anderson, 2005).

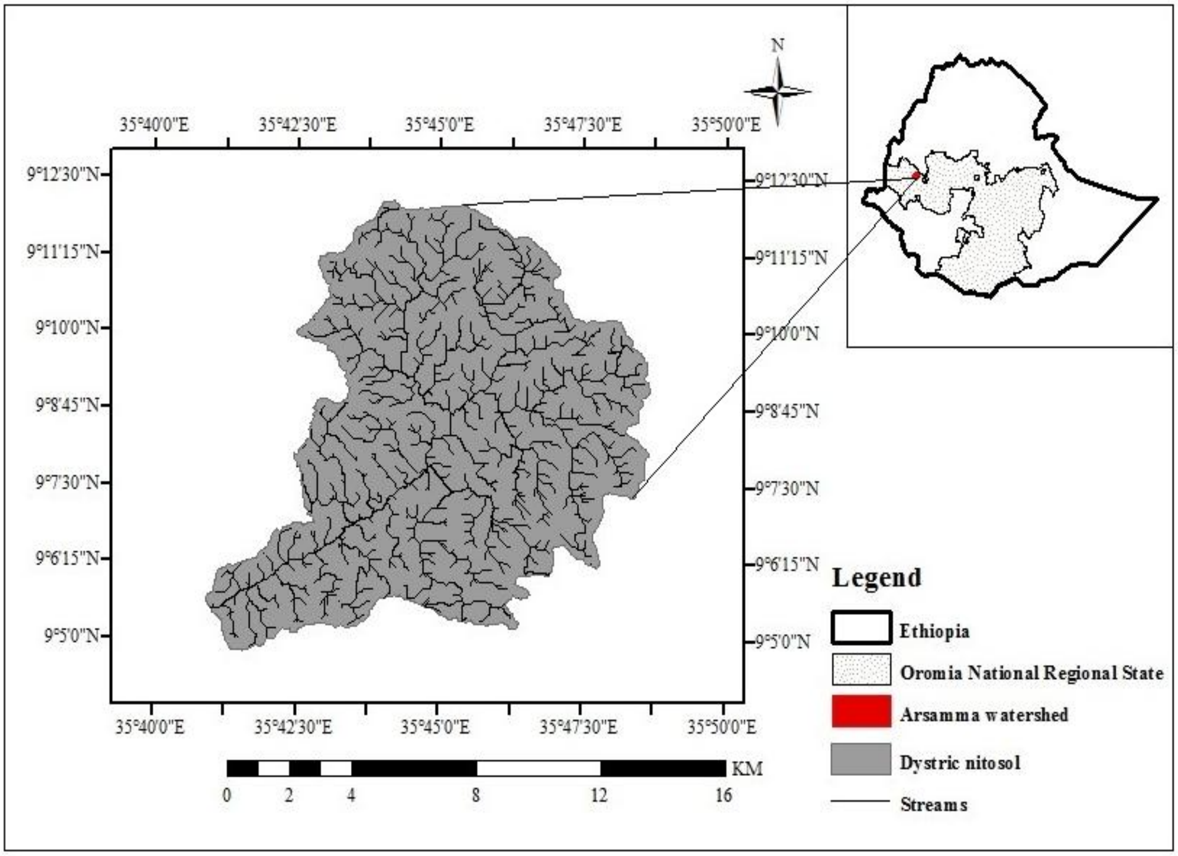


Figure 2.1. Soil of Arsamma Watershed, Southwestern Ethiopian Highlands (Archives from Ministry of Agriculture).

Both annual and perennial crops are grown side by side in the study watershed. While maize, sorghum, millet, barley and root crops are the dominant annual crops grown for subsistence, coffee is a single most important perennial cash crop. Description of the major land use types under consideration is given in Table 2.1.

Table 2.1. Major land use types in Arsamma Watershed, Southwestern Ethiopian Highlands

Land use type	Description
Forestland	A type of land that is covered by dense vegetation. The vegetation consists of dense tree species that perpetuates naturally with less human intervention. It consists of a dense canopy layer, bulk litter and leaf falls. The activities of micro and or/macro fauna and flora were observed to be high in this land cover type (Appendix 6)
Multistory canopy coffee farm	A type of perennial cropland in which coffee plants (*Coffea arabica* L.) are grown under widely spaced shade tree species that make up the multiple canopy layer. It has mainly evolved through conversion of natural forests into perennial cropland. Fruits such as, mango, avocado, papaya and banana are occasionally incorporated with this land use type. The canopies of trees in this land use type are less dense than those of forestland. This farmland was usually hoed (Appendix 6)
Coffee monoculture farm	A type of perennial cropland in which coffee plants are grown with no or very scanty incorporation of shade trees. It came into existence through conversion of natural forests and transformation of the multistory canopy coffee farm into coffee farm that consists single coffee species. It was characterized by no/scanty tree canopy layer, and hoeing was a common practice
Annual cropland	A type of farmland used for the production of temporary crops which perform their entire life cycle from germination to harvest within a single year. Maize, sorghum, finger millet and barley were the major crops in this category

Materials and methods

Prior to soil sampling, a transect walk led by key informants was done in the study catchment. The survey included some of the present multistory canopy coffee farms, coffee monoculture and annual cropland that have been under similar land use (natural forests) for the last 40 to 50 years, the present forestland being the remnant of the former natural forest. Land use/land cover change studies, which have been intensively conducted in recent years, indicate that there is a high rate of land use/land cover change throughout the highlands of the country (Aklilu et al., 2014; Amare, 2015; Binyam et al., 2015; Lewoye, 2014; Mengistie et al., 2015; Tesfahun & Temesgen, 2014). Land use in the Arsamma watershed is not likely to be an exception to these changes. Hence, spatio-bio sequential analogues were found to be appropriate for characterization of soil property dynamics under such conditions (Ogeh & Ogwurike, 2006; Tilahun & Assefa, 2009; Tsehaye & Mohammed, 2013; Uzoho et al., 2007; Woldeamlak, 2003). In the absence of adequate chronosequence soil data, a spatial analogue approach is the most widely used technique for studying soil property dynamics in the tropics and sub-tropics (Hateminik, 2006). This approach assumes that soils formed on similar lithology under similar climatic condition would have analogous properties provided that there is no difference in land use and/or land management practices. Observed difference in soil properties, therefore, are attributed to variations in land use types and/or land management practices.

The watershed was delineated and mapped using GPS and a topographic map with a scale of 1: 50,000 (EMA, 1983). The land use types in two sites (Buko Asabi and Bonaya Asabi) were sketched on the map and divided into mutually exclusive units (Table 2.1). Forty-two proportionally representative fields, 8 for forestland, 10 for coffee monoculture farm, 14 for annual cropland and 10 for multistory canopy coffee farm, were identified. Unwanted materials, such as dead plants, sediment deposits, furrows in the field and organic piles were excluded from the specific sampling sites in order to minimize outlying results. Then, 42 composite soil samples, 8 from forestland, 10 from coffee monoculture farm, 14 from annual cropland and 10 from multistory canopy coffee farm were collected following a proportional sampling technique from the top 20 cm soil depth during March 2013. Seven sub-samples were collected using an auger for each composite soil sample, and a composite sample for each particular field was produced by hand mixing in a clean plastic bag. Forty-two undisturbed core soil samples, 8 from forestland, 10 from coffee monoculture, 14 from annual cropland and 10 from multistory coffee farms were also proportionally sampled by using a sharp-edged steel cylinder (core sampler) from the surface soil for bulk density analysis. The top 20 cm soil depth was considered for this study as this depth contains the highest concentrations of many of the soil properties and has the strongest response to land use differences, and so is likely to be most vulnerable to soil loss (Assefa et al., 2016). The upper (Bonaya Asabi) and the lower (Buko Asabi) *Kebeles*[1] were selected in order to assess whether there is a significant difference or not between soil nutrient content of the upstream and the downstream sites of the same land use type, as the upstream site is characterized by steeper gradients than the downstream site (Figure 1.3).

Soil analysis was conducted at Holeta Agricultural Research Center following standard scientific procedures. The soil samples were air dried, crushed and passed through a 2 mm sieve for laboratory analysis. Soil particle size distribution was determined by Boycouos hydrometric method, and bulk density was examined from the undisturbed core as outlined by Carter and Gregorich (2008). Assuming particle density of 2.65 g/cm^3 for surface soils, total porosity, was determined as:

$$P = ((1 - BD)/d) \times 100$$

Where P is total porosity (%), BD is the bulk density (g/cm^3) and d is the particle density equal to 2.65 g/cm^3 (Landon, 1991).

Soil pH was examined in 1: 2.5 soil water suspensions as described by Van-Reeuwijk (1993). Soil organic carbon content was measured by the Walkley-Black oxidation method, and the amount of soil organic matter was calculated by multiplying the percent of organic carbon by a factor of 1.724 (Landon, 1991). Total nitrogen was analyzed using the Kjeldahl digestion and distillation method as outlined by Carter and Gregorich (2008). Because the pH value of the soil was low, the available phosphorus content was analyzed by using Bray II method (Bray, 1945). Cation exchange capacity (CEC) and exchangeable bases were determined by the ammonium acetate method. Exchangeable potassium and sodium were measured using a flame photometer, and the exchangeable magnesium and calcium were determined by using atomic absorption spectrophotometer (Carter & Gregorich, 2008). The percentage base saturation was finally calculated by dividing the sum of the base forming cations (K^+, Mg^{2+}, Ca^{2+} and Na^+) by CEC of the soil and multiplying by 100 (Landon, 1991).

The results were analyzed using SPSS version 20. A two way ANOVA, as outlined by Landau and Everitt (2004), was used to test whether soil properties vary across the four land use types and between the two watershed sites, or not. For the statistically significant parameters, Tukey's post hoc test was used to indicate where the variation specifically lies. The percentage change in soil properties of the multistory canopy coffee farm, coffee monoculture and annual cropland was also computed as compared to forestland. Pearson's correlation was used to evaluate associations of the observed parameters among themselves. The mean values of the parameters were finally rated as low, medium or high in order to indicate the overall qualitative picture of soil nutrient content under each land use type based on the established standards for tropical soils, and in accordance with the procedure followed to test the soils (Landon, 1991).

Results and discussions

The physico-chemical soil properties, including particle size distribution, bulk density, total porosity, pH, organic matter, total nitrogen, carbon to nitrogen ratio, cation exchange capacity, available phosphorus, exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and base saturation as influenced by four land use types were analyzed statistically and are presented in the following sections.

Particle size distribution

The average percentage of the sand fraction varied from 21.9% in forest soils to 34% in soils of annual crops (Table 2.2). This variation was attributed to greater selective removal of clay and silt fractions through leaching and/or downwashing from soils covered by a sparse canopy layer compared to forested soils. The silt fraction varied from 22.7% in soils of annual crops to 32.2% in soils of forests (Table 2.2). The ANOVA test indicated significant statistical difference ($F(3, 34) = 4.972$, $p < 0.01$) of silt content

Table 2.2. Physico-chemical soil properties under four land use types for the top 20 cm soil depth in Arsamma Watershed, Southwestern Ethiopian Highlands

Land use type	Site in the watershed	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)	TP (%)	pH (H_2O)	OM (%)	TN (%)	C: N (ratio)	Av. P (ppm)	CEC (meq./ 100g)	Exchangeable bases (meq./100g)				BS (%)
													Ca^{2+}	Mg^{2+}	K^+	Na^+	
Remnant forest	Buko Asabi	20.31	29.38	50.31	1.06	59.90	5.02	4.09	0.84	8.99	6.90	21.12	6.21	2.31	0.40	0.39	46.83
	Bonaya Asabi	23.44	35.00	41.56	1.04	60.75	5.13	4.13	0.70	14.41	7.60	15.90	5.07	2.27	0.34	0.24	55.94
	Average	21.88	32.19	45.94	1.05	60.32	5.07	4.11	0.77	11.70	7.25	18.51	5.64	2.29	0.37	0.32	51.39
Multistory canopy coffee	Buko Asabi	24.50	31.75	43.75	1.22	53.74	5.11	3.63	0.30	13.25	6.32	18.04	4.65	2.05	0.38	0.31	42.43
	Bonaya Asabi	23.75	29.75	46.50	1.17	55.77	4.63	3.31	0.20	16.68	7.12	13.13	4.03	1.98	0.32	0.18	40.06
	Average	24.13	30.75	45.13	1.20	54.75	4.87	3.47	0.25	14.97	6.72	15.59	4.34	2.02	0.35	0.25	41.25
Coffee monoculture	Buko Asabi	27.50	27.25	45.25	1.23	53.43	4.50	3.63	0.21	21.69	5.76	17.53	4.80	2.24	0.17	0.24	46.85
	Bonaya Asabi	23.50	28.75	47.75	1.19	55.09	4.37	2.62	0.20	14.06	4.88	13.72	3.61	1.92	0.25	0.29	45.81
	Average	25.50	28.00	46.50	1.21	54.26	4.44	3.13	0.21	17.88	5.32	15.63	4.21	2.08	0.21	0.27	46.33
Annual crops	Buko Asabi	31.21	23.39	45.39	1.46	45.07	4.22	3.17	0.21	15.84	5.37	11.75	3.30	1.80	0.27	0.23	48.16
	Bonaya Asabi	36.86	21.96	41.18	1.37	48.30	4.29	2.79	0.16	18.62	4.57	10.73	3.11	1.91	0.34	0.24	41.15
	Average	34.04	22.68	43.29	1.42	46.69	4.26	2.98	0.19	17.23	4.97	11.24	3.21	1.86	0.31	0.24	44.66
All land uses	Buko Asabi	25.88	27.94	46.18	1.24	53.03	4.71	3.63	0.39	14.94	6.09	17.11	4.74	2.13	0.31	0.29	46.07
	Bonaya Asabi	26.89	28.86	44.25	1.19	54.98	4.58	3.21	0.32	15.94	6.04	13.37	3.96	1.99	0.31	0.24	45.74
	Total average	26.39	28.40	45.22	1.22	52.83	4.65	3.42	0.36	15.44	6.07	15.24	4.35	2.06	0.31	0.27	45.91

Note: BD (Bulk Density), TP (Total Porosity), pH (soil pH), OM (Organic Matter), TN (Total Nitrogen), C: N (Carbon to Nitrogen Ratio), Av. P (Available Phosphorus), CEC (Cation Exchange Capacity), Ca^{2+} (Exchangeable Calcium), Mg^{2+} (Exchangeable Magnesium), K^+ (Exchangeable Potassium), N^+ (Exchangeable Sodium), BS (Base Saturation).

across the four land use types (Table 2.3); and the silt contents in soils of forests and multistory canopy coffee farms were significantly ($p < 0.05$) higher than that of annual croplands as depicted by Tukey's post hoc test (Table 2.4). The percentage change of silt content in soils of annual crops was the highest (-29.5%), followed by changes in soils of coffee monoculture (-13.5%) and changes in multistory canopy coffee farm (-4.5%), as compared to the silt content in forestland (Figure 2.2). Significant variation of silt fraction in soils of different land use types was also reported by Agoume and Birang (2009). The average silt content in the upstream site, however, was not significantly different ($p = 0.649$) to that of the downstream site. Clay was the dominant soil fraction in all land use types (Table 2.3). However, the variation across the four land use types was not statistically significant (Table 2.3). Soils of the study catchment contained on average 26.4%, 28.4% and 45.2% sand, silt and clay content, respectively (Table 2.2). Based on the established standard, therefore, soil of the area generally contained moderate sand and silt content with high clay fraction (Hazelton & Murphy, 2007).

Bulk density and total porosity

The bulk density of the soil varied from 1.1 g/cm^3 in forest soils to 1.4 g/cm^3 in soils of annual crops (Table 2.2). The ANOVA test indicated significant statistical variation (F (3, 34, = 13.261, $p < 0.01$) in bulk density values due to land use (Table 2.3). Bulk density value in soils of annual crops was significantly ($p < 0.01$) higher than that of forest soils (Table 2.4). Compared to forest soils, bulk density value increased by 35.2%, 15.2% and 14.3% in soils of annul crop, coffee monoculture and the multistory canopy coffee farm, respectively (Figure 2.2). This indicates an increasing tendency of soil compaction and decreasing water infiltration rate, which also consequently results in increasing obstruction to plant root growth and access to soluble soil nutrients (Landon, 1991), following forestland conversion or modification to other agricultural land uses. Woleamlak (2003) also reported statistically significant variation of soil bulk density values across soils of forestland, cultivated land, grazing land and eucalyptus plantation. The bulk density at the upstream site was not significantly different to the downstream site (Table 2.3). While soils of annual croplands with the average bulk density of 1.4 g/cm^3 showed moderate compactness, soils of forest, multistory canopy coffee farm and coffee monoculture were characterized by optimum bulk density value that do not negatively affect plant growth (Hazelton & Murphy, 2007). Breaking down of soil aggregates due to continuous cultivation, poor organic matter inputs, post harvest grazing, sparse land cover and surface sealing resulting from heavy rainfall, could be responsible for the higher bulk density values observed in the soils of annual crops.

The porosities varied from 46.7% in soils of annual crop to 60.3% in forestland (Table 2.2), and this difference was statistically significant (F (3, 34) = 13.259, $p < 0.01$; Table 2.3). Total pore space was reduced by 22.6% in annual cropland, followed by 10% decrease in soils of multistory canopy coffee farm, and 9.2% reduction in soils of coffee monoculture as compared to total pore space in soils of forest (Figure 2.2). This implies that conversion of forestland to agricultural land use, and the subsequent deterioration of soil pore spaces aggravate surface runoff and then soil nutrient depletion in the study catchment.

Soil pH

The soil pH in all land use types of the study catchment rarely exceeded 5. Soils of forest, multistory canopy coffee farm, coffee monoculture and annual crop had mean pH values of 5.1, 4.9, 4.4 and 4.3, respectively (Table 2.2). Since all soils of the four land use types had mean pH values less than 5.5, all the soils were characterized as strongly acidic regardless of land use types (Hazelton & Murphy, 2007; Landon, 1991). Similar strongly acidic soils were also observed by Abdenna et al. (2013), and Achalu et al. (2012) in Southwestern Ethiopian Highlands.

The differences in pH values across the four land use types was statistically significant (F (3, 34) = 10.383, $p < 0.01$; Table 2.3). The mean difference between forestland and coffee monoculture, forestland and annual cropland, and multistory canopy coffee farm and annual cropland was also statistically significant ($p < 0.01$) as shown by Tukey’s post hoc multiple comparisons (Table 2.4). Compared to the pH value of forest soils, soil pH was reduced by 16%, 12.4% and 3.9% in soils of annual crop, coffee monoculture and multistory canopy coffee farm, respectively (Figure 2.2). This indicates not only the negative implication of land use change from forest to coffee monoculture and annual cropland, but also the possible means of stabilizing soil pH through promoting multistory canopy coffee farming. Statistically significant variation of soil pH across soils of natural vegetation, plantation forest, cropland and grazing land was also reported by Aklilu (2006). The average pH value at the upstream site was not significantly different to the downstream site (Table 2.2) (p = 0.246; Table 2.3).

In strongly acidic soil like that of the study catchment, it is expected that toxicities due to aluminum, hydrogen and manganese and deficiencies of basic nutrients are the major factors impeding crop production (Hillel et al., 2004a).

Table 2.3. Multiple comparisons of selected physico-chemical soil properties of two sites

Soil properties	Land use effect		Site effect		Land use and site interaction effect	
	F	p	F	p	F	p
Sand (%)	2.438	0.081	0.074	0.787	0.373	0.773
Silt (%)	4.972	0.006**	0.211	0.649	0.684	0.568
Clay (%)	0.164	0.920	0.260	0.613	0.497	0.687
BD (g/cm^3)	13.261	0.000**	1.468	0.234	0.104	0.957
TP (%)	13.259	0.000**	0.468	0.234	0.104	0.957
pH (H_2O)	10.383	0.000**	1.391	0.246	1.221	0.317
OM (%)	2.975	0.045*	2.200	0.147	0.548	0.653
TN (%)	4.028	0.015*	0.345	0.561	0.037	0.990
C: N ratio	1.519	0.227	0.215	0.646	1.793	0.167
Av. P (ppm)	0.580	0.632	0.001	0.975	0.103	0.958
CEC (meq./100g)	3.799	0.019*	5.345	0.027*	0.413	0.745
Ca^{2+}(meq./100g)	5.910	0.003**	4.979	0.032*	0.427	0.735
Mg^{2+}(meq./100g)	3.610	0.031*	0.627	0.434	0.303	0.323
K^+(meq./100g)	0.818	0.493	0.020	0.888	0.271	0.846
Na^+(meq./100g)	0.777	0.515	2.077	0.159	1.628	0.201
BS (%)	0.538	0.660	0.004	0.951	0.379	0.769

*Note: ** ($p < 0.01$), *($p < 0.05$), BD (Bulk Density), TP (Total Porosity), pH (soil pH), OM (Organic Matter), TN (Total Nitrogen), C: N (Carbon to Nitrogen Ratio), Av. P (Available Phosphorus), CEC (Cation Exchange Capacity), Ca^{2+} (Exchangeable Calcium), Mg^{2+} (Exchangeable Magnesium), K^+ (Exchangeable Potassium), N^+ (Exchangeable Sodium), BS (Base Saturation).*

The low pH values of the soils are possibly attributed to both natural and human induced factors. The natural factors include the acidic nature of volcanic parent material from which the soil was formed, high topographic dissection and torrential rainfall of the region which accelerate removal of basic cations, and rapid decomposition and mineralization of organic matter due to high temperature and moisture condition (Mesfin, 2007). Mining of basic cations due to continuous cropping, low organic matter input and continuous application of acid inducing chemical fertilizers, such as urea and diammonium phosphate (DAP) to annual cropland could be the major human induced factors.

Soil organic matter

Soils of the study land uses contained 4.1%, 3.5%, 3.1% and 3% of organic matter, respectively, in forestland, multistory canopy coffee farm, coffee monoculture and annual cropland (Table 2.2). The ANOVA test showed a statistically significant difference (F (3, 34) = 2.975, $p < 0.05$) between organic matter content across the four land use types (Table 2.3). However, a significant difference ($p < 0.05$) was observed only between soils of forests and annual crops as shown by Tukey's post hoc multiple comparisons (Table 2.4). Compared to forest soils, organic matter content in soils of the annual crop, coffee monoculture and multistory canopy coffee farm was reduced by, respectively, 27.5%, 23.8% and 15.6% (Table 2.2). After forest soils, the highest organic matter content was observed in soils of multistory canopy coffee farm. This implies that multistory canopy coffee farming has potential to alleviate organic matter deterioration resulting from forestland conversion and agroecosystem transformation.

While soils of forest and multistory canopy coffee farm contained, respectively, high and medium organic matter contents, soils of coffee monoculture and annual cropland contained low organic matter content (Landon, 1991). The high organic matter content of forest soils suggests that forest soils provide a major reservoir of plant essential nutrients (FAO, 2005). This is attributed to the dense canopy layer, bulk litter and leaf fall, and active microorganisms in forestland (Table 2.1). Soil erosion was also minimal under forest, whereas accelerated soil erosion, high rate of organic matter decomposition, insufficient application of organic fertilizers and removal of crop residues from farmland were responsible for the low organic matter observed in annual cropland. Soil organic matter is an important indicator of soil and land quality. It strongly responds to land use change and land degradation processes (Hall, 2008). Soil structure, soil pore space, water infiltration rate and water holding capacity are strongly influenced by the soil organic matter content (Hillel et al., 2004b). Where soils are exploited without organic matter restoration, nutrients may be lost from the soil resulting in the disturbance of the overall agro-ecosystem (FAO, 2005). This suggests that land use practices have strong effect on soil properties due to its strong impact on soil organic matter content. Statistically significant differences in soil organic matter content was also observed across soils of different land use types by Tsehaye and Mohammed (2013). Soil organic matter content at the upstream site was not significantly different to the downstream site (Table 2.3).

Total nitrogen and carbon to nitrogen ratio

Total nitrogen content showed a significant variation (F (3, 34) = 4.028, $p < 0.05$) across the four land use types (Table 2.3). The total nitrogen content in forest soil was significantly ($p < 0.05$) higher than that of annual cropland and coffee monoculture (Table 2.4). Similar to organic matter content, a decreasing pattern of total nitrogen content was observed, sequentially, in soils of forest, multistory canopy coffee farm, coffee monoculture and annual cropland (Figure 2.2). This decreasing pattern was attributed to increasing intensity of soil erosion resulting from the decreasing soil cover. Total nitrogen content was high in forest soil, medium in soil of multistory canopy coffee farm and coffee monoculture, and low in soil of annual cropland (Landon, 1991). The total nitrogen content in the two watershed sites, however, was not significantly different (Table 2.2). Aklilu (2006) also reported statistically significant variation of total nitrogen content across different land use types.

Carbon to nitrogen ratio (expressed in decimal fraction) varied from 11.7 in forestland to 17.2 in soil of coffee monoculture (Table 2.2). Compared to forestland, carbon to nitrogen ratio was higher by 52.8% in coffee monoculture, 47.3% in annual cropland and 27.9% in multistory canopy coffee farm (Figure 2.2). If carbon to nitrogen ratio is less than 10, it likely to break down rapidly, and if greater than 25, it locks up nitrogen as it decomposes and results in reduction of plant available nitrogen (Hazelton & Murphy, 2007). Hence, the carbon to nitrogen ratio was within the optimum range in all soils of the study catchment.

Available phosphorus

The highest (7.25 ppm) and the lowest (4.97 ppm) available phosphorus content were observed in forestland and annual cropland, respectively (Figure 2.2), but the difference was not statistically significant (Table 2.3). In line with Landon (1991), all soils of the four land use types contained low available phosphorus content. The phosphorus content of soil is influenced by complex sets of factors. Among other factors, history and intensity of land use, together with physical, chemical and biological properties of soil determine the status and dynamics of phosphorus in soil (Schjonning et al., 2004).

Table 2.4. Multiple comparisons of soil properties and percent of changes for the statistically significant soil parameters

Soil properties	Land use types	*p*	% of change from the former to the latter land use type
Silt (%)	Forest vs. annual crop	0.010*	-29.5
	Multistory canopy coffee vs. annual crop	0.022*	-26.2
BD (g/cm^3)	Forest vs. annual crop	0.000**	+35.24
TP (%)	Forest vs. annual crop	0.000**	-22.60
pH (H_2O)	Forest vs. annual crop	0.000**	-16.0
	Forest vs. coffee monoculture	0.008**	-12.4
	Multistory canopy coffee vs. annual crop	0.001**	-3.3
OM (%)	Forest vs. annual crop	0.036*	-27.5
TN (%)	Forest vs. annual crop	0.015*	-75.3
	Forest vs. coffee monoculture	0.032*	-72.7
CEC (meq./100g)	Forest vs. coffee monoculture	0.015*	-39.3
Ca^{2+}(meq./100g)	Forest vs. annual crop	0.001**	-43.1
Mg^{2+}(meq./100g)	Forest vs. annual crop	0.021*	-18.8

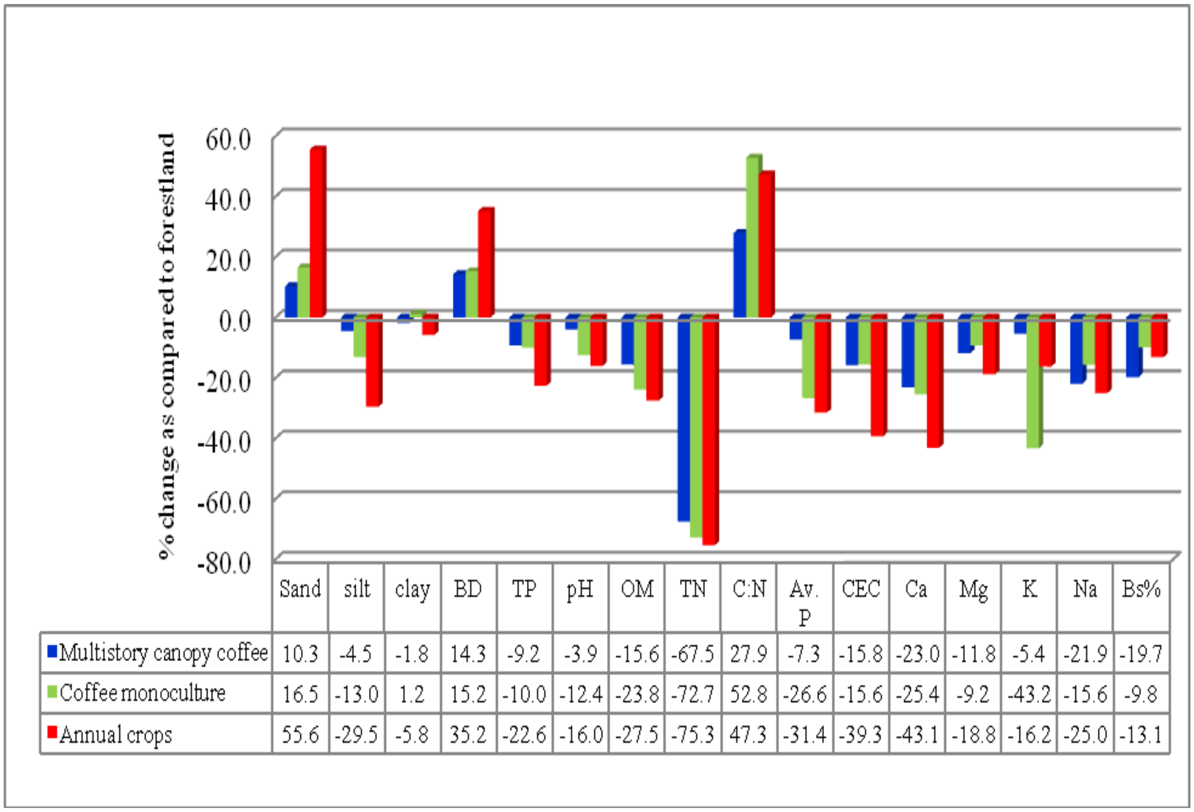
*Note: ** ($p < 0.01$), *($p < 0.05$), BD (Bulk Density), TP (Total Porosity), pH (Soil pH), OM (Organic Matter), TN (Total Nitrogen), CEC (Cation Exchange Capacity), Ca^{2+} (Exchangeable Calcium), Mg^{2+} (Exchangeable Magnesium).*

Cation exchange capacity and exchangeable bases

Cation exchange capacity showed a significant difference due to land use (F (3, 34) = 3.799, $p < 0.05$) and site (F (1, 34) = 5.345, $p < 0.05$) differences (Table 2.3). The CEC of forest soil was significantly higher ($p < 0.05$) than that of annual crops and coffee monoculture (Table 2.4). As compared to forestland, CEC was diminished by 39.3%, 15.6% and 15.8% in soils of annual crops, coffee monoculture and multistory canopy coffee farm, respectively (Figure 2.2). The lower CEC in annual cropland was attributed to the lower organic matter and exchangeable base content, and lower pH value of the annual cropland. After forestland, the highest CEC was observed in multistory canopy coffee farm. This suggests the potential of multistory canopy coffee farm to create optimum soil environments for supplying plant available soil nutrients. The average CEC value in the upper site of the watershed was smaller by 3.74 units than the downstream site. This was due to the higher organic matter and exchangeable base content of the downstream sites than the upstream sites. The CEC was rated as low in soil of annual crops and medium in soil of forest, multistory canopy coffee farm and coffee monoculture (Landon, 1991).

The CEC is a chemical soil property that significantly influences soil nutrient availability to plants as most adsorbed cations are plant nutrients (Hillel et al., 2004a). Therefore, land use practices have had a significant effect on the supply of plant available soil nutrients in the study catchment.

Following the decreasing density of land cover, a decreasing patterns of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) was observed, sequentially, in forestland, multistory canopy coffee farm, coffee monoculture and annual cropland. The differences in Ca^{2+} (F (3, 34) = 5.910, $p < 0.01$) and Mg^{2+} (F (3, 34) = 3.610, $p < 0.05$) contents of the soils were statistically significant (Table 2.3). The Ca^{2+} content was diminished by 43.1%, 25.4% and 23%, respectively, in annual cropland, coffee monoculture and multistory canopy coffee farm as compared to soils of forests. The percentage decrease of Mg^{2+} content was the highest (18.8%) in soil of annual cropland, followed by 11.8% in multistory canopy coffee farm and 9.2% in soil of coffee monoculture (Figure 2.2).



	Sand	silt	clay	BD	TP	pH	OM	TN	C:N	Av. P	CEC	Ca	Mg	K	Na	Bs%
🟦 Multistory canopy coffee	10.3	-4.5	-1.8	14.3	-9.2	-3.9	-15.6	-67.5	27.9	-7.3	-15.8	-23.0	-11.8	-5.4	-21.9	-19.7
🟩 Coffee monoculture	16.5	-13.0	1.2	15.2	-10.0	-12.4	-23.8	-72.7	52.8	-26.6	-15.6	-25.4	-9.2	-43.2	-15.6	-9.8
🟥 Annual crops	55.6	-29.5	-5.8	35.2	-22.6	-16.0	-27.5	-75.3	47.3	-31.4	-39.3	-43.1	-18.8	-16.2	-25.0	-13.1

Figure 2.2. Percentage change in soil properties of multistory canopy coffee farm, coffee monoculture and annual cropland as compared to forestland for the top 20 cm soil depth in Arsamma Watershed.

Note: BD (Bulk Density), TP (Total Porosity), pH (Soil pH); OM (Organic Matter), TN (Total Nitrogen), C: N (Carbon to Nitrogen Ratio), Av. P (Available Phosphorus), CEC (Cation Exchange Capacity), Ca (Exchangeable Calcium), Mg (Exchangeable Magnesium), K (Exchangeable Potassium), Na (Exchangeable Sodium); BS (Base Saturation).

While the Ca^{2+} content was significantly influenced both by types ($p < 0.01$) and sites ($p < 0.05$) of the land uses, Mg^{2+} was only influenced by land use types (Table 2.3). The change in K^+ and Na^+ content was not statistically significant (Table 2.3). This may be due to the smaller K^+ and Na^+ contents in soil compared to the Ca^{2+} and Mg^{2+}. In line with Landon (1991), the Ca^{2+} content was medium in soil of forest, multistory canopy coffee farm and coffee monoculture, and low in soil of annual crops. The Mg^{2+} and K^+ contents were rated as medium in all land use types of the study catchment. Variation of the exchangeable bases content across different land use types was also reported by previous studies (Fantaw, 2007; Habtamu et al., 2014). The differences in Mg^{2+}, $K^{+}$and Na^{+} contents between the two sites were not statistically significant (Table 2.3).

The base saturation varied from 44.7% in soil of annual crops to 51.4% in soil of forests (Table 2.2). As compared to forestland, base saturation diminished by 13.1%, 19.7% and 9.8% in annual cropland, multistory canopy coffee farm and coffee monoculture, respectively (Figure 2.2). Soils with base saturation of less than 50% are categorized as dystric or less fertile soils, and base saturation ranging from 20% to 60% is rated as medium (Landon, 1991). Therefore, all soils of the four land use types contained medium base saturation. The proportion of CEC accounted for by the exchangeable bases is frequently used as an indicator of soil fertility (Hillel et al., 2004a). This indicates the influence of land use types on soil fertility status in the study catchment.

Bivariate correlation relations between selected soil properties

The sand fraction was inversely and significantly correlated with clay ($r = -0.8$, $p < 0.01$) and silt ($r = -0.4$, $p < 0.05$) content (Table 2.5). This implies that land use change from forest to agricultural land results in concentration of the sand content at the expense of the clay fraction, and consequently results in decreasing water and nutrient holding capacity of the soil through time.

Soil pH is one of the major chemical soil properties that reflects the overall well-being of chemical and biological processes in soil (Schaetzl & Anderson, 2005). The positive and significant associations of soil pH with organic matter, total nitrogen, CEC, Ca^{2+} and Mg^{2+} content indicate the influence of soil pH on other chemical soil properties (Table 2.5).

Soil organic matter is considered to be a storehouse of numerous plant nutrients, and influences a number of other soil properties (Hall, 2008).

Table 2.5. Correlations among soil properties in Arsamma Watershed, Southwestern Ethiopian Highlands

Soil property	Sand	Silt	Clay	BD	pH	OM	TN	Av. P	CEC	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
Sand	1												
Silt	-.387*	1											
Clay	-.813**	-.222	1										
BD	-.172	-.315*	.452**	1									
pH	-.155	.169	.057	-.358*	1								
OM	-.232	.268	.076	-.172	.334*	1							
TN	-.016	.151	-.112	-.176	.408**	.338*	1						
Av. P	-.057	.161	-.042	-.135	.136	.255	.064	1					
CEC	-.290	-.008	.312*	-.483**	.342*	.463*	.013	-.156	1				
Ca^{2+}	-.168	.240	.027	-.341*	.313*	.344*	.152	.280	.355*	1			
Mg^{2+}	-.187	.038	.174	-.245	.327*	.176	.145	-.099	.575**	.381*	1		
K^{+}	-.078	.003	.080	-.084	.227	.220	.377*	.152	.114	.160	.389*	1	
Na^{+}	-.175	.172	.076	-.174	.110	.237	-.101	.062	.153	.331*	.058	.081	1

Note: ** (Significant at $p < 0.01$), *(Significant at $p < 0.05$), BD (Bulk Density), pH (Soil pH), OM (Organic Matter), TN (Total Nitrogen), C: N (Carbon to Nitrogen Ratio), Av. P (Available Phosphorus), CEC (Cation Exchange Capacity), Ca^{2+} (Exchangeable Calcium), Mg^{2+} (Exchangeable Magnesium), K^{+} (Exchangeable Potassium), N^{+} (Exchangeable Sodium).

The significant correlation of organic matter with total nitrogen, CEC and Ca^{2+} content shows that soil organic matter is intimately associated with these soil properties. Soil organic matter is also significantly and positively correlated ($r = 0.3$, $p < 0.05$) with total nitrogen (Table 2.5). Hence, it is likely that much of the nitrogen content of the soil is largely released into the soil from the organic fractions of the soil.

The CEC is significantly and positively correlated with the amount of organic matter ($r = 0.5$, $p < 0.05$) and clay content ($r = 0.3$, $p < 0.05$) of the soil. Therefore, it is likely that most of the exchangeable soil nutrients are derived both from soil organic matter and the clay fraction. The CEC was also significantly and positively correlated with soil pH value ($r = 0.3$, $p < 0.05$), Ca^{2+} ($r = 0.4$, $p < 0.05$) and Mg^{2+} ($r = 0.6$, $p < 0.01$) content (Table 2.5). Therefore, organic matter, clay fractions, pH value, and the exchangeable bases (Ca^{2+} and

Mg^{2+}) are the major soil properties that determine CEC of the soil, and then the adsorbing and exchanging capacity of plant available soil nutrients in Arsamma Watershed, Southwestern Ethiopian Highlands.

Conclusions and recommendations

Previous studies have indicated the detrimental effect of land use change from natural ecosystem to agricultural land use (Achalu et al., 2012; Agoume & Birang, 2009; Fantaw, 2015; Tsehaye & Mohammed, 2013). This study showed that similar land use types of different species composition with different density of canopy layer, the multistory canopy coffee and coffee monoculture farm, had different impacts on soil properties.

Statistically significant variations were observed in soil properties of different land use types. These variations were specifically observed between forestland and annual cropland, forestland and coffee monoculture, and multistory canopy coffee farm and annual cropland. Forestland contained higher silt, organic matter, total nitrogen, exchangeable calcium and exchangeable magnesium content than annual cropland. Higher pH (lesser acidity) and lower bulk density (lower compactness) were noted in soils of forests than in soils of annual cropland. Compared to the forest soil, a lower cation exchange capacity, pH value and total nitrogen content was observed in soils of coffee monoculture. Decreasing tendencies of organic matter, total nitrogen, cation exchange capacity and the exchangeable bases content were observed, sequentially, in soils of forest, multistory canopy coffee farm, coffee monoculture and annual crops. This decreasing pattern was attributed to the increasing magnitude of soil erosion and decreasing biomass inputs to the soil following the decreasing density of soil cover. After forest soils, the soils of the multistory canopy coffee farm contained the highest organic matter, total nitrogen and exchangeable bases. Hence, promotion of multistory canopy coffee farm that also consists compatible tree species with coffee plants could alleviate the problem of soil fertility deterioration resulting from forestland conversion to agricultural land uses. Furthermore, working towards certification of shade grown and/or organic coffee, which can help the farmers to obtain premium prices from international coffee market and/or from carbon trade could help to promote multistory canopy coffee farm, and then reduces the rate of land use transformation to coffee monoculture. Tree species in the coffee farm can also be preserved through the promotion of rural electrification and energy saving stoves so that tree species in the remnant forest and in the multistory canopy coffee farm, which may be used for firewood, can be preserved.

The soils were strongly acidic regardless of land use types. This problem could be the major bottleneck of agricultural production and productivity in the study catchment. Hence, promotion of Integrated Soil Fertility Management adoption, with application of calcium carbonates, structural and biological soil conservation measures might alleviate this problem (Mesfin, 2007). Soil liming by calcium carbonates increases soil pH, and makes other essential nutrients more available (Hall, 2008). Considering the general shift of the global coffee market towards organic coffee products, it is also wise to manage coffee soil solely through organic approaches. Hence, organic fertilizers (ash, household wastes, animal and green manures) together with structural and biological soil conservation measures need to be promoted for management of coffee soils. Modifying land use strategies by incorporating acid tolerant plant species is also the other means of adapting to the acidic soils of the study catchment.

Finally, the study indicates further studies on factors driving land use change and agroecosystem transformation in the study catchment.

Endnote

[1] *Kebele is the lowest administrative unit in the Federal Democratic Republic of Ethiopia's government structure*

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Chapter 3

The Nexus between Smallholder Farmers’ Resource Endowment and Soil Fertility Management Practices in Arsamma Watershed, Southwestern Ethiopian Highlands

Abstract

This study examines the link between smallholder farmers’ resource endowment and soil fertility management, soil properties and crop yield performance. A two-stage random sampling technique was used to select 136 sample households. A balanced sampling technique was used to collect soil samples from farmlands owned by poor, medium and rich households. One way ANOVA and a multiple regression model were used to analyze the data. Application of chemical fertilizers, organic fertilizers, use of soil bunds and crop rotations significantly varied due to variation in farmers’ resource endowment. Farmland and livestock size explained about 61% of the variability in organic matter content of the soil. About 56% of variation in crop yield was explained by farmland and livestock size, and 5.2 quintals of yield gap per hectare was observed between the rich and the poor households. The poor farmers need to be emphatically focused in soil fertility management planning. Provision of credit services, subsidizing chemical fertilizers, working towards a fair international coffee market and promotion of off-farm livelihood strategies needs to be prioritized in order to enhance smallholder farmers’ soil fertility management practices.

Key words: resource endowment; soil fertility management; crop yield

Introduction

Ethiopia is the second most highly populated country in Africa, after Nigeria (WB, 2015). With the current annual population growth rate of 2.6 %, the total population of the country is expected to reach 94,351,001 in 2017 (CSA, 2013). Smallholder agriculture is the mainstay of this overwhelming population, where it employees about 85% of the population, generates over 46% of GDP and 80% of export earnings (IFPRI, 2010). Agricultural landholding size is very small and decreasing from time to time. The national average landholding size was merely 0.95 ha/household in 2014 (CSA, 2014), and the number of households who owned less than 0.1 ha increased from 7.3% in 2009 to 9.1% in 2014 (CSA, 2010; 2014). As a result, over cultivation, farming of fragile steep slopes and soil degradation are major features associating with agricultural activities in the highlands of the country (Bezuayehu et al., 2002; Engidawork, 2012). Farmland size is positively and strongly associated with net farm income, and influences soil fertility management practices in most Ethiopian highlands (Headey et al., 2013). This means that the decreasing per capita landholding size is one of the main threats to sustainable soil fertility management in the country (Adugnaw, 2014; Assemu & Shigdaf, 2014; Edwards, 2010).

Soil fertility management practices of smallholder farmers are influenced by complex sets of factors (Mitiku et al., 2007). As farmers make decisions on soil fertility management at household level based on the constraints or incentives imposed by economic factors, resource endowment is an important determinant of the choice and practice of soil fertility management (Hammad & Tumeiz, 2012; Masvaya et al., 2009; Moseley, 2005). Hence, different soil fertility management practices and agricultural yield performances are observed across farmlands owned by the poor, medium and rich farmers even under similar climatic and agro-ecological settings (Sanginga & Woomer, 2009). This variation was observed not because resource-poor farmers are less aware of the benefits of soil fertility management than the rich farmers, but because their immediate concern with subsistence production make them less concerned with long term investment in soil (Blanco & Lal, 2008; Moseley, 2005). Resources required for soil fertility management, such as household wastes, crop residues and compost materials are rarely carried from homestead to farmlands of the poor farmers due to the lack of pack animals and/or sufficient human labor (Ramisch, 2004). Poor farmers are also excluded from credit services that would have been used for soil fertility management since access to credit sometimes requires collateral agreement (Samuel, 2006). To cope up with seasonal food shortage and other problems related to poverty, poor farmers sell or hire a portion of their farmland to the rich farmers which also aggravates pressure and degradation on the remaining part of their farmland (Hammad & Tumeiz, 2012).

A number of studies were conducted on the effects of farmers' resource endowment on soil fertility management. Hoffmann (2002) observed positive association between the volume of farmyard manure carried to farmland and farmers' wealth status in Northwest Nigeria. In Southern Ethiopia, the size of *darkoa* (local term for highly fertile dark soil) land was associated with farmers' resource endowment and households' ability to mobilize sufficient manure and labor for soil fertility management (Alemayehu et al., 2001). Tilahun and Mulugeta (2005) observed that rich farmers use about two-times more farmyard manure, and use five-times more chemical fertilizers than the poor farmers. Despite experiencing problems of soil degradation and acknowledging the benefits of structural soil conservation technologies, the poor farmers in Areka area of Ethiopia avoided structural soil conservation technologies in order not to lose the land that is taken out of production for soil conservation (Tilahun et al., 2001). It was also estimated that one hectare decrease in farmland size reduces fertilizer use by 11 kg (Headey et al., 2013). Amare et al. (2006) found a positive association between nutrient input to the soil positively associates with farmers' wealth status. Soil nutrient contents were also found to be significantly higher in farmlands owned by the wealthy farmers than in farmlands owned by the poor farmers due to variation in soil fertility management practices (Tilahun & Mulugeta, 2005). These variations of soil fertility management and soil fertility status in a given community inevitably results in widening of wealth differences, and hence aggravates soil degradation and rural poverty (Hoffmann, 2002).

Although many studies (for example, Alemayehu et al., 2001; Hoffmann, 2002; Tilahun & Mulugeta, 2005) underline that resource-poor farmers are the proximate causes of soil degradation, some other authors (such as, Gray, 2005; Moseley, 2005) argue the other way round. The study made in Southwestern Burkina Faso showed that wealthier farmers had fewer trees in their fields and use more heavy machines than the poor farmers. As a result, the overall quality of soil was poorer in farmlands owned by the rich farmers than in farmlands owned by the poor farmers (Gray, 2005). In Mali, a variety of environmentally deleterious practices, such as pesticides, herbicides, production of extractive crops, such as cotton, were more frequently used by wealthy than poor farmers. As a result, the rich farmers were found the proximate cause of environmental degradation (Moseley, 2005). Assefa (2005) also observed higher depletion rate of nitrogen, phosphorus and potassium contents in farmlands owned by the rich farmers than those owned by the poor farmers in Northern highlands of Ethiopia.

An understanding of interactions existing between farmers' economic background and soil fertility management provides an opportunity to integrate natural and social sciences for sustainable use of soils (Brevik et al., 2015). Such integrated approach provides an opportunity to understand soil both in the economic and physical context, monitor economic forces driving soil fertility changes and suggest new ways of thinking and acting for sustainable soil fertility management planning (Kessler & Stroosnijder, 2010; Ramisch, 2004). Problems of soil fertility decline faced by millions of resource-poor farmers in Sub-Saharan African countries are also believed to be addressed through proper understanding of the interaction existing between farmers' economic background and their soil fertility management practices (Fairhurst, 2012; Sanginga & Woomer, 2009). As a result, it is argued that any soil fertility management program which disregards the economic background of rural households is considered as an attempt of engaging in soil fertility management intervention through unsustainable approach (Mitiku et al., 2007). Therefore, a study of the interaction existing between smallholder farmers' resource endowment and soil fertility management has been a crucial research priority (IUSS, 2006).

Studies conducted on the nexus between smallholder farmers' resource endowment and soil fertility management, however, remained crude generalization of causal relationship between poverty and soil degradation, and failed to disaggregate soil fertility management practices of the poor, the intermediate and the well-off farmers (Ravnborg, 2011). Farmers’ resource endowment, soil fertility management, soil nutrient content and agricultural yield performance also appeared to be intimately linked with each other. However, integration of these four dimensions for the study of the interaction existing between smallholder farmers’ resource endowment and soil fertility management was not adequately addressed by previous studies. It was observed during the preliminary survey that rural poverty, declining per capita landholding size and increasing pressure on agricultural land were the major threats to sustainable soil fertility management in the study catchment. Therefore, this study aimed to examine the link of smallholder farmers’ resource endowment with soil fertility management, soil properties and crop yield performance in Arsamma Watershed, Southwestern Ethiopian Highlands.

Background of the study area

Arsamma watershed is found in the Southwestern Ethiopian Highlands. It is situated in the West Wellega Administrative Zone of Oromia National Regional State. The watershed is located between 9°05’-9°12’ N and 35°40’-35°50’ E, and covers a total area of 11, 540 hectares (Figure 3.1).

The West Wellega zone receives high rainfall amount (Figure 1.4). The total annual rainfall from the year 1981 to 2010 exceeds 1,900 mm per annum on average. The rainfall pattern is unimodal with a long summer season, and more than 78% of the rainfall is concentrated in months extending from June to September. The region is characterized by mean annual temperature of 20.4°C and mean monthly temperature ranging from 17.8°C in August to 22.5°C in March. The periods of low mean monthly temperature coincide with the periods of high rainfall (Figure 1.4). Owing to torrential rainfall and high topographic dissection, soils in the West Wellega zone are fragile and susceptible to erosion. About 67% of soil in the zone is estimated to have a pH values of less than 6, of which 34% is strongly acidic (pH 4.5 to 5) (Mesfin, 2007).

West Wellega zone is one of the densely populated zones of Oromia National Regional State. With a total area of 13,131 km^2 and total population of 1,523,715, the crude population density of the zone was about 116 persons/km^2 as of July 1, 2011 estimate (BFED, 2013). The distribution of the population varies from 51 persons/km^2 in the western part to over 250 persons/km^2 in the eastern part where the study catchment is located (CSA, 2011). The average farmland size in West Wellega zone was about 1.2 ha/household in 2013 (CSA, 2014).

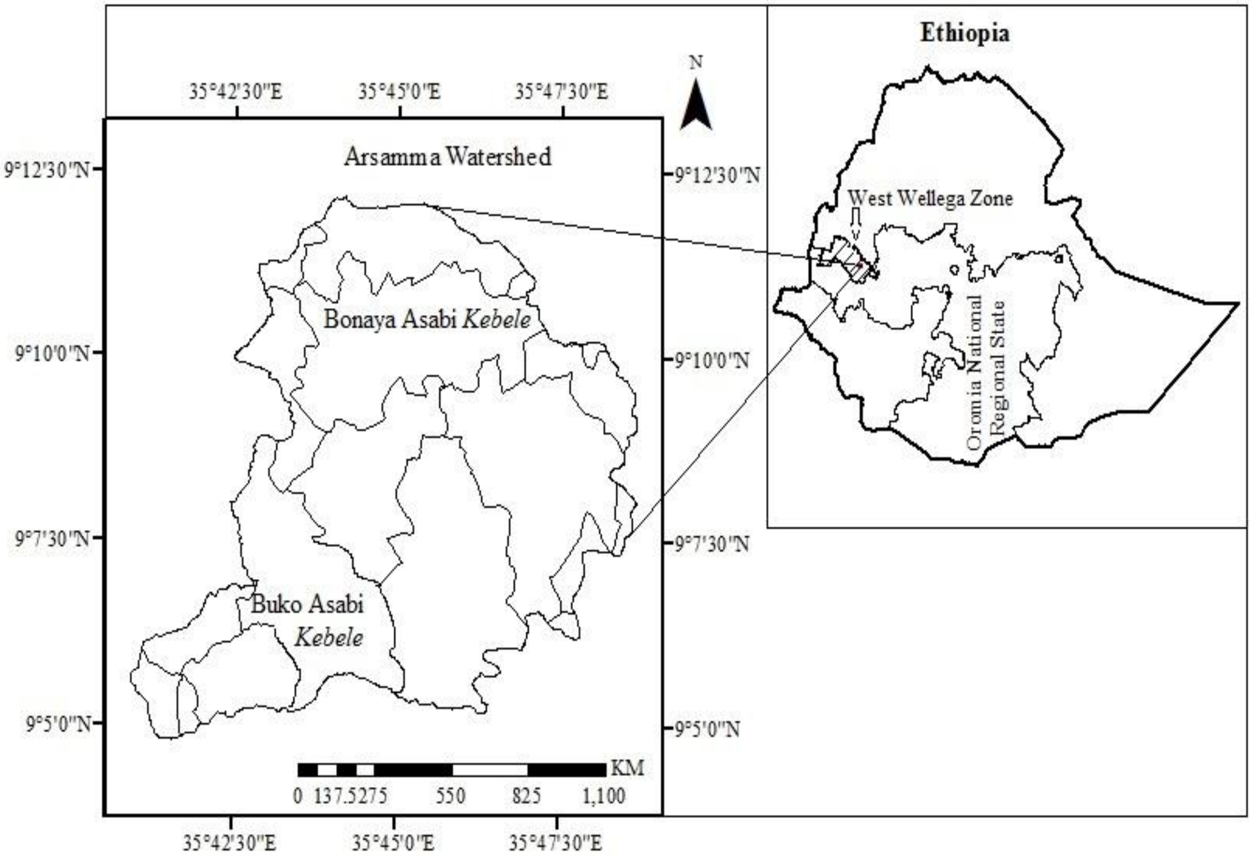

Figure 3.1. The sampled *Kebeles*.

From the 18 Administrative Zones of Oromia National Regional State, the West Wellega zone ranks second from last in terms of its livestock population. Of the 22,958,489 cattle population in Oromia National Regional State in 2013, only 918,028 cattle, accounting for 3.9% of the total, were raised in the zone (BFED, 2013). The torrential rainfall, high topographic dissection, the small farmland size and livestock numbers are likely to be the major threat to sustainable utilization of the soil in the region.

Materials and methods

Arsamma watershed encloses seventeen *kebeles. A kebele* is the smallest administrative unit in Ethiopia. While 11 *kebeles* are partially enclosed, 6 are fully encompassed by the watershed. The study involved a household survey and a soil survey, one after the other.

Household survey

The household survey was conducted from January to February 2013, followed by the soil survey in March 2013. A two-stage random sampling technique was employed to select the sampled households. First, two *kebeles* (the smallest administrative units) namely, Bonaya Asabi and Buko Asabi, were selected from the six *kebeles* that the catchment fully encloses (Figure 3.1). Second, four rural villages (*gotes*), two each from the two *kebeles*, were randomly selected by lottery draw. Finally, a total of 136 households accounting for 30.2% of the total population in the four villages were randomly and proportionally selected.

The surveys were undertaken in the order of preliminary survey, questionnaire survey, soil survey and key informant interview. A semi-structured interview questionnaire was used to collect information on farmers' wealth status, soil fertility management practices and crop yield performance. Indicators of farmers' wealth status were specified through discussion held with key informants. Two development agents were contacted, and five knowledgeable key informants were selected based on the nomination of the development agents. The key informants indicated that farmland size and livestock number were the two most important indicators of farmers' wealth status. These two variables were used as proxy variables to represent the status of farmers' resource endowment. Proxy variables are parameters that serve in place of the unobservable or immeasurable variables, and they are frequently used in social sciences because of the difficulty of obtaining measures of the quantities of interest (Wooldridge, 2009). Based on these proxy variables and the analysis of the collected socioeconomic data, the sampled households were classified as poor, medium and rich households as detailed in Table 3.1.

Soil survey

Spatial analogue approach was used to collect soil samples (Hatemink, 2006). It was assumed that soils formed on similar lithology under similar climate and land use types would have analogous properties provided that there were no variations in soil fertility management and land use types. Observed differences in soil properties were, therefore, assumed to be the result of variation in soil fertility management, which was in turn the result of variation in farmers' resource endowment. The sampled households were classified into three wealth groups by using the definitions specified by the key informants and the preliminary analysis of the collected socioeconomic data. This allowed soil samples to be collected from farmlands owned by the poor, medium and rich households. The sampled household units included 38 poor, 67 medium and 31 rich households. Twelve households (four each from the three wealth groups) were randomly selected by lottery draw. Twelve analogous farm plots used for annual crop production (four each for the three wealth groups) were identified for each respective household. Composite soil samples were collected from the top 20 cm soil depth using an auger. Seven sub-samples were collected for each composite soil sample, and a composite sample for each specific field was produced by hand mixing. Undisturbed core samples were also collected from the surface soil of the respective farm plots for bulk density analysis.

Soil laboratory testing was conducted at Holeta Agricultural Research Center. The soils were air dried, crushed and passed through a 2 mm sieve. Boycouos hydrometric and undisturbed core sampling methods were used, respectively, to test particle size distribution and bulk density (Carter & Gregorich, 2008). Soil pH was measured in 1: 2.5 soil-water suspensions (Van-Reeuwijk, 1993). Organic carbon content was measured by the oxidation method, and soil organic matter content was calculated by multiplying percent of organic carbon by a factor of 1.724 (Carter & Gregorich, 2008). The Kjeldahl digestion and distillation method was used to measure total nitrogen (Bremner & Mulvaney, 1982). Since the tested pH value indicated acidic soil conditions, Bray II method was used to test available phosphorus (Bray, 1945). The CEC was measured by the ammonium acetate method. Exchangeable magnesium and calcium contents were determined by atomic absorption spectrophotometer, and exchangeable potassium and sodium contents were measured by flame photometer (Carter & Gregorich, 2008).

Descriptive statistics, Pearson's correlation, one way ANOVA and a multiple regression model were used to analyze the data. Descriptive statistics were used to establish a base for further analysis by the other tests. Associations of farmland and livestock size with soil fertility management practices and crop yield performance were evaluated by Pearson's correlation. A one way ANOVA was used to test whether there is statistically significant differences in soil fertility management practices, soil properties and crop yield performances across farmlands owned by the three wealth groups, or not. For the statistically significant parameters, Tukey's post hoc test was used to indicate where the variation specifically lies. Finally, a multiple regression model was used to indicate the predicted estimate of soil fertility management practices, soil nutrient content and crop yield performance based on farmers' resource endowment. All the data were analyzed using SPSS version 20.

Although soil fertility management practices are influenced by complex sets of factors, this study was limited to the implications of farmers' resource endowment on soil fertility management practices (chemical fertilizers, organic fertilizers, soil bund and crop rotation), soil properties and crop yield performance. Integration of these four dimensions was expected to minimize limitations that may result from the small soil sample considered for this study. Crop rotation is a very broad concept, but this study considered only simple crop rotations that did not take into account selection of crop species and cycles of rotation. The study considered not the intensity of fertilizer input to the soil, but the amount of farmlands put under different soil management practices.

Table 3.1. Description of variables used in the study

Variables	Variable description
Farmland size (FLS)	Amount of farmland owned by a household, and was measured in hectare. It was used as an explanatory variable, and a proxy variable that indicates a status of households' resource endowment
Livestock size (LS)	Number of livestock owned as measured in Tropical Livestock Unit (TLU). One TLU is equivalent to 1.5 cattle, 10 sheep, 12 goats, 2 donkeys, 1 horse or 0.8 camels (Sys et al., 1991). It was used as an explanatory variable, and a proxy variable that represents households wealth status
Wealth status (WS)	Relative rank of a household in the local community in terms of the major assets a household owned. A household owned ≥ 1.5 ha of land with 3 or more cattle was specified as rich. A household owned 0.5-1.5 ha of land with 2 or 3 cattle was defined as medium, and a household owned < 0.5 ha of land with 1 or no cattle was specified as poor
Farmland size with chemical fertilizer application (FLSWCFA)	The size of farmland on which either urea, DAP or both fertilizers were applied. It was measured in hectare, and was used as a response variable
Farmland size with organic fertilizer application (FLSWOFA)	Amount of farmland on which at least one of animal manure, compost or farmyard manure was applied. It was measured in hectare, and was used as a response variable
Farmland size with soil bund (FLSWSB)	Amount of farmland protected from erosion by using soil bund. It was measured in hectare, and was used as a response variable
Farmland size with crop rotation (FLSWCR)	Amount of farmland covered by crop species which was dissimilar to crop species grown on the same farm plot during the previous year. It was measured in hectare, and was used as a response variable
Crop yield per hectare (CYPH)	Average cereal crop yield harvested. It was expressed in quintal per hectare, and was used as a response variable

Note: The *size of farmland with organic fertilizer, chemical fertilizer, crop rotation or soil bund application was not assumed to be exclusive.*

Results and discussions

Farmers' resource endowment

Of the households surveyed, 27.9%, 49.3% and 22.8% were classified as, respectively, resource-poor (here after named as poor), medium and rich households. The poor households, who accounted for 27.9% of the total population, owned 9.7% of the total farmland (Figure 3.2). The average farmland size for the poor households (0.37 ha) was 2.7 and 4.6 times smaller than that of the medium and the rich households, respectively (Table 3.2). The ratio of the percent of the total farmland size to the corresponding percent of total households in each wealth groups was about 1: 2.9 for the poor, 1: 1.1 for the medium and 1: 0.5 for the rich households (Figure 3.3).

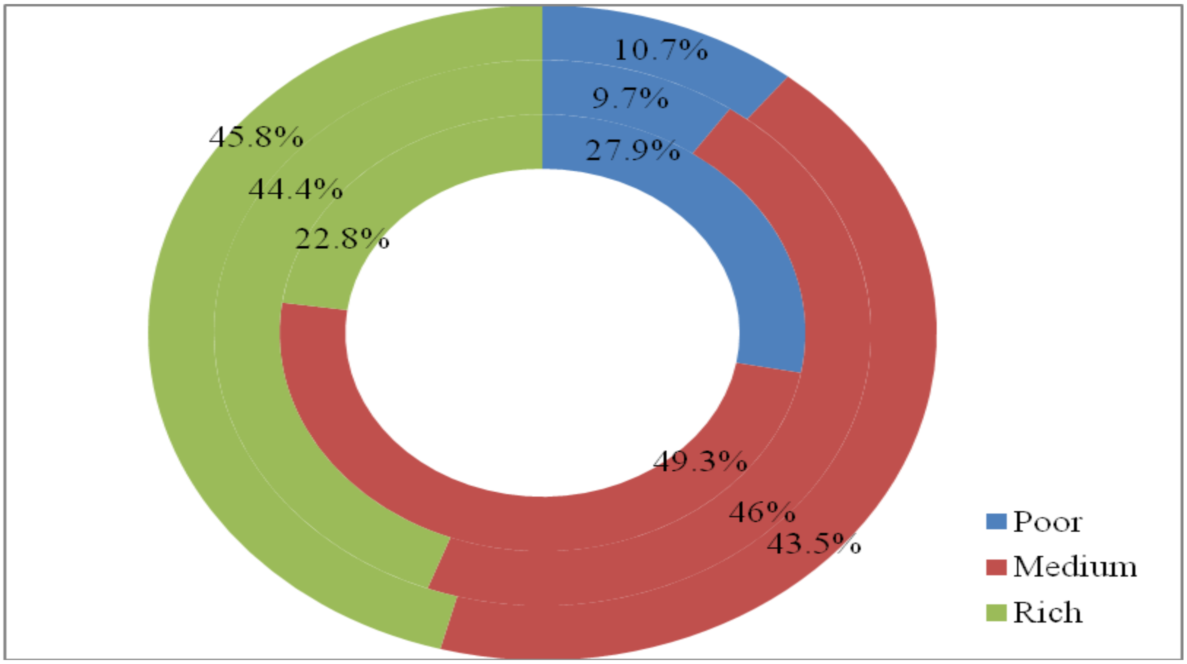

Figure 3.2. Percent of households in each wealth groups (the inner circle), and the corresponding percent of total farmland size (the middle circle), and total livestock number (the outer circle).

Variation in the size of farmlands owned by the three wealth groups was also statistically significant ($p < 0.01$; Table 3.2), and the average farmland size owned by the poor households was significantly smaller than that of the rich and the medium households as shown by Tukey's post hoc test (Table 3.5).

The livelihood of the study population was tightly linked to coffee production as indicated by the key informants. Coffee yield is highly susceptible to climatic factors. Its price is also volatile due to international coffee market. When the coffee yield or price is poor, the poor farmers are often forced to sell their coffee farmland to the rich households to cope up with seasonal food shortage. This implies that rural poverty, 'informal land market' by the name of perennial crops, climatic fluctuation and the volatile international coffee market were the major factors driving farmland size inequalities in the study catchment.

Table 3.2. Multiple comparisons of farmers' resource endowment with soil fertility management practices in Arsamma Watershed, Southwestern Ethiopian Highlands

Variables	Poor (n=38)	Medium (n=67)	Rich (n=31)	Total (N=136)	SD	SE	F value	*p*
FLS (Ha)	0.37	1.00	1.70	0.98	0.64	0.05	78.148	0.000**
LS (TLU)	0.32	0.72	1.64	0.82	1.09	0.09	15.858	0.000**
FLSWCFA (Ha)	0.04	0.17	0.37	0.18	0.17	0.01	61.440	0.000**
FLSWOFA (Ha)	0.05	0.18	0.27	0.16	0.14	0.01	32.918	0.000**
FLSWSB (Ha)	0.02	0.06	0.14	0.07	0.10	0.01	17.048	0.000**
FLSWCR (Ha)	0.04	0.21	0.38	0.20	0.20	0.01	42.170	0.000**

*Note: ** (Significant at $p < 0.01$), FLS (Farmland Size), Ha (Hectare), LS (Livestock Size), TLU (Tropical Livestock Unit), FLSWCFA (Farmland Size with Chemical Fertilizer Application), FLSWOFA (Farmland Size with Organic Fertilizer Application), FLSWSB (Farmland Size with Soil Bund), FLSWCR (Farmland Size with Crop Rotation), SD (Standard Deviation), SE (Standard Error).*

The average livestock number varied from 0.32 TLU for the poor, 0.72 TLU for the medium to 1.64 TLU for the rich households (Table 3.2). The poor households owned about 5 times less livestock than the rich households (Table 3.2). The ratio of the percent of total livestock number for each wealth groups to the corresponding total households was about 1: 2.6 for the poor, 1: 1.1 for the medium and 1: 0.5 for the rich (Figure 3.3). This variation was statistically significant ($p < 0.01$) as shown by one way ANOVA (Table 3.2). Livestock number for the rich households was significantly ($p < 0.01$) larger than that of the medium and the poor households as shown by Tukey's post hoc test (Table 3.5). The total average livestock number (0.81 TLU) was also very low regardless of farmers' wealth class. This was attributed to the shortage of grazing land and animal feed as indicated by the key informants.

Implications of farmers' resource endowment on soil fertility management

Applications of chemical fertilizer, organic fertilizer, and use of graded soil bund and crop rotations were major soil fertility management practices in Arsamma watershed (Table 3.1). These techniques represent, respectively, chemical, organic, structural and biological approaches to soil fertility management. Variation in the use of these techniques, therefore, can have significant influence on the overall soil health of the area.

Of the total 133.3 ha of farmland, calculated by multiplying the average farmland size of 0.98 ha by 136 sample respondents, only 24.5 ha (18.4%) was amended by chemical fertilizers. The farmland size fertilized by chemical fertilizer varied from 0.04 ha for the poor, 0.17 ha for the medium to 0.37 ha for the rich farmers, with 0.17 SD and high (94.4%) coefficient of variation. This variation was also statistically significant ($p < 0.01$; Table 3.2). The poor households amended significantly smaller ($p < 0.01$) farmland size by chemical fertilizers than the rich and the medium households (Table 3.5).

Animal manure, farmyard manure and compost were major organic fertilizer inputs to the soil in the study watershed (Table 3.1). Organic fertilizer was applied to 16.3% of the total farmland. This means that only one-sixth of the total farmland owned by the total respondents was amended through organic approach. The rich farmers fertilized as much as 5.4 times more farmland size by organic fertilizers than the poor farmers. The difference in the application of organic fertilizers was also statistically significant ($p < 0.01$) across the three wealth groups (Table 3.2). Hoffmann (2002) also observed positive association between the volume of organic fertilizers carried to farmland and farmers' wealth status.

Graded soil bund was the major structural soil conservation technique in the study watershed. Due to high topographic dissection and torrential rainfall of the area, structural soil conservation measures are very critical to address the problem of soil degradation. However, only 9.52 ha, accounting for 7.1% of the total farmland, were protected from erosion by using soil bund. The average farmland size with soil bund was 0.02 ha for the poor, 0.06 ha for the medium and 0.14 ha for the rich households, and this variation was statistically significant ($p < 0.01$; Table 3.2). The rich households protected a larger area of farmland against erosion than the poor and the medium households as shown by the Tukey's post hoc test (Table 3.5). Tilahun et al. (2001) also reported that farmers with small farmland size less practice structural soil conservation measures than farmers with large farmland size.

Because farming system in Arsamma watershed was partly perennial in nature, only a small proportion of the farmland (20.4%) was put under crop rotation. The size of farmland with crop rotation varied from 0.04 ha for the poor to 0.38 ha for the rich households. The ratio of farmland size put under crop rotation to the total farmland size was about 1: 9.3 for the poor, 1: 4.8 for the medium and 1: 4.5 for the rich households. This variation was statistically significant ($p < 0.01$) across the three wealth groups (Table 3.2).

Implications of farmers' resource endowment on soil properties

The combined effect of differences in the application of chemical fertilizers, organic fertilizers, and use of soil bunds and crop rotations, which were mainly attributed to differences in farmers' resource endowment, was reflected in soil properties.

The proportion of sand content in farmlands owned by the poor households was greater by 20% and 5%, respectively, as compared to farmlands owned by the rich and the medium households. This means that farmlands owned by the poor farmers were sandier than farmlands owned by the rich and the medium households, and characterized relatively by poor water and nutrient holding capacity. This higher sand fraction in farmlands owned by the poor households was attributed to less protection of the soil from erosion and hence due to selective removal of the silt and clay fractions. The distribution of silt fraction was not significantly different in the farmlands owned by the three wealth groups. Clay was the dominant soil fraction in all farmlands regardless of wealth category, varying from 34% in farmland held by the poor households to 48% in farmlands held by the medium and the rich households (Table 3.3). Clay is one of the major soil constituents with potential to adsorb and supply plant available moisture and nutrients (Hillel et al., 2004). The relatively lower proportion of clay fractions in farmlands owned by the poor households, therefore, indicates relatively poor agricultural performance of these farmlands.

The highest (1.44 g/cm^3) and the lowest (1.39 g/cm^3) bulk density values were observed in farmlands owned by the poor and the rich farmers, respectively. Bulk density value in farmlands owned by the poor households was greater by 0.05 g/cm^3 and 0.04 g/cm^3, respectively, as compared to the farmland owned by the rich and the medium households (Table 3.3). This means that farmlands owned by the poor households were characterized by a higher tendency of soil compaction, lower infiltration rate and higher obstruction to plant root growth than the farmlands owned by the rich and the medium households.

The pH value in farmlands held by the poor households was lower by 0.2 units than in farmlands held by the rich farmers. This means that farmlands owned by the poor farmers were slightly more acidic than the farmlands owned by the rich households. The lower pH value in farmlands owned by the poor households was attributed to less organic matter input and less protection of the soil from erosion, as organic matter retains plant nutrients, including the exchangeable bases, and prevents them from leaching and downwashing (Hall, 2008). Soil pH strongly influences availability of nutrients to plants, reaction of soil nutrient with each other and can significantly influence soil productivity (Hillel et al., 2004). This small difference in soil pH value across farmlands owned by the three wealth groups, therefore, can have significant influence on crop yield performance.

Compared to organic matter content in farmlands owned by the rich farmers, soil organic matter contents in farmlands owned by the poor and the medium farmers were lower by 1.6% and 1.2%, respectively. Variation in organic matter content across farmlands owned by the three wealth groups was statistically significant ($p < 0.05$) as shown by one way ANOVA (Table 3.3). The lower organic matter content in farmlands owned by the poor farmers was attributed to low organic fertilizer input and less protection of the soil from erosion. The rich farmers had more livestock size than the poor farmers. These livestock sometimes graze on crop residues left on farmlands of the poor farmers. The poor households also sell animal feed produced from their farmland to the rich households. This means that organic fertilizers flow from farmlands of the poor to the rich farmers due to variation in resource endowment.

Table 3.3. Multiple comparisons of farmers' resource endowment versus soil properties for the top 20 cm soil depth

Soil properties	Poor	Medium	Rich	Total	SD	F value	*p*
Sand (%)	45.13	30.31	25.63	33.69	15.28	2.143	0.17
Silt (%	20.63	21.25	25.63	22.50	6.08	0.770	0.49
Clay (%	34.25	48.44	48.75	43.81	14.74	1.342	0.31
BD (g/cm^3)	1.44	1.41	1.39	1.41	0.11	0.201	0.82
pH (H_2O	4.12	4.28	4.36	4.25	0.20	1.717	0.23
OM (%)	2.33	2.67	3.88	2.96	1.00	4.190	0.05*
TN (%)	0.11	0.17	0.23	0.17	0.06	8.313	0.08
Av. P (ppm	3.10	5.50	6.50	5.03	2.36	2.984	0.07
CEC (meq./100g)	10.42	17.33	17.01	14.92	5.00	3.571	0.10
Ca^{2+} (meq./100g)	2.73	3.50	3.74	3.32	0.99	1.154	0.36
Mg^{2+}(meq./100g)	1.91	1.90	1.96	1.92	0.20	0.106	0.90
K^+ (meq./100g)	0.24	0.40	0.34	0.33	0.25	0.367	0.70
Na^+ (meq./100g)	0.20	0.15	0.33	0.22	0.10	10.647	0.40

*Note: * (Significant at $p < 0.05$), BD (Bulk Density), pH (soil pH), OM (Organic Matter), TN (Total Nitrogen), Av. P (Available Phosphorus), CEC (Cation Exchange Capacity), Ca^{2+} (Exchangeable Calcium), Mg^{2+} (Exchangeable Magnesium), K^+ (Exchangeable Potassium), Na^+ (Exchangeable Sodium).*

Soil organic matter is a major reservoir of soil nutrients. Availability of water and nutrients for plant uptake, stability of soil aggregates, water infiltration rate, moisture holding capacity and activities of soil microorganisms are strongly influenced by soil organic matter (FAO, 2005). Therefore, variation of soil organic matter content across a given spatial area can have a significant influence on soil fertility status, and then on crop yield performance.

Total nitrogen content was 0.11%, 0.17% and 0.23%, respectively, in farmlands owned by the poor, medium and rich farmers. It was smaller by 0.12% in farmlands owned by the poor households as compared to that of the rich farmers. The relatively lower nitrogen content in farmlands owned by the poor farmers was attributed to less application of urea to their farmland due to financial limitation, successive growing of the same crop species on the same plot of land owing to small farmland size and their preference for certain crop species, less protection of the soil from erosion and low application of organic fertilizers, such as animal manure, farmyard manure and compost to their soil. Nitrogen is one of the soil nutrients that is required by plants in large amount. Differences in the nitrogen content of a soil, therefore, can have a strong impact on the productivity of crops in general and on the productivity of highly nitrogen demanding crops, such as maize, in particular (Hall, 2008).

Available phosphorus content varied from 3.1 ppm in farmlands held by the poor households to 6.5 ppm in farmlands held by the rich farmers. This difference was not statistically significant ($p = 0.07$). Available phosphorus is derived both from inorganic (rock minerals) and organic sources (Lal, 2006). Lower available phosphorus content in farmlands owned by the poor farmers is, therefore, partly attributed to less application of organic fertilizers, such as animal manure, compost and farmyard manure to the soil. Higher soil erosion and soil nutrient mining could be the other possible causes.

The CEC ranged from 10.4 meq./100g in farmlands owned by the poor farmers to 17 meq./100g in farmlands held by the medium and the rich farmers. The CEC in farmlands owned by the medium farmers was not significantly different to that of the rich farmers. This was attributed to similar distribution of the clay fractions in farmlands owned by these two wealth groups (Table 3.3). The CEC in farmlands held by the poor farmers was lower by 7 units than that of the medium and the rich farmers owing to low organic and inorganic fertilizer input and less protection of the soil from erosion. This means that farmlands owned by the poor farmers were less able to adsorb, store and exchange plant available soil nutrients (Hall, 2008).

The highest (3.74 meq./100g) and the lowest (2.73 meq./100g) Ca^{2+} content were observed in farmlands owned by the rich and the poor farmers, respectively. However, Mg^{2+} content was not significantly different across farmlands owned by the three wealth groups. K^{+} content was the highest in farmlands owned by the medium farmers, and the lowest in that of the poor farmers. But, the difference was not statistically significant ($p = 0.7$). Na^{+} varied from 0.15 meq./100g in farmlands owned by the medium households to 0.33 meq./100g in farmlands owned by the rich households (Table 3.3).

In summary, statistically significant variation was observed only for organic matter content of the soil. Yet, decreasing tendencies in other soil nutrient contents, and an increasing pattern of soil acidity and soil compaction were observed as one hypothetically moves from farmlands owned by the rich farmers through that of the intermediate to farmlands owned by the poor farmers. The cumulative and combined effects of these many small variations can have significant influence on crop yield performance.

Implications of farmers' resource endowment on selected crop yield

Under similar geological, topographical and climatic settings, variation in crop yield is mainly attributed to variation in soil fertility management. Application of soil fertility management techniques and soil nutrient content were influenced by variation in farmers' resource endowment as discussed earlier. The combined effect of these variations was reflected in the yields of the staple crops, such as maize, sorghum, finger millet and barley grown in the study catchment (Table 3.4).

Table 3.4. Multiple comparisons of farmers' resource endowment versus crop yields

Crop type	Poor (n= 38)	Medium (n=67)	Rich (n=31)	Average (N=136)	SD	SE	F value	*p*
Maize (qt/ha)	21.62	25.15	32.67	26.48	10.96	1.02	9.041	0.000**
Sorghum (qt/ha)	12.49	15.33	17.58	15.13	6.57	0.67	3.031	0.050*
Millet (qt/ha)	12.61	13.05	14.08	13.25	4.67	0.51	0.496	0.611
Barley (qt/ha)	8.26	8.89	11.54	9.56	3.83	0.46	4.664	0.013**
Average (qt/ha)	13.75	15.61	18.97	16.11	6.34	0.55	17.419	0.000**

Note: ****** *(Significant at* $p < 0.01$*),* ***** *(Significant at* $p < 0.05$*).*

Maize yield varied from 21.6 qt/ha for the poor households to 32.7 qt/ha for the rich households. This means that, on average, the rich households harvested 11 more quintals per hectare of land. This variation was statistically significant ($p < 0.01$) as shown by one way ANOVA (Table 3.4). Maize is one of the crops that demands available nitrogen in large quantities (Jones, 2003). Variation in maize yield, therefore, may be partly attributed to differences in the application of nitrogen containing fertilizers such as urea, and variation in making use of nitrogen fixing crops, such as legumes for soil fertility management. Maize is one of the major staple crops grown in the study catchment. The high maize yield-gap observed among the three wealth groups, therefore, suggests that the declining per capita farmland size and livestock number are the major challenges of ensuring sustainable soil fertility management and sustainable livelihood in the study watershed.

The yield-gap between poor and medium and poor and rich households were 2.8 and 5.1 quintals, respectively, for sorghum (Table 3.4). This variation was statistically significant ($p < 0.05$). No significant variation was observed for finger millet. The yield-gaps for millet were 0.4, 1 and 1.5 quintals between the poor and medium, the medium and rich, and the poor and rich households, respectively.

The average yield for barley varied from 8.2 qt/ha for the poor to 11.4 qt/ha for the rich households. This means that barley yield was smaller by 3.2 qt/ha for the poor households as compared to that of the rich ones, and this difference was statistically significant ($p < 0.05$; Table 3.4).

Table 3.5. Multiple comparisons of farmers' resource endowment, soil fertility management practices, soil properties and crop yield for the statistically significant variables

Variables	Resource endowment status	*p*
FLS	poor vs. medium	0.000**
	medium vs. rich	0.000**
	poor vs. rich	0.000**
LS	medium vs. rich	0.000**
	poor vs. rich	0.000**
FLSWCFA	poor vs. medium	0.000**
	medium vs. rich	0.000**
	poor vs. rich	0.000**
FLSWOFA	poor vs. medium	0.000**
	medium vs. rich	0.001**
	poor vs. rich	0.000**
FLSWCR	poor vs. medium	0.000**
	medium vs. rich	0.000**
	poor vs. rich	0.000**
	medium vs. rich	0.000**
	poor vs. rich	0.000**
OMC	poor vs. rich	0.050*
CYPH	poor vs. medium	0.001**
	medium vs. rich	0.005**
	poor vs. rich	0.000**

*Note: ** ($p < 0.01$), *($p < 0.05$).*

Following variation in maize, sorghum and barley yields, the average yield per unit of land was significantly different between the wealth categories ($p < 0.01$). The average yield-gaps between the poor and the rich, the poor and the medium and the medium and the rich households were 5.2, 1.9 and 3.4 quintal/ha, respectively. This difference was mainly attributed to differences in farmers' resource endowment (land size and livestock number) that directly or indirectly influence use of different soil fertility management techniques and then soil nutrient content.

Farmers' resource endowment and the nexus to soil fertility management, soil properties and crop yield performance

Applications of chemical fertilizer, organic fertilizer, and use of soil bunds and crop rotations were influenced by farmers' resource endowment (Table 3.2). The influence of farmers' resource endowment was reflected on soil organic matter content (Table 3.3), and on selected crop yields (Table 3.4). Farmland size and livestock number were the major proxy variables that indicate farmers' resource endowment in the study catchment (Table 3.1). The magnitude of the associations of these proxy variables with soil fertility management, soil nutrient content and crop yield was evaluated using a multiple regression model (Table 3.7).

Resource endowment and the nexus to soil fertility management

The area of farmland amended by chemical fertilizer application significantly and positively ($r = 0.5$, $p < 0.01$) correlated with farmland size and livestock number (Table 3.6). The multiple regression model showed that farmland size and livestock number explained about 66% of the variation in farmland area amended by chemical fertilizers. For each unit increase in farmland size and livestock number, the area of farmland amended by chemical fertilizers is likely to increase by 0.2 and 0.02 units, respectively (Table 3.7). Farmland size and livestock number are sources of capital for investments required for soil fertility management. Farmers with limited farmland and livestock numbers are also incapable of affording chemical fertilizers. Because poor farmers are likely to be pre-occupied with off-farm and non-farm livelihood strategies to earn a living, they are less concerned with soil fertility management. Therefore, the decreasing per capita farmland size and livestock numbers were the major challenges to soil fertility management in the study catchment.

The farmland area amended by organic fertilizer application positively and significantly associated with farmland size ($r = 0.5$, $p < 0.01$) and livestock number ($r = 0.4$, $p < 0.01$) owned by the farmers (Table 3.6). About 33% of variation in farmland area amended by organic fertilizers was explained by variation in farmland size and livestock number (Table 3.7).

Table 3.6. Correlation matrix of farmland and livestock size with soil fertility management, soil properties and crop yield

Variables	FLS	LS	FLSWCFA	FLSWOFA	FLSWSB	FLSWCR	OMC
FLS	1						
LS	0.412**	1					
FLSWCFA	0.494**	0.470**	1				
FLSWOFA	0.527**	0.449**	0.465**	1			
FLSWSB	0.456**	0.223**	0.413**	0.339**	1		
FLSWCR	0.758**	0.503**	0.475**	0.533**	0.458**	1	
OMC	0.676*	0.790**	0.740**	0.727**	0.708**	0.829**	1
CYPH	0.727**	0.467**	0.389**	0.515**	0.356**	0.615**	0.647*

*Note: ** (Significant at $p < 0.01$), * (Significant at $p < 0.05$), FLS (Farmland Size), LS (Livestock Size), FLSWCFA (Farmland Size with Chemical Fertilizer Application), FLSWOFA (Farmland Size with Organic Fertilizer Application), FLSWSB (Farmland Size with Soil Bund), FLSWCR (Farmland Size with Crop Rotation), OMC (Organic Matter Content), CYPH (Crop Yield per Hectare).*

For each unit increase in farmland size and livestock number, the area of farmland amended by organic fertilizer application was predicted to increase by 0.1 and 0.04 units, respectively (Table 3.7). The influence of farmland size and livestock number on organic fertilizer supply is intimately interlinked. Farmland size determines the biomass available for livestock feed, and livestock are the medium through which these biomasses are converted to manure. Farmland size also influences the volume of biomasses available for compost production. Hence, farmland size and livestock number positively and significantly influenced the area of farmland amended by organic fertilizer application.

Stone terraces were not common in the study catchment. Leveled soil bunds, which cannot hold excessive water and sediment resulting from high rainfall and dissected topography of the region, were also rarely seen. Graded soil bunds, which are inclined against the contour so that excessive runoff is drained to adjoining natural or artificial waterways, was the major structural soil conservation measure in the watershed. The size of farmland protected from erosion by using soil bunds significantly and positively (*r* = 0.5, *p* < 0.01) associated with the size of farmland held by the farmers (Table 3.6). Farmland and livestock size explained about 20% of the variation in the size of farmlands protected from erosion by using soil bunds as shown by multiple regression model. Each unit increase in farmland size and livestock number is likely to increase the area of farmland protected from erosion by 0.1 and 0.04 units, respectively (Table 3.7). Because households owning a large farm also tended to have a large number of livestock, a positive association was observed between livestock number and the area of farmland protected from erosion by soil bund construction (Table 3.6). Soil bunds take some parts of farmland out of production. Its construction also requires huge labor. Therefore, the size of farmland protected from erosion by soil bund construction was positively influenced by farmers' resource endowment.

Farmland area covered by crop rotation was strongly (*r* = 0.8, *p* < 0.01) influenced by the size of farmland owned by the farmers (Table 3.6). About 63% the variability in farmland size put under crop rotation was attributed to the variation in farmland size and livestock number (Table 3.7). The regression model indicated that the larger the size of farmland and number of livestock owned, the higher the likelihood of keeping more farmland under crop rotation. However, increasing pressure on agricultural land, land use competition between annual and perennial crops, high susceptibility of certain crop varieties to wildlife damage and farmers' preferences for certain crop varieties were the major factors threatening crop rotation practices in the study catchment as indicated by the key informants.

Resource endowment and the nexus to soil properties

Organic matter content significantly varied across farmlands owned by the three wealth groups (Table 3.3). Soil organic matter content significantly and positively correlated with the size of farmland managed through chemical fertilizer, organic fertilizer, crop rotation and soil bunds (Table 3.6). A strong positive correlation (*r* = 0.8, *p* < 0.01) was also observed between livestock size and organic matter content of the soil. About 61% of the variability in organic matter content was attributed to variation in farmland and livestock size as shown by multiple regression models (Table 3.7).

Table 3.7. Multiple regression model outputs showing association of farmers’ resource endowment with soil fertility management, soil nutrient content and crop yield performance

Variables	Unst. B	SE	Std. B	t	*p*
Constant	-0.035	0.016		-2.258	0.026*
Farmland size	0.203	0.015	0.762	13.921	0.000**
Livestock size	0.019	0.009	0.119	2.116	0.032*
Dependent variable FLSWCFA					
R = 0.818, R square = 0.669, Adjusted R^2 *= 0.664*					
Constant	0.042	0.019		2.281	0.024*
Farmland size	0.092	0.017	0.412	5.341	0.000**
Livestock size	0.037	0.010	0.279	3.618	0.000**
Dependent variable FLSWOFA					
R = 0.585, R square = 0.343, Adjusted R^2 *= 0.333*					
Constant	0.002	0.014		0.145	0.885
Farmland size	0.068	0.013	0.439	5.184	0.000**
Livestock size	0.004	0.008	0.042	0.499	0.618
Dependent variable FLSWSB					
R = 0.458, R square = 0.210, Adjusted R^2 *= 0.198*					
Constant	-0.040	0.019		-2.094	0.038*
Farmland size	0.222	0.018	0.715	12.448	0.000**
Livestock size	0.030	0.011	0.164	2.855	0.005**
Dependent variable FLSWCR					
R = 0.797, R square = 0.635, Adjusted R^2 *= 0.630*					
Constant	1.758	0.341		5.153	0.001**
Farmland size	0.300	0.240	0.301	1.246	0.244
Livestock size	0.240	0.139	0.6032	2.501	0.034*
Dependent variable OMC					
R = 0.825, R square = 0.680, Adjusted R^2 *= 0.609*					
Constant	4.573	0.687		6.654	0.000**
Farmland size	6.364	0.626	0.642	10.161	0.000**
Livestock size	1.226	0.366	0.212	3.348	0.001**
Dependent variable AYPH					
R = 0.752, R square = 0.566, Adjusted R^2 *= 0.559*					

*Note: ** (Significant at* $p < 0.01$*), *(Significant at* $p < 0.05$*), FLS (Farmland Size), LS (Livestock Size), FLSWCFA (Farmland Size with Chemical Fertilizer Application), FLSWOFA (Farmland Size with Organic Fertilizer Application), FLSWSB (Farmland Size with Soil Bund), FLSWCR (Farmland Size with Crop Rotation)), OMC (Organic Matter Content), CYPH (Crop Yield per Hectare).*

This intimate association of farmland and livestock size with organic matter content indicates that soil fertility status is facing severe challenges due to the decreasing per capita farmland size and livestock numbers. Higher soil nutrient content was also observed by Tilahun and Mulugeta (2005) in farmlands owned by the wealthy farmers than in farmlands owned by the poor farmers.

Resource endowment and the nexus to crop yield performance

The combined effect of variation in farmers' resource endowment, soil fertility management practices and soil nutrient content was reflected in crop yield performance. The average crop yield was significantly and positively influenced by farmland size ($r = 0.7$, $p < 0.01$) and livestock number ($r = 0.5$, $p < 0.01$). Crop yield was also positively and significantly influenced by the size of farmland managed through chemical fertilizer, organic fertilizer, crop rotation and soil bunds (Table 3.6). Consequently, farmland and livestock size explained about 56% of the variability in average crop yield harvested per unit of land. For each unit decrease of farmland and livestock size, the average crop yield was predicted to decrease by 6.4 and 4.6 units, respectively (Table 3.7).

In summary, soil fertility management, soil nutrient content and agricultural yield performance varied due to differences in farmers' resource endowment. In the absence of pro-poor soil fertility management intervention, this variation inevitably results in widening of wealth differences that ultimately aggravates soil fertility decline, and forces the poor farmers to become both the agents and victims of soil degradation.

Conclusions and policy implications

The link between farmers' resource endowment and soil fertility management has been controversial. Although most studies conducted on farmers' resource endowment and the nexus to soil fertility management underline that resource-poor farmers are the proximate cause of soil degradation (Headey et al., 2013; Hoffmann, 2002; Tilahun & Mulugeta, 2005), some authors argue the other way round (Gray, 2005; Moseley, 2005). These studies remained not only crude generalization of causal relationship between poverty and soil degradation, but also not adequately integrated with the economic and physical aspect of soil for the better understanding of the interactions existing between farmers' resource endowment and soil fertility management. Hence, this study aimed to integrate farmers' resource endowment, soil fertility management practices, soil nutrient content and crop yield performance to examine the nexus between farmers' resource endowment and soil fertility management.

The study indicated that application of chemical fertilizer, organic fertilizer, soil bunds and crop rotation were significantly influenced by farmers' resource endowment (farmland and livestock size), where poor farmers were at the lowest stage in the application of these techniques. The synergistic effect of variation in the application of these techniques reflected on soil nutrient content across farmlands owned by the three wealth groups. Farmland size and livestock number explained 61% of the variability in organic matter content of the soil. A unit decrease in farmland size was predicted to decrease soil organic matter content by 0.3 units. The combined effect of variation in farmers' resource endowment, soil fertility management practice and soil nutrient content reflected on the yields of the staple crops grown in the study catchment. Farmland size and livestock number explained 56% of the variability in crop yield harvested per unit of land; and for one unit decrease of farmland size and livestock number, the average crop yield was predicted to decrease by 6.4 and 4.6 units, respectively. About 5.2 quintals per hectare average yield gap was observed between the rich and the poor farmers. In the absence of pro-poor soil fertility management interventions, therefore, this variation inevitably results in widening of wealth differences that ultimately aggravates soil fertility decline, and forces the poor farmers to become both the agents and victims of soil degradation.

Therefore, pro-poor approach of natural resource management needs to be a top environmental policy priority, and the poor farmers need to be emphatically focused in soil fertility management planning. Rural poverty, informal land market, climatic fluctuation, and the volatile international coffee markets were the major factors driving farmland inequalities across the study population. Provision of credit services without tightened pre-conditions can tackle the problem of land market which is always heightened during poor coffee yield and/or prices. Subsidizing chemical fertilizers and working towards assuring fair international coffee markets can be one of the possible ways of promoting sustainable soil fertility management. Promotion of off-farm and non-farm livelihood strategies can alleviate the pressure on agricultural lands so that the poor farmers get access to farmland through share cropping agreement. Changing or modifying the land use strategies to land saving agricultural practices, such as improved coffee-based agroforestry can assure sustainable soil fertility management and sustainable livelihood in the study catchment.

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Chapter 4

Determinants of Integrated Soil Fertility Management Adoption under Annual Cropping System in Arsamma Watershed, Southwestern Ethiopian Highlands

Abstract

Ethiopia faces a complex set of soil fertility problems requiring approaches going beyond the application of chemical fertilizers. The physical structure oriented soil conservation strategy could not adequately address the problem of soil fertility deterioration. The attempts of promoting Integrated Soil Fertility Management (ISFM) strategies have been at in an early stage and limited in implementation and wider dissemination. This study was conducted to identify determinants of ISFM adoption under annual cropping systems in Arsamma Watershed, Southwestern Ethiopian Highlands. The data used for the study were collected from 136 sample respondents who were randomly selected by employing a two-stage random sampling technique. Binary logistic regression models were used to characterize factors driving adoption of ISFM. Findings show that farmland size, farmer training, participation in agricultural extension programs, years of chemical fertilizer application to farmland and perception of farmers toward continuous use of mono-chemical fertilizers were the statistically significant predictors of ISFM adoption. Improving the productivity of the limited farmland, designing pro-poor approaches, provision of action-based farmer training, targeting agricultural extension programs and raising awareness of farmers about negative impacts of mono-chemical fertilizer technology are key areas of intervention to enhance adoption of ISFM in the study catchment.

Key words: soil fertility management; chemical fertilizer; soil acidity

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Introduction

Though sustainable management of soil resources is an issue of national and international policy priority for Sub-Saharan Africa, decline in soil fertility has remained one of the most important factors explaining the significant gap observed between potential and actual food production in the region (Scoones, 2001; Swift & Shepherd, 2007). More than two-thirds of the global population growth by 2050 is expected to come from this region despite the prevailing food gap (FAO, 2007). In order to narrow this gap, significant efforts and strategies have been made to introduce different soil fertility management technologies to smallholder farmers in various countries of Africa (Sanginga & Woomer, 2009).

However, long practiced soil conservation methods, such as soil and stone bunds, tied ridges, check dams, grass strips and afforestation programs, could not adequately address the problem (Aklilu, 2006; Anley et al., 2007; Nyssen et al., 2000; Tenge et al., 2004). Hence, soil fertility management through chemical fertilizers has remained one of the prioritized and widely promoted strategies in this region. However, various indicators show that strong dependence on mineral fertilizer technology alone failed to alleviate the problem of soil fertility decline, mainly due to unavailability of sufficient and appropriate mineral fertilizers, rising costs of mineral fertilizers, and little yield response of depleted soils to mineral fertilizers (Fairhurst, 2012; Sanginga & Woomer, 2009).

Chemical fertilizers are also associated with unforeseen problems. For instance, urea ($CO(NH_2)_2$), ammonium sulfate ($(NH_4)2SO_4$), and diammonium phosphate (DAP) have a strong soil acidifying effects (Daniel et al., 2009). If these fertilizers are applied to acidic soils (pH less than 5.5), about 100 kg of calcium carbonate ($CaCO_3$) is required, respectively, for 79, 74 and 110 kg of urea, ammonium sulfate, and diammonium phosphate to neutralize their acidifying effect (Hatfield et al., 2004). An experiment conducted for 30 years showed that the lowering of soil pH from 5.6 to 4.8 resulted in impoverishment of soil microorganisms and loosening of symbiotic interactions existing between nitrogen fixing soil microorganisms and plant roots (Barak et al., 1997). Mitigation of soil acidity is a challenging and costly problem which takes up to 25 years in silt loam and up to 78 years in clay loam soils to increase soil pH value by one unit (Hatfield et al., 2004). In the absence of locally available organic amendments, soil erosion control measures and improved crop management practices, even recommended dose of chemical fertilizer application give poor yield response due to the constraints of soil acidity (Fairhurst, 2012).

The problem of soil acidity is exacerbated in tropical highlands due to complete removal of crop residues from the farm, washing away of basic cations due to high rainfall, rapid mineralization resulting from high temperature and microbial activities, and washing away of organic matter as a result of accelerated soil erosion (Scholl & Nieuwenhuis, 2004). In order to overcome the problem induced by exclusive dependence on chemical fertilizers, a growing consensus has been made toward the promotion, dissemination and proper implementation of Integrated Soil Fertility Management (ISFM) technologies (Fairhurst, 2012; Kanyama-Phiri et al., 2000).

Development of ISFM is believed to be a result of a series of transitions in soil fertility management paradigms since 1960s. The period of 1960s and 1970s is considered to be the period of external input paradigm. During this period, chemical fertilizers and lime were the major recommended external inputs for soil fertility management (Sanginga & Woomer, 2009). Due to the shortage of supply, problem of lack of infrastructure, and low adoption by farmers, little success was achieved from this approach in Sub-Saharan African countries (IFPRI, 2010). In the 1980s, practices were shifted to an organic approach, in which organic fertilizers were considered as a major entry point for soil fertility management (Vanlauwe, 2004). Yet, little progress was made due to the scarcity of organic resources and extensive land and labor needs of organic fertilizer preparation (Vanlauwe et al., 2010). Exclusive application of organic fertilizers to farmland also could not release adequate soluble nutrients to plants (Bationo et al., 2004). This necessitated a search for an approach that occupies a middle ground between the organic and inorganic approaches of soil fertility management (Killham, 2010). Consequently, practices shifted to the ISFM paradigm, which has been ongoing since the mid of 1990s (Vanlauwe et al., 2010).

ISFM is very broad soil fertility management concept that integrates chemical, biological (Vanlauwe, 2004) structural soil and water management (Sanginga & Woomer, 2009), and improved crop management practices with local adaptation (Killham, 2010; Vanlauwe et al., 2014). It enables best use of inherent soil nutrient stocks, agro-minerals, locally available organic resources with mineral fertilizers to increase soil fertility and productivity (Fairhurst, 2012). Within this broad concept, chemical fertilizers, organic fertilizers and improved crop management are considered to be the basic components of ISFM (Vanlauwe et al., 2010). In this study, ISFM refers to the application of chemical fertilizer, organic fertilizer and improved seed on the same plot of land during the same cropping season.

To be widely adopted, soil fertility management technologies need to have benefits that attract farmers. The advantages of ISFM, among others include economic benefits that improve agricultural productivity, agronomic benefits that improve soil productivity, environmental benefits that protect soil and make agriculture more sustainable, and social benefits that enable division of labor for soil fertility management (Agegnehu et al., 2014; Bationo et al., 2012; Farouque & Takeya, 2007; Mutegi & Zingore, 2014; Ugboh & Ulebor, 2011; Vanlauwe et al., 2014). Empirical evidence indicates the high potential of ISFM for improving soil and agricultural productivity in Sub-Saharan African countries. Integration of mineral fertilizers, animal manure and crop residues with leguminous crop rotation increased millet yield by 1400 kg/ha as compared to farm plots treated with crop residues and animal manure in Niger (Bationo et al., 2012). In Nigeria, a combination of chemical fertilizers with leguminous crop rotation improved maize yield by 365 kg/ha as compared to natural fallow practices (Carsky et al., 1999). Combinations of improved seeds, chemical fertilizers and crop rotation increased soybean yield by 100% in Uganda (Mutegi & Zingore, 2014). Integration of chemical fertilizers with animal manure and compost increased wheat yield by 151% in the Ethiopian Highlands (Agegnehu et al., 2014). Therefore, scaling up of ISFM adoption is considered to be one of the pathways of narrowing the gap between potential and observed agricultural yields in Sub-Saharan African countries (Sanginga, 2012). On top of this, its eco-friendly, cost-effectiveness, and adaptability to diverse biophysical and socioeconomic conditions of a region have been widely acknowledged (Bationo et al., 2006).

ISFM is not totally free of constraints. Farmers with limited livestock, farm equipment, labor, and farmland are less likely to use ISFM technologies (Kato et al., 2011). As a result, ISFM can be considered as a pro-rich approach of soil fertility management. Some ISFM technologies also have achieved limited success due to the difficulty of matching technologies developed at plot level research center to the complex biophysical and socioeconomic variability that characterize smallholder farms in the tropics (Giller et al., 2006). Therefore, recommending transfer of ISFM technologies from the research center to specific farmland is associated with huge data requirements and complex research activities (Vanlauwe et al., 2014).

Integrated soil fertility management shares many common features with conservation agriculture (CA), which is considered as the mainstay of addressing the problem of soil degradation, poor agricultural performance and climatic variability (Giller et al., 2009; Kassam et al., 2009). Of course, conservation agriculture is concerned with broader environmental management issues than that of ISFM; and it prioritizes minimum or no soil tillage, permanent organic soil cover and diversified crop associations and rotations (FAO, 2012; Thierfelder et al., 2015). Yet, fertilizer micro-dosing, surface mulching, efficient organic fertilizers management, crop-livestock integration, water harvesting and addressing the problem of soil nutrient depletion are common specific features of CA and ISFM (Fairhurst, 2012; Vanlauwe et al., 2014). Similar to CA, ISFM can promote carbon sinks and can mitigate global climate change by increasing biomass production and organic soil cover (Bryan et al., 2013; Zanatta & Salton, 2010). This implies that ISFM can establish a firm foundation for CA, and can potentially support greenhouse gas mitigation and small-scale farmers' adaptation to climate changes (Milder et al., 2011; Sanginga & Woomer, 2009). Therefore, scaling up of ISFM can establish a foothold for the carbon-free and climate resilient green economy, which is being considered to be one of the environmental policy priorities of Ethiopia (EPA, 2011).

Ethiopia has made various efforts to improve soil fertility, agricultural production and productivity under the framework of national economic development strategy of the country known as Agriculture Development Led Industrialization (ADLI) (Kassa, 2003; Mulat et al., 1998). The Participatory Demonstration and Training Extension System (PADETS) program from 1993 to 1999 and the National Agricultural Extension Intervention (NAEI) Program from 1995 to present day have been the major examples (Spielman et al., 2011). The key objectives of these programs were improving chemical fertilizer supply and extension services to smallholder farmers and then promoting agricultural production and productivity with particular emphasis on cereal crop production (Kassa, 2003). Chemical fertilizers and improved seeds have been the key entry points for soil nutrient management and agricultural yield improvement in those programs. Consequently, the total fertilizer consumption at country level grew from 250,000 tons in 1995 (Spielman et al., 2011) to 710,464.5 tons in 2013 (CSA, 2014).

Despite such a rise in fertilizer consumption, the country faces wide sets of complex soil fertility problems that need strategies going beyond the application of chemical fertilizers (Betru, 2002). It was indicated that the focus on chemical fertilizer alone increased grain yield only by 10% despite a five times growth in fertilizer application since the 1980s (IFPRI, 2010). Spielman et al. (2011) calculated chemical fertilizer to economic yield cost ratio from 1992 to 2008, to estimate the profitability of chemical fertilizer application to farmland in Ethiopia. Taking an economic yield to chemical fertilizer cost ratio threshold value of 2, beyond which application of chemical fertilizers is assumed to be profitable, the average value declined from 3.74 to 1.91 for *teff*[1] and from 4.24 to 2.18 for maize from 1992 to 2008 across the country. The study also showed that the value declined from 3.84 to 1.83 for maize in the Wellega and Keffa regions (parts of Southwestern Ethiopian Highlands). This indicates that soil fertility management and ensuring food security through sole dependence on mono-chemical fertilizer technology faces severe challenges across the country in general and in areas of soil acidity problem in particular. The physical structure oriented soil and water conservation strategy, which has been weakly integrated with other soil enrichment practices, also could not adequately address the problem of soil fertility decline and agricultural yield stagnation in the country (Betru, 2002; Gerishu & Mvena, 2011). This evidence suggests that ISFM is a more feasible option for sustainable soil fertility management that could provide a more holistic, lower cost, and more sustainable solution to the complex socioeconomic and biophysical problems of the country. However, attempts to scale up best agricultural practices of the model farmers and promotion of ISFM as part of NAEIP in various parts of Ethiopia has not only been sluggish, but also lacks proper implementation and wider dissemination (IFPRI, 2010). This suggests the need for a study on factors influencing adoption and scaling up of sustainable soil fertility management practices in the country.

The various soil fertility management technologies developed so far and introduced to smallholder farmers have been found to be influenced by complex sets of demographic, socioeconomic, institutional, and biophysical factors. Berhanu et al. (2003) and Gerishu and Mvena (2011) observed that adoption of soil bunds and stone terraces was influenced by demographic variables, such as age, sex and family size of households. Akinbile and Odebode (2007) noted that multiple cropping, use of cover crops and planting of multipurpose tree species for soil fertility management were influenced by socioeconomic factors, including off-farm income, land and livestock sizes. Farm characteristics, such as slope and home-farmland distance were also found to influence adoption of soil bunds and *fanyajuu*[2] (Anley et al., 2007). Atakilt (2003) indicated the potential influence of land tenure systems, top-down or bottom-up approaches of natural resource management, access to agricultural extension and credit services on land management practices of smallholder farmers. Moreover, an approach that uses a "silver bullet response that assumes one size-fits-all," and neglects adaptability to local conditions has remained the major institutional bottleneck affecting wider dissemination of sustainable soil fertility management practices in many developing countries (Fairhurst, 2012). Factors influencing adoption of ISFM cannot be exceptional to those factors influencing other soil fertility management practices. However, very little research has been conducted on ISFM adoption as compared to studies conducted on other soil fertility management technologies (Sanginga & Woomer, 2009). Thus, this paper contributes to the growing literature on ISFM, including among others, Kanyama-Phiri et al. (2000), Akinbile and Odebode (2007), Daniel et al. (2009), Giller et al. (2009), Sanginga and Woomer (2009), Killham (2010), Bationo et al. (2012), Agegnehu et al. (2014), Mutegi and Zingore (2014) and Vanlauwe et al. (2014).

The study contributes in at least four aspects to the existing literature. First, the study evaluates factors driving adoption of ISFM by integrating variables related to demographic, socioeconomic, institutional and farm characteristics at catchment level, which is also regionally representative. It is argued that broad generalization and inference from a variety of studies conducted elsewhere to the specific spatial context is ambiguous due to the complexity of agro-ecological and socioeconomic conditions of a given region (Anley et al., 2007). Furthermore, ISFM is locally coined and adaptive to diverse local conditions (Fairhurst, 2012). This means that studies on ISFM yield actionable findings within the biophysical and socioeconomic context under which a given ISFM technology is practiced. Secondly, combinations of descriptive and inferential statistics, and regression models were used to evaluate factors driving adoption of ISFM while most of the studies made on ISFM are either experimental or descriptive in nature. Thirdly, ISFM technology has only recently been introduced to Ethiopia. As a result, our knowledge of factors influencing adoption of ISFM is very limited. Lastly, there is a general paradigm shift towards the ISFM approach (Vanlauwe et al., 2014) and a growing policy interest to enhance wider adoption and scaling up of sustainable land management and productivity enhancing practices in many Sub-Saharan African countries (Asfaw et al., 2014). As a result, the study also contributes to policies to promote wider adoption, adaptation and scaling up of sustainable soil management practices. Therefore, this study was conducted to identify determinants of ISFM adoption under annual cropping system in Arsamma Watershed, Southwestern Ethiopian Highlands.

Both annual and perennial crops are grown in the study catchment. Application of ISFM on perennial cropland was unusual as chemical fertilizer, which is an entry point for ISFM adoption, was rarely applied to the perennial cropland. Therefore, the scope of this study was delimited to annual cropping system. The data used for the study were collected from 136 randomly selected farm households; and binary logistic regression models were used to identify factors driving adoption of ISFM in the study area. The rest of this paper deals with background of the study area, methodological approaches used in the study, and the results and discussions sections. Lastly, the paper presents conclusion and policy implication of the study.

Arsamma watershed: the study area

This study was conducted in Arsamma Watershed of the Southwestern Ethiopian Highlands. The watershed is located in the West Wellega Administrative Zone of Oromia National Regional State (Figure 3.1). It covers a total area of 115.4 km^2. Geographically the area lies between 9°05’-9°12’ E, and 35°40’-35°50’ N; and it is situated at about 475 km West of Addis Ababa. The watershed shares similar geographic features with the Southwestern Ethiopian Highlands. This makes possible spatial conceptualization of the catchment within the framework of the broad Southwestern Ethiopian Highland region.

The Southwestern Ethiopian Highland is a result of the combined effect of tertiary volcanic and advanced erosion accompanied by the heavy precipitation of the region. Its altitude gradually decreases from an elevation of above 2000 m in the eastern part to less than 1000 m toward the Sudanese border and northwards toward the Benishangul Gumuz lowlands (PPDO, 1997).

Having most of its surface lying between 1500 and 2000 m above sea level (msl), a variety of landforms including rugged mountains, deep gorges, flat and narrow topped plateaus are the major topographic features in the West Wellega Zone (CRSO, 2000; CSA, 2011). The central part of the zone is made up of undulating landscapes broken by mountain ranges, and the southern and southwestern parts are dissected by tributaries of the Baro River (PPDO, 1997).

The Southwestern Ethiopian Highlands (including the West Wellega Zone) fall under the influence of equatorial westerly winds that blow from the Atlantic Ocean and Gulf of Guinea to most parts of Central Africa and into the low pressure areas of Inter Tropical Convergence Zone (Danial, 1977). The dominant climate in the region is humid warm-temperate, having distinct dry months in winter and a long rainy season in summer (EMA, 1988). The mean monthly temperature ranges from 16-20°C (IFPRI & CSA, 2010). Heavy mean annual rainfall that surpasses 2000 mm is very frequent. As a result, average yearly annual runoff exceeding 600 cm^3 per hectare is very common (Daniel, 1977). This heavy and erratic rainfall, which is also accompanied by high topographic dissection and population pressure, is the major threat to the highly fragile soil resources of the region (Wood, 1993).

The West Wellega Zone is endowed with agro-minerals. Phosphate rock, which could potentially be used as an input for ISFM, was discovered in Bikilal area of West Wellega zone (Assefa, 1991). Bikilal is situated at about 40 km east of the study catchment.

Methodology

A cross-sectional survey research design was employed to gather information related to demographic, socioeconomic, institutional, and farm characteristics. A two-stage random sampling technique was employed to select the sampled farmers. First, two *kebele*[3] administrations were selected from six *kebeles* that the catchment fully encloses. Then, four rural villages (two each from the two *kebeles*) were randomly selected. The households in the four villages were registered and found to be 450 household units. From this population, we tried to estimate the sample size using CRS (2012) approach. Sample size estimation following this approach yielded very high sample size of 206 household units (46%) of the study population. Then we followed a "rule of thumb" for sample size determination for binary logistic regression modeling, i.e. 10 cases for each predictor variable (Stack Exchange Inc., 2013). Since 13 predictor variables were considered to model factors driving adoption of ISFM, 136 samples (13 predictors * 10 respondents) + 6) were selected. The plus six respondents were considered to meet this threshold requirement in case that non-response or dropout may occur. Accordingly, a total of 136 households (30.2%) of the study population were randomly and proportionally sampled from the four villages. The data used for the study were generated through a semi-structured questionnaires administrated to the sampled respondents through face to face interviews, conducted from January to February 2013.

Descriptive statistics (mean, percentage and cross-tabs), Pearson's correlation, chi-square test of independence, independent t-test and binary logistic regression modelling were used to analyze the data. The descriptive statistics were used to establish a base for the other tests.

Pearson’s correlation was used to assess the pattern of association existing between the response and explanatory variables. It was also used to test the presence or absence of multicollinearity problems among the explanatory variables. The chi-square test of independence and the independent t-test were used to evaluate whether there is a significant difference between adopters and non-adopters in terms of the variables explaining adoption of ISFM, or not. Finally, binary regression modelling, which is also discussed below in detail, was used to produce an explanatory model of factors driving adoption of ISFM in the study area (Landau & Everitt, 2004). In running the regression model, a forward conditional method was used to prioritize variables having strong explanatory power on the response variable. All the data were computed using SPSS (Statistical Package for Social Sciences) version 20.

Variables and model specification

Integrated Soil Fertility Management is a broad concept, but application of chemical and organic fertilizers with improved crop management practice is mostly considered as a necessity rather than an option (Vanlauwe et al., 2010). The criteria for classifying farmers as adopters or non-adopters of ISFM were set based on this minimum requirement, and discussions held with development agents working in the study area. Hence, adoption of ISFM is loosely defined from the local context. A farmer was considered as an adopter of ISFM if he/she has ever applied chemical fertilizer, organic fertilizer, and improved seed with or without measures of erosion control and improved crop management practices on the same plot of land during the same cropping season. If not, he/she was considered as a non-adopter. The inorganic fertilizers referred to were application of DAP (diammonium phosphate) and/or urea (ammonium nitrate) which were the two types of chemical fertilizers commonly applied to farmland in the study catchment. The organic fertilizers considered were application of at least one of animal manure, compost or farmyard manure.

Table 4.1. Description of response variable (adoption of ISFM) and the explanatory variables

Variables specified in the model	Variable's definition	EDI (-/+)
Y_{ISFM} (Integrated Soil Fertility Management)	ISFM is a binary response variable. It was assigned a value of '1', if a farmer has ever practiced ISFM and '0', if not	
X_1=GENHH (Gender of a Household Head)	GENHH was assigned a value of '1', if a household is male headed and '0', if female headed. It is generally recognized that males have better access to socioeconomic opportunities than females	+
X_2 =AGHH (Age of a Household Head)	AGHH was given in year. While age can be considered as an archive of history through which individuals gain knowledge and experience (Maser 2011), a person may lose ability and energy to get involved in ISFM adoption as he/she gets older and older	-/+
X_3=EDUCLHH (Education Level of a Household Head)	EDUCLHH was measured in grade level attained. Education can play a fundamental role in introducing and familiarizing smallholder farmers with improved agricultural technologies	+
X_4=TOTFS (Total Farm Size)	TOTFS was measured in hectare. The amount of farm size owned is an indicator of wealth and source of capital for soil fertility management	+
X_5=OFFARE (Off-farm Income)	OFFARE provides a farmer with more resources to adopt ISFM. It was assigned a value of '1' if a farmer had access to off-farm income and '0', if not	+
X_6=FTR (Farmer Training)	FTR was assigned a value of '1', if a farmer has ever been trained on improved agricultural practices and '0', if not. Training is one of the major ways through which farmers acquire knowledge of improved agricultural technologies	+
X_7=AEALHH (Adult Equivalent Agricultural Labor of a Household Head)	AEALHH was measured in terms of average adult labor actively participated in agricultural activities per day, based on the respondents estimate. Rather than measuring household size as an indicator of labor potential, since some family members may be engaged in non-farm activities like schooling and petty trading, AEALHH could be a better estimate	+
X_8= PAGEX (Participation in Agricultural Extension)	PAGEX refers to making use of chemical fertilizer and improved seeds. It was coded '1', if a farmer was participating in agricultural extension program and '0', if not	+
X_9=LIVS (Livestock Size)	Livestock are sources of manure, cash and labor all of which are invaluable for soil fertility management. It was measured in TLU (Tropical Livestock Unit). One TLU is equivalent to 250 kg living weight, which was estimated to be equal to 1.5 cattle, 10 sheep, 12 goats, 2 donkeys, 1 horse or 0.8 camels (Sys et al., 1991)	+
X_{10}=PTCMCHFA (Perception Toward Continuous use of Mono-Chemical Fertilizer)	PTCMCHFA was assigned a value of '1', if a farmer perceived negative impact of mono-chemical fertilizer technology, and '0'if not. Farmers who perceived negative impact of mono-chemical fertilizer technology are likely to adopt ISFM	+
X_{11}=YCHFERAP (Years of Chemical Fertilizer Application)	YCHFERAP was measured in year. Those households made use of chemical fertilizers for a longer period of time more perceive its negative impact than households made use of it for a shorter duration	+
X_{12}=AVFARDIS (Average Farm Distance)	AVFARDIS was measured in minutes taken by human walk. Home-farmland distance negatively influences degree of interactions existing between farmers and farmlands	-
X_{13}=NFPLT (Number of Farm Plots)	NFPLT is an indicator of farm fragmentation, or large farmland size owned. Hence, it may positively or negatively influences adoption of ISFM	-/+

Note: EDI refers to expected direction of influence.

Measures of erosion control referred to the use of structural soil and water conservation measures, such as soil bunds, grass strips and diversion of water ways. Improved crop management implied to pest and weed protection. Neither the total volume of fertilizer applied nor the total farmland area fertilized is the concern of this study; the likelihood of the occurrence of the event (adoption of ISFM) was the key consideration.

A set of qualitative and quantitative variables were used to model factors driving adoption of ISFM. The response variable was a binary variable which was assigned a value of '1**'**, if a farmer has ever used chemical fertilizer, organic fertilizer and improved seed with or without measures of soil conservation and improved crop management practices. A value of '0' was assigned if a farmer has never applied at least combination of chemical and organic fertilizer with improved seed on the same plot of land during the same cropping season, prior to the data collection period of this study.

Thirteen explanatory variables (Table 4.1), of which five of them were picked by the regression model (forward entry method), were considered for this study. Binary logistic regression is widely applied because of its flexibility and wider accommodation of different variables having different characteristics (Landau & Everit, 2004). Following Chattefuee and Hads (2006) approach, the binary logistic regression model for this study was defined as follows.

$$Y_{ISFM} = f\left(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{13} X_{13}\right)$$

where:

Y_{ISFM} : is likelihood of adopting ISFM

$X_1, X_2, \ldots, X_{13}$: are explanatory variables defined in Table 4.1

$\beta_1, \beta_2, \ldots, \beta_{13}$: are estimated regression coefficients/parameters associated with the explanatory variables $(X_1, X_2, \ldots, X_{13})$, respectively.

β_0 : is a constant (random error)

The explanatory variables used in the model were selected based on empirical literature dealing with adoption of various soil fertility management technologies discussed earlier and exploratory survey of factors expected to influence adoption of ISFM in the study catchment. The hypothesized explanatory variables and their direction of association with the response variable are given in Table 4.1.

Retention of an adopted soil fertility management technology is as important as adoption of the technology itself. However, this study was limited to the likelihood of adopting ISFM, because retention of ISFM technology is more important in areas that have longer period of adoption than in the study catchment, where the technology has been recently introduced. Exhaustive testing of numerous predictor variables in the regression model is preferable. However, only 13 predictor variables were tested to model factors driving adoption of ISFM in the study catchment.

Results and discussions: factors influencing adoption of ISFM

Households' demographic factors

Gender and age of the household heads were cross-tabulated against adoption of ISFM. From the 136 sampled households, 75.7% were male headed and 24.3% were female headed. The cross-tabulation of male and female headed households against adoption of ISFM showed that most adopters of ISFM were male headed households (91.4%). The difference in the distribution of adopters and non-adopters by male and female headed households was also statistically significant ($p < 0.05$; Table 4.2).

The mean age of farmers included in the study was 41. 6 years, with a standard deviation (SD) of 9.5. This implies that most of the respondents were at middle stage of adulthood. No significant difference was observed in the mean age of adopters and non-adopters (Table 4.2).

Households' socioeconomic factors

Factors related to households' socioeconomic characteristics including farm size, involvement in off-farm income generating activities, labor and livestock number were cross-tabulated against adoption of ISFM.

The average land holding size of respondents was 0.98 hectare with a SD of 0.64 and a 65.3% coefficient of variation, implying a large spread of farmland areas owned among the study population. The average farm size of adopters of ISFM (1.41 ha) was significantly ($p < 0.01$) higher than that of non-adopters (0.84 ha). Less than one-fifth (19.1%) of respondents were engaged in off-farm income generating activities; and there was no statistically significant difference between adopters and non-adopters engaged in off-farm income generating activities (Table 4.2). Traditional timber production and petty coffee trading were the major off-farm income earning activities in the study area. These activities were mostly practiced by the poor farmers, who owned limited farm size. Farmers engaged in these activities could not raise sufficient income to invest on soil fertility management. They also have little time to follow up on the labor intensive management requirements of ISFM. Hence, involvement of farmers in off-farm income generation activity negatively ($r = -0.1$) correlated with adoption of ISFM (Table 4.3). The average livestock number, which was 0.82 TLU per household, indicates that livestock husbandry was not a major source of livelihood in the study watershed. Livestock are sources of cash, manure and drafting power, all of which are key components of ISFM adoption. Hence, the average livestock size for adopters (1.52 TLU) was significantly ($p < 0.01$) higher than that of non-adopters (0.57 TLU; Table 4.2). The average adult equivalent agricultural labor of households engaged in agricultural activities (AEALHH) was 1.88. The mean AEALHH of adaptors was 1.6 times higher than that of non-adaptors, and the difference was also statistically significant ($p < 0.01$; Table 4.2).

Institutional factors

Institutional variables including farmer training, participation in agricultural extension programs, and level of education were cross-tabulated against adoption of ISFM. Training is one of the ways through which farmers gain knowledge and skills of improved agricultural technologies. In Arsamma watershed, however, less than one-third (32.4%) of the sampled farmers had ever received training on improved agricultural practices. While more than three-fourth (77.1%) of adopters had received training, only 16.8% of non-adopters were trained; and the difference was statistically significant ($p < 0.01$; Table 4.2). Furthermore, less than half (45.6%) of the farm households had ever participated in agricultural extension programs. Of the farmers participating in agricultural extension programs, 85.7% and 14.3% were adopters and non-adopters of ISFM, respectively; and this difference was statistically significant ($p < 0.01$; Table 4.2). This indicates an opportunity for promoting adoption of ISFM by increasing involvement of farmers in agricultural extension and farmer training programs. Moreover, there is an actionable room for all stakeholders concerned with wider adoption and scaling up of ISFM in the study catchment.

The average level of formal education of all respondents was 3.21 years. This showed that farmers' formal schooling did not exceed primary level in the study catchment. The mean education level of adopters (4.9) was significantly higher than that of non-adopters (2.6) ($p < 0.01$; Table 4.2).

Farm characteristics and other farmland related factors

Home-farmland distance, number of farm plots, and number of years chemical fertilizers applied to farmland were cross-tabulated against adoption of ISFM. The average distance between home and farmland for all respondents was 13.1 minutes, and the average home-farmland distance for adopters (10.9 minutes) was significantly shorter than that of non-adopters (13.8 minutes) ($p < 0.05$; Table 4.2). Home-farmland distance was also negatively ($r = -0.2$, $p < 0.05$) associated with adoption of ISFM (Table 4.3). This was due to the negative impact of larger distances on plowing, transportation of organic fertilizers, fertilizer micro-dosing, and closer monitoring of the farmland on which time, income and energy were invested.

Number of farm plots, which is an indicator of farm fragmentation, was 4.7 per farmer with fairly equal distribution ($p = 0.906$) between adopters and non-adopters of ISFM (Table 4.2).

Table 4.2. Cross-tabulation of ISFM adoption against explanatory variables

Binary explanatory variables	Responses	Adopters		Non-adopters		Total				
		No.	%	No.	%	No.	%	X^2	df	*p*
Gender	Male	32	91.4	71	70.3	103	75.7	6. 316	1	0.012*
	Female	3	8.6	30	29.7	33	24.3			
Involvement in off-farm income generating activities	Yes	4	11.4	22	21.8	26	19.1	1.802	1	0.179
	No	31	88.6	79	78.2	110	80.9			
Receiving training on agricultural extension service	Yes	27	77.1	17	16.8	44	32.4	43.200	1	0.000**
	No	8	22.9	84	83.2	92	67.6			
Participation in agricultural extension programs	Yes	30	85.7	32	31.7	62	45.6	30.91	1	0.000**
	No	5	14.3	69	68.3	74	54.4			
Perception of farmers on the impact of continuous mono-chemical fertilizer application	Positive	3	8.6	66	65.3	69	50.7			
	Negative, or neutral	32	91.4	35	34.7	67	49.3	33.521	1	0.000**

Non-binary explanatory variables	Adopters		Non-adopters		Total				
	Mean	SD	Mean	SD	Mean	SD	t	df	*p*
Age of farmers in years	43.74	8.17	40.87	9.78	41.61	9.45	1.557	134	0.122
Education level in year of schooling	4.89	3.76	2.63	3.27	3.21	3.53	3.374	134	0.001**
Farm size in hectare	1.41	0.80	0.84	0.51	0.98	0.64	4.866	134	0.000**
Labor in adult equivalent estimate	2.63	1.11	1.62	0.80	1.88	0.99	5.763	134	0.000**
Home-farmland distance in minutes	10.91	6.13	13.83	6.76	13.08	6.70	-2.252	134	0.026*
Livestock size in TLU	1.52	1.65	0.57	0.66	0.82	1.09	4.803	134	0.000**
Year of chemical fertilizer application	8.66	5.55	1.94	3.15	3.67	4.87	8.786	134	0.000**
Number of farm plots	4.66	2.52	4.71	2.37	4.70	2.40	-0.118	134	0.906

*Note: ** (Significant at $p < 0.01$), * (Significant at $p < 0.05$).*

Farmers' perception and experience of past soil fertility management strategies influence current and future soil fertility management choices and practices of the farmers. About 49.3% of the sampled households perceived that application of mono-chemical fertilizer to farmland has had negative impacts on the characteristics of their soil. On the other hand, 91.4% and 34.7% of adopters and non-adopters, respectively, have had the opinion that mono-chemical fertilizer application has negative impact on the fertility of their soil; and the difference in the percentage frequency distribution of the two groups was statistically significant ($p < 0.01$; Table 4.2).

One of the strategies of soil fertility management in Arsamma watershed was application of chemical fertilizers (DAP and/or urea) to farmland. These fertilizers have strong soil acidifying effect, as discussed earlier. On average, farmers in the watershed applied chemical fertilizers (urea and/or DAP) for 3.67 years. The average year of chemical fertilizer application for adopters (8.7 years) was significantly ($p < 0.01$) greater than that of non-adopters (1.9 years) (Table 4.2).

Factors driving adoption of ISFM practices

Four groups of explanatory variables including demographic, socioeconomic, institutional, and farm characteristics were considered so as to explain factors driving adoption of ISFM in the Arsamma watershed. The correlation matrix of these variables indicated positive and significant association ($p < 0.05$) between adoption of ISFM, and GENHH, TOTFS, AEALHH, EDUCLHH, FTR, PAGEX, LIVS, YCHFERAP and PTCMCHFA (Table 4.3).

The correlation between adoption of ISFM and AVFARDIS was negative and significant ($r = -0.2$; $p < 0.05$). Overall, YCHFERAP and FTR strongly correlated with adoption of ISFM. On the other hand, the correlation between adoption of ISFM and AGHH and NFPLT was not statistically significant. The correlation matrix also indicated that there is no multicollinearity problem since none of the explanatory variables are strongly correlated with each other (Table 4.3). Hence, it is possible to produce an explanatory model of factors driving adoption of ISFM in Arsamma watershed.

Of the 13 variables tested in the binary regression model, farm size, farmer training, participation in agricultural extension, years of chemical fertilizer application to farmland and perception of farmers toward continuous application of mono-chemical fertilizers were found to be the statistically significant factors driving adoption of ISFM.

In agreement with the initial hypothesis, gender was positively associated with adoption of ISFM, implying that male headed households were more likely to practice ISFM than female headed households (Table 4.3). This positive association between the two variables is attributed to better socioeconomic opportunities of male headed households than female headed households. However, gender was not picked by the forward conditional binary regression model as one of the factors driving adoption of ISFM. This is due to the greater weight of other factors in explaining adoption of ISFM than gender. The correlation matrix also showed positive association ($r = 0.1$) between age of farmers and adoption of ISFM. However, the association was not statistically significant ($p = 0.1$; Table 4.3). Age is considered as the archive of history through which individuals gain knowledge and experience of life (Maser, 2011). As a result, the higher the age of the household heads, the greater the likelihood of adopting ISFM.

Level of education positively ($r = 0.3$, $p < 0.01$) associated with adoption of ISFM (Table 4.3). Education can play fundamental roles in introducing and familiarizing smallholder farmers with improved agricultural technologies. As a result, the higher the level of education attained by the farmer, the better the likelihood of adopting ISFM. However, education was not picked by the forward conditional binary regression model as the major factors driving adoption of ISFM. This is due to the greater influence of other factors in predicting adoption of ISFM than the level of education attained by farmers.

Table 4.3. Correlation of explanatory variables with response variable

Variables	ISFM	GENHH	AGHH	EDUCLHH	TOTFS	OFFARE	AEALHH	FTR	AVFARDIS	PAGEX	LIVS	YCHFERAP	PTCMCHFA	NFPLT
ISFM	1													
GENHH	.216**	1												
AGHH	.133	-.022	1											
EDUCLHH	.280**	-.059	-.118	1										
TOTFS	.388**	.054	.163	.248	1									
OFFARE	-.115	-.030	.004	.077	.136	1								
AEALHH	.446**	.159	.091	.141	.339	.037	1							
FTR	.564**	.135	.080	.217	.253	-.176	.354	1						
AVFARDIS	-.191*	.011	.083	.178	.013	.007	.059	.137	1					
PAGEX	.474**	.277	.151	.196	.155	-.070	.424	.171	.054	1				
LIVS	.383**	.138	.188	.127	.412	.059	.218	.232	.000	.385	1			
YCHFERAP	.605**	.127	.080	. 127	.325	-.117	.486	.419	-.110	.445	.135	1		
PTCMCHFA	.496**	.112	.209	.346	.122	.142	.059	.356	-.035	.397	.292	.449	1	
NFPLT	.010	.065	.156	.127	.270	.030	.040	-.038	.180	.103	.186	.111	.087	1

*Note: **(p < 0.01), *(p < 0.05), ISFM (Integrated Soil Fertility Management), AGHH (Age of a Household Head), GENHH (Gender of a Household Head), EDUCLHH (Education Level of a Household Head), TOTFS (Total Farm Size), OFFARE (Off-farm Income), FTR (Farmer Training), AEALHH (Adult Equivalent Agricultural Labor of a Household Head), PAGEX (Participation in Agricultural Extension), LIVS (Livestock Size), PTCMCHFA (Perception Towards Continuous Mono-Chemical Fertilizer Application), YCHFERAP (Year of Chemical Fertilizer Application), AVFARDIS (Average Farm Distance), NFPLT (Number of Farm Plots).*

Education level may not have a significant positive effect on adoption of sustainable soil fertility management in the absence of components of environmental education, follow up training and participation in agricultural extension programs. Adoption of ISFM also requires building on indigenous soil fertility management practices rather than attaining more years of schooling. Therefore, level of education was found to be not as important as other explanatory variables (TOTFS, FTR, PAGEX, YCHFERAP and PTCMCHFA) in explaining adoption of ISFM in the study catchment. Off-farm income was negatively (r = -0.1) associated with ISFM adoption, implying that the more the farmers get involved in off-farm income generating activities, the smaller the likelihood of adopting ISFM (Table 4.3).

Traditional timber production and petty coffee trading were the major off-farm income earning activities in the study area. These activities were mostly practiced by the poor farmers, who owned limited farm size. Farmers engaged in these activities may not raise sufficient income to invest on soil fertility management. They may also have little time to follow up on the labor intensive management requirements of ISFM. As a result, access to off-farm income generating activities was negatively correlated with adoption of ISFM. Some earlier studies also noted negative association between farmers' involvement in off-farm income generating activities and adoption of structural soil conservation measures (Aklilu, 2006; Anley et al., 2007).

In agreement with the hypothesis, the correlation between farm size and adoption of ISFM was not only positive (r = 0.4), but also statistically significant (Table 4.3). Farm size is source of wealth and capital for investments required for soil fertility management. Households with a large farm size have good potential to generate the cash needed to purchase chemical fertilizers. They can also produce sufficient biomass for animal feed and compost production, all of which are key components of ISFM adoption. On the other hand, poor farmers, who owned a small area of land, may not be willing to put a significant part of their limited land to ISFM strategies that take some parts of the land out of crop production. Therefore, the model showed that for every one unit increase of farm area owned, adoption of ISFM increases by a factor of 3.641 (Table 4.4).

Home-farmland distance was a farm characteristics as well as a geographic variable that influences adoption of ISFM. Transportation of organic fertilizers from home to farmland, protection of crops from attack by wildlife, and close monitoring of farmlands become difficult with increasing distance from home. As a result, a significant and negative association ($r = -0.2$; $p < 0.05$) was observed between home-farmland distance and adoption of ISFM (Table 4.3). Hence, it is likely that ISFM is mostly practiced on farmyard fields in the study catchment.

As it was expected, farmer training (FTR) was positively and significantly ($p < 0.01$) influenced adoption of ISFM (Table 4.4). In many cases, provision of training service to farmers is one of the major ways through which knowledge and skills about improved agricultural technology can flow from research institutions to the end user of the technology. Hence, farmers who had received some agricultural training were 9.2 times more likely to adopt ISFM than farmers who had not. Similarly, participation of farmers in agricultural extension program (PAGEX) positively and significantly ($p < 0.01$) influenced adoption of ISFM (Table 4.4).

In Ethiopia, the key objective of agricultural extension programs was application of chemical fertilizers and improved seeds to promote agricultural production and productivity. Farmers who were participating in this program had better experience of using chemical fertilizers, improved seeds and improved crop management practices than farmers who were not. As a result, the more the farmers get involved in agricultural extension program, the more the probability of increasing adoption of ISFM.

Year of chemical fertilizer application to farmland (YCHFERAP) was one of the major statistically significant predictors of ISFM adoption ($p < 0.05$; Table 4.4). Urea and DAP were the major chemical fertilizers commonly applied to farmland in the study watershed. These fertilizers have strong soil acidifying effect, as discussed earlier. The catchment is also characterized by high topographic dissection and intense rainfall that accelerate the removal of basic cations from the soil. As a result, soils of the area are strongly acidic, with a pH value of less than 5.5.

Table 4.4. Results of logistic regression (forward conditional) model showing factors driving adoption of ISFM in Arsamma Watershed, Southwestern Ethiopian Highlands

Variables	B	S.E.	df	*P*	Exp(B)
TOTFS	1.292	0.572	1	0.024*	3.641
FTR	2.220	0.651	1	0.001**	9.208
PAGEX	1.654	0.724	1	0.022*	5.227
YCHFERAP	0.165	0.070	1	0.019*	1.179
PTCMCHFA	2.101	0.885	1	0.018*	8.171
Constant	-6.741	1.313	1	0.000**	0.001

*Note: ** ($p < 0.01$), * ($p < 0.05$), -2 Log likelihood function = 64.852, X^2 = 90.264, df = 5, Constant = -6.741, Cox and Snell R square = 0.485, Nagelkerke R square = 0.713, TOTFS (Total Farm Size), FTR (Farmer Training), PAGEX (Participation in Agricultural Extension), YCHFERAP (Year of Chemical Fertilizer Application), PTCMCHFA (Perception Toward Continuous Mono-Chemical Fertilizer Application).*

Farmers who applied mono-chemical fertilizers (urea and/ DAP) to their soil were likely to be more experienced with the problem associated with mono-chemical fertilizer technology than those farmers who had recently become familiar with chemical fertilizers. Therefore, the longer the durations of chemical fertilizer application to farmland, the greater the possibility of encountering soil acidity problem, which subsequently increases the probability of shifting toward adoption of ISFM. In the same way, farmer’s negative perception towards continuous use of mono-chemical fertilizer technology positively and significantly ($p < 0.05$) influenced adoption of ISFM (Table 4.4).

Number of farm plots owned positively associated with adoption of ISFM (Table 4.3). Because, farmers owned large farmland size also tends to have more number of farm plots. Therefore, the positive impact of large farm size which was also accompanied by farmland fragmentation was more important than the negative influence of farm fragmentation on adoption of ISFM.

In general, the binary logistic regression model showed that adoption of ISFM in the study area was estimated as a function of:

$$ISFM = -6.741 + 2.220(FTR) + 2.101(PTCMCHFA) + 1.654(PAGEX) + 1.292(TOTFS) + 0.165(YCHFERAP).$$

In summary, institutional (FTR and PAGEX), socioeconomic (TOTFS), farm characteristics, and farm-related (YCHFERAP and PTCMCHFA) variables were the major factors driving adoption of ISFM in Arsamma watershed. The magnitude and pattern of the influence of these variables were in the order of institutional, farm characteristics and socioeconomic factors. None of the demographic variables was found to be significant predictors of ISFM adoption in Arsamma watershed.

Conclusions and policy implications

Ethiopia faces complex sets of soil fertility problems requiring approaches going beyond the application of chemical fertilizers. The physical structure oriented soil conservation strategy could not adequately address the problem of soil fertility decline. The attempts to promote ISFM as part of NAEIP remain in an early stage and limited in its wider dissemination and proper implementation. Hence, this study was conducted to identify determinants of ISFM adoption under annual cropping system in Arsamma Watershed, Southwestern Ethiopian Highlands.

The study showed that a combination of factors, namely socioeconomic, institutional, farm characteristics, and other farm-related variables influence adoption of ISFM in the study area. Farm size, farmer training, participation in agricultural extension, years (duration) of chemical fertilizer application to farmland and farmer’s perception toward continuous use of mono-chemical fertilizers were found to be the major statistically significant factors driving adoption of ISFM. The magnitude and patterns of the influence of these factors were in the order of institutional, farm characteristics and socioeconomic factors. On the other hand, none of the demographic variables were found to be significant predictors of ISFM adoption. The Cox and Snell R^2 (=0.485) and Nagelkerke R^2 (=0.713) of the regression model indicated that between 49% and 71% of the total variation in adoption of ISFM was explained by the variables considered in the study (Table 4.4). Hence, an understanding of the implication of these factors is indispensable to create enabling policy environments that enhance adoption of ISFM.

Farm size was positively and significantly determined adoption of ISFM. Farm size is a source of wealth and capital for investments required for soil fertility management. Households with a large farm size can raise the money required for the purchase of chemical fertilizers. They can also produce ample biomass used for animal feed and compost production, all of which are key pillars for ISFM adoption. However, the association between farm size and adoption of ISFM is a challenging problem since the poor farmers, who had limited farm size, are unlikely to adopt ISFM. Promotion of non-farm economic sectors can be one of the policy directions to alleviate the problem of small and declining farm size. Hence, farmers with limited farm size can benefit from share cropping or other land leasing agreements. Concerted efforts are also required to improve the productivity of the limited farmland by any possible means. Pro-poor approaches (subsidizing chemical fertilizers, promoting leguminous crop rotations, supply of agro-minerals at low costs) can be some of the policy options to scale up adoption of ISFM. The Bikilal phosphate rock (discussed in the text) can be developed with further scientific investigation to support adoption of ISFM at low costs in Arsamma watershed.

The study showed that only 32.4% of the total farmers were trained in improved agricultural practices. The proportion of farmers involved in the agricultural extension package program also accounted only for 45.6% of the total farmers (Table 4.2). The positive impact of farmer training and participation in agricultural extension programs on adoption of ISFM on one hand, and the small involvement of farmers in these programs on the other hand, indicate potential action that could be taken by stakeholders concerned with the promotion of ISFM adoption to improve uptake. Therefore, targeting farmer training and agricultural extension programs could be one of the feasible policy directions to scale up adoption of ISFM. The results of the study also showed that farmers who had made use of chemical fertilizers for a longer period of time were more likely to adopt ISFM than farmers who had only recently become familiar with chemical fertilizers. This could point to not only the observed and perceived negative impacts of continuous exclusive use of chemical fertilizers, but also the need and opportunity to move towards rigorous ISFM adoption in the study catchment. Moreover, farmers who perceived negative impact of mono-chemical fertilizer application were found more likely to exercise ISFM than farmers who did not perceive its negative impacts. Therefore, raising awareness of farmers of the positive and negative impacts of different soil fertility management approaches could be one of the possible ways of promoting ISFM adoption. Level of education was found not as important as other explanatory variables (TOTFS, FTR, PAGEX, YCHFERAP, and PTCMCHFA) in explaining adoption of ISFM in the study catchment. Therefore, ISFM and conservation agriculture paradigms for natural resource management need to be emphasized in the school curriculum of the country.

Finally, the study recommends the need for experimental research on the implications of mono-chemical fertilizers versus ISFM on the quality of soil and agricultural productivity; and also on optimum cohabitations of chemical and organic fertilizers to enhance soil fertility, increase yields and resilience to climate variability and changes at affordable costs.

Endnotes

[1] *Teff (Eragrostis tef) is an annual grass crop native to Ethiopia*

[2] *Fanyajuu is a type of terracing where a trench is excavated to form an embankment on the upper side by throwing the excavated soil uphill*

[3] *Kebele is the lowest political administrative unit in the Federal Democratic Republic of Ethiopia's government structure*

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Chapter 5

Factors Influencing Scaling up of Agroforestry-Based Spatial Land Use Integration for Soil Fertility Management in Arsamma Watershed, Southwestern Ethiopian Highlands

Abstract

This study was set to examine factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow in Arsamma watershed. A semi-structured questionnaire was used to gather necessary information. Contingency table, chi-square, *phi* and Cramer's *V* were used to analyze the data. Access to seedlings was the most important determinant of agroforestry upscaling; farmers' production orientation, farm size and wealth status ranked, respectively, second, third and fourth. Inter-plot organic fertilizer transfer was primarily influenced by participation in agricultural extension. Wealth status and number of livestock owned ranked, respectively, second and third in influencing inter-plot organic fertilizer transfer. The study indicated a geographic concept of spatial land use integration for soil fertility management and key factors influencing agroforestry-based spatial land use integration for soil fertility management. Agroforestry-centered diversified small-scale agricultural commercialization, integration of trees, crop and livestock, promotion of agricultural extension services, and supply of multi-purpose tree species are potential ways to upscale agroforestry and agroforestry-based spatial land use integration.

Key words: agroforestry upscaling; land use integration; soil fertility management

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Introduction

Soil fertility decline in smallholder farms is one of the major biophysical factors responsible for the declining per capita food production in Africa (Ajayi et al., 2012). In the absence of sustainable soil fertility management, this problem is predicted to continue, even if other agricultural constraints are alleviated (Maithya et al., 2006).

To address this problem, a number of soil management strategies were designed and implemented in various developing countries (Blanco & Lal, 2008). Scaling up of indigenous agroforestry is envisaged as the most holistic, economically feasible and environmentally sustainable soil fertility management option for these countries, among others (Ajayi et al., 2008; Kang & Akinnifesib, 2000; Place et al., 2005). For instance, a single agroforestry tree species, known as piasang (*Quercus griffithii)*, was found to enhance sustainable livelihoods, biodiversity conservation, and sustain eleven indigenous cropping systems of the Monpa and Brokpa peoples of India (Singh et al., 2015a). These multiple use benefits make agroforestry an essential way of bridging the conflicting outcomes that persist between agricultural practices and environmental management goals in developing countries (Tarigan & Darma, 2002).

Agroforestry generates visible and invisible ecosystem services at various spatial scales (Franzel et al., 2002). Tree species in agroforestry farms circulate soil nutrients from the sub-surface to surface soil, and also moderate the microclimate of the area (Faleyimu & Akinyemi, 2010; Zomer et al., 2009). Spatial land use integration, in which potential sources of organic supplies are grown on one plot of land and then transferred to another farm plot for the purpose of soil fertility management, is also one of the key functions that agroforestry plays off-site (Wassie & Shiferaw, 2009). In Western Kenya, spatial land use integration, which was practiced by transferring the biomass generated from agroforestry fields to maize fields, increased maize yields by 167% over the plot that was not spatially integrated (Place et al., 2005). In Southern Ethiopia, wheat yield was increased by 189% by transferring biomass of *Erythrina bruci*, a nitrogen fixing tree, from an agroforestry field to an annual crop field (Wassie & Shiferaw, 2009). In addition to enabling extensive use of indigenous knowledge, ensuring animal feed security and providing alternative sources of cash, spatial land use integration was found to generate better total benefits than the sum of non-integrated individual farm plots. It also encouraged more involvement of resource poor farmers in an environmental conservation program than other approaches that used for environmental management (Devendra, 2011).

Agroforestry is believed to be as old as the evolution of agricultural activities in Ethiopia (Tesfaye et al., 2006). However, its use remains very limited due to the lack of scientific experimentation, adequate market, and experience sharing mechanisms among the farmers (Tadesse, 2002). Limited technical know-how of agricultural and rural development agents and other stakeholders in the field also impede the development of the sector (SLUF, 2006). As a result, agroforestry is perpetuated only by the traditional practice of smallholder farmers (Tadesse, 2002).

However, scaling up of agroforestry and agroforestry-based spatial land use integration is needed for many reasons. The problem of soil degradation, which is exacerbated by dissected topography, poverty, population pressure and land fragmentation, makes agroforestry an irreplaceable environmental management option in Ethiopia (Badege & Abdu, 2003). The different approaches of indigenous and modern soil fertility management strategies so far implemented in Ethiopia have been unable to adequately address the problem of soil degradation (Lakew et al., 2000; Menale et al., 2008). For instance, fallowing, which is one of the old age indigenous soil fertility management strategies in Ethiopia, is obstructed by the decreasing landholding size (Assefa, 2005). Reforestation and afforestation programs are also hampered for the same reason (Badege, 2001). Most resource poor farmers of the country cannot afford chemical fertilizers (IFPRI, 2010; Pound & Ejigu, 2005). Soil fertility management through an organic approach is also impeded by the shortage of grazing land and limited biomass supply (Betru, 2002). Coffee soil fertility management is facing a dilemma between organic and inorganic approaches due to the growing needs for ‘green consumerism’ and organic coffee products (Albertin & Nair, 2004). Therefore, searching for new soil fertility management options, which are not only locally suited but also land use specific, is of critical importance to address these challenges. Agroforestry upscaling and agroforestry-based spatial land use integration has potential to address the many challenges of soil management strategies (Angima, 2009).

However, dissemination and scaling up of agroforestry is influenced by complex sets of socioeconomic, demographic, technological and institutional factors (McGinty et al., 2008; Tesfaye et al., 2006). Kabwe et al. (2009) reported that farmer-centered scientific experimentation, agricultural extension service, local institutional capacity and market conditions influence upscaling of agroforestry. Farmers' experience and cultural diversity were also found to influence conservation of agro-biodiversities (Singh et al., 2013). Social customs, farmers' resource endowment, perception of tenure security, land use preferences and exposure to mass media were also found to determine use of agroforestry (Lambert & Ozioma, 2001; Neupane et al., 2002). Schroth and Sinclair (2003) indicated that crop pests, diseases and wildlife associated with the tree-crop interface influence agroforestry adoption.

These studies mainly dealt with factors affecting agroforestry adoption and agroforestry upscaling from the viewpoint of ensuring sustainable livelihoods, and conservation of soil and biodiversities in situ. However, factors influencing the off-site service of agroforestry, i.e., agroforestry-based spatial land use integration for the sake of off-site soil fertility management, were overlooked by these studies. A few studies, such as Wassie and Shiferaw (2009) and Place et al. (2005), considered the technical aspect of spatial land use integration. Therefore, this study fills a gap in the literature in that it tries to apply a geographic concept of agroforestry-based spatial land use integration for soil fertility management. Factors influencing agroforestry upscaling and agroforestry-based spatial land use integration (inter-plot organic fertilizer transfer and inter-plot income flow) are schematically presented in Figure 5.1.

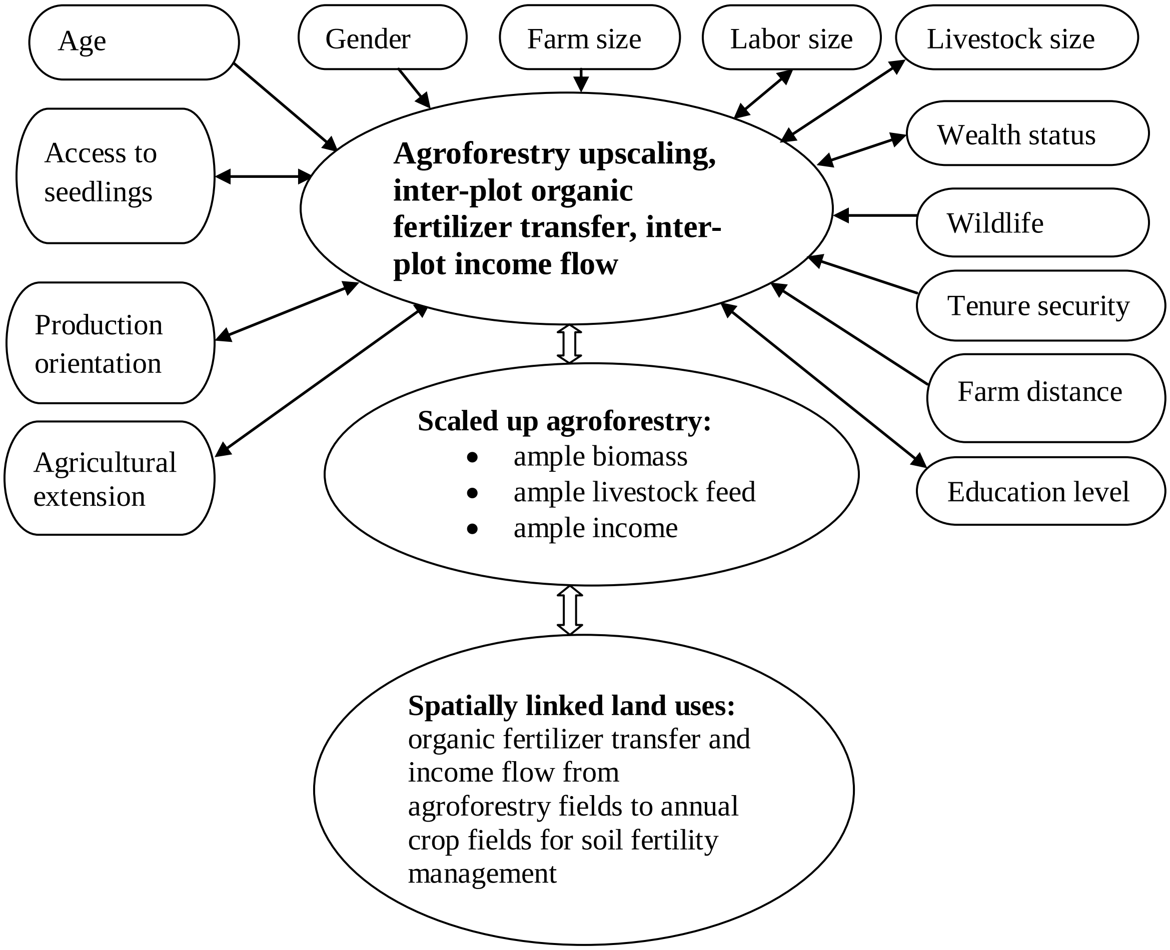

Figure 5.1. Schematic presentation of factors influencing agroforestry upscaling and agroforestry-based spatial land use integration for soil fertility management in Arsamma Watershed, Southwestern Ethiopian Highlands (adapted from Franzel et al., 2004).

The farming system in the study catchment was characterized as an annual-perennial cropping complex. Both perennial and annual crops were grown side by side having some form of spatially delineated boundaries. Coffee (*Coffea arabica* L.) was the most important perennial crop in the region. The land use system of the area could provide an opportunity for sustainable soil fertility management by spatially integrating farmlands used for perennial crop production with that of annual crops. The coffee-based traditional agroforestry could be potentially scaled up by incorporating multi-purpose tree species, fruits and disease resistant coffee varieties that could provide an opportunity to transfer the biomass and income generated from the coffee-based agroforestry farm to that of annual crops for the improvement of the soil. However, it was observed that agroforestry upscaling and agroforestry-based spatial land use integration were scarcely practiced, despite the opportunity provided by the land use pattern of the area (Figure 5.2). Therefore, this study aimed to examine factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow in Arsamma Watershed, Southwestern Ethiopian Highlands. The study was also intended to indicate to all stakeholders the need and opportunity for scaling up the traditional coffee-based agroforestry, and agroforestry-based spatial land use interaction for sustainable soil fertility management.

Background of the study area

Arsamma catchment is located in the West Wellega Administrative Zone of Ethiopia. The catchment is a part of the Southwestern Ethiopian Highlands. It is located between 9°05’-9°12’ North, and 35°40’-35°50’ East. It extends from 1,500 to 1,900 masl (EMA, 1983). The area is characterized by mean monthly temperature ranging from 16 to 20°C, and receives a total annual rainfall exceeding 2000 mm. The dry season is from November to April, while the rainy season extends from May to October (CRSO, 2000).

Arsamma watershed is situated in the moist warm temperate zone of the Southwestern Ethiopian highlands (Hurni, 1998). The farming system is dominated by small-scale production of cash and subsistence crops. The region is described as a coffee-maize-sorghum livelihood cluster zone with an annual-perennial cropping complex (ONRS, 2009). About 40%-50% of total coffee production and 60% of the country's coffee exports come from the Southwestern Ethiopian Highlands where the study catchment is situated (Wood, 1993).

Materials and methods

There are seventeen *kebeles* in the study catchment. *Kebele* is the smallest administrative unit in Ethiopia. The watershed partially encompasses eleven *kebele* administrations and fully incorporates six of them. A two-stage random sampling technique was employed to select the sampled respondents. First, two *kebeles* were selected from six *kebeles* that the catchment fully encompasses. Next, four villages (*gotes*), two each from the two *kebeles*, were randomly selected. Finally, a total of 136 households were randomly and proportionally selected from the four villages (Table 5.1).

Table 5.1. Households sampling procedure

Kebele	Village/*gote*	No. and % of households		No. and % of sampled households	
		No.	%	No.	%
Bonaya Asabi	*Gote* 3	119	26.4	36	30.3
	Gote 4	84	18.7	25	29.8
Buko Asabi	*Gote* 1	130	28.9	39	30.0
	Gote 4	117	26.0	36	30.8
Total		450	100.0	136	30.2

This study made use of mixed research design. A semi-structured interview questionnaire was used to gather information related to response variables agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow. Factors expected to influence these variables, such as households' demographic characteristics (age and gender), socioeconomic variables (wealth status, farm size, labor and livestock size), institutional factors (education level, tenure security and participation in agricultural extension), farm characteristics and other farm-related variables (home-farm distance, farmers' production orientation, problem of crop damage by wildlife and access to agroforestry seedlings) were gathered. These variables were selected based on an exploratory survey, literature review, personal observation and discussion held with development agents. The content validity of the questionnaire was checked by cross-validating with literature.

Table 5.2. Description of agroforestry upscaling, inter-plot organic fertilizer transfer, inter-plot income flow and the determinant variables

Variables	Descriptions and classification of variables	EDI
Agroforestry upscaling	Intentional upgrading of the traditional coffee-based agroforestry by incorporating multi-purpose tree species, disease resistant coffee varieties and/or fruits. A value of ‘1’ was assigned if a farmer exercised agroforestry upscaling and ‘0’, if not	
Inter-plot organic fertilizer transfer	Refers to the moving of biomass generated from the coffee-based agroforestry field to that of annual crops in the form of compost and/or animal manure. It was assigned ‘1’ if inter-plot organic fertilizer transfer was there and ‘0’, if not	
Inter-plot income flow	Refers to the utilization of the money generated from the coffee-based agroforestry field to fertilize the soils used for annual crop production. A value of ‘1’ was assigned if a farmer practiced inter-plot income flow and ‘0’, if not	
Age	Age is a phase in the lifetime of a farmer. A value of 1, 2 and 3 was, respectively, assigned to young adult (20-39), middle adult (40-59) and old adult (≥60) years	+
Gender	Refers to the biological sex of a household head. A value of ‘0’ and ‘1’ was assigned to female and male headed households, respectively	+
Wealth status	Refers to relative rank of a farmer due to major assets (land and livestock) he/she owned. Farmers were classified as poor, medium, or rich by the criteria set by key informants, and were assigned a value of 1, 2 and 3, respectively. A farmer owned ≥ 1.5 ha of land with 3 or more cattle was specified as rich. A farmer owned 0.5-1.5 ha of land with 2 or 3 cattle was defined as medium, and a farmer owned < 0.5 ha of land with 1 or no cattle was defined as poor.	+
Education level	Refers to a grade attained by a farmer due to formal schooling. A value of 1, 2, 3, and 4 was assigned to, respectively, illiterate (unable to read and write), primary (grade 1-4), junior secondary (grade 5-8), and high school (grade 9 and above)	+
Farmland size	The amount of farmland owned by a farmer. A value of ‘1’ was assigned if a farmer owned ≥ 0.98 ha (the mean farmland size in the study catchment) and ‘0’, if not	+
Labor size	The average adult equivalent labor size engaged in agricultural activities per day per household as estimated by the respondent. A value of ‘1’ was assigned if the labor size was ≥ 1.88 (the mean labor size in the catchment) and ‘0’, if not	+
Home-farmland distance	The space between a farmer’s home and his/her farmland as estimated in terms of minutes taken by a human on foot. It was assigned ‘0’, if the distance was ≤ 13.08 minutes (the average home-farm distance in the catchment) and ‘1’, if not	_
Tenure security	A state of safety that a farmer feels about his/her ownership of farmland. A value of ‘1’ was assigned if a farmer felt secure about his /her ownership of farmland at least in his/her lifetime and ‘0’, if not	+
Participation in extension	Involvement of a farmer in an agricultural extension program. A value of ‘1’ was assigned if a farmer participated in agricultural extension programs and ‘0’, if not	+
Production orientation	Relative tendency of a farmer either toward perennial cash crop or annual crop production. It was assigned ‘1’, if a farmer allotted at least half (≥0.49 ha) of his/her farmland to perennial cash crop production and ‘0’, if not	+
Livestock size	The total amount of livestock owned by a farmer. It was measured in TLU (Tropical Livestock Unit). One TLU is equivalent to 1.5 cattle, 10 sheep, 12 goats, 2 donkeys, 1 horse or 0.8 camels (Sys et al., 1991). A value of ‘1’ was assigned if a farmer owned ≥ 0.82 TLU (the mean livestock size in the catchment) and ‘0’, if not	+
Crop damage by wildlife	Destruction of crops by wildlife harbored by trees in agroforestry. A value of ‘1’ was assigned if a farmer faced problems of crop damage by wildlife and ‘0’, if not	-
Access to seedlings	Access of farmers to seedlings either from the government, NGOs or from their own farmland. It was assigned ‘1’ if a farmer had access to seedlings and ‘0’, if not	+

Note: EDI refers to Expected Direction of Influence.

The questionnaire was pre-tested using split-half method to check for its internal consistency. Farmers' practice of agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow was determined through discussion held with development agents and key informants; and they were specified and operationalized from the local context (Table 5.2). Knowledgeable elders were selected based on the nomination of the development agents for the key informant interviews in order to supplement the questionnaire survey.

Though intra-plot organic fertilizer transfer and income flow was possible, this study was limited to the flow of organic fertilizer and income from the coffee-based agroforestry fields to that of annual crops, where soil fertility status and soil fertility management requirement is spatially distinct.

A combination of descriptive statistics (cross-tabulation and percentage), and inferential statistics (chi-square test) was used to evaluate factors influencing the scaling up of agroforestry, inter-plot organic fertilizer transfer and inter-plot income flow. To measure the direction of association between these two groups of categorical variables, a non-parametric correlation coefficient of *phi* or Cramer's *V* was used. For variables with 1 degree of freedom, a coefficient of *phi* was used and for variables with ≥ 2 degree of freedom, a coefficient of Cramer's *V* was used (Agresti, 1996).

Results and discussions

Farmland utilization and soil fertility management practices

Agroforestry and agroforestry-based spatial land use integration was one of the indigenous soil fertility management strategies in Arsamma watershed. Coffee-based traditional agroforestry was practiced by 94.1% of the sampled households (Figure 5.2). Scaling up of this indigenous practice could provide an opportunity for sustainable soil fertility management. However, less than one-third (30.1%) of the total farmers engaged in intentional upscaling of the traditional agroforestry (Figure 5.2).

About 83.1% of the farmers grew both annual and perennial crops (Figure 5.2). Such joint agricultural activity could provide an opportunity to sustainably manage the soil through spatial integration of the land uses. However, agroforestry upscaling and agroforestry-based spatial land use integration practices were very weak. Only 34.6% of the total farmers made use of inter-plot organic fertilizer transfer practice to amend the nutrient content of soils used for annual crop production.

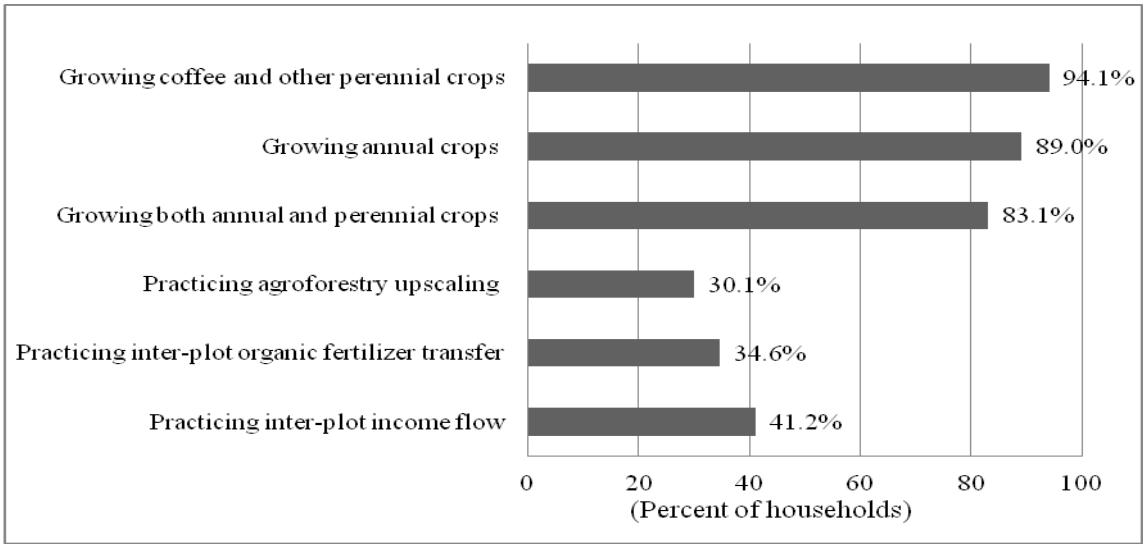

Figure 5.2. Land utilization, agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow in Arsamma Watershed, Southwestern Ethiopian Highlands.

Coffee was the high-value cash crop grown by most of the households. However, only 41.2% of the total farmers employed the income generated from the coffee-based agroforestry field to fertilize the nutrient content of soils used for annual crop production (Figure 5.2).

Factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow

A number of demographic, socioeconomic, institutional, farm characteristics and other farm-related factors were found to influence agroforestry upscaling, and agroforestry-based spatial land use integration. Table 5.3 indicates factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow in the Arsamma Watershed, Southwestern Ethiopian Highlands.

Demographic factors

Agroforestry upscaling was practiced by 32% and 24.2% of male and female headed households, respectively (Table 5.3). Only 40.8% of male and 15.2% of female headed households amended the nutrient content of their soil through inter-plot organic fertilizer transfer. The proportion of male headed households who practiced inter-plot organic fertilizer transfer was significantly higher ($p < 0.01$; $phi = 0.2$) than that of female headed households (Table 5.3). In rural Ethiopia, men have better access to resources, information and other socioeconomic opportunities, and bear fewer burdens of household chores than women. Farmers' knowledge of tree species are also influenced by gender (Singh et al., 2015b). As a result, soil fertility management through spatial land use integration was better exercised by male headed households than female headed households. A study made by Kiptot et al. (2014) indicated that though women are as aware as men of the benefits of agroforestry, their level of participation in agroforestry adoption is constrained by cultural norms and lack of resources.

Agroforestry upscaling was also influenced by age differences. The proportion of old and young farmers, who were involved in agroforestry upscaling, was about 38% and 29%, respectively. The data in Table 5.3 indicated that a larger proportion of the middle-aged adults exercised inter-plot organic fertilizer transfer and inter-plot income flow than the young and old adults (Table 5.3). It was observed that knowledge and valuation of plants increases with farmers' age (Brandt et al., 2013; Singh et al., 2015b). This implies that knowledge and experience exchange among the farmers is one of the possible ways of agroforestry upscaling and agroforestry-based spatial land use integration.

Socioeconomic factors

Wealth status, farm size, labor potential and livestock size were the major socioeconomic factors that influenced agroforestry upscaling and agroforestry-based spatial land use integration. Agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow were exercised by 48.4%, 61.3% and 64.5% of the rich farmers, respectively. On the other hand, less than a quarter of the poor households engaged in agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow. Wealth status also significantly and positively influenced agroforestry upscaling ($p < 0.05$; Cramer's $V = 0.2$) and inter-plot organic fertilizer transfer ($p < 0.01$; Cramer's $V = 0.3$). A study made by Tesfaye (2013) indicated that while resource poor farmers focus on the production of subsistence crops, rich farmers are market oriented and they allocate a large portion of their farmland to cash crop production. Resource poor farmers have limited access to farmland, agricultural labor, credit, agricultural extension services and agroforestry seedlings. They are rather pre-occupied with their current survival. Hence, resource poor farmers are less involved in agroforestry upscaling and agroforestry-based spatial land use integration.

The average households' farm size was 0.98 ha in the study catchment. About half of the farmers who were holding relatively large farmland size ($\geq$ 0.98 ha) exercised agroforestry upscale, inter-plot organic fertilizer transfer and inter-plot income flow. A statistically significant positive correlation ($p < 0.01$; $phi = 0.3$) was observed between farmland size and the proportion of farmers who practiced agroforestry upscale**.** Farmland size also significantly and positively correlated with the proportions of farmers transferring organic fertilizer ($p < 0.05$; $phi = 0.2$) and flow income ($p < 0.05$; $phi = 0.2$) between the two land use types. Farmers who owned large farmland can allocate a large proportion of their farmland to coffee production; and the coffee farmland can be potentially scaled up into intentionally improved agroforestry. They can be able to generate more biomass and income that can be used for soil fertility management.

Table 5.3. Cross-tabulation, chi-square test and non-parametric correlation coefficients showing factors influencing agroforestry upscaling, inter-plot natural fertilizer transfer and inter-plot income flow (N = 136)

Variables (factors)		Agroforestry upscaling				Inter-plot organic fertilizer transfer				Inter-plot income flow			
		Yes (%)	No (%)	*p*	*phi/CV*	Yes (%)	No (%)	*p*	*phi/CV*	Yes (%)	No (%)	*p*	*phi/CV*
Gender	Male(N=103)	32.0	68.0	0.396	0.073	40.8	59.2	0.007**	0.231	41.7	58.3	0.811	0.021
	Female(N=33)	24.2	75.8			15.2	84.8			39.4	60.6		
Age	20-39(N=48)	29.2	70.8	0.892	0.041	33.3	66.7	0.796	0.058	35.4	64.6	0.553	0.093
	40-59(N=80)	30.0	70.0			36.3	63.7			45.0	55.0		
	≥60(N=8)	37.5	62.5			25.0	75.0			37.5	62.5		
Wealth status	Poor(N=38)	21.1	78.9	0.015**	0.248	18.4	81.6	0.000**	0.345	13.2	86.8	0.000**	0.381
	Medium(N=67)	22.4	77.6			26.9	73.1			34.3	65.7		
	Rich(N=31)	48.4	51.6			61.3	38.7			64.5	35.5		
Education level	Illiterate(N=58)	29.3	70.7			19.0	81.0			27.6	72.4		
	Primary(N=39)	25.6	74.4			46.2	53.8			51.8	46.2		
	Junior secondary(N=20)	25.0	75.0	0.344	0.156	40.0	60.0	0. 910	0.292	45.0	55.0	0.043*	0.243
	≥High school(N=19)	47.4	52.6			52.6	47.4			54.6	47.4		
Farm size	≥Mean (0.98 ha) (N=51)	49.0	51.0	0.001**	0.319	45.1	54.9	0.045*	0.172	52.9	47.1	0.031*	0.185
	< Mean (0.98 ha)(N=85)	18.8	81.2			28.2	71.8			34.1	65.9		
Labor size	≥ Mean (1.88)(N=78)	30.8	69.2	0.855	0.016	46.2	53.8	0.111	0.028	46.2	53.8	0.171	0.117
	< Mean (1.88)(N=58)	29.3	70.7			19.0	81.0			34.5	65.5		
Home-farm distance	> Mean (13.08)(N=68)	25.0	75.0	0.191	-0.112	29.4	70.6	0.207	-0.108	34.8	63.2	0.296	-0.090
	≤ Mean (13.08)(N=68)	35.3	64.7			39.7	60.3			45.6	54.4		
Tenure security	Secure(N=77)	35.0	65.0	0.153	0.122	36.4	63.6	0.163	0.043	44.2	55.8	0.420	0.069
	Insecure(N=59)	23.7	76.3			32.2	67.8			37.3	62.7		
Participation in extension	Yes(N=62)	30.6	69.4	0.908	0.010	53.2	46.8	0.000**	0.359	54.8	45.2	0.003**	0.254
	No(N=74)	29.7	70.3			18.9	81.1			29.7	70.3		
Production orientation	Mainly Cash crop(N=82)	45.1	54.9	0.000**	0.402	42.7	57.3	0.014**	0.211	48.8	51.2	0.026*	0.190
	Mainly Food crop(N=54)	7.4	92.6			22.2	77.8			29.6	70.4		
Livestock size	≥Mean (0.82 TLU)(N=56)	32.1	67.9	0.671	0.036	53.6	46.4	0.000**	0.334	51.8	48.2	0.035*	0.180
	< Mean(0.82 TLU)(N=80)	28.8	71.2			21.3	78.7			33.8	66.2		
Crop damage by wild life	Yes (N=97)	29.9	70.1	0.556	-0.051	36.1	63.9	0.920	0.009	44.3	55.7	0.239	-0.101
	No(N=39)	30.8	69.2			30.8	69.2			33.3	66.7		
Access to seedlings	Yes(N=35)	71.4	28.6	0.000**	0.530	57.1	42.9	0.001**	0.280	62.9	37.1	0.002**	0.259
	No(N=101)	15.8	84.2			26.7	73.3			33.7	66.3		

Note: ** ($p < 0.01$), *($p < 0.05$), TLU (Tropical Livestock Unit), *CV* (Cramer's *V*).

Previous studies also indicated a positive association between farmland size and agroforestry adaption (Bifarin et al., 2013; Mulatu et al., 2014). The prospects of agroforestry upscaling and agroforestry-based symbiotic land use integration, therefore, can be severely influenced by the declining per capita land holding size in the study catchment.

The average adult-equivalent labor size actively participating in agricultural activities was 1.88 persons per household. The difference in households involved in agroforestry upscaling and agroforestry-based spatial land use integration between large and small household labor sizes was not statistically significant (Table 5.3).

The average number of livestock owned was 0.82 TLU per household. As compared to farmers who owned a large number of livestock (≥ 0.82 TLU), the proportion of farmers practicing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow was lower for farmers who owned a small number of livestock. Statistically significant associations were observed between number of livestock owned, and the proportion of farmers who exercised inter-plot organic fertilizer transfer ($p < 0.01$; *phi* = 0.3) and inter-plot income flow ($p < 0.05$; *phi* = 0.2). In the study catchment, cattle and equine stock sometimes feed on shoots and buds of trees grown in coffee farms. Small ruminants, such as sheep and goats, also commonly graze on the undergrowth of the coffee farm. The farmers mostly apply the manure produced by these animals to farmlands used for annual crop production. This means that the farmers use their livestock as a medium through which they recycle soil nutrients between farm plots of different land use types. Livestock are also sources of cash and draft power that directly or indirectly contributes to soil fertility management. Hence, as livestock size increases, it positively influences symbiotic spatial integration of land uses. An interviewee in Buko Asabi *Kebele* commented on his animal rearing and inter-plot organic fertilizer transferring practices as:

> There is a critical shortage of grazing land in this area. Sometimes I feed my cattle the leaves and buds of trees grown in coffee farm. My sheep also commonly graze on undergrowth of the coffee farm. However, only a few tree

> species in my coffee farm is usable for animal feed. As a result, I raise very few livestock. I have no experience in preparing compost from the biomass grown on the coffee farm, but I frequently apply animal manure to maize fields. (Field interview 2014)

Therefore, the supply of multi-purpose tree species that can be used for animal feed, nitrogen fixing and shade value can promote mutual integration of tree-crop-livestock farming in the study catchment. Previous studies also indicate that the use of fodder shrubs in the agroforestry farm promotes animal production and productivity (Kiptot et al., 2014; Tesfaye, 2013). Towards this end, farmer-centered scientific experimentation, experience sharing and agroforestry oriented agricultural extension services can play an indispensable role.

Institutional factors

Institutional factors, such as education level, tenure security and participation in agricultural extension programs were found to determine agroforestry upscaling and agroforestry-based spatial land use integration that the farmers practiced for soil fertility management.

About 54.6% of farmers who had at least high school level of education fertilized their soil through inter-plot income flow. Association between the level of education and inter-plot income flow was also statistically significant ($p < 0.05$). However, the influence of education level on agroforestry upscaling and inter-plot organic fertilizer transfer was not statistically significant. Farmers' perceptions of tenure security were not significantly associated with agroforestry upscaling and agroforestry-based spatial land use integration. Farmers' ownership rights for coffee farmland were not threatened by the land redistribution program that was implemented by the then Ethiopian government during the 1970s and 1980s. It was also observed that farmers in the study region expand coffee plantations into farmland used for grazing and staple crop production in order to strengthen their tenure security. The recent land use right certification program of the country might also alleviate the problem of tenure insecurity to a certain extent. Hence, tenure insecurity was not a significant challenge in influencing agroforestry upscaling and agroforestry-based spatial land use integration in the study catchment.

The proportion of households who exercised agroforestry upscaling and agroforestry-based spatial land use integration was higher for households who were participating in an agricultural extension programs as compared to the non-participants. Participation of farmers in agricultural extension programs was also significantly and positively associated with inter-plot organic fertilizer transfer ($p < 0.01$; $phi = 0.4$) and inter-plot income flow ($p < 0.01$; $phi = 0.3$). Agricultural extension programs equip farmers with the knowledge and skills for sustainable environmental management. However, only 45.6% of the total farmers had ever participated in an agricultural extension package. Previous studies indicate that collaboration of scientists and development agents with local innovators promotes wider dissemination and scaling up of indigenous agroforestry practices (Espinosa, 2013; Nyando et al., 2013; Reed, 2007). To be effective, however, agroforestry extension needs to fit in with the dynamics of the farming system, local socioeconomic and technological systems and land use constraints (Glendinning et al., 2001). Therefore, agroforestry extension services and collaboration of rural development agents with the local agroforestry innovators can promote symbiotic spatial integration of land uses, and then can enhance sustainable soil fertility management.

Farm characteristics and other farm-related factors

Farm characteristics and other farm-related factors, such as home-farmland distance, farmers’ production orientation and access to agroforestry seedlings were cross-tabulated against agroforestry upscaling, and agroforestry-based spatial land use integration (Table 5.3).

Home-farmland distance influences the degree of interaction that exists between the farmers and the farmlands. Hence, it was inversely associated ($phi = -0.1$) with the proportion of farmers who exercised agroforestry upscale and agroforestry-based spatial land use integration (Table 5.3). However, the association was not statistically significant.

General orientation of farmers either towards cash or food crop production influenced agroforestry upscaling and agroforestry-based land use integration. The proportion of farmers exercising agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot cash flow was higher for farmers who allocated a large proportion of their farmland to cash crop production, as compared to farmers who were oriented toward the production of staple crops. Market-oriented farmers have more ambition and experience to upgrade the indigenous coffee-based agroforestry than those farmers primarily concerned with the production of subsistence crops. Farmlands used for perennial crop production can also be used to generate more income and biomass per unit of land than farmlands used for annual crop production. The increased income and biomass can be used to spatially integrate the land uses for the sake of sustainable soil fertility management. Therefore, orientation of farmers towards perennial cash crop production significantly and positively influenced agroforestry upscaling ($p < 0.01$; $phi = 0.4$) inter-plot organic fertilizer transfer ($p < 0.01$; $phi = 0.2$) and inter-plot income flow ($p < 0.05$; $phi = 0.2$) (Table 5.3). This indicates that agroforestry-based diversified smallholder agricultural commercialization can promote agroforestry upscaling and agroforestry-based symbiotic spatial land use integration.

The problem of crop destruction by arboreal wild animals, which are harbored by tree species grown in agroforestry farms, was the other factor that influenced the scaling up of agroforestry and spatial integrity of the land uses for soil fertility management. The problem of crop damage by wildlife negatively influenced the number of farmers practicing agroforestry upscale and inter-plot income flow ($phi = -0.1$). An interviewee in Bonaya Asabi *Kebele* commented on the impact of arboreal wildlife as:

> Before some 15 or 20 years, several naturally grown big tree species were found in my coffee farm. These trees harbored a number of arboreal wildlife. These wild animals frequently damaged my crops. As a result, I cleared most

> of the trees found along the coffee-annual cropland interface, and those found around homestead to save my crops. Due to the problem of wild animals, I rarely incorporate fruits and other crops which are susceptible to wildlife in my coffee farm. (Field interview 2014)

The benefit that the farmers get from agroforestry upscaling and spatial land use integration possibly outweigh the problem imposed by arboreal wildlife. As a result, the impact of wildlife on agroforestry upscaling was not statistically significant. This problem can be alleviated through proper selection of plant species that are incorporated in the agroforestry farms in the area. *Enset* (*Inset ventricosum*) and root crops can serve this purpose. *Enset* is a key crop species which is often described as a "tree against hunger" in the indigenous agroforestry systems of the Southwestern Ethiopian Highlands. It is a multipurpose plant, and less susceptible to damage by wildlife (Tadesse, 2002). However, *enset* agriculture was not common in the agroforestry systems of the study catchment. This indicates the possibility of upscaling the agroforestry system of the study area through proper selection of plant species. Therefore, agricultural extension programs in the area need to target on the supply of agroforestry seedlings which are compatible with the farming system and less susceptible to damage by wildlife.

Seedlings are the building blocks of agroforestry. Of the total farmers who have had access to agroforestry seedlings, most of them exercised agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow. Access to seedlings significantly and strongly correlated with agroforestry upscaling ($p < 0.01$; *phi* = 0.5). Inter-plot organic fertilizer transfer ($p < 0.01$; *Phi* = 0.3) and inter plot income flow ($p < 0.01$; *phi* = 0.3) also positively associated with access to seedlings. An interviewee in Bonaya Asabi *Kebele* commented on his demand for seedlings as:

> Coffee yield is highly seasonal. It is severely affected by coffee berry disease and rainfall condition. I rarely get disease resistant coffee seedlings and tree species that are compatible with coffee plant. During earlier period, I used to prevent coffee berry disease with chemical spray. There is no such practice

> nowadays. When the climate is good and the coffee berry disease is less prevalent, and I can afford to use chemical fertilizer. When the rainfall comes late and the coffee berry disease is widespread, not only is my farmland left unfertilized but also my family faces seasonal food shortage. (Field interview 2014)

Due to the global market shift towards organic coffee supply, prevention of coffee berry disease through chemical spray was not common in most coffee growing regions of Ethiopia. Therefore, supply of disease resistant coffee seedlings and multi-purpose tree species which are compatible with coffee plants can enhance agroforestry upscaling and the spatial symbiotic integrity of the land uses for sustainable soil fertility management.

In general, access to seedlings (*phi* = 0.5) was found to be the most significant factor influencing agroforestry upscaling. Farmers' production orientation (*phi* = 0.4), farm size (*phi* = 0.3) and wealth status (*phi* = 0.2) came, respectively, second, third and fourth in influencing agroforestry upscaling. Farmers who participate in an agricultural extension programs may be more enthusiastic about applying chemical and organic fertilizers with improved crop management practices on annual cropland than the non-participants. This can promote production of organic fertilizers from the biomass grown in the coffee-based agroforestry and its application to farmlands used for annual crop production. Participation in an agricultural extension program, therefore, was found to be the most important factor (*phi* = 0.36) influencing inter-plot organic fertilizer transfer. Wealth status (*CV* = 0.35), livestock size (*phi* = 0.33) and access to seedlings (*phi* = 0.28) ranked, respectively, second, third and fourth in influencing inter-plot organic fertilizer transfer. The influence of wealth status (*CV* = 0.38) on inter-plot income flow exceeded all other factors; and access to seedlings, participation in extension and education level came second, third and fourth, respectively.

Therefore, any stakeholder concerned with sustainable soil fertility management through agroforestry upscaling and agroforestry-based spatial land use integration needs to consider the relative weight of these variables.

Conclusion and recommendation

Agroforestry is believed to be as old as the evolution of agricultural activities in Ethiopia. However, its use and scaling up remains very limited in the country. Therefore, this study aimed to examine factors influencing agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow in the Arsamma Watershed, Southwestern Ethiopian Highlands. The study was also intended to indicate to all stakeholders the need and opportunity of scaling up the traditional coffee-based agroforestry and agroforestry-based spatial land use integration for the purpose of sustainable soil fertility management.

Various studies were conducted on agroforestry practices from the viewpoint of ensuring sustainable livelihoods, and conservation of soil and biodiversities in situ (Kabwe et al., 2009; McGinty et al., 2008; Schroth & Sinclair, 2003; Tesfaye et al., 2006). These studies crudely indicate that adoption and dissemination of agroforestry is influenced by complex sets of demographic, socioeconomic institutional and technological factors. However, factors influencing the off-site service of agroforestry, i.e., agroforestry-based spatial land use integration for the sake of off-site soil fertility management, were overlooked by these studies. A few studies, such as Wassie and Shiferaw (2009) and Place et al. (2005), considered the technical aspect of spatial land use integration. However, agroforestry-based spatial land use integration for off-site soil fertility management requires an understating of the key determinant factors. Therefore, this study indicated that scaling up of agroforestry-based spatial land use integration requires specific factors to be considered, such as seedlings supply, farmers’ production orientation, farmland size, gender, wealth status, livestock size, education level and participation of farmers in agricultural extension programs, among others.

Access to seedlings was found to be the strongest determinant of agroforestry upscaling. Farmers’ production orientation, farmland size and wealth status came, respectively, second, third and fourth in influencing agroforestry upscaling. Participation in agricultural extension programs strongly influenced inter-plot organic fertilizer transfer, among others. Wealth status, livestock size, access to seedlings and gender ranked, respectively, second, third, fourth and fifth in influencing inter-plot organic fertilizer transfer. The influence of wealth status on inter-plot income flow exceeded all other factors, followed by, sequentially, access to seedlings, participation in agricultural extension and education level.

In order to promote agroforestry-based spatial land use integration, agroforestry-centered diversified small-scale agricultural commercialization needs to be promoted, so that the agricultural practice is environmentally friendly on the one hand and it protects the farmers against production and market risks on the other hand. The tree-crop-livestock farming system of the area needs to be well integrated. Such intimately integrated agricultural activity enhances agricultural sustainability, resource use efficiency, sustainable livelihoods and resilience to climatic change. Towards this end, farmer-centered scientific experimentation is very critical to identify trees, crops and livestock species which are compatible and mutually synergistic. Due to the shortage of grazing land, small ruminants deserve better attention than cattle and equine stock, so that the tree-crop-livestock farming system will be well integrated on the limited farmland. Supply of multi-purpose tree species that can be used for nitrogen fixing, income generation, animal feed and canopy cover needs to be prioritized by agricultural extension programs in the area. In addition, supply of disease resistant coffee varieties needs to be a key area of intervention. Pro-women and pro-poor rural development approaches that enable most of the farmers in the area to be involved in soil management programs need to be prioritized. Working towards certification of shade grown and/or organic coffee, which helps the farmers to obtain premium prices from the international coffee market or carbon trade, is another possible means of encouraging the farmers to scale up the traditional coffee-based agroforestry farming.

Finally, this study would like to indicate the need for further research to model inter-land use type soil nutrient flux, identification of multi-purpose tree species which are compatible with coffee plants, evaluate the impacts of the perennial-annual crop interface on soil fertility management practices.

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Chapter 6

Farmers' Perception of Soil Fertility Change and Their Preferences for Soil Fertility Management Techniques for Different Land Use Types in Arsamma Watershed, Southwestern Ethiopian Highlands

Abstract

This study aimed to assess farmers' perceptions of soil fertility change and their preferences for soil fertility management techniques for different land use types in Arsamma Watershed, Southwestern Ethiopian Highlands. A two-stage random sampling technique was employed to select the sampled households. A smaller proportion of farmers perceived soil fertility decline in perennial cropland than in annual cropland as the farmers appeared to be less aware of below-ground processes of soil degradation. The farmers used physical, chemical and biological indicators to evaluate soil fertility change. The rate of soil fertility decline and the occurrence of the contributory factors were found to be land use specific. Increasing fertilizer requirement of croplands and decreasing yield per unit of land were the main indicators of soil fertility decline in annual and perennial cropland, respectively. Farmers' preference for soil fertility management techniques was also found to be specific to the land use types. Integrated Soil Fertility Management (ISFM) and agroforestry were the top priorities of the farmers for annual and perennial cropland management, respectively. Farmers' knowledge of below-ground processes of soil degradation by leaching, nutrient mining and soil acidity needs to be increased; and ISFM options for annual cropland and tree based soil fertility management intervention for perennial croplands need to be emphasized in the study catchment.

Key words: Coffee; land use; indigenous knowledge; soil fertility

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Introduction

A study of farmers' perceptions is important because perception influences how humans adapt to the changing environment (Carterette & Friedman, 1999; Master, 2010).

A number of studies were conducted on farmers' perception of soil fertility status (Desbiez et al., 2004; Getahun, 2006). Considerable indigenous knowledge of soil fertility evaluation techniques has also been documented (Dea & Scoones, 2003; Dixon, 2005; Teklu & Gezahegn, 2003). These studies indicate that farmers' understanding of soil is more general and holistic than that of scientists. Farmers use various indicators to evaluate soil fertility status and soil fertility changes. For instance, farmers in Dejen district of Ethiopia use symptoms of gullies, soil productivity, soil depth, water holding capacity and crop yield performance to evaluate soil fertility change (Getahun, 2006). In Western Kenya, crop growth vigor, soil color and types of weeds grown in farmlands are major indicators of soil fertility status (Odendo et al., 2010). Farmers in Tigrai region of Ethiopia make use of crop yield, degree of weed infestation, appearance of rocky outcrops and crop wilting to evaluate soil fertility change (Corbeels et al., 2000).

A study of farmers' perception of soil provides an opportunity to understand farmers' sense of land resources, and helps to synthesize and interpret farmers' responses to soil dynamics. Hence, meanings attached to a given soil by farmers helps land use planners to focus on hot spot areas of problems associated with the utilization of the soil (Stedman, 2005). In this regard, indigenous knowledge of farmers plays a great role as farmers' perception towards soil fertility decline influences their decision to adopt various soil fertility management techniques (Asrat et al., 2004; Mekoya et al., 2007; Zenebe et al., 2003). Farmers' knowledge of soil and soil related processes is also found to be complementary to scientists' knowledge (Desbiez et al., 2004). Understanding of this knowledge, therefore, facilitates communication between researchers, development agents, policy makers and farmers (Barrios et al., 2006; Izac, 2003). Participatory soil fertility management and adoption of various soil fertility management technologies can be enhanced through proper understanding of farmers' perception of soil degradation and soil fertility management technologies (Maro et al., 2013; Tesfaye & Debebe, 2013). A number of soil fertility management programs so far implemented attained little success due to little consideration of farmers' perception of soil degradation, and less valuation of farmers' priorities for various soil management technologies (Glover, 2012).

Soil degradation is always clearly observed on bare land, such as annual cropland, and it may be unobservable or obscure on perennial cropland. Thus, farmers' understanding of soil fertility change varies with different land use types. A number of studies so far conducted on farmers' perception of soil fertility status overlooked farmers' understanding of soil fertility change for different land use types. Integration of farmers' perceptions of soil fertility change with farmers' preferences for soil fertility management techniques was also not well addressed. Besides, indigenous knowledge of soil and soil fertility management is likely to be location specific, based on specific socio-cultural and biophysical environment of an area (Getahun, 2006). Therefore, this study aimed to assess farmers' perceptions of soil fertility changes and their preferences for soil fertility management techniques for annual and perennial cropland in Arsamma Watershed, Southwestern Ethiopian Highlands.

Arsamma watershed: the study area

Arsamma watershed is a part of the Southwestern Ethiopian Highlands. It is located in the West Wellega Administrative Zone of Oromia National Regional State, along the Southwestern part of Gimbi District, and Southeastern part of Lalo Asabi District. The catchment covers a total area of 115.4 km^2 (Figure 1.2).

Arsamma watershed is a part of the western physiographic unit of Oromia National Regional State. This physiographic region is a segment of the extensive Afro-Arabian plateau, which is mainly of volcanic origin and known for its high topographic dissection (PPDO, 1997). The watershed extends from 1,500 to 1,900 masl (EMA, 1983). Slope gradients that range from 0-15%, 16-30% and > 30% cover about 33%, 43% and 24% of the total area of the study catchment, respectively (Figure 1.3). This implies that about a quarter of the catchment is characterized at least by steep slope (FAO, 2006). Nitisols of the dystric sub-group is a dominant soil type in and around the study region (EMA, 1988). The dystric soil sub-group is always poor in base saturation, low in pH value and generally rated as less fertile (Landon, 1991).

Arsamma watershed falls under the influence of equatorial westerly winds that blow from the Gulf of Guinea to most parts of Eastern African highlands (CRSO, 2000). This region is characterized by a warm temperate humid climate with distinct dry months in winter and main rainy period in summer (BFED, 2013). For the period between 1981 and 2010, the average annual rainfall was about 1,900 mm. The rainfall pattern is unimodal with a long summer season. More than 78% of the total annual rain falls from June to September. The region is characterized by a mean annual temperature of 20.4 °C, and a mean monthly temperature ranging from 17.8 °C in August to 22.5 °C in March. The periods of low mean minimum, mean maximum and mean monthly temperature coincide with the periods of high rainfall amount (Figure 1.4). This torrential rainfall and high topographic dissection are the major factors driving accelerated soil erosion and wide prevalence of acid soils in Southwestern Ethiopian Highlands (Mesfin, 2007).

Materials and methods

There were 17 *kebeles* (smallest administrative units) in the study catchment. The watershed fully encloses 6 *kebele* administrations, and partially incorporates 11 of them. A two-stage random sampling technique was employed to select the sampled farmers. First, 2 *kebele* administrations were selected from the 6 *kebele*s that the catchment fully encloses. Then, 4 rural villages (2 each from the 2 *kebeles*) were randomly selected by lottery draw. There were 450 household units in the 4 villages, from which 136 household were randomly and proportionally selected. A household head was targeted to generate the data as household headship is very important to make decision on soil fertility management in Ethiopia.

A reconnaissance survey was made to identify local indicators of soil fertility change and farmers' priorities for various soil fertility management techniques. Ten major indicators of soil fertility change and nine soil fertility management techniques were identified to be covered by the questionnaire survey.

Table 6.1. Major soil fertility management practices in Arsamma watershed

Management type	Description
Organic fertilizer	Making use of animal manure, compost or farmyard manure
Chemical fertilizer	Application of urea, DAP or both to annual cropland
ISFM	ISFM (Integrated Soil Fertility Management) refers to application of chemical fertilizer, organic fertilizer and improved seed with or without erosion control measures on the same farmland during the same cropping season
Agroforestry	Coffee farms that incorporate multi-purpose tree species, disease resistant coffee varieties and fruits. It is used only for perennial cropland management in the context of the study catchment
Crop rotation	Growing of different crop species sequentially on the same farmland in order to improve the nutrient content of the corresponding cropland. It is applicable only for annual cropland
Intercropping	Growing of two or more crop species at the same time on the same farmland
Soil bund	A type of structural soil conservation practice which is inclined by some degrees against the contour so that excessive runoff is drained to adjoining natural waterways without causing severe erosion
Kolasu	*Kolassu* is an indigenous soil fertility management practice where soils are cultivated during late autumn, immediately after harvest period, so that crop residues are mixed with the soil. The farmers believe that soils which are plowed during late autumn season and 'burnt up' by high temperature of the winter and spring seasons give good yields. NB. High temperatures are recorded in winter and spring seasons in Ethiopia
Xaessu	*Xaessu* is an indigenous soil fertility management practice where cattle are kept on farmland using fenced enclosures made of woods so that the manure and urine of the cattle nourish the soil. It is used only for annual cropland.

The survey questionnaire was used to collect four categories of data. The first category was on farmers' general perception of soil fertility change in annual and perennial cropland. In this category the farmers were asked to indicate their views on soil fertility change as 'decreasing', 'no change', or 'increasing'. The second category was on farmers' view on soil fertility status ranking for four land use types. The farmers were asked to rate the comparative fertility status of soils covered by remnant forest, multistory canopy coffee, coffee monoculture and annual crops as 'very high', 'high', 'medium', ‘low’ or ‘very low’. The third category was on farmers’ views on major indicators of soil fertility change and farmers’ preferences for soil fertility management techniques.

A five-point Likert scale-rating questionnaire was developed to evaluate farmers’ perceptions towards soil fertility change and their preferences for various soil fertility management techniques. Each question contained five response categories that indicate the occurrence of soil fertility changes as ‘very high’, ‘high’, ‘moderate,’ ‘low’ or ‘very low’ with a weighted score value of, respectively, 5, 4, 3, 2, and 1. Similarly, each question on soil fertility management technique contained five response categories of preferences; ‘very high’, ‘high’, ‘moderate’, ‘low’ or ‘very low’ with a weighted score of 5, 4, 3, 2, and 1, respectively. Finally, percentage and mean values of these responses were computed to evaluate farmers’ perception towards soil fertility change and their priorities for soil fertility management techniques both for annual and perennial cropland. The questionnaire was pre-tested by using split-half method to check for its internal consistency, and a Cronbach’s alpha (α) of 0.8 was obtained. The questionnaire survey was supplemented by an interview with key informants, who were selected based on the nomination of development agents.

Results and discussions

Farmers’ understanding of soil fertility change

While annual and perennial crops were grown side by side on smallholder farms, intercropping of tree and herbaceous crops was less common in the study catchment. Coffee (*Coffea arabica* L.) was a single most important cash crop in the perennial cropping system.

Farmers’ perception towards soil fertility change in annual and perennial cropland was more or less the same. Most of the farmers perceived that the nutrient content of the soil is decreasing both in annual and perennial cropland. However, the proportion of farmers who noticed soil fertility decline in annual cropland was higher by 21.4% than the proportion of farmers who noticed soil fertility decline in perennial cropland. About 19.9% of the farmers perceived that the nutrient content of soil is increasing in perennial cropland, whereas only 2.2% of the farmers perceived an increasing soil nutrient content in annual cropland (Table 6.2).

Table 6.2. Farmers' perception of soil fertility change in annual and perennial cropland (N = 136)

Land use type	Farmers' response							
	Decreasing		No change		Increasing		Total	
	No.	%	No.	%	No.	%	No.	%
Annual cropland	132	97.1	1	0.7	3	2.2	136	100
Perennial cropland	103	75.7	6	4.4	27	19.9	136	100

It is likely that the farmers assume that perennial crops protect soil of the corresponding farm fields against erosion and soil degradation. Various indicators show that soil fertility decline can be high in coffee farms with no adequate shade, on steep slopes and in new coffee plantations (Hartemink, 2006). Farmers are also less aware of below-ground processes of soil, such as leaching, nutrient mining, soil acidity or alkalinity that result in soil fertility decline than the above-ground process of soil degradation (Mcdonald et al., 2003). Therefore, a smaller proportion of farmers perceived soil fertility decline in perennial cropland than in annual cropland. An interviewee in Bonaya Asabi *Kebele* explained his observation of soil fertility change in perennial cropland as flows.

> A few decades ago, coffee plants were grown under diverse tree species. Most of these trees were dried up due to old age, some were destroyed by wind and others were used up for timber and firewood. Tree seedlings which we plant in coffee farm are rarely grown because of damage by small ruminants which graze on undergrowth of the coffee plant. As a result, the coffee farm is gradually shifting towards coffee monoculture, and becoming more and more susceptible to soil degradation. (Field interview 2014)

Farmers' rating of soil fertility status for the four land use types is presented in Table 6.3. The finding indicated that forestland, multistory canopy coffee farm, coffee monoculture and annual cropland were ranked first, second, third and fourth, respectively (Table 6.3). This implies that the farmers associate soil fertility status with the density of soil cover.

With the average score value of 4.2, forestland soils were rated as the most fertile of all land use types. About 44.9% and 40.4% of the total interviewed farmers perceived that the fertility of soils of remnant forestland was very high and high, respectively (Table 6.3). Nearly 93% of the farmers considered that the fertility of soils of multistory canopy coffee farm was higher than or equal to the median score value (≥ 3) of the soil fertility rating index, and only 7.3% rated it as below the median score (< 3). Soils of coffee monoculture were rated as moderate by 67.6% of the respondents, and they attained an average score of 2.8. Soils used for annual crop production came at the bottom of the ladder of the soil fertility indices with an average score value of 1.6. About 47.8% and 46.3% of the total respondents indicated that the fertility of soils used for annual crop production was low and very low, respectively.

Table 6.3. Farmers' view on soil fertility status in four land use types (N = 136)

Land use type	Number and percent of farmers' rating					Mean
	5	4	3	2	1	
Remnant forestland	61(44.9)	55(40.4)	10(7.3)	2(1.5)	8 (5.9)	4.2
Multistory canopy coffee farm	6(4.4)	67(49.3)	53(39.0)	7(5.1)	3(2.2)	3.5
Coffee monoculture	4(2.9)	6(4.4)	92(67.6)	28(20.6)	6(4.4)	2.8
Annual cropland	2(1.5)	3(2.2)	3(2.2)	65(47.8)	63(46.3)	1.6

Notice: 5 = very high, 4 = high, 3 = moderate, 2 = low, 1 = very low, N = total number of respondents, and numbers in parentheses are percentages.

Previous studies also indicated positive associations between density of soil cover and soil nutrient content (Eni et al., 2011; Iwara et al., 2011). Therefore, the farmers were aware of the detrimental effect on soil resources of land use change from natural ecosystem to agricultural land use and agroecosystem transformation from multistory canopy coffee farm to coffee monoculture. It appeared that farmers thought in a systematic way to evaluate the fertility of their soil, and their evaluation was also harmonious with that of the technical evaluation of researchers.

Local indicators of soil fertility change

Understanding of farmers' knowledge of soil nutrient decline and its contributory factors is a key to any effort to alleviate the problem (Teklu & Gezahegn, 2003). While 132 (97.1%) of the total interviewed farmers noted soil fertility decrease in annual cropland, only 103 (75.7%) perceived soil fertility decrease in perennial cropland (Table 6.2). The farmers used combinations of indicators, such as physical (rills, soil friability, plough/hoe layer and runoff), biological (weeds, crop colors, earthworms and crop yield) and chemical (soil color and fertilizer requirement of cropland) to evaluate soil fertility change. The farmers noted that the rates of the occurrence of these indicators were specific to the land use types (Table 6.4).

Increasing fertilizer requirement of croplands was the main indicator of soil fertility decline in annual cropland. Of the total farmers who noticed soil fertility decline in annual cropland, 75% responded that an increase in fertilizer requirement of annual cropland was very high. This means that annual cropland is demanding more fertilizer inputs through time owing to the decreasing nutrient content of the soil. An old farmer described his observation on increasing fertilizer requirement of cropland, which also subsequently modified the cropping pattern of the area as follows.

> I am 55 years old. During my childhood, maize was the single dominant and most productive cereal crop grown in this village. We used to grow maize without any animal manure or chemical fertilizer input. Nowadays, maize does not respond at all unless aided by chemical fertilizer, animal manure or both. Because maize is demanding more and more fertilizer input, the farming system is being shifted towards sorghum, millet, sweet potatoes and coffee which require less fertilizer than maize. (Field interview 2014)

Table 6.4. Farmers' rating of soil fertility change indicators in Arsamma Watershed, Southwestern Ethiopian Highlands

Indicators of soil fertility decline	No. and % of farmers' rating for annual cropland (**N = 132**)							No. and % of farmers' rating for perennial cropland (**N = 103**)						
	5	4	3	2	1	Mean	Rank	5	4	3	2	1	Mean	Rank
Physical indicators														
Increasing incidence of rills	40(30.3)	42(31.8)	33(25.0)	14(10.6)	3(2.3)	3.8	3	0(0)	0(0)	8(7.8)	31(30.1)	64(62.1)	1.5	10
Decreasing soil friability	4(3.0)	9(6.8)	42(31.8)	58(43.9)	19(14.5)	2.4	7	5(4.9)	11(10.7)	22(21.3)	32(31.1)	33(32.0)	2.3	7
Decreasing plough (hoe) layer	11(8.3)	18(13.6)	44(33.5)	46(34.8)	13(9.8)	2.8	6	8(7.8)	22(21.4)	34(33.0)	21(20.4)	18(17.4)	2.8	5
Increasing incidence of muddy runoff	50(37.9)	46(34.8)	24(18.2)	8(6.1)	4(3.0)	4.0	2	4(3.9)	1(1.0)	17(16.5)	31(30.1)	50(48.5)	1.8	8
Average	105 (19.9)	115(21.8)	143(27.1)	126(23.9)	39(7.4)	**3.25**	**II**	17(4.2)	34(8.3)	81(19.7)	115(27.9)	165(40.0)	**2.10**	**III**
Biological indicators														
Emerging of unusual weeds on infertile soils	2(1.5)	5(3.8)	6(4.5)	57(43.2)	62(47.0)	1.7	10	0(0)	2(1.9)	18(17.5)	26(25.2)	57(55.4)	1.7	9
Incidence of crop color change to yellowish	7(5.3)	6(4.5)	27(20.5)	73(55.3)	19(14.4)	2.3	8	23(22.3)	25(24.2)	29(28.2)	14(13.6)	12(11.7)	3.3	3
Decreasing incidence of earthworms	19(14.4)	25(18.9)	50(37.9)	32(24.3)	6(4.5)	3.1	5	18(17.5)	25(24.3)	25(24.3)	23(22.3)	12(11.6)	3.1	4
Decreasing yield per unit of land	25(18.9)	31(23.5)	58(43.9)	12(9.2)	6(4.5)	3.4	4	7(36.0)	19(18.4)	24(23.3)	14(13.6)	9(8.7)	3.7	1
Average	53(10.0)	67(12.7)	141(26.7)	174(33.0)	93(17.6)	**2.63**	**III**	48(19.0)	71(17.3)	96(23.3)	77(18.7)	90(21.9)	**2.95**	**I**
Chemical indicators														
Increasing fertilizer requirement of cropland	99(75.0)	22(16.7)	11(8.3)	0(0)	0(0)	4.7	1	16(15.5)	39(37.9)	32(31.1)	6(5.8)	10(9.7)	3.4	2
Incidence of soil color change to reddish	1(0.8)	4(3.0)	27(20.5)	87(65.9)	13(9.8)	2.2	9	4(3.9)	9(8.7)	30(29.1)	37(35.9)	23(22.4)	2.4	6
Average	100(37.9)	26(9.9)	38(14.4)	87(33.0)	13(4.9)	**3.45**	**I**	20(9.7)	48(23.3)	62(30.1)	43(20.9)	33(16.1)	**2.90**	**II**

Notice: 5 = very high, 4 = high, 3 = moderate, 2 = low, 1 = very low, N = total number of respondents, and numbers in parentheses are percentages. The bold values are aggregate average of mean or rank.

With the average score value of 3.7, yield reduction per unit of land was the most important indicator of soil fertility decline in perennial cropland (Table 6.4). This means that yield decline was more severe for coffee (the major perennial crop in the region) than for cereals. While production of cereal crops was relatively aided by agricultural extension services, it was observed that coffee soils lack any rigorous approach of organic, inorganic, biological and ISFM. Hence, yield reduction was found to be a more important indicator of soil fertility decline in perennial cropland than in annual cropland. Increasing muddy runoff was the second most important indicator of soil fertility decline in annual cropland (Table 6.4). About 37.9% and 34.8% of the total farmers who noticed soil fertility decline in annual croplands indicated that the extent of increasing muddy runoff was very high and high, respectively (Table 6.4). An interviewee in Buko Asabi *Kebele* explained his observation of increasing water erosion problem as follows.

> About thirty or thirty-five years ago most of the land in our village was densely vegetated. We could get clean water here and there in fields during summer season. The runoff from coffee farm and grazing land was very clean. We even used to wash our legs with this runoff sometimes. Nowadays crop cultivation is ‘climbing up’ a hill, and the land is becoming less and less vegetated. Hence, everything changes to mud even after a little rainfall. (Field interview 2014)

In the case of perennial cropland, increasing fertilizer requirement of cropland was the second most important indicator of soil fertility decline. Crop color change from green to yellowish was the third important indicator of soil fertility decline in perennial cropland, and the increasing incidence of rills was the third most important indicator of soil fertility decline in annual cropland (Table 6.4).

The mean score value given in Table 6.4 also indicated that decreasing yield per unit of land, decreasing incidence of earthworms, decreasing plough layer, decreasing soil friability, increasing incidence of crop color change to yellowish, soil color change to reddish and emergence of unusual weeds on infertile soils were in decreasing order of importance from the rank of four to ten in indicating soil fertility decline in annual cropland. On the other hand, decreasing incidence of earthworms, decreasing hoe layer, soil color change to reddish, decreasing soil friability, increasing incidence of muddy runoff, emergence of unusual weeds on infertile soils and increasing incidence of rills were in decreasing order of importance in indicating soil fertility decline in perennial cropland (Table 6.4).

In summary, chemical parameters were the most important indicators of soil fertility decline in annual cropland. This was mainly attributed to the increasing fertilizer requirement of annual cropland, mainly that of cereals, with which the farmers were familiar. Soil fertility decline in perennial cropland was primarily described by biological indicators because of the long duration of crops on perennial farmland, which helped the farmers to observe more color change on perennial crops than on annual crops. Yield reduction had a higher index value of 3.7 in indicating soil fertility decline in perennial cropland than in annual cropland which had an index value of 3.4 (Table 6.4), as production of annual crops, mainly cereals, was better supported by agricultural extension than coffee. Physical and biological indicators ranked, respectively, second and third for annual cropland, whereas chemical and physical indicators ranked, respectively, second and third for perennial cropland.

These findings indicate that the rate of soil fertility decline and the rate of the occurrence of the contributory factors were land use specific. Therefore, land use specific soil fertility management interventions are required to address the problem of soil fertility decline in the study catchment.

Towards prioritizing farmers’ preference for soil fertility management planning

A study of farmers’ understating of soil fertility decline is useful only if farmers are aware of soil fertility management strategies that can be used to alleviate the problem. Farmers’ decision to use a particular soil fertility management strategy is influenced by their perceptions and preferences, as discussed earlier.

Various soil fertility management techniques, such as structural (soil bunds), organic (organic fertilizers), inorganic (chemical fertilizers), biological (agroforestry, crop rotation and intercropping), ISFM and indigenous (*xaessu* and *kolasu*) were practiced in the study catchment (Table 6.1). Farmers' preference for these soil fertility management techniques was found specific to the types of land uses. Integrated Soil Fertility Management was at the top of farmers' preferences with an average score of 4.8 for annual cropland (Figure 6.1). Empirical evidence indicate that ISFM is a cost effective, locally adaptive and sustainable soil fertility management approach that enables small-scale farmers to overcome the many limitations of other soil fertility management strategies used in Sub-Saharan Africa (Mutegi & Zingore, 2014; Sanginga, 2012; Vanlauwe et al., 2014). In the case of perennial cropland, it was agroforestry that was at the top of farmers' preference of soil fertility management indices (Figure 6.1). Agroforestry is believed to be an irreplaceable soil fertility management option for the highly dissected topography, increasing land fragmentation and degradation problems of the Ethiopian highlands (Badege & Abdu, 2003). It bridges the conflicting outcomes that persist between the effects of most agricultural practices and the goals of environmental management programs of developing countries (Tarigan & Darma, 2002). It is highly likely that farmers in the study watershed were well aware of the multiple benefits of ISFM and agroforestry. Therefore, prioritizing ISFM for the annual cropland and tree-based soil fertility management for perennial cropland is expected to give feasible outcomes.

While chemical fertilizer application was the second choice for annual cropland, organic fertilizer was the second choice of the farmers for perennial cropland management. The third preferences were organic fertilizer and ISFM, for annual and perennial cropland, respectively (Figure 6.1).

Crop rotations, soil bunds, *kolasu*, intercropping and *xaessu* were ranked, respectively, fourth, fifth, six, seventh and eighth for the management of annual cropland, but, chemical fertilizer, intercropping, soil bunds and *kolasu* were ranked, respectively, fourth, fifth, sixth and seventh for the management of perennial cropland (Figure 6.1).

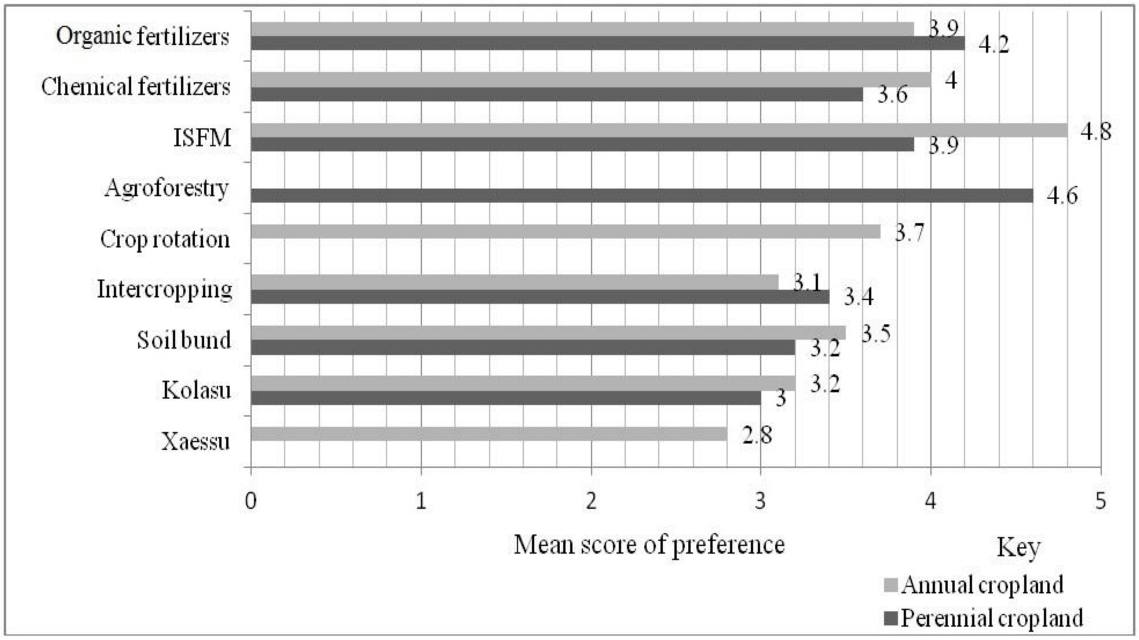

Figure 6.1. Indices of farmers' preference for various soil fertility management techniques.

There was no report of lime application during the preliminary survey. However, soils of the region are strongly acidic (Abdenna et al., 2013; Achalu et al., 2012). About 67% of soils in Wellega province (the province which encloses the study catchment) were estimated to have a pH value of less than 6; of which 34% were very strongly acidic (pH value of 4.5 to 5) (Mesfin, 2007). Therefore, supplying lime to the farmers at affordable costs in order to treat the acidic soils of the region can improve the efficiency of other soil fertility management techniques used in the catchment.

In general, the farmers were well aware of soil fertility decline and the detrimental effect of land use change from natural ecosystem to agricultural land use. They were also aware of the negative impact of agroecosystem transformation from multistory canopy coffee farm to coffee monoculture. Therefore, the issue of farmers' capability is very important for soil fertility management planning. Therefore, soil fertility management programs should consider the land use pattern of the catchment, and farmers' relative priorities for various soil fertility management techniques for different land use types.

Conclusions and recommendations

The study indicated that the farmers are well aware of soil fertility decline and the detrimental effect of land use change from natural ecosystem to agricultural land use. The farmers have a good understanding of the negative impacts of agroecosystem transformation from multistory canopy coffee farm to coffee monoculture. The findings also showed that the farmers associated soil nutrient content with the density of soil cover, which was also supported by the technical evaluation of researchers. However, a smaller proportion of farmers perceived soil fertility decline in perennial cropland than in annual cropland. This is likely to be because farmers are less aware of below-ground soil processes, such as leaching, nutrient mining or soil acidity than the above-ground process of soil degradation.

A number of physical, chemical and biological indicators were used by the farmers to indicate soil fertility change. The farmers noticed that the rates of the occurrence of these indicators were different between annual and perennial cropland. Increasing fertilizer requirement of cropland was the main indicator of soil fertility decline in annual cropland, whereas yield reduction per unit of land was the main indicator of soil fertility decline in perennial cropland. This implies that the rate of soil fertility decline and the rate of the occurrence of the contributory factors were influenced by land use types.

The farmers used various structural, organic, inorganic, biological, integrated and indigenous approaches to alleviate the problems of soil fertility decline. However, farmers' relative priorities for these soil fertility management techniques were different for the annual and the coffee-based perennial cropland. While ISFM was at the top of farmers' preference for annual cropland, agroforestry was their top preference for perennial cropland. Although soils of the study region were acidic, no lime application was reported.

Therefore, the study suggests that agricultural extension services need to educate farmers about below-ground processes of soil nutrient deterioration by various pedogenic processes. This can encourage farmers to give adequate care to soil fertility decline in perennial cropland. Soil fertility management programs need to consider the land use pattern of the area and farmers' priorities for various soil fertility management techniques, both for annual and perennial cropland. Prioritizing ISFM for annual cropland and agroforestry for the coffee-based perennial cropland is advisable. Lime supply at affordable costs so as to treat the acidic soils of the annual cropland can improve the efficiency of soil fertility management practices of the farmers.

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Chapter 7

Summary and Conclusion

Soil nutrient decline is one of the major environmental challenges threatening the livelihoods of millions of farm households in Ethiopia. The problem varies spatially depending on variation in geology, relief, ecology, rainfall, land use and population pressure. It is exceptionally severe in the highlands of the country where the majority of human and livestock population is concentrated. Hence, there is a strong need to study soil fertility change and soil fertility management practices in order to alleviate the problems in this region. A typical watershed was selected for this purpose. The general objective of the study was set to evaluate soil fertility change and soil fertility management practices, and then to indicate the need and possibilities of scaling up Integrated Soil Fertility Management adoption, agroforestry-based spatial land use integration and land use specific soil fertility management practices in Arsamma Watershed, Southwestern Ethiopian Highlands. The study catchment is located in western part of the Oromia National Regional State of Ethiopia at about 475 km west of Addis Ababa, the capital of Ethiopia. It extends from 9°05’-9°12’ N and 35°40’-35°50’ E, and covers a total area of 115.4 km^2.

Land use change from natural ecosystem to agricultural land use, and agroecosystem transformation were the critical environmental problems responsible for the declining soil nutrients in the Arsamma watershed. Conversion of natural forests to annual cropland, and the creation of pure standing coffee monoculture from forests and multistory canopy coffee farms had detrimental effects on the nutrient content of the soil. Forestland contained higher silt, organic matter, total nitrogen, exchangeable calcium and exchangeable magnesium content than annual cropland. Decreasing levels of organic matter, total nitrogen, cation exchange capacity and exchangeable bases were observed, sequentially, in forestland, multistory canopy coffee farm, coffee monoculture and annual cropland. This decreasing trend was attributed to the increasing magnitude of soil erosion and decreasing biomass inputs to the soil following the decreasing density of soil cover.

Similar land use types with different species composition and different intensities of canopy layer, the multistory canopy coffee and coffee monoculture in the case of this study, had different impacts on soil properties. Next to forest soils, soils of the multistory canopy coffee farm contained high organic matter, total nitrogen and exchangeable bases content. This indicates that promotion of multistory canopy coffee farm is one of the potential ways of alleviating soil fertility decline resulting from land use change and agroecosystem transformation. Hence, working towards certification of shade grown and/or organic coffee, which helps the farmers to obtain premium prices from the international coffee market or carbon trade, can help the promotion of multistory canopy coffee farm and reduces the rate of agroecosystem transformation, and then soil fertility decline. Tree species in the coffee farm can be preserved through promotion of rural electrification and energy saving stoves. Taking into account the global coffee market shift towards green consumerism and organic coffee products, it is advisable to focus on organic approaches of coffee soil fertility management.

Soils of the study area were strongly acidic regardless of land use types. This low pH value was possibly attributed to both natural and human induced factors. The natural factors include the acidic nature of volcanic parent material from which the soil was formed, high topographic dissection and torrential rainfall which accelerate removal of basic cations, and rapid decomposition and mineralization of organic matter due to high temperature and moisture condition of the region. Mining of basic cations due to continuous cropping, low organic matter input and continuous application of acid inducing chemical fertilizers, such as urea and DAP to annual cropland could be the major human induced factors. This strong soil acidity could be the major bottleneck of agricultural production and productivity in the study catchment. Hence, promotion of Integrated Soil Fertility Management adoption, application of calcium carbonates, use of structural and biological soil conservation measures are the way out to arrest the problem. Modifying the land use strategies by incorporating acid tolerant plant species can be an important means of adapting to the acidic soils of the study catchment.

Soil nutrient content was also influenced by farmers' resource endowment (farmland and livestock size). Decreasing tendencies of soil nutrient contents and increasing patterns of soil acidity and soil compaction were observed as one hypothetically moves from farmlands owned by the rich farmers through that of the intermediate to farmlands owned by the poor households. Soil organic matter content significantly varied across farmlands owned by the poor, medium and rich households, among others. About 61% of the variability in organic matter content was attributed to variation in farmland and livestock size; and a unit decrease in farmland size was found to reduce organic matter content by 0.3 units. This tendency of association between farmers' resource endowment and soil nutrient content was attributed to the effect of farmland size and livestock number on soil fertility management practices, such as application of chemical fertilizers, organic fertilizers, graded soil bund and crop rotation, which were the major soil fertility management practices in the study catchment.

The farmland size managed by the use of chemical fertilizers, organic fertilizers, soil bund and crop rotations significantly varied across the three wealth groups. Farmland and livestock number explained about 66% of the variability in farmland size amended by chemical fertilizer application. A unit increase in farmland size and livestock number was found to increase the size of farmland amended by chemical fertilizer application by 0.2 and 0.02 units, respectively. About 34% of the variability in farmland size amended by organic fertilizer was explained by variation in farmland and livestock size. For one unit increase in farmland size and livestock number, the size of farmland fertilized by organic fertilizer was predicted to increase by 0.1 and 0.04 units, respectively. Similarly, applications of soil bunds and crop rotations were significantly and positively influenced by farmers' resource endowment. These all indicate that the four aspects of soil fertility management: chemical (chemical fertilizer), organic (organic fertilizer), structural (soil bund) and biological (crop rotation) were influenced by farmers' resource endowment.

The combined effect of variation in farmers' resource endowment, soil fertility management practices and soil nutrient contents reflected on the yield of the staple crops grown in the study catchment. The average cereal crop yield (maize, sorghum, finger millet and barley) varied from 13.75 for the poor, 15.61 for the medium to 18.91 qt/ha for the rich households. This variation was statistically significant. An average yield gap of 5.2, 1.9 and 3.4 quintal/ha was observed between the poor and rich, poor and medium and medium and rich households, respectively. Farmland and livestock size explained about 56% of the variability in the average crop yield harvested per unit of land. For one unit decrease in farmland and livestock size, the average crop yield per unit of land was predicted to decrease by 6.4 and 4.6 units, respectively.

This intimate association of farmers' resource endowment with soil fertility management practices, soil nutrient contents and agricultural yield performance inevitably results in widening of wealth differences that ultimately aggravates soil fertility decline, and forces the poor farmers to become both the agents and victims of soil fertility decline. This means that rural poverty in general and the decreasing per capita farmland and livestock size in particular, are the major challenges of sustainable soil fertility management in the study catchment. Therefore, pro-poor approaches of soil fertility management need to be a top environmental policy priority. It was observed that rural poverty, informal land market, climatic fluctuation that affects coffee yields, and the volatile international coffee markets were the major factors driving high farmland size inequalities in the study catchment. Hence, provision of credit services without tightened pre-conditions can tackle the problem of land market which is always heightened during poor coffee yield and/or prices. Subsidizing chemical fertilizers and working towards fair international coffee market can be possible ways of encouraging sustainable soil fertility management. Promotion of off-farm and non-farm livelihood strategies can alleviate the pressure on agricultural lands so that the poor farmers can get access to farmland through land lease or share cropping agreement. Changing or modifying the land use strategies to land saving agricultural practices, such as improved coffee-based agroforestry can assure sustainable soil fertility management and then can enhance sustainable livelihood in the study catchment.

It is widely recognized that Integrated Soil Fertility Management and agroforestry are the most holistic, economically feasible and environmentally sustainable soil fertility management options that enable the many limitations of various soil management strategies and soil nutrient decline that smallholder farmers face in Sub-Saharan Africa, including Ethiopia.

Yet, adoption of ISFM was influenced by complex sets of socioeconomic, institutional, farm characteristics and other farm-related variables in the study catchment. Farmland size, farmer training, participation in agricultural extension, duration of chemical fertilizer application and farmer's perception towards continuous use of mono-chemical fertilizers were the major factors driving adoption of ISFM; and between 49% to 71% of total variation in adoption of ISFM was explained by these variables. Strong positive association was observed between farmland size and adoption of ISFM. This is a challenging problem since the poor farmers, who had limited farmland size, are unlikely to adopt ISFM. This problem can be alleviated by promoting non-farm economic sectors that minimizes pressure on agricultural lands. Hence, farmers with limited farm size can be benefitted through share cropping or other land leasing agreements. Pro-poor approaches (subsidizing chemical fertilizers, promoting leguminous crop rotations, supply of agro-minerals at low costs) can be some possible ways of scaling up adoption of ISFM. The positive impact of farmer training and participation in agricultural extension programs on adoption of ISFM, and the small involvement of farmers in these programs indicate the presence of actionable room for all stakeholders concerned with the promotion of ISFM adoption.

Upscaling of indigenous agroforestry and agroforestry-based spatial land use integration were influenced by complex sets of variables related to demographic (age and gender), socioeconomic (wealth status, farm size, labor potential and livestock size), institutional (education level, tenure security and participation in agricultural extension program) and farm characteristics and farm-related variables (home-farm distance, farmers' production orientation and access to seedling). Access to seedling was the most important determinant of agroforestry upscaling; and farmers' production orientation, farmland size and wealth status ranked, second, third and fourth, respectively. Farmers' participation in agricultural extension program was the most important factor influencing inter-plot organic fertilizer transfer while wealth status, livestock size, access to seedling and gender ranked, sequentially, second, third, fourth and fifth. The influence of wealth status on inter-plot income flow exceeded all other factors, followed sequentially by access to seedling, participation in agricultural extension and education level. Hence, agroforestry-centered diversified small scale agricultural commercialization need to be promoted so that the agricultural practice is environmental friendly on one hand and it protects the farmers against production and market risks on the other hand. Close integration of the tree-crop-livestock farming system of the area can enhance agricultural sustainability, resource use efficiency, sustainable livelihood and resilience to climatic change. Towards this end, farmer-centered scientific experimentation is very critical to identify trees, crops and livestock species which are compatible and synergetic with each other. Because of the shortage of grazing land, small ruminants deserve better attention than cattle and equines, so that the tree-crop-livestock farming system is efficiently integrated on the available limited farmland. Supply of multi-purpose tree species and disease resistant coffee varieties need a key consideration in agricultural extension program of the area. Pro-women and pro-poor rural development approaches deserve a priority in order to scale up the traditional coffee-based agroforestry and the spatial symbiotic integrity of the land uses for sustainable soil fertility management.

Proper understanding of farmers’ knowledge of soil fertility change and their preferences for soil fertility management techniques is indispensable to promotes wider adoption and scaling up of sustainable soil fertility management. Farmers of the study catchment were well aware of soil fertility decline and the detrimental effect of land use change from natural ecosystem to agricultural land use. Their evaluation of soil fertility status was also apparently in agreement with that of the technical evaluation of researchers. A smaller proportion of the farmers, however, perceived soil fertility decline in perennial cropland than in annual cropland as the farmers appeared to be less aware of below-ground processes of soil degradation by processes such as leaching, nutrient mining and soil acidity. This indicates the need of cultivating farmers’ knowledge of below-ground processes of soil degradation so that the farmers give appropriate weight to soil fertility decline in perennial cropland.

The farmers inferred soil fertility decline from combinations of physical, chemical and biological indicators. These indicators showed that the magnitude of soil fertility decline and the rate of the occurrence of the contributory factors were land use specific. While increasing fertilizer requirement of cropland was the main indicator of soil fertility decline in annual cropland, decreasing yield per unit of land was the main indicator of soil fertility decline in perennial cropland. In alleviating the problem of soil fertility decline, farmers' preference for soil fertility management techniques was specific to the land use types. Integrated soil fertility management was at the top of farmers' preference for annual cropland, and agroforestry was the first choice of the farmers for perennial cropland. Empirical studies indicate that ISFM and agroforestry are the two most promising and sustainable soil fertility management in Tropical Africa, including Ethiopia. Therefore, proper understanding of the cropping pattern of the area and farmers' priorities for various soil fertility management techniques need to be prioritised for soil fertility management planning. Hence, it is advisable to move rigorously towards wider adoption of ISFM for annual cropland and scaling up of the traditional coffee-based agroforestry for the perennial cropland. Spatially symbiotic, and mutually synergetic integration of the tree-crop-livestock farming system of the study catchment need to be a top environmental policy priority in order to encourage not only sustainable but also land use specific soil fertility management practices in Arsamma Watershed, and in other areas with similar agro-ecological settings.

Appendices

Appendix 1. Questionnaire

Household ID-------------------

Dear respondent,

You have been randomly chosen for this interview. The purpose of this interview is to understand soil fertility management practices in annual-perennial cropping system of Arsamma watershed. Your genuine responses are extremely valuable for the success of this study, and will be kept in complete confidentiality and anonymity.

A. Socioeconomic, demographic, institutional and farm characteristics expected to influence soil fertility management practices

1. Name of the interviewee ---Age -------
   Sex: 1. Male 2. Female (circle one)
2. What is the size of your family? --------------
3. For how long have you been practicing agricultural activities? --------- (years)
4. Did you attend formal schooling? 1. Yes 2. No (circle one)
5. If your answer is '**yes**' to question no.4, what was the highest grade you completed? -------- (grade level)
6. Have you ever participated in farmer training program? 1. Yes 2. No
7. If your answer is '**yes**' to question no.6, for how much duration?----------- (weeks)
8. Do you have any off-farm income generating sources? 1. Yes 2. No
9. What is the total size of your farmland? --------- (*sanga*). *NB: (4 sanga = 1ha).*
10. How many farmland plot(s) do you have? ----------
11. How many person(s) in your family carry out agricultural activates per day on average? ---------- (estimated in labor equivalent to adult person)
12. How many hired labor(s) do you employ to perform agricultural activities per month on average, if any? ----------
13. How much is the average distance of your farmland from your home on average? ---------- (minutes taken on walk)
14. How do you evaluate the distance of your farmland from your home on average? 1. Far 2. Medium 3. Near
15. Have you ever received consultancy service on how to manage the fertility of your soil? 1. Yes 2. No
16. Do agricultural extension workers visit your farmland? 1. Yes 2. No
17. If your answer is '**yes**' to question no.16, how many visits per cropping season on average?---------

18. Do you feel that your farmland belongs to you at least in your life time? 1. Yes 2. No
19. If your answer is ‘**no**’ to question no. 18, please specify the reason(s).------------------- ---
20. Do you have access to television or radio? 1. Yes 2. No
21. Do you have access to credit service? 1. Yes 2. No
22. Have you ever participated in agricultural extension program? 1. Yes 2. No
23. If your answer is ‘**yes**’ to question no. 22, for how many years?---------------
24. If your answer is ‘**no**’ to question no. 22, what were the hindering factors? ------------ ---
25. Have you ever applied chemical fertilizer (s) to your farmland? 1. Yes 2. No
26. If your answer is ‘**yes**’ to question no. 25, for how much duration?----------(year)
27. Do you think that continuous application of mono-chemical fertilizer to farmland harm soil health? 1. Yes 2. No
28. How do you evaluate the agricultural practices towards which you are inclined? 1. Coffee production 2. Annual crop production 3. Livestock rearing 4. Coffee and annual crop production 5. Coffee production and livestock raring 6. Livestock rearing and coffee production 7. Mixed coffee-annual crop-livestock production
29. Do you face a problem of crop damage by wildlife? 1. Yes 2. No.
30. How do you evaluate the slop of your farmland on average? 1. Steep 2. Moderate 3. Flat

B. Land utilization, farmland size, livestock size and crop yield performance

1. Please indicate the size of your farmland as specified in the following table, if any.

Land use type	Multistory Canopy coffee	Coffee monoculture	Other perennials	Annual cropland	Fallow land	Grazing land
Area (*sanga*)						

2. Please indicate the size of your farmland and crop yield you obtained during the last cropping season as specified in the following table, if any.

Crop type	Multistory Canopy coffee	Coffee monoculture	Maize	Sorghum	Millet	Barley
Area (*sanga*)						
Yield (qt.)						

3. How do you evaluate crop yield that you have been harvesting per unit of land? 1. Increasing 2. Decreasing 5. No change

4. If your answer is ‘**decreasing**’ for question no. 3, please specify the extent of the following possible causes by putting ✓ in the space provided.

Factors	Very high	High	Moderate	Low	Very low
Soil fertility decline					
Climate variability					
Crop pests and disease					
Crop damage by wildlife					
Other, please specify					

5. Please indicate the number of your livestock in the space provided below, if any?

Livestock type	Cattle	Sheep	Goat	Donkey	Mule	Horse
Number						

6. How do you evaluate the number of livestock you have been rearing since you have started farming, if any? 1. Increasing 2. Decreasing 3. No change
7. If your answer is ‘**decreasing**’ for question no. 6, what were the major reasons?---------
----

C. Integrated Soil Fertility Management, agroforestry upscaling and agroforestry-based spatial land use integration

1. Have you ever applied chemical fertilizer (s), organic fertilizer (s) and improved seed on the same farm plot during the same cropping season? A. Yes B. No.
2. If your answer is ‘**yes**’ to question no. 1, please indicate if there was any additional treatment that you made to the same farmland during the same cropping season.--------
----
3. Do you use chemical and organic fertilizer with improved coffee varieties on the same farm plot? A. Yes B. No.
4. If your answer is ‘**yes**’ to question no. 3, please indicate if there was any additional treatment that you made to the same farmland ---
----
5. Do you exercise upscaling of your coffee farm by incorporating multi-purpose tree species, disease resistant coffee varieties and/or fruits? 1. Yes 2. No
6. If your answer is ‘no’ to question no. 5, please indicate the major hindering factors. ----
----
7. Do you produce organic fertilizer (either in the form of compost or animal manure) from plants grown in your perennial cropland? 1. Yes 2. No
8. If your answer is ‘**yes’** to question no. 7, do you apply the fertilizer you produce to annual cropland? 1. Yes 2. No

9. Do you use the income you generate from perennial cropland to amend the fertility of your soils used for annual crop production, if any? 1. Yes 2. No
10. Do your livestock get adequate feed? A. Yes B. No.
11. Do you grow forage plants in your coffee farm? 1. Yes 2. No
12. Do you have access to agroforestry seedlings? 1. Yes 2. No
13. Do you have access to improved coffee seedlings? 1. Yes 2. No
14. How do you evaluate the integration of your annual and perennial cropland in improving the fertility of your soil, if any? 1. Strong 2. Moderate 3. Weak
15. How do you evaluate the integration of your cropland and livestock in improving the fertility of your soil, if any? 1. Strong 2. Moderate 3. Weak
16. How do you evaluate the overall richness of shade tree species in your coffee farm, if any? 1. Increasing 2. Decreasing 3. No change

D. Perception of soil fertility changes and preferences for soil fertility management techniques

1. How do you evaluate the fertility of your soils used for annual crops production, if any? 1. Increasing 2. Decreasing 3. No change
2. If your answer is '**decreasing**' for question no. 1, please list the major possible causes.
   i)---
   ii) ---
   iii) ---
   iv) ---
   v) ---
3. If the response is '**decreasing'** for question no. 1, please go to question no. 7, column **A**.
4. How do you evaluate the fertility of your soils used for perennial crops production, if any? 1. Increasing 2. Decreasing 3. No change
5. If your answer is **'decreasing'** for question no.**4**, please list the major causes?
   i)---
   ii) ---
   iii) ---
   iv) ---
   v) ---

6. If the response is '**decreasing**' for question no. 4, please go to question no. 7, column **B.**

7. Please indicate the rate of the occurrence of the following farmland attributes through which you may evaluate soil fertility decline in annual and perennial cropland by putting ✓ in the space provided.

Indicators of soil fertility decline	Extent of occurrence in annual cropland: *Column **A***					Extent of occurrence in perennial cropland: *Column **B***				
	Very high	High	Moderate	Low	Very low	Very high	High	Moderate	Low	Very low
Increasing incidence of rills										
Incidence of soil color change to reddish										
Decreasing soil friability										
Decreasing plough (hoe) layer										
Increasing incidence of muddy runoff										
Emerging of unusual weeds on infertile soils										
Incidence of crop color change to yellowish										
Decreasing incidence of earthworms										
Increasing fertilizer requirement of cropland										
Decreasing yield per unit of land										
Other, please specify										

8. Please indicate the relative fertility status of soils used for the following land use types by putting ✓ in the space provided.

Land use type	Very high	High	Moderate	low	Very low
Coffee monoculture					
Multistory canopy coffee farm					
Forestland					
Annual cropland					

9. Please specify if you have applied the following soil fertility management practices during 2012/13 cropping season by putting ✓ in the space provided; and indicate the farmland size under each treatment, and rank your preference as specified in the table.

Types of soil fertility management	Annual cropland				Perennial cropland			
	Yes	No	If 'yes' area in *sanga*	Preference (1st, 2nd, 3rd etc)	Yes	No	If 'yes' area in *sanga*	Preference (1st, 2nd, 3rd etc)
Organic fertilizers								
Chemical fertilizers								
Soil bund								
Crop rotation								
Agroforestry								
ISFM								
Xaessusu								
Intercropping								
Kolasu								
Others								

E. Miscellaneous

1. Did you apply chemical fertilizer to your farmland during 2012/13 cropping season? 1. Yes 2. No
2. If your answer is '**yes**' to question no.1, please specify the total volume of fertilizer you used and the crop types to which the fertilizer was applied as specified below.

Fertilizer types	Quantity (kg)	Area (*Sanga*)	Crop type (s) to which the fertilizer was applied
Urea			
DAP			
Urea+ Dap			

3. Do you use soil bund to protect your farmland from soil erosion? 1. Yes 2. No
4. If your answer is '**yes**' to question no. 6, please specify the total length of soil bund you have on your farmland? ----------- (m).
5. Have you ever applied lime to your soil? 1. Yes 2. No
6. Do you use chemical spray to protect coffee berry diseases? 1. Yes 2. No

Appendix 2. Guidelines for key informant interview

- Indicators' of farmers' wealth status
- Causes for farmland size variation
- Major soil fertility management practices
- Context of Integrated Soil Fertility Management
- Context of agroforestry upscaling, inter-plot organic fertilizer transfer and inter-plot income flow
- Factors influencing crop rotation
- Factors influencing animal rearing
- Access to improved seedlings
- Indicators of soil fertility decline
- Soil fertility decline and possible solutions
- Tree-crop interface, wildlife and soil fertility management
- Agroecosystem transformation and soil fertility status

Appendix 3. Soil data

SC	Site	LUT	Sand (%)	Silt (%)	Clay (%)	pH (H_2O)	OC (%)	OM (%)	TN (%)	C:N (ratio)	CEC (meq./ 100g)	BD (g/cm^3)	PD (g/cm^3)	TP (%)	Av.P (ppm)	Exchangeable Bases (meq./100g)				BS (%)
																K	Na	Ca	Mg	
1A	DS	ACL	31.00	21.25	47.75	3.80	1.84	3.16	0.31	10.19	6.94	1.42	2.65	46.42	0.4	0.17	0.22	1.64	1.84	55.76
1B$^{(PWG)}$	US	ACL	58.00	13.75	28.25	3.83	1.23	2.12	0.11	19.27	17.48	1.38	2.65	47.92	2.0	0.09	0.22	2.50	1.76	26.14
2A$^{(RWG)}$	DS	ACL	17.50	23.75	58.75	4.31	2.17	3.73	0.18	20.72	12.36	1.34	2.65	49.43	6.4	0.27	0.24	2.70	1.94	41.67
2B$^{(PWG)}$	US	ACL	17.50	18.75	63.75	4.17	1.76	3.03	0.14	21.64	11.62	1.25	2.65	52.83	5.6	0.70	0.23	3.17	2.37	55.68
3A	DS	RF	30.00	26.25	43.75	5.46	2.47	4.25	2.27	1.87	18.20	1.18	2.65	55.47	10.0	0.38	0.17	4.31	2.05	37.97
3B	US	RF	32.50	36.25	31.25	5.17	2.88	4.95	2.17	2.28	12.20	1.13	2.65	57.36	3.2	0.98	0.18	5.45	2.65	75.9
4A$^{(MWG)}$	DS	ACL	42.50	23.75	33.75	4.23	1.47	2.53	0.14	18.07	18.58	1.42	2.65	46.42	4.8	0.52	0.15	4.00	2.19	36.92
4B$^{(MWG)}$	US	ACL	42.50	13.75	43.75	4.38	1.19	2.05	0.13	15.77	17.92	1.30	2.65	50.94	2.4	0.16	0.13	4.25	1.83	35.55
5A$^{(PWG)}$	DS	ACL	55.0	16.25	28.75	4.14	1.27	2.18	0.12	18.17	6.38	1.56	2.65	41.13	3.2	0.07	0.20	3.50	1.74	86.36
5B$^{(PWG)}$	US	ACL	50.00	33.75	16.25	4.33	1.15	1.98	0.08	24.75	6.20	1.57	2.65	40.75	1.6	0.09	0.13	1.75	1.76	60.16
6A	DS	MCC	45.00	36.25	18.75	5.22	2.17	3.73	0.39	9.56	17.02	1.20	2.65	54.72	14.4	0.55	0.19	5.02	2.22	46.89
6B	US	MCC	35.00	32.5	32.50	4.75	2.33	4.01	0.21	19.10	16.26	1.33	2.65	49.81	4.4	0.23	0.33	3.70	1.90	37.88
7A	DS	CM	26.25	28.75	45.00	4.25	2.74	4.71	0.14	33.64	11.58	1.45	2.65	45.28	14	0.16	0.20	7.50	1.83	83.68
7B	US	CM	25.00	31.25	43.75	4.44	1.47	2.53	0.23	11.00	11.42	1.37	2.65	48.30	4.0	0.53	0.12	3.00	2.20	51.23
8A	DS	CM	17.50	31.25	51.25	4.25	1.92	3.3	0.09	36.67	31.25	1.07	2.65	59.62	2.4	0.13	0.25	6.60	3.80	34.50
8B	US	CM	17.50	31.25	51.25	4.24	0.94	1.62	0.17	9.53	11.90	1.16	2.65	56.23	2.0	0.26	0.42	2.50	1.93	42.94
9A	DS	CM	45.00	26.25	28.75	4.71	2.41	4.15	0.23	18.04	13.66	1.32	2.65	50.19	5.2	0.26	0.37	4.73	1.93	53.37
9B	US	CM	33.75	26.25	40.00	4.79	1.35	2.32	0.14	16.57	13.80	1.25	2.65	52.83	2.0	0.20	0.26	6.67	1.87	65.22
10A	DS	MCC	20.00	33.75	46.25	5.07	1.61	2.77	0.30	9.23	19.34	1.15	2.65	56.60	5.2	0.05	0.18	3.52	1.72	28.28
10B	US	MCC	25.00	31.25	43.75	4.90	1.30	2.24	0.18	12.44	16.84	1.10	2.65	58.49	5.2	0.15	0.13	1.62	1.82	22.09
11A	DS	MCC	30.00	26.25	43.75	5.23	2.62	4.51	0.23	19.61	23.68	1.10	2.65	58.49	4.4	0.85	0.50	4.32	2.52	34.59
11B	US	MCC	27.50	16.25	56.25	5.12	1.47	2.53	0.22	11.50	12.88	1.05	2.65	60.38	18.0	0.61	0.12	4.55	2.28	58.7
12A	DS	RF	20.00	33.75	46.25	4.58	2.09	3.59	0.35	10.26	14.74	1.14	2.65	56.98	9.2	0.39	0.66	7.82	2.06	74.15
12B	US	RF	20.00	46.25	33.75	4.34	2.27	3.90	0.19	20.53	10.32	1.04	2.65	60.75	18.4	0.16	0.24	5.63	1.83	76.16

Appendix 3 continues

SC	Site	LUT	Sand (%)	Silt (%)	Clay (%)	pH (H$_2$O)	OC (%)	OM (%)	TN (%)	C:N (ratio)	CEC (meq./ 100g)	BD (g/cm^3)	PD (g/cm^3)	TP (%)	Av.P (ppm)	Exchangeable Bases (meq./100g)				BS (%)
																K	Na	Ca	Mg	
13A$^{(RWG)}$	DS	ACL	27.50	23.75	48.75	4.26	2.94	5.06	0.25	20.24	19.14	1.45	2.65	45.28	7.6	0.41	0.31	3.50	1.88	31.87
13B$^{(MFW)}$	US	ACL	20.00	21.25	58.75	4.00	1.64	2.82	0.21	13.43	19.74	1.31	2.65	50.57	7.6	0.81	0.15	3.50	1.81	31.76
14A	DS	CM	17.50	31.25	51.25	4.86	2.15	3.70	0.31	11.94	18.46	1.13	2.65	57.36	4.4	0.16	0.22	2.55	1.83	25.79
14B	US	CM	15.00	28.75	56.25	4.18	1.57	2.70	0.27	10.00	19.34	1.02	2.65	61.51	2.4	0.09	0.15	3.25	1.76	27.15
15A	DS	RF	17.50	36.25	46.25	4.37	2.64	4.54	0.41	11.07	24.54	0.73	2.65	72.45	4.4	0.25	0.37	6.72	1.92	37.73
15B	US	RF	15.00	31.25	53.75	5.25	2.30	3.96	0.23	17.22	17.54	0.89	2.65	66.42	6.0	0.12	0.38	4.59	1.79	39.22
16A	DS	MCC	11.25	28.75	60.00	5.44	1.47	2.53	0.33	7.67	17.12	1.16	2.65	56.23	4.4	0.22	0.33	6.00	1.89	49.3
16B	US	MCC	22.50	25.00	52.5	4.11	2.90	4.99	0.21	23.76	16.52	1.17	2.65	55.85	5.2	0.12	0.15	4.11	1.79	37.35
17A	DS	MCC	16.25	33.75	50.00	4.60	2.70	4.64	0.23	20.17	13.06	1.52	2.65	42.64	3.2	0.25	0.37	4.41	1.92	53.22
17B	US	MCC	8.75	43.75	47.50	4.27	1.64	2.82	0.17	16.59	13.14	1.21	2.65	54.34	2.8	0.48	0.19	3.00	2.15	44.29
18A$^{(MWG)}$	DS	ACL	16.25	26.25	57.50	4.50	1.90	3.27	0.21	15.57	13.06	1.60	2.65	39.62	7.2	0.09	0.15	2.25	1.76	32.54
18B$^{(RWG)}$	US	ACL	28.75	26.25	45.00	4.56	2.58	4.44	0.20	22.20	20.76	1.35	2.65	49.06	4.0	0.34	0.46	3.25	2.01	29.19
19A	DS	RF	13.75	21.25	65.00	5.68	2.30	3.96	0.31	12.77	27.00	1.20	2.65	54.72	4.0	0.55	0.35	6.00	3.22	37.48
19B	US	RF	26.25	26.25	47.50	5.36	2.15	3.70	0.21	17.62	23.56	1.10	2.65	58.49	2.8	0.12	0.15	4.59	2.79	32.47
20A	DS	CM	31.25	18.75	50.00	4.44	1.33	2.29	0.28	8.18	12.68	1.20	2.65	54.72	2.8	0.13	0.15	2.60	1.80	36.91
20B	US	CM	26.25	26.25	47.50	4.20	2.29	3.94	0.17	23.18	12.16	1.15	2.65	56.60	14.0	0.18	0.49	2.65	1.85	42.52
21A$^{(RWG)}$	DS	ACL	28.75	28.75	42.50	4.32	1.33	2.29	0.29	7.90	15.76	1.40	2.65	47.17	8.0	0.35	0.32	5.50	2.02	51.97
21B	US	ACL	41.25	26.25	32.50	4.76	1.78	3.06	0.23	13.30	11.40	1.43	2.65	46.04	8.8	0.20	0.33	3.25	1.87	49.56

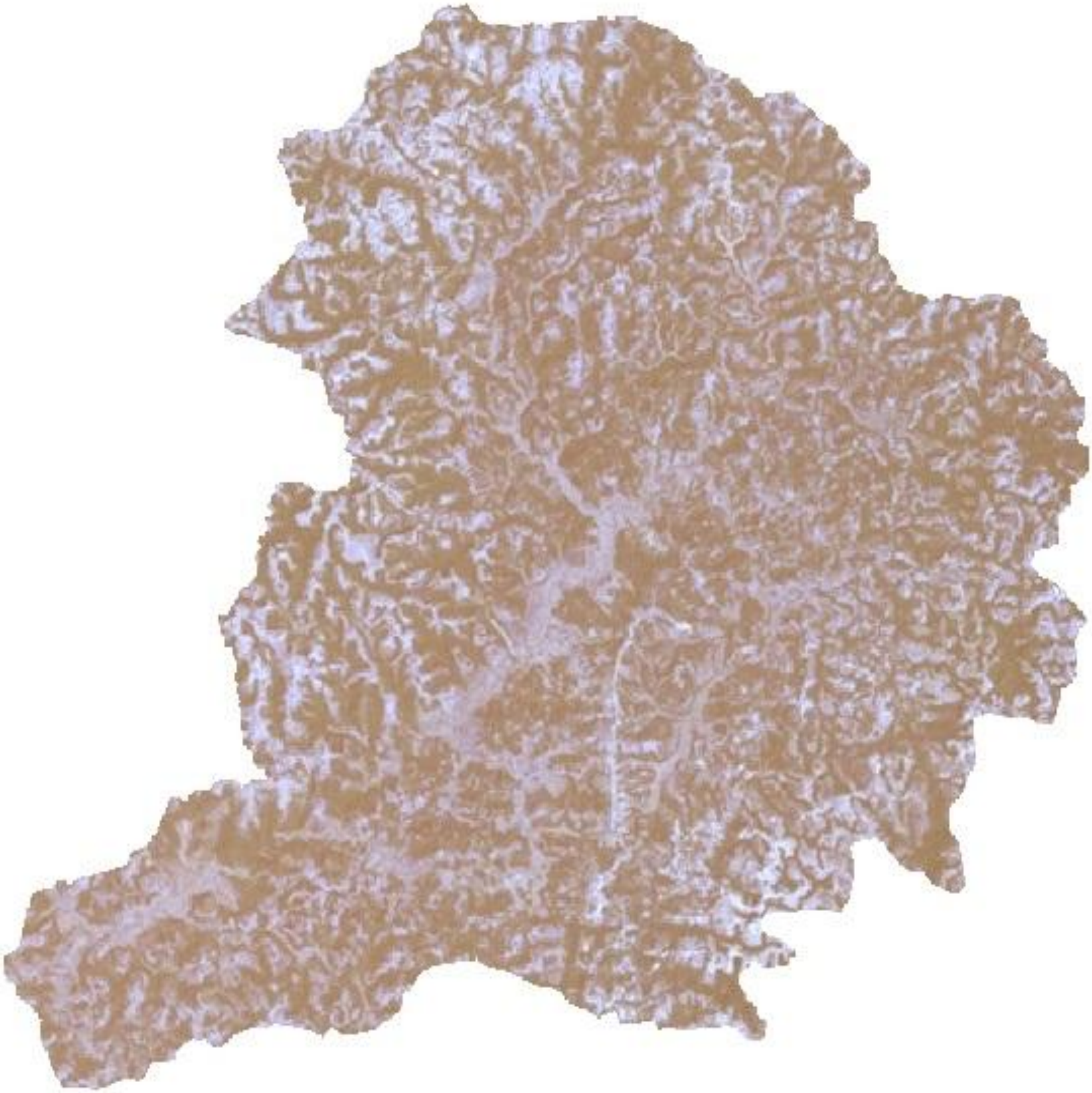
Note: SC (Sample Code); PWG (Poor Wealth Group); RWG (Rich Wealth Group); MWG (Medium Wealth Group); LUT (Land Use Type); ACL (Annual Cropland); CM (Coffee Monoculture); MCC (Multistory Canopy Coffee); RF (Remnant Forest); WG (Warm Group); BD (Bulk Density); TP (Total Porosity); pH (soil pH); OC (Organic Carbon); OM (Organic Matter); TN (Total Nitrogen); C:N (Carbon to Nitrogen Ratio); Av. P (Available Phosphorus); CEC (Cation Exchange Capacity); Ca^{2+} (Exchangeable Calcium); Mg^{2+} (Exchangeable Magnesium); K^{+} (Exchangeable Potassium); N^{+} (Exchangeable Sodium); BS (Base Saturation).

Appendix 4. Temperature and rainfall records at Gimbi Meteorological Station (1981-2010)

Temperature (^{o}C)	J	F	M	A	M	J	J	A	S	O	N	D	Mean/Total
Mean Maximum	27.94	28.98	29.74	28.93	26.64	24.05	22.82	22.68	24.13	25.34	25.80	26.88	26.16
Mean Minimum	13.58	14.40	15.32	15.49	14.58	13.37	12.98	12.91	12.95	13.39	13.22	13.39	13.80
Mean Monthly	20.76	21.69	22.53	22.21	20.61	18.71	17.90	17.80	18.54	19.37	19.51	20.14	19.98
Rainfall (mm)													
Mean Monthly	2.85	7.93	24.37	64.92	177.02	319.89	359.09	329.29	314.13	126.02	17.05	4.09	1946.63

Source: National Meteorological Agency of Ethiopia

Appendix 5. Satellite image showing land use/cover types in Arsamma watershed (TM 2011, path 168 and row 057)



Appendix 6. Pictures showing land use types in Arsamma watershed

A. Remnant forests

B. Multistory canopy coffee farm

C. Mixed coffee-fruits (scaled up agroforestry)

D. Tendency towards coffee monoculture

E. Annual and perennial crops side by side

F. Topographic dissection and gully erosion

Declaration

I, the undersigned, declare that this thesis is my original work, and all sources used in the dissertation have been duly acknowledged.

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Signature: ________________________

Date: ____________________________