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Land Use/Cover Changes and the Role of Agroforestry Practices in Reducing Deforestation and Improving Livelihoods of Smallholders in Maytemeko Watershed, Northwest Ethiopia

Dissertation for obtaining a doctorate degree at the
University of Natural Resources and Life Sciences, Vienna, Austria

Submitted by

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Vienna, March 2015

Declaration

I, the undersigned, hereby declare that this is my original research work and all the resources and materials used are duly acknowledged. This work has not been submitted to any other educational institutions for achieving any academic degree awards.

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Acknowledgments

First and foremost, I praise the Almighty God, who helped me throughout my life and to begin and finish this study through the intercession of Virgin Saint Mary and the prayers of all other Saints.

My deepest and heartfelt gratitude extends to my supervisor Prof. Herbert Hager, who accepted me as his student and went through each step of my work from the draft proposal to the final thesis write up including field visit and guidance in Ethiopia. Without his continuous support, encouragement, scientific guidance and patience, it would have not been possible to finish the work as it would. I learned a lot from his lifelong experience more than I express in words. I would like to express my deepest gratitude to my co-supervisor Dr. Monika Sieghardt for her unreserved support from the beginning to the end by giving valuable scientific comments. I sincerely thank Prof. Demel Teketay for his scientific guidance, valuable comments and encouragement throughout my study. His continuous, unreserved support including Skype discussions are unforgettable. I am also grateful for Dr. Belayneh Ayele for his help and support during my field work.

I would like to thank all members of the Institute of Forest Ecology for socialization and friendship during my stay. I am grateful to Prof. Klaus Katzensteiner for his help in statistical analysis part and Prof. Helmut Schume for his help in graphics and translating the abstract to German language. My kind appreciation goes to Marcel Hirsch for his unreserved help during soil laboratory analysis. I am also grateful for Martin Wresowar for his help in computer related issues. I thank Sigrid Gubo and Victoria Iby for helping me in administrative issues.

I am grateful to the Austrian Partnership Programme in Higher Education and Research Development (APPEAR) for giving me the scholarship award to pursue my study in Austria. I thank Elke Stinnig for her help during the application of the scholarship and her kind help to facilitate my trip to Ethiopia when I had personal problem in the between. I am very grateful to Prof. Herbert Hager and Dr. Monika Sieghardt for covering the expenses of the workshop. I thank the staffs of OeAD Regional Office for their contribution in administration issues during my stay in Austria. I would like to extend my appreciation to Hulet Eju Enessie District and Motta Town Agriculture and Development Office experts and development agents in the watershed for their valuable information and help during data collection. All district offices who allowed me to use their vehicles when I was in field work are highly acknowledged. My appreciation goes to Haimanot Abiy for his help in tree measurement and organizing the workshop in Motta. I thank Abate Tsegaye, from ARARI, Gondar Centre for sharing his expertise about future management of the watershed during the workshop. My heartfelt appreciation goes to farmers in the watershed for giving me their time for discussion, interviews, workshop participation and their hospitalities during my field work. I am grateful to Melsew Worku, Dessalegn Bekele, Yilkal Tsegaye, Kefale Belay, Zelalem, Abebe and Alemayehu for their help during data collection. I am grateful to my home institution, University of Gondar for the study leave. I would like to thank the staffs of Department of Geography and Environmental Studies for their encouragement and support. I am grateful to Demis Mengist, Assayew Nebere and Tirualem for signing as a bail for my academic leave.

I am grateful to my Ethiopian friends at BOKU University, Dr. Tesfaye Feysa, Dr. Abrham Abiyu, Dr. Menale Wondie Dr. Sayeh Kassaw, Dr. Lalisa Alemayehu, Dr. Shimelash Zeleke, Dr. Hailemariam Birke, Tesfaye Getachew, Yosef Tewodros, Dessie Assefa, Getu Abebe, Kumela Gudeta, Assaminew, for their friendship and socialization. I am grateful to Dr. Menale Wondie for his help in remote sensing and Getu Abebe for his graphics help. I would like to extend my deepest gratitude to my best friends and sisters Atiklt Abebe, Atsede Desta, Dr. Lemlem Behailu, Dr. Kahsa Tadele Dr. Wossen Argaw and Dr. Atitegeb Meaza for their friendship, encouragement and valuable advice during my stay in Vienna. Your contribution is great for the success, God bless you all!

I am very grateful to Ethiopian Orthodox Church Community in Vienna and members of the Sunday school in Kidanemihret Church for their valuable contribution in my spiritual life. My special appreciation goes to my spiritual and respected father Melake Sibhat Aba Birhanu Kassaw for his prayers, advice and encouragement from the beginning to the end. I am also grateful to Woizero Menbere, Samrawit and Tariku for their invitation to pass enjoyable holidays in their home. Really, I feel at home when I was with you. I thank Ato Seifu and his wife Tewabu, Dn Dawit, Dn Yared for their spiritual service in the church.

I would like to extend my thanks to my families, my father Ato Kassie Desta and my mother W/ro Tobiyanesh Yenesew, my mother in low Amahu Getinet, my sisters, brothers, nephews, nieces, cousins, and in laws for their prayers, encouragement and moral support for the success. I thank Alem, Tize, Wale, Fasik, Yilkal Kassa and his families for their frequent visit and taking care of my husband at the time of difficulty when I was away.

Last but not least, I am grateful to my beloved husband Adugna Getachew, for endurance and understanding when I was away for such a long time and his continuous encouragement and prayer throughout my study. Here after, God's will, no more loneliness Adu.

Finally, this work is dedicated to my younger brother, Teshome Kassie who passed away at the age of 22, a year after his graduation in forestry.

"Thanks be unto God for His unspeakable gift!" 2 Corinthians 9: 15

Abstract

Increasing demands for agricultural land to feed the growing population and high dependency of the people on biomass fuel for energy are causing extensive degradation of the natural resource base in the highlands of Ethiopia. These vicious cycles exacerbate the food insecurity problem in the country. On the other hand, agroforestry practices could have a potential contribution to save the remaining forest and improve the livelihoods of smallholders. However, the potential of these practices have not been given much attention both in forest resource assessment and agriculture studies. The main objective of this study was to assess the extent of deforestation through land use/cover changes over time and to examine the potential of agroforestry practices in reducing burden on natural forest resources and improving the livelihoods of smallholders in the Maytemeko Watershed. Data was generated from two series of satellite images of 1986 and 2011, field surveys and measurements, household questionnaire surveys, focus group discussions, interviews and workshops. The result showed that the area of cropland increased at the expense of the forestland, shrubland and grassland over the 25 years. Tree planting in homegardens, alley cropping, small-scale woodlots and scattered trees on farmlands were identified as major agroforestry practices in the watershed. Soil OC, N, available P (Ava P) and exchangeable K^+ were significantly higher in agroforestry land use types (LUTs) compared with the single cereal croplands. The relative soil improvement index (RSII) showed that farmlands with *Croton macrostachyus* Del. exhibited the highest soil nutrient contents followed by soils from homegardens (HG) and from alley cropping with *Rhamnus prinoides* L'Herit. With respect to canopy conditions in HG, soils under tree canopies showed significantly higher macro nutrient contents than soils outside the canopies. Furthermore, soils covered by indigenous tree species showed significantly higher OC, N, Ava P and K^+ than those beneath canopies of exotic tree species. The contribution of agroforestry to the overall fuelwood production was high, which helped to reduce wood extraction from natural forests and shrubland areas. Agroforestry LUTs also showed better economic returns than the mono-cropping ones. A survey showed that farmers were aware of the decline in forest cover and farmland productivity in the watershed through time. Moreover, they had recognized the importance of planting trees to improve soil fertility, which was supported by lab analyses of the soil. However, farmland shortage, free grazing and land tenure insecurity were pointed out by farmers as major constraints of tree and shrub planting in agroforestry. Since agroforestry could be the best option for sustainable management of both the forest and soil resources, in turn improving the livelihoods of smallholders, its implementation in wider areas should be encouraged.

Key words: Soil improvement, fuelwood, food security, indigenous trees

Zusammenfassung

Der steigende Bedarf an landwirtschaftlicher Fläche zur Ernährung der Bevölkerung einerseits und die hochgradige Abhängigkeit von Biomasse als Energieträger andererseits verursachen im Hochland von Äthiopien eine flächige Degradation der natürlichen Ressourcenbasis. In einem Teufelskreis verschärft das die unsichere Ernährungslage im Land. Agroforstwirtschaft (AF) ist ein potentieller Beitrag, den verbliebenen Wald zu erhalten und gleichzeitig die Lebensgrundlage von Kleinbauern zu verbessern. Dem Potenzial derartiger Landnutzungspraktiken wurde bisher weder in forstlichen Überlegungen noch in landwirtschaftlichen Studien eine entsprechende Aufmerksamkeit zuteil. Diese Arbeit zeigt anhand des Maytemeko Einzugsgebiets das Ausmaß der Entwaldung durch Landnutzungsänderung über 25 Jahre, sowie das Potenzial der AF, die Belastung natürlicher Waldressourcen zu verringern und die Lebensgrundlage von Kleinbauern zu verbessern. Als Datenquellen dienten Satellitenbilder aus den Jahren 1986 und 2011, sowie eigene Felderhebungen und Messungen, Befragungen von Haushalten mittels Fragebögen, Diskussionsrunden mit Betroffenen, Interviews und Arbeitskreise. Die Ergebnisse zeigten, dass in 25 Jahren die landwirtschaftliche Anbaufläche auf Kosten der Wald- und Gehölzfläche und des Grünlandes zunahm. Die Anlage von Baumgärten, Reihenpflanzung von Holzgewächsen in Kombination mit Feldfrüchten sowie kleine Waldungen oder lichte Baumbestände auf landwirtschaftlichen Flächen stellten im Untersuchungsgebiet die bedeutendsten agroforstlichen Praktiken dar. Bodenanalysen ergaben signifikant höhere Gehalte an organischem Kohlenstoff (OC), Stickstoff (N), pflanzenverfügbarem Phosphor (P) und austauschbarem Kalium (K^+) in Böden unter agroforstlicher Nutzung im Vergleich zu monospezifischen Getreidefeldern. Der relative Bodenverbesserungsindex (RSII) zeigte, dass Anbauflächen von *Croton macrostachyus* Del. die höchsten Nährstoffgehalte im Boden aufwiesen, gefolgt von Böden aus Baumgärten und aus Reihenpflanzungen von *Rhamnus prinoides* L'Herit. In Baumgärten wurde festgestellt, dass überschirmte Teilflächen signifikant höhere Makronährstoffgehalte aufwiesen als nicht überschirmte, und außerdem Böden unter dem Schirm heimischer Arten signifikant reicher an OC, N, verfügbarem P und K^+ waren, als Böden unter dem Schirm fremdländischer Arten. Der Beitrag der AF zur gesamten Brennholzproduktion im Einzugsgebiet ist hoch, wodurch Holznutzung in Naturwaldresten minimiert wird. Ökonomisch betrachtet waren agroforstliche Landnutzungsformen rentabler als rein landwirtschaftliche. Eine Umfrage zeigte, dass sich die Bauern des Waldschwundes und der Degradation von landwirtschaftlichen Flächen im Einzugsgebiet bewusst waren. Außerdem hatten sie die bodenverbessernde Wirkung des Anbaus von Holzgewächsen erkannt, was durch chemische Bodenanalysen bestätigt wurde. Mangel an Anbauflächen, freie Weidehaltung und unsichere Besitzverhältnisse wurden jedoch als die entscheidenden

Hemmnisse für den Anbau von Holzgewächsen im Rahmen agroforstlicher Nutzung genannt. AF könnte die beste Option für eine nachhaltige Bewirtschaftung von Wald und Boden darstellen, umso mehr als sie im Gegenzug die Lebensgrundlage von Kleinbauern verbessert. Daher sollte ihre Einführung in größerem Maßstab gefördert werden.
Keywords: Bodenverbesserung, Ernährungssicherheit, Brennholzbedarf, heimische Baumarten

Table of Contents

List of Tables

List of Figures

List of appendices

1.INTRODUCTION

1.1 Background

Deforestation and unsustainable land use are causing extensive degradation of the natural resource base throughout the developing world. A near total loss of tropical forest is foreseen, and newly cleared as well as older agricultural lands suffer from increasing degradation (Angelsen, 2007; Eludoyin, 2011; FAO, 2012). The problem of deforestation is much higher in East Africa than other parts in the continent which have altered the natural forest cover to farmlands, grazing land , settlements and urban centres (Maitima et al., 2009). The main driving force for deforestation in developing countries, including Ethiopia, is population growth (Eludoyin et al., 2011; Yeshaneh et al., 2013). With low productivity of land, the only option of smallholder farmers to feed the growing population is getting more land for crop production.

Ethiopia is a country where the largest share of its economy is derived primarily from agriculture. Moreover, Ethiopia follows an Agricultural Development Led Industrialization (ADLI) policy (Bishaw et al., 2013). However, agricultural production is mostly subsistence in its nature, and a large part of commodity exports are provided by the smallholders' agricultural cash crop sector. The low productivity of the agricultural sector leads to an increasing demand of food in Ethiopia to feed the growing population. As population has been increasing through time, there is an obvious fact that the deforestation rate becomes very high in subsistence farming system leading to changes in land use/cover from forest to cropland, grazing land and settlement areas.

Though there is inconsistency of data about forest resources in Ethiopia, the general trend showed a decline in forest cover through time (Teketay et al., 2010). Between 1955 and 197 9, over 77% forested areas disappeared, and the disappearance continues by 8% of the remaining forests annually (FAO, 2010). Following this, Muluneh (2010) also proved that during 1980–2000, the land cover change showed continuous decline of shrub and forest cover by the expansion of counteracting agricultural and grazing lands. In most parts of the Ethiopian highlands, the expansion of cultivation land continued to very steep slopes and marginal lands that were formerly covered by forest.

This aggravates the problem of soil degradation, especially, in the highlands of Ethiopia through over exploitation of the soil resource and exposing it to water and wind erosion.

Leaving the bare cultivation and grazing lands together with poor management activities aggravated soil degradation problems (Teketay, 2001; Anteneh, 2010).Thus, the soil and water resources, which are crucial for food production are being degraded (Taddese, 2001; Taye, 2006; FAO, 2013a). As a result, essential sources of food, fuel, shelter, medicine, fodder and many other products are disappearing.

The diminishing soil fertility through degradation have resulted in the decline of crop yield in Ethiopia (Taye, 2006). It was shown that productivity of land was the lowest in Africa which is about 1.5 tons ha^{-1} for cereals and around 1.1 tons ha^{-1} for pulses (Taffesse et al., 2011).

The extensive need for energy, which leads to widespread cutting of trees is also becoming another threat in the country for the remaining forest and soil fertility (Teketay, 2004; Duguma, 2010). The majority of the Ethiopian population relies on biomass fuel for energy production (Bewket, 2003; Mekonnen & Kohlin, 2008). Scarcity of firewood has become severe problem in many parts of the country causing a rise in price and, thus, increasing economic burden on the household budget. As a result, animal dung and crop residues are increasingly being used for household fuel rather than improving the fertility of the soil (Teketay, 2001; Taye, 2006; Anteneh, 2010; Duguma, 2010; FAO, 2013a). These vicious cycles of land degradation have become a major threat of the country leading to food insecurity problems.

An increasing food demand in spite of the decline in productivity of farmlands as well as deforestation and use of animal dung and crop residues to satisfy the increasing demand for fuel indicates the urgent need to find alternatives that have the potential to reduce deforestation by fully or partially substituting with wood products outside the forest area. Moreover, the production of fuelwood outside the forest might also have the potential to improve soil fertility by replacing the fuel from animal dung and crop residuals to be used for soil fertility management for smallholder farmers. Trees and shrubs grown in AFPs have the potential to reduce deforestation rate, improving income for smallholder farmers and directly or indirectly contributing to soil fertility improvement (FAO, 2013b).

Smallholder farmers in the study watershed also depend on subsistence farming system leading to further degradation of the forest and soil resources. On the other hand, there are promising agroforestry practices in few pocket areas of the watershed though the potential of these practices in reducing deforestation and improving the livelihoods of farmers was not documented.

1.2 Statement of the problem

Unsustainable land management and long periods of tillage activities are major threats of the agricultural productivity of smallholder farmers in the highlands of Ethiopia. Many studies in different parts of the developing countries of Asia, Latin America and Africa indicated that agroforestry-based intervention strategy has a great potential in addressing environmental degradation problems facing the uplands and hilly lands (Nair, 1993; Russell & Franzel, 2004; FAO, 2013b). For developed countries having smaller proportion of farmers and relatively large area of farmlands, agroforestry may not have equal importance compared to developing nations. In the case of Ethiopia, the majority of the people depend up on limited farmlands leading to further replacement of the forest land by agricultural land to feed the growing population. Now, the use of this fragmented land for separate purpose (i.e. for food crop and tree planting) is not feasible for land users. Agroforestry (multi-purpose use of a plot of land) is a promising option to solve environmental problems and to improve household food security by diversifying farm products, and reducing vulnerability for seasonal food and fodder shortages (Duguma, 2010; Oosting et al, 2011). In line with this idea, it was also indicated that a comprehensive agroforestry-based conservation agricultural system can show promising effects in many parts of Africa for addressing global challenges of food security and climate change (Russell & Franzel, 2004; Garrity, 2004). Moreover, agroforestry has been recognized for its potential to contribute for sustainable development by international policy treaties, such as United Nations Framework Convention on Climate Change (UNFCCC) and the Convention of Biodiversity (CBD), which resulted in substantiating increased investment in its development (FAO, 2013b).

In Ethiopia, the practices of growing agricultural crops and trees along with animal husbandry in home lots has been observed for centuries, even before the term agroforestry was developed (Gebrehiwot, 2004; Yadessa et al., 2006; SLUF, 2006). Despite the tremendous economic and ecological benefits of the multi-strata agroforestry land uses, no adequate efforts have been made to document and improve the practices. it was indicated that although traditional agroforestry practices are playing important roles in improving the livelihoods of farmers in many ways, their economic values, ecological services and social benefits have not been documented (SLUF, 2006). Moreover, it was pointed out that the entire evolutionary development of the practice was left to the farmers who have consistently employed local knowledge inherited from past generations (Yadessa et al., 2006). Duguma (2010) also explained despite superiority of agroforestry practices (AFPs) for livelihoods improvement, the practical limiting factors for implementation and expansion of these AFPs is an essential point to be addressed.

In Ethiopia, greater attention in research has been given to physical measures for soil and water conservation since the drought years of 1970s (Taye, 2006; SLUF, 2006). Few studies concerning agroforestry are also concentrated in some pocket areas of southern Ethiopia. They did not give much attention to the major potentials that AFPs could play for the reduction of deforestation, improvement of livelihoods for smallholder farmers and their contribution to ecosystem services in different agro-ecological regions of Ethiopia. In line with this idea, FAO (2013b) also observed that despite of the fact trees and shrubs in agroforestry often play a significant role for livelihoods of the rural population, they are often overlooked both in forest resource assessments and in policy and decision-making processes. Gebrehiwot (2004) also stated that though Ethiopia faces high rates of deforestation, knowledge on the forest resource and agroforestry farming system is in the process of getting lost. Consequently, the scarcity of information on both the forest resources and AFPs in diverse agro-ecologies made it impossible to draw conclusions on these resources.

This study aimed at filling the gap concerning how the forest cover is changing over time and the potential of AFPs to conserve the remaining natural forest resource at watershed level. Moreover, having paramount differences in agro-ecologies of the country, assessing major agroforestry components at watershed level is believed to have significant importance for sustainable use of the land and expansion of the practices to similar agro-ecological and socio-economic settings in the country that in turn reduces the food insecurity problem.

2. LITERATURE REVIEW

2.1 Land use/cover changes in Ethiopia

Land use/cover change over time is the result of both anthropogenic and physical disturbances occurring worldwide (Clark et al., 2004; Chu et al., 2009; Hong et al., 2010; Eludoyin et al., 2011; FAO, 2012; Wondie et al., 2012; Kindu et al., 2013; Yeshaneh et al., 2013). However, for most developing countries anthropogenic factors are the main driving forces for land use/cover changes. These changes most likely cause a net loss of forest resource in many areas (Maitima et al., 2009; FAO, 2010).

The problem of deforestation is aggravated in developing countries that they are facing major challenges to their rural land use, including, increasing scarcity of wood products and environmental degradation on their fragile agricultural land (Clark et al., 2004; Eludoyin et al., 2011). The transformation of land uses from vegetation cover to farmlands, grazing lands, settlements and urban centres in East Africa is the worst in the world (Maitima et al., 2009).

As it is stated earlier, Ethiopia is one of the countries that is faced with rapid deforestation and land resource degradation problems, resulting in continuous livelihood and food security problems of the people (Bishaw, 2001;Teketay, 2001; Zeleke & Hurni, 2001; Bewket, 2002; Taye, 2006). This causes several socioeconomic and environmental challenges that have strongly affected the capacity of forests to provide ecosystem services (Bishaw, 2001; Teketay, 2001; Teketay 2004; Teketay et al., 2010; Tesfaye et al., 2014).

Ecological and historical studies have demonstrated the dramatic human influences on the forest vegetation of Ethiopia (Zeleke and Hurni, 2001;Tegene, 2002; Teketay et al., 2010; Yeshaneh et al., 2013). Though there are debates on the past forest cover of Ethiopia (Teketay et al., 2010), some estimates indicated that a century ago, Ethiopia had a forest cover of around 40% , which has diminished to less than 3% by now (Bishaw, 2001). On the other hand, FAO (2010) estimates indicated the forest cover of Ethiopia is about 11%. These differences might be related to the method used to estimate the forest cover and differences arising from various definitions of the forest resources of Ethiopia. It was estimated that the annual loss of forest resources of Ethiopia is about 141,000 ha (FAO, 2009). This was the third largest deforestation rate in East Africa next to Sudan and Tanzania. The main driving forces behind deforestation are the expansion of agricultural land, unrestrained exploitation of forest resources for fuel, fodder and construction, overgrazing and establishment of new settlements into forested land coupled with increasing population pressure (Teketay et al., 2010; Mekonnen & Damte, 2011; FAO, 2012; Yeshaneh et al., 2013; Tesfaye et al, 2014). Many plant species are diminishing in number and area of coverage as a result of massive deforestation rates through time.

Various studies in different parts of Ethiopia such as (Zeleke & Hurni, 2001;Tegene, 2002; Yeshaneh et al., 2013; Kindu et al., 2013) indicated that the trend of land use/cover change is in most cases the conversion of forest land to agricultural and grazing lands. A review on land use/cover change at the country level also showed a continued decline in shrub and forest cover during 1980–2000, but improvements in vegetation cover in some areas was observed (Muluneh, 2010). The expansion of cultivated land continued to very steep slopes and marginal lands that lead to land degradation problem in the highlands of Ethiopia (Kindu et al., 2013).

On the contrary, an increasing trend of forest cover was also reported in some areas (Bewket, 2002; Wondie et al., 2011). Bewket (2002) indicated that a slight increase in forest cover in Chemoga Watershed is recognized due to improvement in households' tree planting practices. In Simen Mountain National Park, an increase in forest cover was attributed to the special attention given to the area since the park is one of the world heritage sites (Wondie et al., 2011). However, the overall result showed that Ethiopia is experiencing a high rate of deforestation with little success to reverse the situation through plantation efforts (Muluneh, 2010).

Deforestation is also an important issue in the discussion of fuel consumption of rural households in many developing countries. Various studies have focused on this subject. In Ethiopia, where 94% of the energy comes from bio-fuels like wood, dung and crop residuals (Damte et al., 2012). The Woody Biomass Inventory Strategy Program Project (WBISPP) of the Ministry of Agriculture indicated that among the different biomass energy sources, firewood gathered from common forests takes the largest share that accounts for around 78% of the total energy demand, while animal dung and crop residue account for 12 and 9%, respectively (MOA, 2004).

Thus, the high dependency on forest resources for fire and construction wood from natural open access forest represents further burden on the national forest resource of Ethiopia. Prediction on the forest resource in Ethiopia also showed that, referring to the current trend of development, an area of nine million ha might be deforested between 2010 and 2030 for agricultural land. In the same period, annual fuelwood consumption may increase by 65%, requiring more than 22 million tons of woody biomass, which in turn may further exacerbate forest clearing (FRDE, 2011).

Agroforestry can have significant role to reduce wood harvest pressure in forest through sustainable management of trees on farm (Long & Nair, 1999; Nair, 1993; Duguma & Hager, 2010; Bishaw et al., 2013). In Ethiopia, the contribution of agroforestry trees and shrubs for the increasing wood demand is very high since most of the population depend on wood based products for fuel and construction materials as stated earlier (Damte & Koch , 2011). However, the contributions of trees and shrubs in agroforestry for wood production have not been well documented (Kituyi, 2004; Jama et al., 2008). Therefore, quantification of fuelwood and construction wood consumption from agroforestry trees and shrubs is an important issue to recognize its current significance and to acknowledge its future potential for proper management. It is also believed that the analysis of land use/cover change may help to document the current and past status of the forest cover and to link the trend with current potential of agroforestry to save the remaining forest.

2.2 Aboveground biomass status in forests of Ethiopia

Aboveground biomass (AGB) refers to all living biomass above the soil, including stem, stump, branches, bark, seeds and foliage (Brown & Lugo, 1984; FAO, 2010). Data on AGB status in Ethiopia are very scarce due to various reasons. Few estimates of AGB of the forest were documented (Brown, 1997; Abate, 2004; Sutcliffe, 2006; Sutcliffe, 2009; Watson et al., 2013) in southwest Ethiopia. One of the most important problems in biomass estimation is lack of inventory data on key tree parameters of the natural forests in Ethiopia (Watson et al., 2013).

During the 1980s, the national potential AGB of Ethiopia was estimated at 101 tons ha^{-1} compared with the actual value (52 tons ha^{-1}), showing a degradation ratio of 0.5 of the AGB (Brown, 1997). But the data that was analyzed by WBISPP in 2005 showed that the average AGB of the country is about 58.5 ton ha^{-1} (Moges et al., 2010). However, as stated earlier, many of the studies in land use/cover change indicated that the forest cover of Ethiopia has shown a decreasing trend (Zeleke & Hurni, 2001; Tegene, 2002; Yeshaneh et al., 2013) that could possibly cause reduction in the AGB. Another study also found that deforestation due to land-clearing for agriculture and settlement caused annual losses of 65,540, 91,400, and 76,400 ha of high forest, woodland and shrubland, respectively, that corresponding to woody biomass losses of approximately 3.5 million tons (Sutcliffe, 2006) . This figure also showed discrepancies in estimation of the biomass loss when we compare the area lost and estimated biomass for each forest class documented by Moges et al. (2010) as shown in Table 1. The wood biomass loss alone would be 11.7 million tons y^{-1}. When we expand these values based on the expansion factors 2.74, 6.9 and 8.2 for high forest, woodlands and shrublands as used by Moges et al. (2010), the total biomass loss would be 27.3 million tons. This variation might be due to the uses of different methods for the estimation of the biomass. FAO assessments of AGB in Ethiopia also showed similar trend of reduction. For instance, from years 1990 to 2000, the AGB of Ethiopia showed 12% loss due to forest clearing (FAO, 2010).

Site specific studies on AGB estimation may show better values compared with the gross estimates. In line with this idea, Sutcliffe (2009) found AGB of 82 tons ha^{-1} in Baro Akobo basine. Watson et al. (2013) reported 390 tons ha^{-1}. The study conducted by Abate (2004) also found 13 tons ha^{-1} for selected tree species in the natural forest in Munessa-Shashemene forest.

Recently, the need of biomass data is getting attention in REDD+ and carbon financing projects in Ethiopia. It was indicated that the forest resources in Ethiopia store 2.76 billion tons of carbon in the AGB, which will be released to the atmosphere in 50 years if deforestation continues at the present rate of about 2% (Moges et al., 2010). When forests are transformed into agricultural land, the consequent land use systems implemented determine the amount of potential biomass restocking that takes place. Wood cleared for agriculture involves a complete change in land cover from shrub land, woodland or forest to “non forest land” and an almost complete removal of AGB (Moges et al., 2010). The annual croplands may have maximum carbon in the AGB at the stage of maturity, while they will emit the same amount of carbon during harvest especially if none is returned to the soil. Hence, the net AGB remains nearly zero. This might not be always true when these agricultural plots have managed trees and shrubs that have greater potential in storing AGB or carbon.

The majority of AGB in Ethiopia is derived from woodland forests (45.7%) and shrublands (34.4%) (Table 1). This is due to largest spatial coverage (90% of the forest area) of these two land use types compared with the high forests, which account for only 6.6% of the forest area.

Table 1. Aboveground biomass (AGB) of different forest classes in Ethiopia

Forest category	AGB (tons ha^{-1})	Area (Million ha)	Proportion of Area (%)	Total biomass stock (million tons)	Proportion of AGB (%)
High Forest	213.36	4.07	6.6	868.3752	15.71004
Woodland	85.5	29.55	48.0	2526.525	45.70814
Plantation	246	0.50	0.8	123.0	2.225231
Lowland bamboo	95.0	1.07	1.7	101.65	1.838982
Highland bamboo	168.46	0.03	0.05	5.0538	0.09143
Shrubland	72.08	26.4	42.8	1902.912	34.42617
Total				5527.516	

Source: modified from Moges et al. (2010)

The above data did not include the biomass estimates from AFPs though trees on farmlands have also significant amount of AGB.

The distribution of the AGB in the country also follows the spatial pattern of the forest cover showing the highest AGB in southwest and southern parts of the country and declining as one moves to the east and northern parts of the country (MOA, 2013).

2.3 Soil erosion and nutrient depletion in Ethiopia

Soil erosion and nutrient depletion are seen as the most important biophysical limiting factors which are responsible for the decline in per capita food production in the majority of African small farms (Muzoora et al., 2011). The arable soils in Ethiopia are amongst the oldest in Africa and highly degraded and eroded by a combination of water and wind erosion (Hurni, 1993; Mekonnen & Kohlin, 2008; FAO, 2013a).

Because of intensive cultivation and other natural problems, such as rugged topography and intensive nature of rainfall, vast areas in the highlands of Ethiopia are in danger due to accelerated soil erosion. Compared to other East African and developing countries, Ethiopia is among the countries with the highest soil erosion, with respect to the total available land and 31% of the total land area in the country is eroded by wind and water (FAO, 2013a).

Though there is greater variability in soil loss estimation and prediction, soil loss from cultivation land may reach up to 130 tons ha^{-1} yr^{-1} and 35–42 tons ha^{-1} yr^{-1} in the highlands (Hurni, 1993). Soil nutrient loss is also the highest in East Africa that showed depletion rates of around 122, 13 and 82 kg ha^{-1} yr^{-1} of N, P and K, respectively, from the highlands of Ethiopia (Haileslassie et al., 2005). With an increasing cost of inorganic fertilizer, this depletion rate cannot be replaced by small holder farmers to produce enough food, and the food insecurity problem will continue as a vicious cycle. Mekonnen & Kohlin (2008) also stated that Ethiopia is one of the lowest users of fertilizer in Africa.

Despite agriculture is playing the leading role in its contribution to the national GDP of the country, Ethiopia is currently unable to produce enough food to meet the demands of its ever increasing population (Haileslassie et al, 2006; Vågen et al., 2013; Haile & Mamo, 2013).

Apart from soil erosion by water and leaching losses, removal of harvested crop products and total or partial removal of crop residues from agricultural fields has been one of the major pathways for soil nutrient losses in Ethiopia (Haileslassie, 2005; Haileslassie et al., 2006; Anteneh, 2010). The crop residues are used for animal feed and source of fuel in many parts of the country. Moreover, the potential of animal dung to improve the fertility of the soil might be reduced due to the consumption of this dung as fuel in many parts Ethiopia (Taye, 2006; Duguma, 2010). Four decades ago, nitrogen and phosphorus were identified as being the most deficient soil nutrients in almost all parts of Ethiopian (Haile & Mamo, 2013). On the other hand, Taye (2006) found that on average, a farm household annually uses about 43.5, 9 and 41.4 kg y^{-1} of N, P and K, respectively, through the use of animal dung for cooking in central highlands of Ethiopia. Duguma (2010) also found that 3.22×10^5 kg yr^{-1} cattle dung containing 6.14×10^3 N and 1.1×10^3 kg P was burnt by the studied 381 households that could potentially produce 4.2×10^4 or 5.9×10^4 kg of wheat or maize, respectively, which could have fulfilled the annual cereal requirement of 39 or 55 households with the respective crops. Partial or full replacement of the energy sources from agroforestry may contribute to use animal dung and crop residues for soil fertility management (Bishaw et al., 2013).

2.4 Agroforestry practices (AFPs) and their contribution

2.4.1 Major AFPs in Ethiopia

Agroforestry is not a new concept in Ethiopia. It is an age-old practice whereby farmers maintain trees on croplands. Integration of tree/shrub species into the agricultural activities is believed to have emerged together with agriculture (Hailu & Asfaw, 2011). It is estimated that the growing of fruit crops in widely isolated gardens started during the early periods of Christianity in Ethiopia and the cultivation of both domesticated and wild fruits was reported to have concentrated in monasteries and isolated churches as sources of food for nuns, monks, hermits and warriors (SLUF, 2006).

Agricultural land in Ethiopia is estimated to cover 52.62 million ha which is about 46% of the total area (Brown et al., 2012) and expected to sustain the livelihoods of more than 83% of the population, form 80% of export earnings and 73% of the raw materials in agro-based industries (Bishaw et al., 2013). Though the area of agroforestry system is not well documented, according to some estimates based on satellite imagery for the base year 2006, it was around 2.32 million ha (Brown et al., 2012). The figure did not include scattered trees on crop and grazing lands.

The homegardens are the most popular agroforestry systems in most parts of Ethiopia (Abebe, 2005; Mengistu & Hager, 2009; Agize et al., 2013). Taking altitude, topography, and intensity of land use systems into consideration, Hoekstra et al. (1990) identified AFPs like alley cropping, trees in homegardens, fodder tree planting, trees as living fences, farm boundary and road side planting, trees on contour bunds, and gully planting as age-old AFPs in Ethiopia.

Tesemma (2007) identified nine types of AFPs in various parts of Ethiopia providing diverse ecological and socioeconomic services. These are banana-based multi-storey gardens, tef and acacia integrated agroforestry, boundary eucalyptus and cereal crops in agroforestry, conservation based agroforestry, vertically and horizontally packed agroforestry, multi-strata perennial crop agroforestry, enset-coffee-tree-spice-based agroforestry, fruit trees-bamboo combined with enset-vegetable farming and bamboo combined with cereal farming. These agroforestry systems are primarily aimed at meeting household food needs (Tesemma, 2007; Negash, 2013).

Moreover, Bishaw (2001) indicated that alley cropping with hedgerows of trees or shrubs and annual crops, fodder tree planting mixed with grass and herbaceous legumes on unproductive pasturelands are important AFPs. He also indicated that small-scale woodlots, living fences on farm boundaries and roadsides, and tree planting on contour structures, inside and along gullies are also appropriate AFPs in Ethiopia.

The diverse agro-ecological nature of the country favours various combinations of trees and shrubs with annual and perennial crops. Thus, describing the existing AFPs in few pocket areas may have significant contribution to expand these practices to area with similar physical and socio economic settings.

2.4.2 The role of agroforestry practices

2.4.2.1 Soil nutrient improvement

Soil fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per-capita food production in Sub-Saharan Africa, including Ethiopia (Shepherd et al., 1996; Maithya et al., 2006; Girmay et al., 2008). On the other hand, it is also indicated that trees on farmlands have significant values for soil nutrient improvements either by preventing or mitigating soil erosion, in turn, reducing nutrient losses from the system (Breman, 2001; Bishaw, 2001; Anteneh, 2010) or by increasing the total content of nutrients in the soil-plant system (Haileslassie et al., 2005). Out of the several benefits obtained from agroforestry systems in terms of soil fertility, soil nutrient cycling is the most predominant. In a soil-plant system, plant nutrients are in a state of continuous, dynamic transfer (Breman, 2001) and plants take up nutrients from the soil and use them for metabolic activities. In-turn, these nutrients are returned back to the soil either naturally as litter fall or through pruning and mulching in some agroforestry practices and through root litter (Nair, 1993; Jose, 2009).

Different studies on soil-plant-crop relations in AFPs showed that selected trees and shrubs improve soil fertility which results in boosting of crop yield. For example, Pre-Smith (2010), in his ten years experiment in Malawi, found that using fertilizer trees, such as *Tephrosia vogelii* Hook. f. and *Gliricidia sepium* (Jacq.) Kunth ex Walp., resulted in maize yields that have averaged 3.7 tons ha^{-1} compared with the one ton ha^{-1} in plots without fertilizer trees. The legume tree leaves, which fall naturally or are cut regularly by farmers and spread among the food plants as green manure, decompose and release nitrogen as well as other elements to be used by the crops. About 60% of this released nitrogen is lost to the atmosphere or to the subsoil and streams (leaching), leaving only 40% available to the crops (Garrity, 2004). Sanchez (2002) also pointed out those leguminous trees of the genera *Sesbania, Tephrosia* and *Crotaria* interplanted in maize and allowed to grow as fallow during dry season, accumulate 100 to 200 kg of N ha^{-1} over the period of six months to two years in regions of East and South Africa. Breman (2001) also indicated that the average N concentration in top soil under woody canopies is 1.9 times than the N in open fields.

Agroforestry practices have a potential to provide a valuable organic matter, which improve the nutrient and water holding capacity, increased cation exchange capacity, buffering of the soil against acidification as well as aluminium and iron toxicity (Breman, 2001). The occupation of phosphorus fixation sites by organic matter also increases phosphorus availability (Bishaw, 2001; Breman, 2001; Bishaw et al., 2013). An increase in soil organic matter also contributes indirectly to phosphorus availability by forming organic complexes with aluminium and iron, thus the formation of insoluble iron and aluminium phosphates is prevented (Brady & Weil, 2002).

Studies in Ethiopia also showed AFPs have greater potential in improving soil nutrient status (Gindaba et al., 2005; Anteneh, 2010; Duguma et al., 2010; Manjur et al., 2014) compared with conventional mono-cropping systems. Nutrient depletion studies also showed that higher amounts of soil nutrients are lost from conventional mono-cropping systems than agroforestry systems through crop and crop residual harvest (Haileslassie et al., 2006). Nutrient storage and cycling by woody species might have a positive influence on the understory and annual crop through litter fall and decomposition, which, in turn, increases soil nutrient supply for the understory. On the other hand, Anteneh (2010) also indicated that the soil loss due to rill and inter-rill erosion is higher in open fields than agroforested fields. Understanding site and species-specific variations in tree-soil interactions in agroforestry have crucial and immediate concern to farmers and expertise to improve land productivity (Rhoades, 1997; Muzoora et al., 2011). Natural plant-soil systems also provide a guide for understanding the direction and magnitude of tree influences upon soil nutrient status in agroforestry land use types. But information regarding the effect of multipurpose trees in agroforestry on soil to improve farm level agricultural productivity is very scarce in Ethiopia (Manjur et al., 2014).

2.4.2.2 Ecosystem services

Ecosystem services are the benefits that people gain from the ecosystems for their well-being (MEA, 2005; Nair, 2011). Forest resources are major providers of provisional and regulatory ecosystem services. But deforestation is endangering the provision of these services at local and global levels (Teketay, 2001; Koanga, 2012; Teketay et al., 2010).

Likewise, the forest resources in Ethiopia have reached their worst stage through deforestation creating several socioeconomic and environmental challenges that have strongly affected the capacity of forests to provide ecosystem services (Bishaw, 2001; Teketay, 2001; Teketay et al., 2010). On the other hand, it is also pointed out that agroforestry has a great potential for reduction of deforestation and forest degradation, providing for rural livelihoods and habitats for species outside formally protected areas, and alleviate resource users pressure on conservation areas (Mercer, 2004; Abebe, 2005; Kalaba et al., 2010; Mcneely & Schroth, 2006; Koanga, 2012; Souza et al., 2012).

Biodiversity conservation is one of the most important ecosystem services since trees and shrubs in agricultural systems provide habitat and resources that are otherwise scarce in conventional mono-cropping systems (Yadessa et al., 2006). It was also pointed out that structurally heterogeneous perennial vegetation can provide more niches for native flora and fauna than structurally arranged annual cropping systems and pasture lands (Schroth et al., 2003).

Agroforestry systems also play a significant role on carbon stocks and carbon flows in an ecosystem. A study conducted by Nair (2011) compared aboveground carbon stocks of different land use systems. He found out that while the aboveground biomass carbon under tree-based land use systems increases, the net gain of carbon under annual crops remained nearly zero since the products are removed for human consumption and animal feeds.

Moreover, studies on the contribution of agroforestry trees on below ground carbon sequestration also showed that soils taken under the canopies of the tree with high tree density per unit land area stored more soil organic matter in upper layers of soils even comparable to that under adjacent natural forests (Rhoades, 1997; Manjur et al., 2014). The average net carbon flow for 30 years under agroforestry land use system in Philippines indicated that annually, about 5.65 tons ha^{-1} of carbon accumulated in agroforestry system compared with zero ton ha^{-1} of carbon for maize-based annual cropping system (Predo & Francisco, 2012).

Most of the studies carried out on ecosystem services, such as biodiversity studies and carbon sequestration focus on forest resources and little attention has been given to trees on agricultural landscapes.

2.4.2.3 Economic contribution

The economic potential of AFPs influences the nature and extent of adoption of this practice (Mercer & Hyde, 1991; Nair, 1993). Franzel et al. (2001) also stated that profitability is one of the determinants for the potential adoptions of AFPs. It was also pointed out that national planners are not willing to support AFPs since few analyses have been carried out to assess the profitability of the cultivation and commercial success of tree products in agroforestry (Shackleton et al., 2003). Recently, Leakey (2013) indicated that agroforestry trees and shrubs have never been assessed adequately for their economic and ecological importance. It is now increasingly understood that to encourage agroforestry, there is a need to consider it as a competitive land use, not just as a supplementary strategy to satisfy subsistence needs. This requires detailed evaluation of agroforestry systems with other competing land use systems in terms of financial and economic feasibility. Thus, the intent of financial assessment of land use types, including AFPs, is to provide data and fact for more informed decision making as it concerns regarding the use of scarce resources available to the smallholder farmers (FAO, 1992).

A range of traditional AFPs have been analyzed in different parts of Ethiopia (Gebrehiwot, 2004; Yadessa et al., 2006; SLUF, 2006). But all these studies concentrated on the biophysical aspect of agroforestry. Very few studies were conducted on financial analysis of AFPs in a few parts of Ethiopia. For example, Duguma (2012) carried out financial analyses of small-scale woodlot, homegardens and boundary planting in central highlands of Ethiopia. Collier (2010) compared the financial returns of coffee-enset-based AFPs with that of parkland agroforestry in southern Ethiopia. The former found that small-scale woodlots are economically more attractive compared with the other AFPs in the central highlands of Ethiopia whereas the latter found that coffee-enset based AFPs showed higher economic returns compared with parkland AFPs. The diverse nature of AFPs in different parts of Ethiopia revealed that economic evaluation of specific AFPs in various agro-ecologies is needed for the successful adoption of these practices in specific areas.

2.5 Woody plant species composition and diversity on agricultural landscape

Ecosystems and species important in sustaining human life and the health of our planet are disappearing at an alarming rate due to unwise use of the forest resources in most of the developing countries (Teketay, 2001; Jose, 2009; Betemariam, 2011).

This disaster reveals itself in various ways including global climate change, desertification and loss of biodiversity, which influence human livelihoods at large scale. All forms of land use changes involving land resource utilization affect the biodiversity of an area directly or indirectly (Maitima et al., 2004). The conversion of the forest land to agricultural and grazing land is one of the most devastating procedures causing biodiversity loss through removal of different tree species and influencing the habitat of diverse biological organisms (Maitima et al., 2009; Kindu et al., 2013). This problem is exacerbated in Ethiopia due to over utilization of forest resources to satisfy the food and energy needs of the increasing population in the country (Bishaw, 2001; Bewket, 2003; Betemariam, 2010; Betemariam, 2011).

The threats facing biological diversity call for investigations on the aspects of conservation of biological resources of an area outside the forest since the forest resources of developing countries, including Ethiopia, are declining over time. The term agro-biodiversity specifies the variety and variability of plants, animals and microorganisms that are essential for sustaining key functions of the agricultural system (FAO, 2005). These functions directly denote AFPs on farmlands. In areas where deforestation is very high, the contribution of the agricultural landscape to conserve biodiversity has equal importance with the forest land biodiversity (Jose, 2009). It is pointed out that AFPs are widely contributing for biodiversity conservation in degraded forest areas (Schroth et al., 2003).

Zomer et al. (2009) indicated that 46% of the agricultural lands in the world have more than 10% of the tree cover, and 7.5% of the agricultural lands have tree cover of more than 50%. This shows that AFPs are potential areas of conservation of biodiversity outside the forests and protected areas. Many studies in woody plant diversity in Ethiopia focus on forest lands and give little attention for other agricultural land uses for woody plant composition and diversity analyses. Some of the studies on biodiversity in AFPs particularly in homegardens also concentrated in pocket areas of southern Ethiopia (Abebe, 2005; Agize et al., 2013; Yakob, et al., 2014; Amberber et al., 2014). Tiruneh (2008) conducted a study on friut trees species diversity in western Amhara Regional State. Recently, Asefa & Worku (2014) and Tefera et al. (2014) carried out woody plant diversity analysis on croplands in northern Ethiopia. Woody plant diversity might be affected by specific socio-economic and bio-physical environment. Though there are various woody plants in farmlands of the Maytemeko Watershed, their composition and diversity have not been yet documented. Therefore, biodiversity analysis at specific watershed level may contribute for the conservation of woody plants in particular agro-ecological regions.

2.6 Farmers perception of deforestation and AFPs

As stated earlier, deforestation is continuing at an alarming rate in many parts of Ethiopia, leading to other environmental problems that impose greater pressure on the livelihoods of human population. Perception of farmers towards natural resource degradation problems has its own role for the conservation and management of these resources on the landscape (Taye, 2006).

Though studies on land use/cover change confirmed a decrease in forest cover in many parts of Ethiopia, the limited efforts in restoring the forest cover of the country have not been successful (Zeleke & Hurni, 2001;Tegene, 2002; Yeshaneh et al., 2013). Many governmental and non-governmental organizations have been involved to restore the forest cover of the country since the 1970s. But the rate of deforestation continued unabated. As indicated by FAO (2010), between 1990 and 2000, the deforestation rate of the country was very high compared with the successes in plantation. One of the reasons for the failure of the attempts was the perception of farmers towards deforestation problems. Amsalu & Graaf (2006) indicated that farmers' decision to preserve natural resources is determined by their knowledge on the severity of the problems and the perceived benefits of conserving the natural resource base.

It was also witnessed that farmers started to cut trees even from the protected areas during the transition period of the two governments at the beginning of the 1990s (Holden & Pender, 2003). This indicates that either forest owner protection was not accepted by the people during the 'Derg' regime or people were less aware of the advantages of the forest resources since many of the conservation and plantation practices were practiced with massive and forceful actions. Like that of other natural resource management activities, forest protection and management also need the acceptance of farmers using benefit sharing. Every year, it has been reported that paramount seedlings are planted in communal areas to reverse the forest cover in Ethiopia, but with little success.

A general problem of AFPs, farmers may also perceive trees as incompatible with their farming activities and may not benefit from planting and managing trees and shrubs on their farm plots (FAO, 2013b). This can also influence the adoption and implementation of AFPs in wider areas. Lack of knowledge on the benefits of the trees and shrubs on farmlands also leads to the perception that the mono-cropping activities are the only preferred methods for smallholder farmers.

2.7 Constraints of tree planting for AFPs

Heavy dependence on woody biomass for fuel, increasing demand for grazing and agricultural land, and demand for other wood products contribute to the severe deforestation and forest degradation in Ethiopia (Mekonnen & Damte, 2011). One possible solution to reduce high dependency on products from the forest land is finding other alternatives to produce wood products for fuel and construction materials outside the natural forest region. With less than half a hectare of natural forest remaining per person in most of the developing countries of the tropics, trees on farms have become more important for tree product supplies than forests (Zomer et al., 2009). Tree and shrub integration on farmlands has been encouraged as a means of enhancing rural livelihoods through sustaining provision of services and products by the watershed area (Sisay & Mekonnen, 2013). Garrity (2004) also pointed out that advance in agroforestry is one of the most important tools to meet Millennium Development Goals (MDG) in reducing poverty.

Though the importance of agroforestry in improving the livelihoods of smallholder farmers and its greater potential to provide environmental services are recognized, there are so many challenges for the implementation and expansion of these practices (FAO, 2013b). Outdated policy objectives and legislations, often, act as an obstacle to greater investment in trees on farms by farmers and entrepreneurs as discussed by (Scherr, 2004) in the global context. Even where forest removal may facilitate to tree cultivation, small-scale farmers are not sufficiently prepared to diversify their tree production on their farmlands.

The overall lack of information at all levels on markets for agroforestry products, and the challenges to outgrowing schemes and contract farming inhibit the growth of the smallholder tree product sector in Africa outside of traditional products (Russell & Franzel, 2004). This causes spoilage of perishable tree products, lost income for producers and restricted choices for consumers. The rural poor are further deprived by lack of market price transparency, infrastructure and the absence of processing techniques to add value to tree products (Garrity, 2004).

In addition to this, there are also household and plot level determinants for the implementation and expansion of AFPs. Franzel (1999) identified labour constraints, low base yield and high opportunity cost of AFPs as major limiting factors for the implementation and expansion of intensive agroforestry in different parts of Africa. In Ethiopia, Mekonnen & Damte (2011) indicated that tree growing on farmland is influenced by male labour availability, risk aversion of long-term investments and farm size. Predo & Francisco (2012) also indicated that household wealth status has a positive influence on tree planting, that rich people planted more trees than the poor.

Moreover, land tenure policies may also limit the expansion of AFPs since tree planting on farm is a long-term investment. When the rights to land are not clearly stated by law, the absence of legal recognition makes any long-term investment, such as agroforestry measures, unattractive. This can be also seen as a conflict of interest between the state and land users, especially where state ownership of land appears to be the main inhibitor of action (FAO, 2013b).

Despite the crucial contribution of agroforestry in reducing deforestation, conserving biodiversity, tackling environmental problems and improving livelihoods of farmers through provision of timber and non-timber tree products, assessment of major challenges for the implementation and expansion of AFPs in different agro-ecological areas has been given less attention in Ethiopia.

3.OBJECTIVES OF THE STUDY

3.1 General objective

The main objective of this study was to assess the extent of deforestation through land use/cover changes over time and to examine the potential of agroforestry practices (AFPs) in reducing burden on natural forest resources and improving the livelihoods of smallholders in Maytemeko Watershed.

3.2 Specific objectives

The specific objectives of this study were to:

- assess the temporal and spatial land use/cover changes in the study area for the last 25 years;
- identify and describe the existing AFPs based on their spatial distribution and components;
- compare soil chemical properties in agroforested and non-agroforested land use types;
- examine major contributions of AFPs to the local farmers and to minimize natural forest degradation;
- assess the perception of farmers towards deforestation and AFPs; and
- explore major constraints for tree and shrub planting in AFPs in the study area.

3.3 Research questions/hypotheses

- Is there any significant land use/cover change for the last 25 years?
    - The woody vegetation cover reduced over time in the area.
    - There is a loss in aboveground biomass due to deforestation in the watershed.
- How does the nature of existing AFPs look like in the area?
    - There is spatial variability in the nature and extent of AFPs in the watershed.
    - There is significance difference in woody species richness between farmlands and homegardens.
- Is there any difference in soil chemical properties between agroforested and non-agroforested land use types?
    - There is significance difference in soil chemical properties between agroforested and non-agroforested land use types.

    - There is significant difference in soil chemical properties under the canopies of different tree species and outside the canopies in homegardens.
- What are other major contributions of agroforestry to the local people and for reducing natural forest degradation?
    - At household level, the contribution of AFPs for fuel and construction wood is higher and, hence, they save the nearby remnant natural forests and shrubs.
    - AFPs reduce burden of women by reducing the time spent and efforts for fuelwood collection.
    - Agroforestry farm plots have better net return than conventional mono-cropping farm plots.
- What is the perception of farmers towards current deforestation and AFPs in the area?
    - Farmers recognized the problems of deforestation and land productivity decline in the area.
    - Number of woody species on farm plots and farmers' soil fertility rating of the farm plots has systematic relation, i.e. farm plots with higher number of woody species are labelled as more fertile than plots with lower number of woody species.
    - Farmers' preferences of planting trees for fertility management match with the results of the soil laboratory analyses results.
- What are the major constraints that hinder tree and shrub planting in AFPs?
    - Number of active labour, farm size and land tenure security have positive contribution for tree and shrub planting on farm; while free grazing, distance of the plot from home, slope of the farm plots negatively influences tree and shrub planting for AFPs.

4. MATERIALS AND METHODS

4.1 The study area

4.1.1 Location

Maytemeko Watershed is located in Hulet Eju Enessie District (HEED), East Gojjam Administrative Zone, Amhara National Regional State, Northwestern highlands of Ethiopia. Geographically, it extends from 11^0 2' 30" to 11^0 6' 00'' North and from 37^0 47' 0" to 37^0 51' 00" East (Figure 1). Maytemeko is one of the head water tributaries of Abaya River which finally drains into Blue Nile River. The area of the watershed is estimated to be 2819 hectares with varying land features ranging from level plateaus to steep slope escarpments. The altitude of the watershed ranges from 1670-2400 m.a.s.l, where the lowest altitude being at Abaya River and the highest at the plateau in the south.

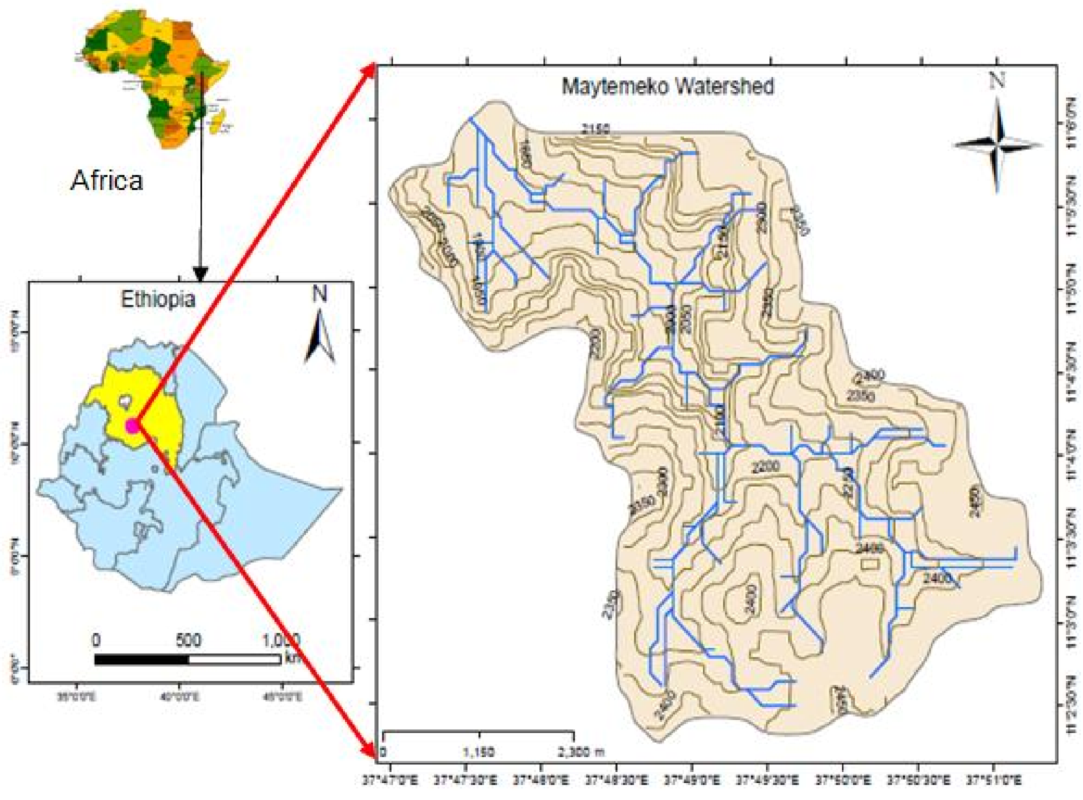


Figure 1. Map of the study area.

4.1.2 Climate

Climate data was obtained from meteorological station located in Motta Town which is 13 km away from the watershed. The mean maximum temperature ranges from 20.5 ^{0}C in October to 26 ^{0}C in May and the mean minimum temperature ranges from 7.0 ^{0}C in January to 12.3

°C in August during the years 2001 and 2011 (Figure 2). The general trends of 11 years mean maximum and minimum annual temperatures show stability in the beginning and the rise and fall of temperature after year 2005. This might be due to general climatic disorders in the area.

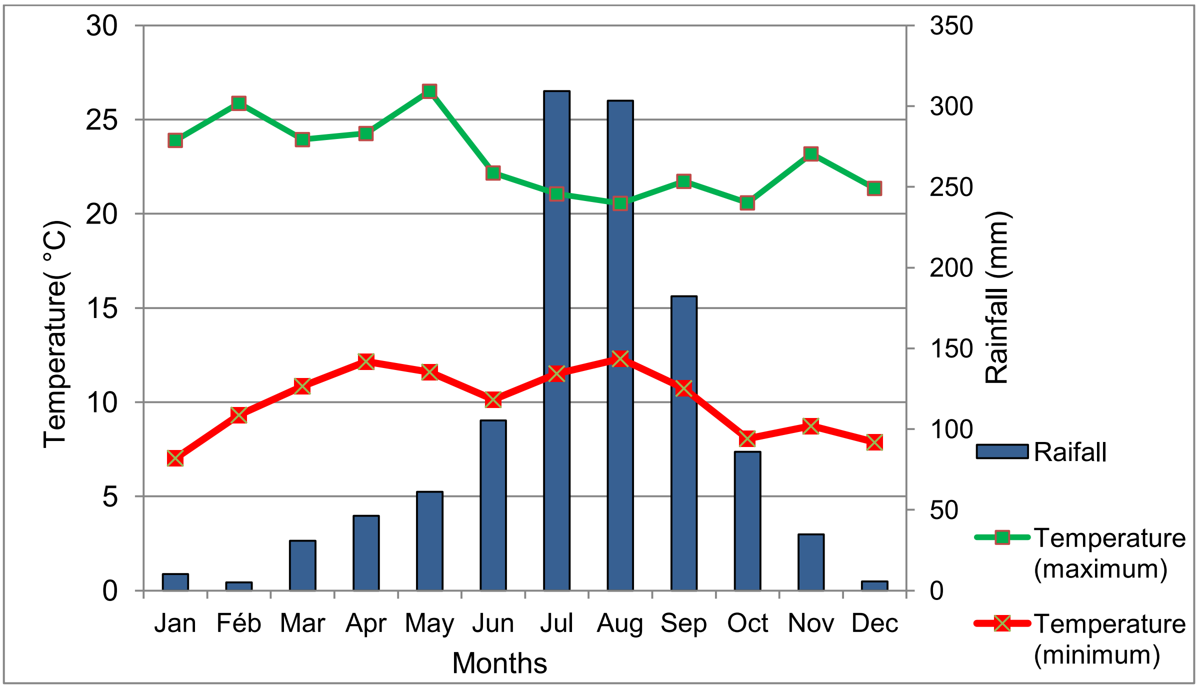


Figure 2. Mean monthly rainfall and temperature distribution of the study area.

The mean annual rainfall for the 11 years under consideration in the watershed is 1180 mm ranging from 761mm in 2009 and 1404 mm in 2006 (Figure 3). The total annual rainfall amount showed flattening at the beginning and the rising and falling after the year 2004 (Figure 3) that could possibly show larger disturbances. The rainfall also shows large seasonal variability. More than 87% of the annual rainfall is concentrated during the months of June, July, August and September (Figure 2). There is also sporadic rain in April and May, which farmers need for land preparation as well as sowing annual crops that require long rainy seasons, such as sorghum and millet.

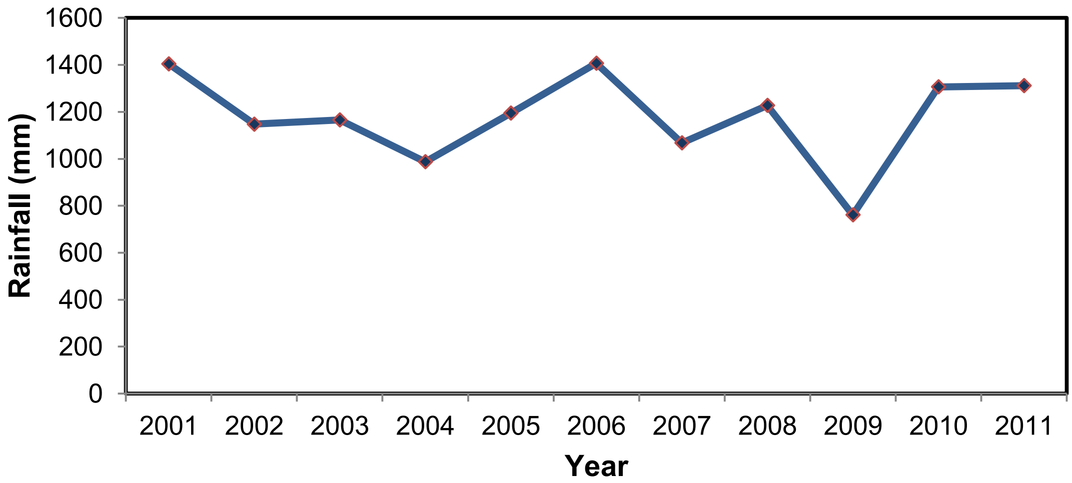


Figure 3. Total annual rainfall of the study area from 2001 to 2011.

4.1.3 Land use types of Hulet Eju Enessie District (HEED)

The total area of the district covers around 138,986 ha of which the largest share is taken by crop and grazing lands followed by forest and shrub lands and settlement. The degraded area covers about 4% (Figure 4).

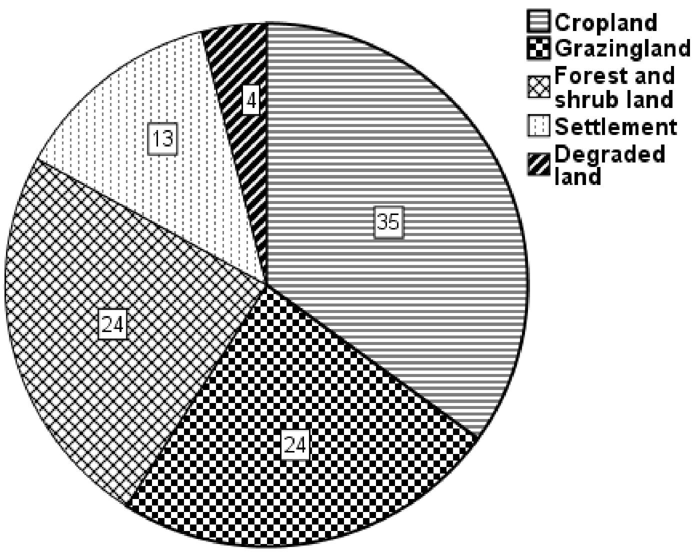


Figure 4. Land use types in HEED (Source: HEED agriculture development office)

4.1.4 Farming system

The main economic activity of farmers in the study area is mixed farming, including crop production with animal husbandry. Oxen are used for draft in most cases, though cows that cannot give birth to calves are also sometimes used. Small ruminants, such as sheep, and goats in the upper and lower watershed, respectively, are common meat and additional income sources. Milk is only produced from cows since it is not common to use goat milk in the area. Donkeys are used to transport harvested crops from field to home and any products to and from the market.

Combination of crop and livestock production on the same farm has evolved because of the inseparable nature of the food production sector from animal husbandry. In this mixed farming systems, livestock husbandry and crop production are complementary in that livestock are the source of power and manure while crop production provides residues for animal feed as it was described by Haileselassie et al.(2005).

4.1.5 Vegetation cover

The woody vegetation cover of the area is very sparse. The dominant tree species in the remnant forest are *Combretum molle* R.Br. ex G.Don and *Terminalia schimperiana* Hochst. Very rare tree species such as *Rhus glutinosa* A.Rich, which is included in red list by World Conservation and Monitoring Centre (WCMC, 1998) is also found in the patch forest area of the watershed. *Dodonaea anguistifolia* L. *f*. is the shrub dominating most of the hill slope areas in the watershed. The available remnant forest resources in the area are concentrated on steep slope areas, around churches and along river valleys. Since the remnant forest is highly degraded because of human interference for extraction of fuelwood, construction materials and cultivation land expansion, it cannot be considered as high forest according to FAO forest classification in Ethiopia. Thus, the forest type of the area is considered as woodland forest with crown coverage of > 20% (FAO, 2010).

Small-scale woodlot plantations are also observed in the upper watershed. Eucalypts are the dominant species in these woodlots. Since the average farm size per household has been decreasing through time, the scarcity of land for agricultural activities leads to further expansion of agricultural land towards the remnant forest and shrublands even in very steep slope areas. The presence of scattered trees on farmlands can be taken as an indicator that the area was once covered with forest.

The watershed was purposely selected to assess the spatial and temporal land use/cover changes, to characterize the existing AFPs and examine possible potentials and benefits of AFPs in the area. The main reason for the selection of the watershed was: first, it is witnessed that the watershed was covered by dense forest area in the past though it became very sparse at present time. However, spatial and temporal pattern of the land use/cover change has not been documented. Second, though there are promising AFPs in a few areas of the watershed, their potential for the conservation of the remnant natural forest, contributions for the local people was not documented. Last but not least, I have known the area before so that it was not difficult to communicate with the community and district officials during data collection.

4.2 Data collection

Both quantitative and qualitative approaches were used to obtain the required data for the study. The data were generated from primary sources of household questionnaire surveys, field surveys and measurements, focus group discussions, interviews, workshop as well as from secondary sources like satellite images, topographic maps and other documentary sources.

The field work was arranged two times in different seasons during the course of the study. The first and second field works were carried out from July to October 2012 and February to October 2013, respectively.

To classify households into different wealth categories, focus group discussions were used with farmers. They developed criteria to classify farmers in the watershed as poor, medium and rich. The criteria used were size of land holding, the number of oxen and type of house the farmers have. By this way, the household survey data were categorized using these wealth classes at different stages of the study.

Table 2. Criteria used for wealth classification

Criteria	**Wealth classes**		
	Rich	**Medium**	**Poor**
Number of oxen	more than two	one or two	No
Land holding size (ha)	More than one	0.5 to 1	Less than 0.5
House type	At least one corrugated iron roof and kitchen separately	One corrugated iron roof	One thatched grass roof

Moreover, a workshop was organized in the district with stakeholders, including farmers who are living in the watershed, development agents and district officials from agriculture development office and government officials to communicate main preliminary results for feedbacks and discuss possible solutions for major identified problems for sustainable management of the watershed in general and the implementation of AFPs in particular. Following the workshop, field visits were organized in the watershed to discuss the reality in the field with experts, farmers and government officials (Figure 5B).

Figure 5. Photos showing field data collection methods.

(A) - tree measurement for biomass estimation, (B) - Field visit after workshop, (C) - interview and (D) - soil samples

The methods of data collection and sampling procedures were designed according to the formulated objectives as follows.

4.2.1 Land use/cover change and biomass

Topographic map of the area and digital elevation model (DEM) were used for defining the study watershed. After doing delineation of the study watershed, Landsat satellite images were acquired from the Global Visualization Viewer (GloVis) (http://glovis.usgs.gov). Two datasets of Landsat images (1986 and 2011) were obtained to map land use/cover types (LUCTs) and to assess the land use/cover change in the Maytemeko Watershed. ERDAS IMAGINE and Arc GIS software were used for image classification and processing. Photographs were taken from sample land use types to support image classification.

Thus, four LUCTs (cropland, grassland, shrubland and forestland) were produced from the satellite image. Each LUCT was described as shown on Table 3. Ground Control Points (GCPs) were obtained using GPS to verify image classification. The GCPs were relatively permanent objects.

Table 3. Description of the land use/cover types (LUCTs) used in classification

LUCT	**General description of land use/cover categories**
Cropland	All areas of cultivation land covered annual crops with or without scattered trees. These areas include both lands currently covered with crops and under preparation for cultivation.
Forestland	Areas dominated by trees of height ≥ 5 m with crown coverage of approximately > 20%.
Grassland	All areas dominantly covered by natural grass with small shrubby species used for animal grazing and browsing.
Shrubland	All areas of land dominantly covered by woody vegetation of shrub mostly < 5 m in height, bush lands, young tree covers (*D. anguistifolia* is the dominant species).

The four LUCTs were used to estimate the aboveground biomass (AGB) change. To estimate the loss/gain of AGB, between the two reference years, the existing AGB of the LUCTs were estimated first. The procedure used to estimate AGB of the existing LUCT was different since the LUCTs had different structure and densities of biomass. It was assumed that the crop component would not have any AGB remained since all is harvested and consumed as food, animal feed and fuel as indicated by IPCC (2003) that the net AGB become nearly zero. Moreover, the degradation of the woody biomass through time was not considered due to data limitation. Thus, the loss estimation due to area changes can be considered as the actual loss of AGB.

To estimate the AGB of the existing remnant forest, individual tree measurement on a 20 X 20 m sample plot was carried out by selecting relatively undisturbed site in the remnant forest (Figure 5A). Only trees greater than 5 cm diameters at breast height (DBH) were considered for measurement. Tree height, DBH, trunk height, base diameter and length of branches, crown diameter and crown length were measured for each tree.

There is no specific wood density and biomass expansion factor for indigenous tree species in the natural forest of Ethiopia (Henry et al., 2011) to estimate AGB. Even though estimation of AGB of trees using allometric equation is site and species specific, the AGB in this study was estimated based on allometric equations developed by Brown et al. (1989) for pan tropical regions that consider rainfall (< 1500 mm) and DBH (5 to 80 cm) ranges. The diverse nature of the tree species in the forest makes destructive method of tree biomass estimation impractical. Moreover, it was also observed that the remnant natural forest is dominated by tree species that are rare, thus, cutting these trees would become against conservation idea. Thus, the AGB of the existing individual trees in the forest was calculated following Brown et al.(1989) as shown below:

$$\mathbf{AGB = 34.4703 - 8.0671DBH + 0.6589DBH^2} \quad (1)$$

The sum of individual tree biomass gave biomass at plot level and the result was finally converted to one hectare of the existing forest. This was used as a conversion factor to estimate per hectare loss or gain in biomass due to change from the forest land to other LUCTs or vice versa.

To estimate the shrubland biomass of an area, destructive methods were used. Three representative 2 x 2 m plots were selected in the watershed for complete removal of shrubby species. Total fresh weight was measured and samples were taken to Bahir Dar Soil Testing Laboratory to determine the oven dry weight.

To estimate the AGB of grasslands, the same destructive method was used on grasslands on three plots with 2 x 2 m area. The plots were first fenced and prevented from grazing for three months during the wet season (June to September). All the aboveground green biomass was harvested and weighed. To determine the oven dried weight, samples were taken.

On agricultural lands, tree sample measurements were carried out since there are remnants and/or planted trees on the farmland. Six representative sample plots having one ha area each were selected by considering altitudinal variation (Appendix 1). Tree measurements were undertaken with the same procedure in the forest plot and the AGB was also estimated using similar equation used for the forest plot as described by Brown (1997).

Cropland samples with an average tree cover of 8 ha^{-1} (Appendix 1) taken. However, there are also cropland plots with no tree cover in the watershed. At the same time the grasslands in the study watershed are degraded though we took samples from plots that were controlled for three months in the wet season. Therefore, the biomass loss estimation can be undertaken using two different assumptions. The first assumption considers if all the cropland plots would have tree cover like that of the sampled plots and the grassland would have similar AGB with that of the sampled plots (best case). The second assumption considers if the cropland and grassland plots would not have perennial AGB since there is no tree planting and managing as well as over grazing on these land use types (worst case).

4.2.2 Description of agroforestry practices (AFPs)

A multi-stage approach was used to describe the existing AFPs in the watershed. First, household survey data were used to identify the dominant AFPs at farm plot level. Second, transect walk and field observation was carried out to describe the dominant AFPs qualitatively. Third, inventories of woody plant species in homegardens and on farm plots were used as these were dominant AFPs in the watershed.

For the household survey, 138 household heads (about 8% of the total households) were randomly selected from the three *kebeles*[1] in the watershed. Proportional allocation of sample households to the number of households in each *kebele* was carried out to get representative samples from each *kebele* (Table 4). Systematic random sampling was used from the list of households that the first was chosen through lottery method from the list one to 23 and the remaining were selected following the same interval of 23 in the list of households in each *kebele*.

Table 4. Household distribution in *kebele*s found in the watershed

Number	*Kebele*	Number of households	Samples taken
1	Bezabizuhan	1942	83
2	Ayenbirhan	562	24
3	Tiruselam	725	31
Total		3229	138

These households were classified into three wealth classes as poor, medium and rich based on the results of the focus group discussion with the criteria described earlier. Accordingly, 47.1, 37.7, and 15.2% of the households were classified as rich, medium and poor, respectively.

In administering questionnaires, to avoid language difficulties, questions were translated from English to Amharic (local language) by three independent translators, who were experts in the field of forestry. Both closed- and open-ended questionnaires were used to collect quantitative and qualitative data. Major AFPs used on farm plots, contributions of AFPs, perception of farmers for deforestation and AFPs, constraints of AFPs were major focuses of the questionnaire. Moreover, socioeconomic variables such as land holding size, number of livestock, number of trees and shrubs in each plot were included in the questionnaire (Appendix 5).

[1] The lowest administrative unit next to Woreda/district.

Four data collectors with minimum of college diploma in related fields of agriculture and forestry were employed for data collection. Before they started enumeration, a brief explanation about the objectives of the survey and the meaning of each question were given. The data collectors used face to face interviews as many of the respondents were expected to be illiterates.

To describe the overall combination of trees, crops and their interaction, transect walks across the watershed was used. To evaluate the overall woody species composition and diversity in the major AFPs (the homegardens and open farmlands) 54 plots in total (22 homegardens and 32 farmland plots) were taken. A complete census of woody plant species was carried out on one hectare area of systematically selected plots for the respective land use types. Slope and average elevation of the plots were recorded using clinometers and GPS, respectively. Local and scientific names of trees and shrubs were recorded in the field with the assistance of an expert in forestry working in the district Agriculture Development Office (ADO) and with local farmers. Specimens of species that were not identified during the field work were collected, dried and taken to the National Herbarium in Addis Ababa University for identification. Woody plant nomenclatures in this study follows published volumes of Edward et al. (1995), Hedberg et al. (2003), Hedberg et al. (2004) and Hedberg et al. (2006). Primary uses of the woody species were identified through discussion with farmers.

4.2.3 Soil data collection and laboratory procedures

To evaluate the difference in the status of soil nutrients between agroforested and non-agroforested land use types, three dominant components of AFPs plots, *Croton macrostachyus* Hochst. ex Del. scattered trees on farm (CMF), alley cropping within the rows of *Rhamnus prinoides* L'Hérit shrubs (ACS) and homegardens (HG) were considered. In addition, single cereal cropland plots (SCC) were considered for comparison as a control. To see soil nutrient differences in alley cropping between rows and within the shrub lines, soil samples were also taken in between rows of *R. prinoides* (ACR), hereafter considered as one land use type. All the sample plots considered were under the same traditional farm management level and had similar soil types (the red nitosols). To avoid soil property variability that could be seen due to difference in crop rotation, the farmlands chosen for this study were sown with *Eragrostis tef* (Zucc.) Trotter (locally known as '*Teff*') to maintain homogeneity. Four replicates of soil samples were taken from two soil depth classes (0 to 15 cm and 15 to 30 cm).

For CMF land use type, samples were taken from three points at a distance of two-third of the canopy radius from the tree trunk to get one composite soil sample from the respective soil depths (Figure 6). The three points were chosen by considering wind direction effects on the movement of litter fall and shade variability effects as the shade may have its own impact on the decomposing litter.

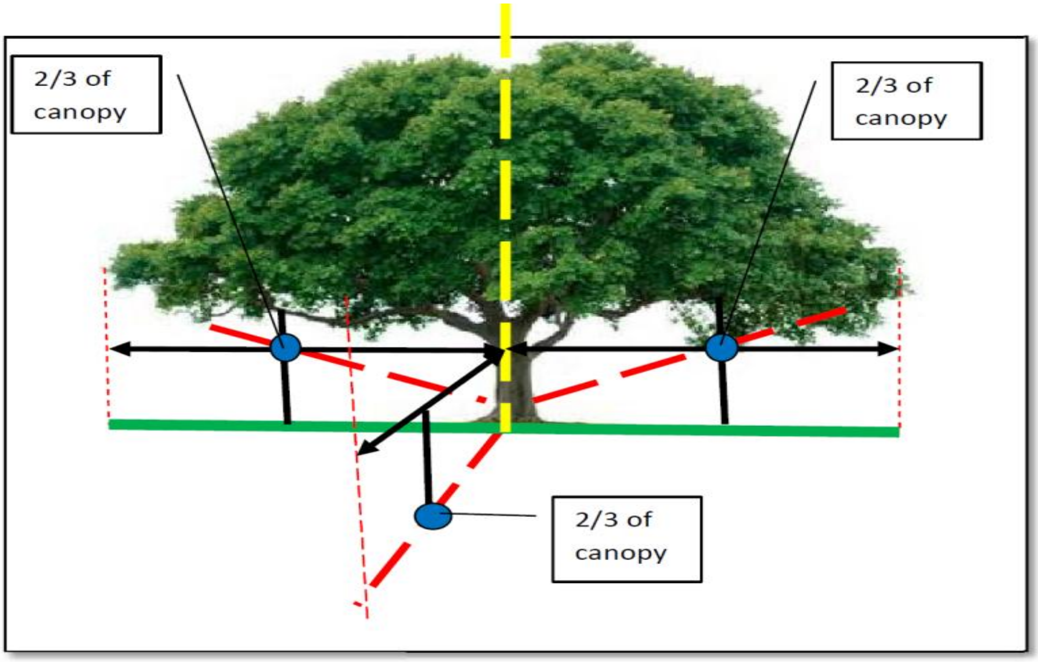


Figure 6. Soil sampling points from *C. macrostachyus* trees scattered on farm (CMF)

For the alley cropping plots with *R. prinoides*, samples were collected at three points within rows of shrubs (ACS) (Figure 7). To evaluate the soil nutrient status in between rows of *R. prinoides*, samples were also taken along the transect lines at the mid points in between rows (ACR).

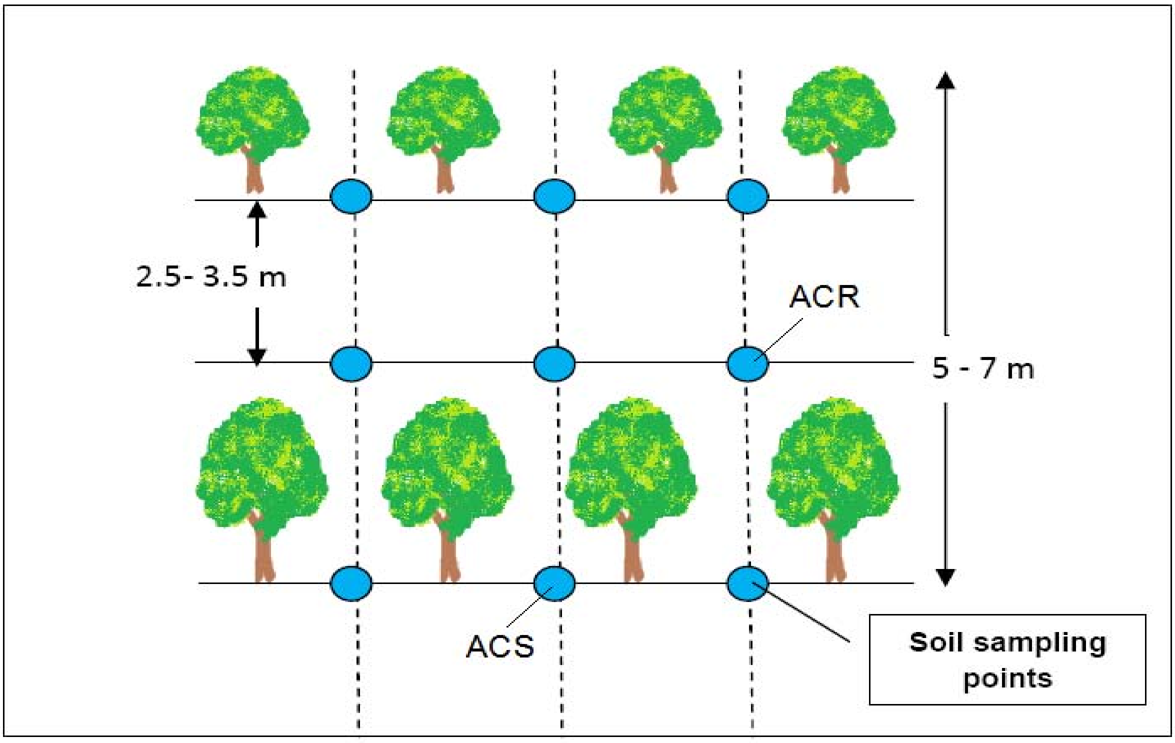


Figure 7. Soil sampling points in the *R. prinoides* alley cropping agroforestry practice.

For mono-cropping plots, 5 x 5 m plots and samples were taken from 5 sampling spots (from four corners and the centre) as shown in Figure 8. To avoid edge effects, the sampling plot was placed at least 5 m from the field boarder. Samples were mixed to form a homogeneous composite sample for each of the respective soil depths.

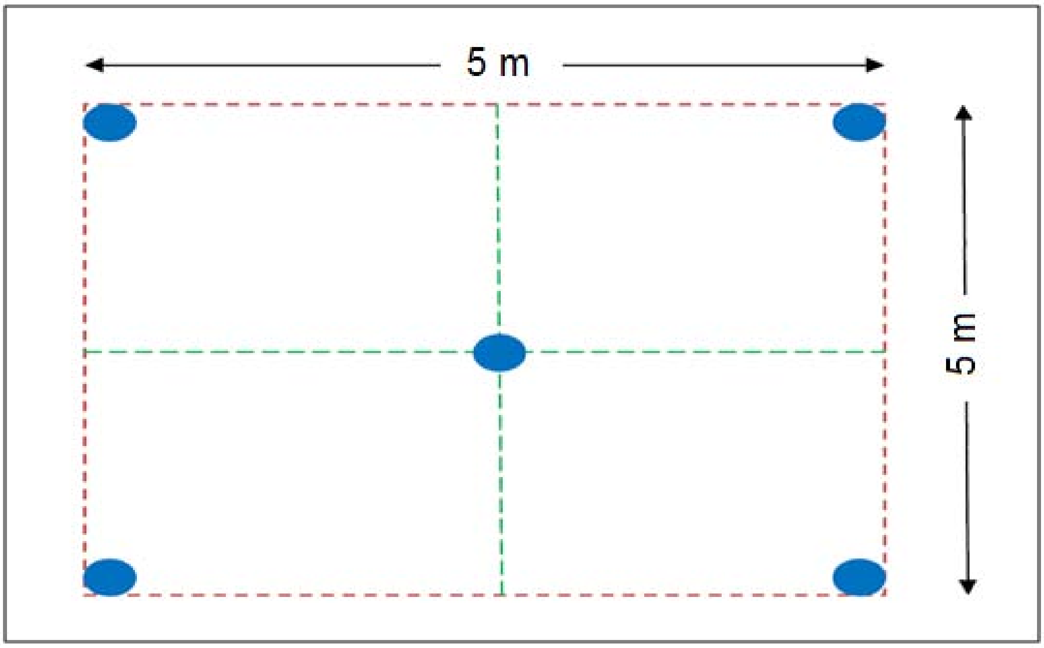


Figure 8. Soil sampling points for single cereal plots

The nature of homegardens is very complex in terms of the composition of tree and shrub species (Abebe, 2005; Amberber et al., 2014) compared with the other land use types described above. Therefore, to compare the soil parameters of the homegardens with other land use types, further soil samples were collected from four homegarden plots with similar management level under the canopies of various dominant tree species and outside the tree canopies. Three indigenous tree species, namely: *Cordia africana* Lam., *Croton macrostachyus* Del. and *Acacia abyssinica* Hochst. ex Benth. and two exotic species of *Sesbania sesban* (Jacq) W. Wight and *Eucalyptus camaldulensis* Dehnh. were considered. Areas, which are relatively outside the influence of the tree canopies and root lateral growth, were also taken for comparison purpose. Thus, from the homegardens alone, 160 soil samples were collected. The same procedure was used like that used for CMF plots to take soil sample of specified distances from the tree trunks (Figure 6).

Following this, to compare the soil parameters in homegarden with other AFPs land use types and single cereal plots, the weighted averages from all canopies of the tree species and outside the canopies of each of the soil parameters in homegardens were used and the four homegarden plots were considered as replications in this case.

Finally, a total of 192 composite soil samples (32 from the four land use types and 160 from homegarden plots) were collected from the two depth classes in four replications. All soil sample collection was carried out after crop harvest from February to June 2013. Soil samples were, then, passed in 2 mm sieve, air dried and packed into coded plastic bags.

Soil laboratory procedure

All sieved and air dried soils were transported to Vienna and the analysis was done in the soil laboratory of the Institute of Forest Ecology following the standardized procedures. Soil pH, organic carbon (OC), total nitrogen (N), soil total nutrients (Ca, Mg, Na, K, P, Mn, Fe, Al and S), available phosphorous (Ava P), cation exchange capacity (CEC) and base saturation percentage (BSP) were determined for the respective soil depths following the standardized soil laboratory procedures.

Soil pH was determined in a suspension of 1:2.5 (soil: water) in deionized water and 0.01 M CaCl2 solution using potentiometeric pH meter.

OC and N were determined by a LECO TruSpecCN analyzer using oven dried soil samples. The analysis process involved dry combustion at 950 °C in pure O_2 atmosphere and infrared detection of evolved CO_2 and thermal conductivity detection of N_2 (ÖNORM L1080).

For total nutrient analysis, 700 mg of oven dried soils were digested by aqua-regia acid. Under a fume hood, 15 ml of 37% HCl and 5 ml of 65% HNO_3 were added into a tube with the soil samples. Then, the solution was digested for two hours period and deionized water was added following the cooling. After filtration, the total nutrients were determined by using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) measurement based on Austrian standard (ÖNORM L 1085).

Available P of the soil was determined by employing Olson method using 0.5 M sodium bicarbonate solution for extraction.

Exchangeable cations (Na^+, K^+, Mg^{2+}, Ca^{2+} and Mn^{2+}) were determined by using 1 M of Barium chloride solution and taking 5 gm of air dried soil. Finally, the result was converted into oven dried soil bases using the moisture percentage of oven dried soils. Cation exchange capacity was determined by summing the charge concentration of cations, and the base saturation percentage (BSP) was determined as follow:

$$\text{BSP} = \left(\frac{\text{Ca + Mg+ Na +K}}{\text{CEC}}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

4.2.4 Assessment of other benefits of agroforestry practice

After identification and description of major AFPs based on their components, their contribution to the local farmers’ livelihoods was assessed through household survey and plot level data collected from the selected farms. This assessment included benefits of AFPs as sources for fuel and construction wood. This, in turn, was used to estimate the contribution of AFPs for the conservation of the remnant natural forest and shrublands by replacing the wood products from the forest. Moreover, their contribution in reducing burden of women was also considered as one aspect of the social benefit of AFPs.

To evaluate the contribution of AFPs for the conservation of the remnant forest resources through the provision of forest products, the source and amount of annual fuelwood consumption of households was considered. First, households were asked to estimate the amount of their fuelwood consumption for the year 2012/13 from different sources. The available sources of fuel considered were natural forest and shrublands, trees and shrubs from farmers’ own farm (agroforestry), animal dung, crop residues and other sources. From this, the proportion of fuel obtained from the AFPs could be estimated for individual households. Moreover, the loss of major soil nutrients from the use of dung for fuel was estimated. This was explained using the wealth classes of the households since resource availability may also determine the choice and amount of fuel consumption from different sources. Moreover, the number of pole wood used for house construction obtained from open access forests and AFPs before 20 years ago and within the last 20 years was estimated by farmers to evaluate the contribution of the two sources for house construction through time. To assess the burden of fuelwood collection in different household members who are using their own fuel sources from agroforestry trees and those who are collecting fuel from natural forests and shrublands, households were also asked about the responsibilities for fuelwood collection among household members and the time spent to collect fuelwood from different sources.

To analyze the annual income of the households from the sale of fruits and vegetables from AFPs, questions were incorporated in the household survey. This result was compared among the three household wealth classes.

In addition, the economic returns of AFPs were assessed by plot level analysis of cost and revenue/benefits on 52 plots of alley cropping with *R. prinoides*, small-scale eucalypts woodlots and conventional mono-cropping plots. The woodlots and alley cropping are rarely used, while mono-cropping is commonly used practice in the watershed. The criteria used for the selection of the land use types is based on: a) the presence of the land use types on the plot; b) the selected land use should be practiced at least for 15 years to see the contribution of the tree component as used by (Collier, 2010; Duguma, 2012); and c) the willingness of farmers to give the revenue and cost estimate data. Based on these criteria, 32, 18 and 12 mono-cropping, alley cropping and small-scale woodlots were selected, respectively.

Production and financial data were generated on an annual basis for each selected land use type on the basis of the local land measurement unit, *timad*[2]. The entire yield was converted to monetary values in ETB[3] and estimates were recalculated on ha^{-1} basis.

In farms with alley cropping practice, the revenue was estimated from the annual crop production in between rows of *R. prinoides,* i.e. both from sales and household consumption. Price data for crops were obtained from Small Scale Micro Finance Office of the District to calculate the revenue gained in terms of money. But, for *R. prinoides*, annual sale of leaves and young stem and estimated prices for household consumption were considered since there were no price data available at the district level. The cost of establishment and management of *R. prinoides* comprise labour cost for field preparation both for nursery and

[2] *Timad* is the local unit for land area approximately equivalent to a quarter of a hectare.
[3] Ethiopian Birr equivalent to 0.05 USD based on the exchange rate of 06.06.2013. http://www.combanketh.et/More/CurrencyRate.aspx

main plot, planting, watering, digging, collecting leaves and transporting the collected leaves to the market for sale. In addition, seedling cost was also added, if farmers bought the seedlings from the market. It was assumed that there will not be significant difference on the estimated cost for seedling buyers from the market and for those who produce seedling for themselves since labour is the cheapest input in rural areas.

In the small-scale woodlots, stands with, at least, three phases of rotation/harvest within the 15 years life span under consideration were used. Though the maximum rotational production period of eucalypts in the country is about 19 years (Moges et al., 2010), key informant interviews in the area indicated that the rotation period could even reach up to 30 years based on the purpose. They also pointed out that the first product can be harvested between 5 to 7 years. The second and third harvest time of coppices will be reduced down to four years depending on the purpose. The revenue gained from the sale of wood products and estimated prices of wood for household consumption for cooking and construction were considered. Cost of seedlings, labour for watering and digging as well as labour costs for fencing were considered.

The revenues from mono-cropping farms were obtained through yield data that was retrieved from farmers, price data from Small Scale Micro Finance Office and the estimated wood product values of scattered trees and shrubs on the field. The tree products are used for fuelwood consumption, fencing and preparing farm equipment. This was estimated in monetary terms based on farmers' experience. The cost included in mono-cropping farms to produce annual crops were costs for fertilizer, seeds, pesticides, herbicides as well as family and hired labour costs for ploughing, weeding, harvesting and transporting. All the above costs incurred in mono-cropping farms were also included for the annual crop component in the alley cropping. The labour cost for managing the scattered trees through coppicing, pollarding and transporting was also considered.

To assess the revenue gained and cost invested on different land use types, cost and revenue accounting data sheets were developed based on literature. Separate data sheets were developed for the three land use types since there is variation in both type of yield and the costs invested on them. Plot area, lists of possible outputs (from annual crop and tree) as indicator of revenues and costs for fertiliser, seed, herbicides, pesticides and management costs were included in the data sheet. The management costs were accounted for as days of labour per person, which was changed into monetary values using the average annual rates of rural wages. The data sheet was pre-tested by interviewing 10 farm households in order to include all the revenues gained and cost invested from the farmers' side since there are spatial and individual variability of these parameters. Then, the data sheet was re-arranged based on the feedback during the pre-test and filled using face to face interview with the owners of the plots. In cases of one farmer having two or more of the selected land use types, interviews were made at the farm one after the other. In case the household head could not remember the costs and revenues, other members of the household were consulted to retrieve the revenues they gained and the cost invested on each land use type for successive periods.

4.2.5 Assessment of farmers' perception

To assess the perception of farmers about deforestation and AFPs, both household questionnaire surveys and focus group discussions were administered. In the household survey, farmers were asked about the natural forest and land productivity condition in the area through time, the contribution of trees on farm for soil nutrient improvement. They were also asked to rate their farm plots into different fertility classes as infertile, medium, fertile and very fertile based on their own criteria. These fertility classes helped to see the relationship between number of trees and shrubs on the farm plots and farmers' rating of farm plots.

Tree preference ranking was done by four groups of farmers during the workshop where the results of the soil laboratory analyses were compared with farmers' rankings of different tree species for fertility management of farm plots. The three groups had eight members each and one of the groups was with seven members. Since the trees were already chosen for the soil sample collection, farmers were provided with the lists for ranking. Accordingly, the five tree species were given codes from 1 to 5. A tree with highest preference value was given the score 5 and least preferred tree scored 1. The average scores to the nearest whole number were taken for the four groups to compare directly with the scores from soil laboratory analysis. Four major soil parameters (OC, N, Ava P and K^+) were taken and ranked according to the mean values of each parameter from 0 to 30 cm soil depth. The value with the highest mean of each parameter was given a score of 5 and the lowest was scored 1. The overall rank was obtained by adding the scores of each parameter to compare the result with farmers' ranking.

In the focus group discussions, the number of members was between 6 and 10 in a group to make the groups manageable. Guidelines for thematic areas were prepared to discuss the issues to the point. With this, the status of current forest cover compared with that of the past as well as major sources and problems of deforestation were assessed. Moreover, the uses of AFPs were also discussed.

4.2.6 Constraints of tree and shrub planting for agroforestry practices

To examine socioeconomic, bio-physical and institutional factors that have potential influence on tree and shrub planting in AFPs, a household questionnaire survey was used as a main tool to collect data. Socioeconomic data, including age, land holding size, livestock ownership, family size, number of active labour (age between 15 to 64) from household members and distance of the house from the remnant forest as well as institutional factors, including land tenure security and extension support, were collected through the household questionnaire survey. The impacts of all the above variables were seen on tree and shrub planting and managing behaviour of households on their farmlands were assessed. Moreover, the number of trees and shrubs on the farm were compared among different wealth classes since resource availability of the households may also affect tree planting. Plot level data gathered from households were used to see the relationship between slope and soil fertility classes and the number of trees and shrubs.

Both structured and semi-structured interviews were also administered to government officials of ADO in the district to identify institutional support to the local farmers and the plan they have related to AFPs. Experts of the district in ADO and development workers in respective *kebele*s in the watershed were considered as interviewees since they are key informants to the subject matter. The response they gave was qualitatively described and used to supplement response of farmers obtained through the household questionnaire survey.

4.3 Data analyses

4.3.1 Land use/cover change and biomass data

Land use/cover types (LUCTs) were produced and mapped based on supervised classification to show spatial and temporal variations in land use/cover from the two land sat images. Thus, systematic interpretations of the maps were held. A total of 63 sample points (21, 14, 19 and 9 cropland, grassland, shrubland and forestland, respectively) were taken using GPS for accuracy assessment of the 2011 image. An error matrix was used to see the accuracy of the classification using the sample points from the LUCTs following Jensen (1996). These helped to know how many classes are correctly classified. The Kappa coefficient was calculated based on the accuracy of the image classification following Ismail & Jusoff (2008).

The biomass change (loss/gain) data analysis was based on the land use/cover changes by taking the existing land use type as reference. After calculating the biomass of the existing land use types per ha, the biomass changes between the years 1986 and 2011 were calculated for the LUCTs based on the IPCC (2003) consideration. For example if one ha of forestland (LUCT1) was changed into the same area of cropland (LUCT2), the change in AGB (CAGB) is the difference between the exiting forest AGB and cropland. Thus, the CAGB can be calculated for 12 possible combinations of changes from the four LUCTs as follow:

$$\mathrm{CAGB} = \mathrm{A}\,(\mathrm{AGB}\,LUCT1 - \mathrm{AGB}\,LUCT2) \qquad (3)$$

Where, CAGB is the change in AGB due to change in LUCT; A is the area (ha) of the LUCT that is changed from *LUCT1* to *LUCT2*; AGB*LUCT1* is the existing AGB (ton ha^{-1}) of an area converted to other LUCT and AGB*LUCT2* is AGB (ton ha^{-1}) of the existing LUCT already converted from LUCT1.

IPCC (2003) also considers the annual change in biomass to estimate the change in biomass which was not considered in this study since there were no adequate available data. Therefore, it was assumed that the changed LUCTs would have similar biomass status with the current LUC of similar type.

4.3.2 Existing agroforestry practice data analysis

To describe AFPs, descriptive statistics from household data was used to get preliminary information on dominant AFPs. Then, the dominant AFPs were described based on their spatial coverage and components. Data from inventory of woody plant species were also analyzed using different indices. The Shannon diversity index (H') was used (Magurran, 1988). The Shannon diversity index (H') is calculated as:

$$\mathrm{H}' = -\sum_{i=1}^{s} \mathrm{pi} \times \ln \mathrm{pi} \qquad (4)$$

Where, *s* = the number of species and *pi* is the relative abundance of the *i* th species
Relative abundance of woody species and total number of woody species per unit area was also calculated to see the variation of woody species richness in homegardens and open farmland plots. Moreover, variation in the composition of species among the farmlands and the homegardens was determined by computing Beta diversity (β). β is usually expressed in terms of a similarity index between different habitats in the same geographical area (Huston, 1994). It is calculated using the formula:

$$\beta = 1 - Cj \quad \text{...} \quad (5)$$

where Cj is Jaccard's similarity index (Magurran, 1988)

Cj = j/(a+b - j) where *j* = the number of species shared by farmlands and homegardens, *a* = the number of species in farmland; and *b* = the number of species in homegardens.

4.3.3 Soil data analysis

The statistical package for social sciences (SPSS) version 20 (IBM, 2011) was used for all statistical analyses considered below.

For soil data, analysis of variance (ANOVA) was used using General Linear Model (GLM) to see variation of soil nutrients among different land use types and tree species in homegardens. When significant differences of means were obtained, multiple comparisons using Tukey Honestly Significant Difference Test (THSDT) was also held. The Pearson Correlation Coefficient was used to test the relationship between soil parameters. Moreover, principal component analysis was used to identify major components of soil parameters and see the relation of these components to the land use types. By considering OC, N, pH, CEC, BSP, total K, Ava P, exchangeable K^+, total Mg and exchangeable Na^+, the most important component that can best explain the land use types in relative terms as compared to other land use types were produced. Rotated principal components (PCs) were used for the interpretation because the rotation maintains the cumulative percentage of variation explained by the extracted components. The variation was also more evenly spread over the components and helps to determine what the components represent. By using the screen plots and Eigen values, the number of PCs was decided. Thus, components with Eigen values greater than one were considered to explain the total variation. Afterwards, PCs were compared between land use types.

In addition, the relative soil improvement index (RSII) was calculated by using major soil nutrient parameters (OC, N, K^+ and Ava P) considering the SCC land use type as reference. This helped to see the soil nutrient status of different land use types in their order of improvements in comparison to the SCC land use type. First the variation of these soil parameters relative to the SCC land use types was calculated in percentage following Duguma et al. (2010). Thus, soil nutrient variation in one of the land use types can be calculated as:

$$\textbf{Variation } \boldsymbol{CMF}\ \% = \left(\frac{Value\ CMF - value\ SCC}{value\ SCC}\right) \times \mathbf{100} \text{.......} \quad (6)$$

Similarly, this was done for other land use types as well. Then, RSII was calculated as the sum of all the variation of the major soil nutrients as follow:

$$\mathbf{RSII} = \sum \% \, \boldsymbol{Variation\ Land\ use}\ (\mathbf{OC}, \mathbf{N}, \mathbf{Ava\ P}, \mathbf{K^{+}}) \ldots\ldots\ldots\ldots \quad (7)$$

4.3.4 Other agroforestry benefits

To analyze the importance of AFPs as sources for fuel and construction wood, the household survey data were analyzed using descriptive statistics and mean comparison. Comparison of mean values of fuel consumption from various sources was undertaken using one-way ANOVA. The potential supply of fuel was estimated from the forests, shrublands and agroforestry trees to evaluate the sustainability of these sources. Paired sample t-test was used to compare pole wood consumption for house construction before 20 years ago and within the last 20 years from the forest and agroforestry trees at household level.

Average annual income from the sale of fruits and vegetables from AFPs was also compared among different wealth classes to see the respective contribution. Moreover, the data from the accounting data sheet were entered into excel spread sheet and the average revenues from outputs and costs for inputs were calculated for comparison of alley cropping with *R. prinoides*, small-scale woodlots and mono-cropping plots.

4.3.5 Farmers' perception

For the perception study, descriptive statistics (percentages and graphs) were used to see the proportion of farmers' view for deforestation and soil fertility status of their farm plots. Moreover, to see the mean difference in tree and shrub number on different fertility classes labelled by farmers, ANOVA was performed. The preferences of trees for soil nutrient improvement by farmers was also compared with the soil laboratory results to see the relationship of soil nutrient status under the canopies and farmers' view for the value of tree species for their farmland improvement. This was done by giving scores for the five selected tree species based on major soil nutrients (OC, N, Ava P and K^{+}) and comparing the result with farmers' scores for the same tree species (Cotton, 1996).

4.3.6 Tree planting constraints

To assess the constraints of AFPs, correlation matrices were used to see the relationship between variables such as number of trees and shrubs on the farm as dependent variable and farm size, family size, number of active labour and distance of the house from natural forest, distance of the plot from home, as independent variables. Moreover, one way ANOVA was used to compare the mean number of trees and shrubs among wealth classes, distance ranges from home to the open access forest, fertility and slope classes of farm plots. When significant differences were obtained, multiple comparisons using THSDT was also held.

Generally this study comprised two major components, namely environment and socio-economic components that were addressed using different procedures. The summery of procedures and outcomes are shown on Figure 9 below.

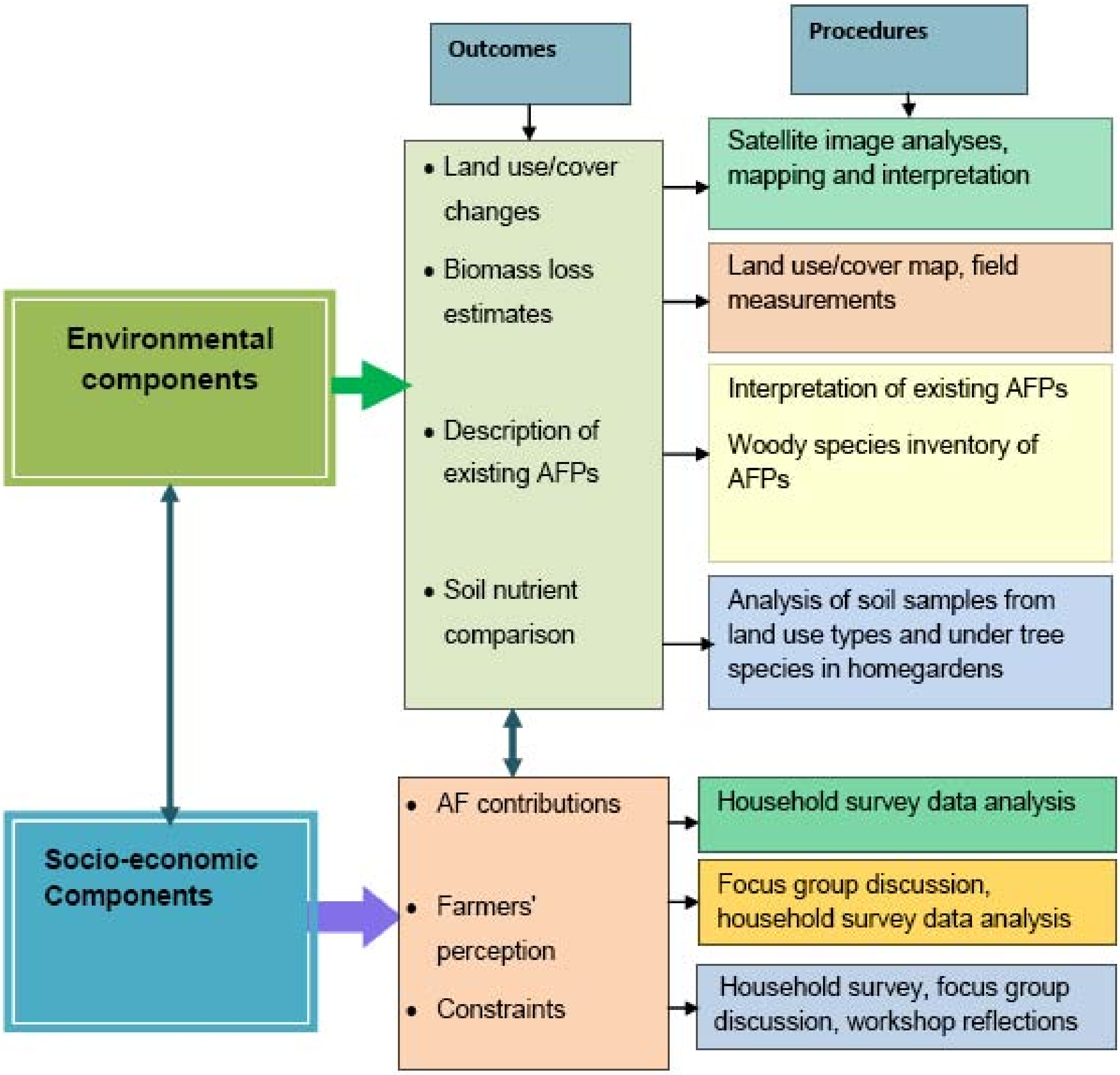


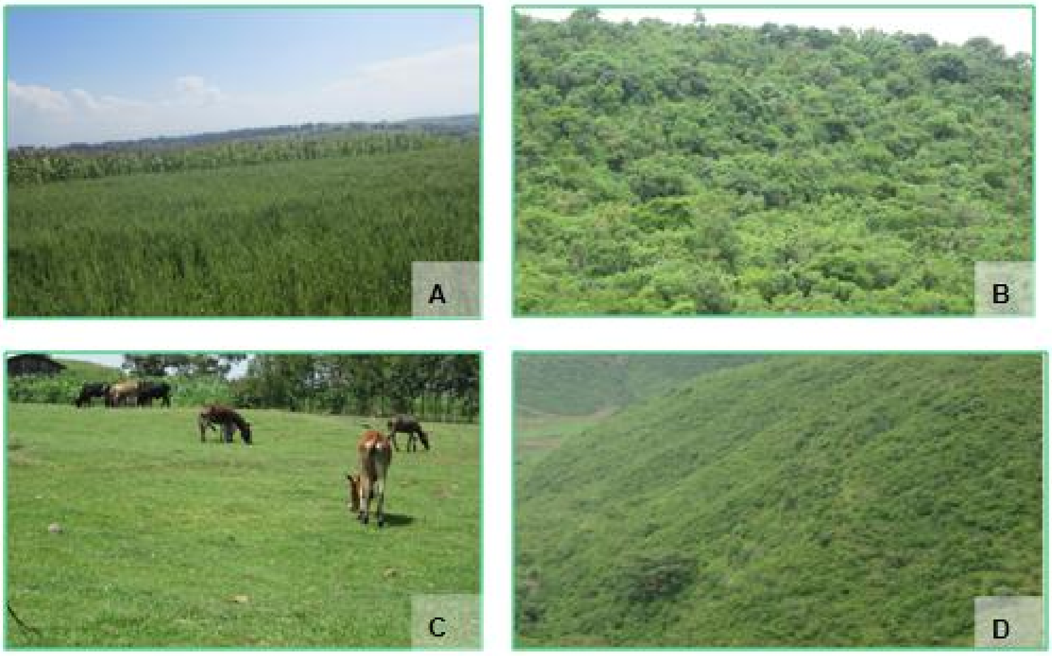
Figure 9. Summary of main components and procedures of the study.

5. RESULTS AND DISCUSSIONS

5.1 Land use/cover and aboveground biomass (AGB) changes

5.1.1 Land use/cover types (LUCTs)

In Maytemeko Watershed, four major LUCTs were identified from the Landsat image, namely cropland, forestland, grassland and shrubland. Cereal crops dominantly covered the cropland area with few fields covered with legumes in rotation. Teff, wheat, barley and maize are important food crops in the upper watershed. In the lower watershed, sorghum and millet are also grown with beans, pea and chickpea. The forestland and shrubland areas are located at steep slopes and following the main river, Maytemeko.



A = cropland, B = forestland, C = grassland and D = shrubland.
Figure 10. Major land use/cover types in Maytemeko Watershed.

The overall accuracy of the classified image was 82.5% and the Kappa value was 0.76. The individual LUCT accuracy was 71.4, 92.9, 88.9 and 84.2% for cropland, grassland, forestland and shrubland, respectively. There were three cropland samples, which were misclassified as grassland and two of them were also incorrectly classified as shrublands. On the other hand, two of the shrubland and one grassland samples were misclassified as cropland samples. The misclassification in the other categories was relatively low (Table 5).

Table 5. Error matrix of field data versus 2011 image classification results

Reference data	Classified data					
	Cropland	Grassland	Forest land	Shrubland	Row Total	PA (%)*
Cropland	**15**	3	1	2	21	71.4
Grassland	1	**13**	0	0	14	92.9
Forestland	0	0	**8**	1	9	88.9
Shrubland	2	0	1	**16**	19	84.2
Column Total	18	16	10	19	63	-
UA (%)*	83.3	81.3	80	84.2	-	-

* PA = producer's accuracy and UA = user's accuracy. Numbers in bold along the diagonal are correctly classified samples

5.1.2 Land use/cover changes

Land use/cover change studies are important to see the temporal and spatial trends of land uses/cover in the area. Moreover, this information is also useful to estimate the change in AGB and potential primary productivity due to the changes.

From the two data sets of the years 1986 and 2011, the LUCTs showed changes in spatial extent due to changes from one category to the other. Spatial variability was also observed on the extent of the changes.

The 1986 image showed that the cropland and grassland covered 51.9 and 17.3% of the total watershed, respectively (Table 6). This indicates that the highest proportion of the area was used for crop cultivation. The area of the shrubland and forestland contributed about 21 and 9.8%, respectively, of this reference year. During this year, the dominant area of the upper part of the watershed had no forest cover compared with the lower part (Figure 11). The forestland was concentrated in few pockets on steep slope areas at the lower part of the watershed that are not easily accessible for human utilization.

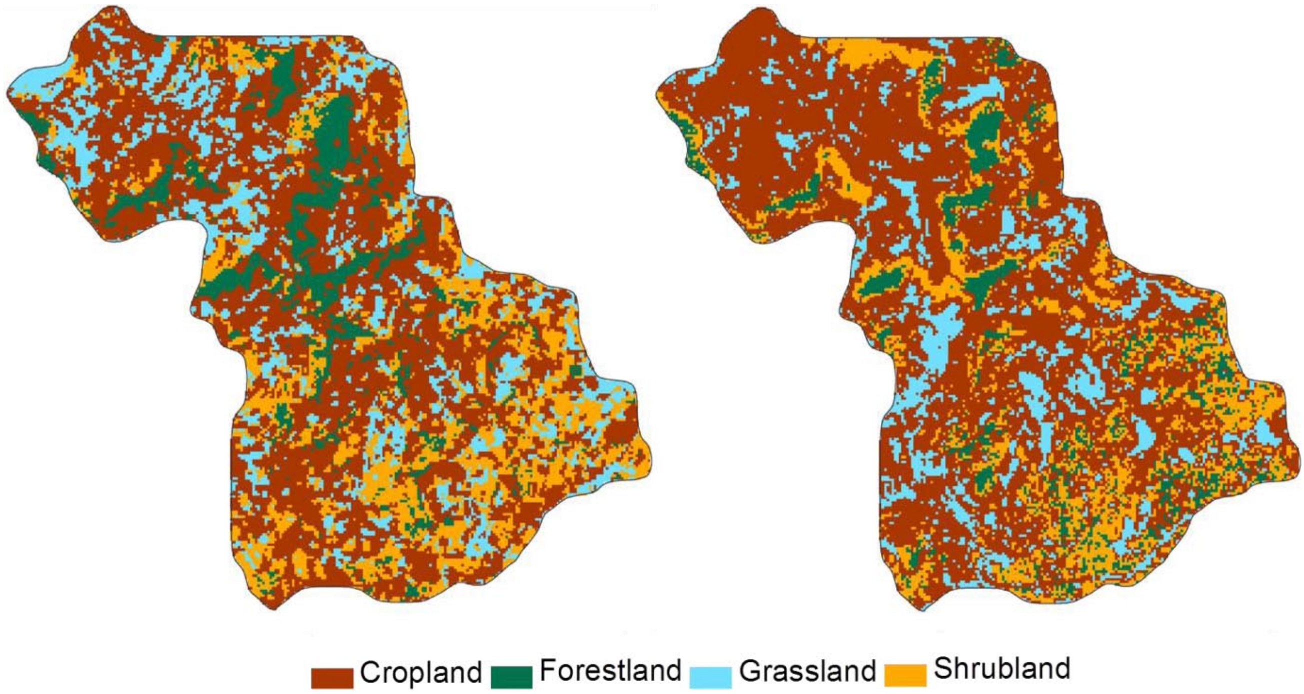


Figure 11. Map of major land use/cover types in 1986 (left) and 2011 (right)

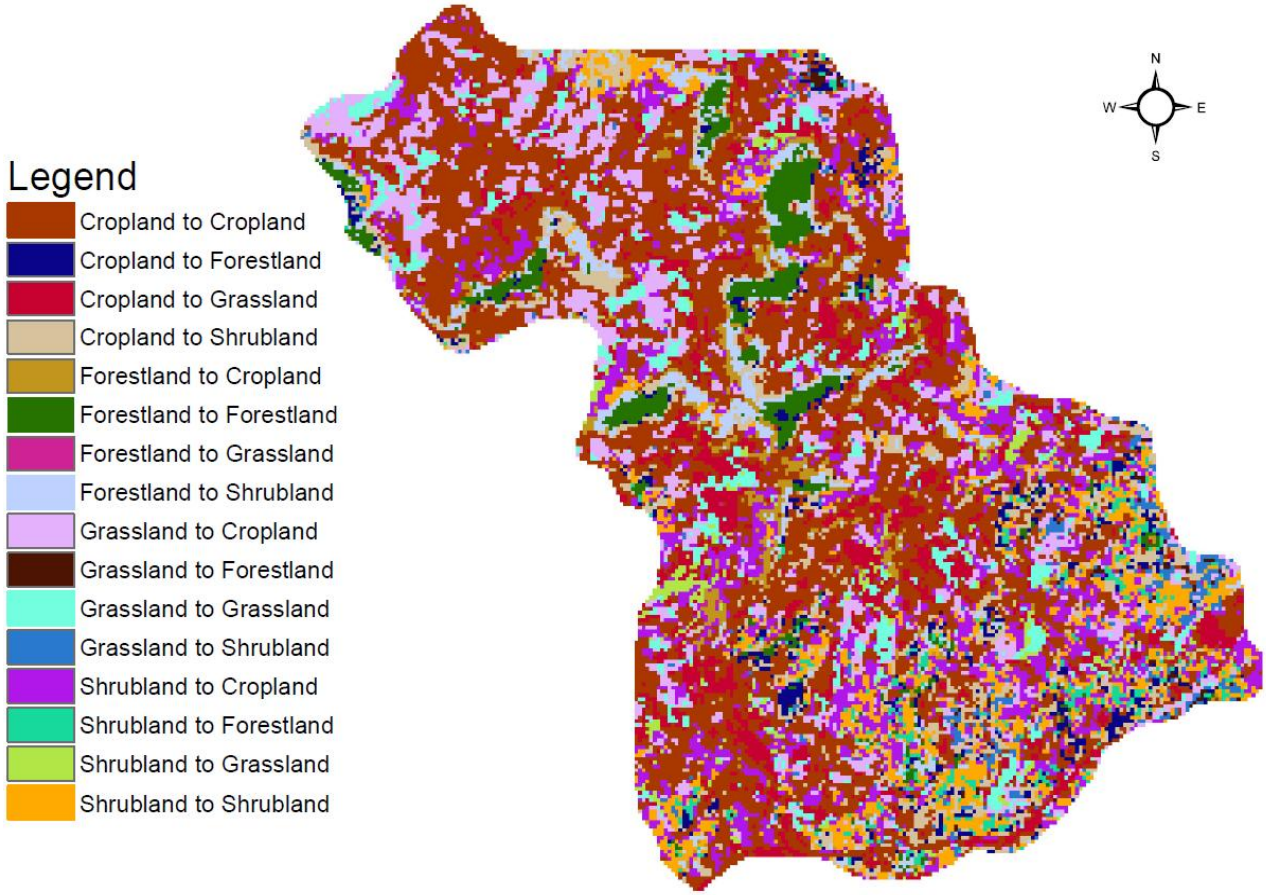


Figure 12. Land use/cover change map between years 1986 and 2011

In 2011, the proportion of the cropland area increased to 60% of the total watershed area which showed an area expansion of about 15.7% compared with what existed in 1986. The cropland is expanding towards very steep slope areas, and the newly cleared shrublands are used for crop production, especially in the lower part of the watershed (Figure 13). However, the areas of the other three LUCTs had declined in 2011 (Figure 14). The decline in woody vegetation in the watershed from the year 1986 to 2011 is mainly due to the expansion of the agricultural land at the expense of other LUCTs.

Figure 13. Cropland expansion towards steep slope shrubland areas.

In agreement with this study, a reduction in vegetation cover was reported in different parts of Ethiopia (Zeleke & Hurni, 2001;Tegene, 2002; Tsegaye et al., 2010; Shiferaw, 2011; Kindu et al., 2013; Yeshaneh et al., 2013). Tegene (2002) indicated a decline of shrub vegetation from 6.9% to 2.5% from 1986 to 2000 in Amhara National Regional State. Yeshaneh et al. (2013) reported that the decline in woody vegetation cover from 5576 ha to 2563 ha from 1957 to 2010 due to the expansion of the agricultural land in Koga Watershed. Tsegaye et al. (2010) found that woodland vegetation declined by 8.1% from 1972 to 2003 in Afar Region. Shiferaw (2011) pointed out the cropland increased by18.4% of the total area between the years 1972 to 2003 at the expense of the forestland in South Wollo highlands. Alemu et al. (2015) also indicated that the woodland forest in northern Ethiopia declined from 42.17% in 1985 to 25.75% in 2010 due to the expansion of the agricultural land.

However, in contrast to the present study, Bewket (2002) reported the forest cover increased by 27% from the year 1982 to 1998 in Chemoga Watershed due to the expansion of eucalypt plantation in the area compared with the relative loss of the natural forest resources. Nyssen et al. (2009) also reported gradual abandonment of mountain agriculture and an increase in woody vegetation cover from 0.4% in 1965 to 12.7% in 2006 in northern Ethiopia. Similarly

Wondie et al. (2011) reported an increase in the forest areas from 11.7 to 15.6% between 1984 and 2003 in the Simen Mountain Nation Park.

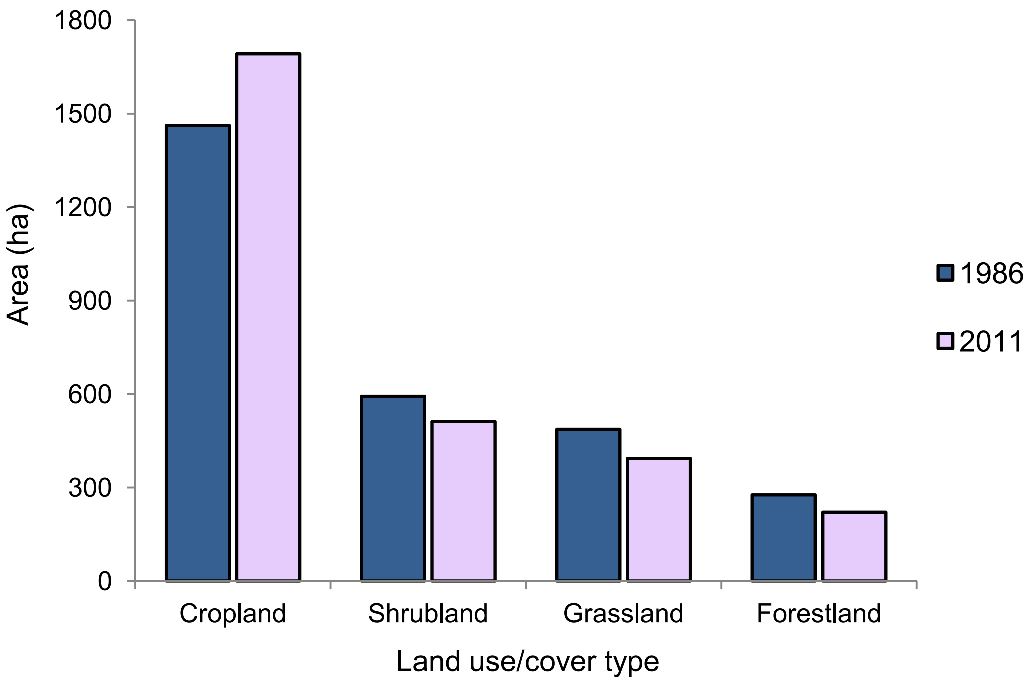


Figure 14. Area of land use/cover types in 1986 and 2011.

The forest area was reduced to 7.9% in 2011 from the available forest area in 1986 with relatively the highest decline (20%). The grasslands and shrublands were reduced to 14 and 18.1%, respectively, with 19 and 13.6% decline relative to their own area between the two years (Figure 14). Very similar result was also reported by Tesfaye et al. (2014) who found that the shrub and grassland areas declined by 18.6 and 6.8% of their total area, respectively, in Gilgel Tekeze Catchment. Shrublands and grasslands were the major contributors to the increase in the cropland area in the watershed (Table 6).

Table 6. Major land use/cover change matrix (ha) from the years 1986 to 2011.

From \ To	Cropland	Grassland	Forestland	Shrubland	Total (1986) [a]
Cropland	**987.7**	222.6	69.3	181.7	1461.3 (51.9%)[c]
Grassland	311.3	**122.2**	10	44.3	487.8 (17.3%)
Forestland	73.6	2	**97.7**	103.7	277.0 (9.8%)
Shrubland	317.4	48.2	44.6	**182.8**	593.0 (21%)
Total (2011) [b]	1,690 (60%)[c]	395 (14%)	221.6 (7.9%)	512.5 (18.1%)	2,819 (100%)

[a] Row sums of the amount of land for each LUCT in the initial year (1986); [b] Column sums of the amount of each LUCT in the year 2011; [C] proportion from the total study area. Values across the diagonal in bold show the amount of each LUCT that remained unchanged.

Clearing of areas covered with forests and shrubs were higher in the lower than the upper parts of the watershed (Figure 11). The forest and shrubland in the upper part of the watershed increased in 2011 compared with that of 1986 (Figure 14). The land use/cover change map also indicated that fields which were croplands in 1986 were converted to forestlands and shrublands despite an increase in the overall area of the cropland in 2011. Such kinds of changes were more often observed in the upper part of the watershed than in the lower part. This might be due to tree planting as small-scale woodlots after the Villagization Program of the Socialist Government in the area during the mid 1980s in the upper watershed. The main objective of villagization was to gather scattered villages in one area for natural resource management and to improve the provision of services, such as schools and infrastructure (Daie, 2012). During this period, people were moved to the upper watershed area and started to plant eucalypts to satisfy their fuel and construction wood demands since the remnant forests became relatively far from their settlement areas. Therefore, distance from the natural forest to collect fuelwood acted as a promoting factor for tree planting in the area.

Key informant interviews with elder people also pointed out that tree planting on private farmlands and boundaries first started to tackle the fuelwood shortage, which is now becoming additional source of income. In the lower part of the watershed, woody plant losses can be easily observed on the land use/cover change maps (Figure 11). Farmers in the lower part of the watershed can easily access wood products from the natural remnant forest and shrublands, and they do not want to plant trees on their farm plots. On the other hand, the area is also less suitable for eucalypt compared with the upper part of the watershed. But, there would be the possibility to sustain other trees such as acacia species on the farm in the lower part of the watershed to satisfy the wood demand, which is not adequately utilized. This indicates that free access and the availability of wood from the natural forest in the nearby area limit tree planting behaviour of farm households. Duguma et al. (2009) also pointed out that farmers who are living closer to Menagesha Suba state forest consume significantly larger amount of wood from the forest compared with farmers living in far distances from the forest.

Sixteen land use/cover class combinations, including no changes, were produced from the four LUCTs (Figure 12) to show which LUCT was specifically changed to the other categories during the period 1986 to 2011. Of the total area covered by 31,327 pixels, 50.6% showed changes from one land use/cover category to the other category whereas, the remaining 49.4% of the area remained unchanged between the years 1986 and 2011 (Table 6). A very similar result was also reported by Kindu et al. (2013) who found that about 60% of the area showed changes from one land use/cover category to the others in Munessa-Shashemene area in the highlands of Ethiopia over the period of 39 years. Wondie et al. (2011) also reported that more than 40% of the area in Simen Mountain National Park showed changes from one category to the other categories. Such kind of dynamism in land use/cover indicates the absence of land use policy in the country and the pressure on land resources since most of the change is from forest and shrub cover to agricultural lands.

Though there were changes from croplands to forestlands and shrublands, mainly, in the upper part of the watershed as stated earlier, the overall result showed a loss in woody vegetation resources in the watershed. This might be related to an increase in human population in the area. Population assessment studies showed that the population of Hulet Eju Enessie District where the study watershed is located increased by 60% between the years 1984 and 2007 (CSA, 1984; CSA, 2007).

The largest proportion of cropland evolved from shrublands and grasslands compared with direct changes from the forestland to croplands. On the other hand, largest proportion of the forest area was changed into shrublands as compared to other land use types (Table 6). This leads the way for the gradual degradation from forest areas to croplands. The selective use of forest products to satisfy wood demands may first lead to forestland conversion to shrublands, then, these areas would be changed into grassland and cropland areas. In line with this idea, FAO (2010) also pointed out that croplands first would expand into non-forested areas, such as shrubland and grasslands, which were more suitable for cropping because of the ease of clearing.

The gradual expansion of the cropland towards the forest and shrubland cover in the study area has an implication for the conservation of the soil resource of the area. Clearing the vegetation cover exposes the land for erosion (Bewket, 2002) and causes soil nutrient depletion (Lemenih et al., 2005; Mojiri et al., 2011). Yimer et al. (2007) pointed out that conversion of the native forestland to cropland resulted in dramatic decline of soil organic carbon and nitrogen. Lemenih et al.(2005) also found a general decline in soil quality after the conversion of the forestland into cultivation land.

Moreover, the conversion of the forestlands and shrublands in the study area may cause loss in biodiversity. Because the forest area is degraded due to interferences, some of the indigenous trees in the forest area, such as *Rhus glutinosa* may be lost since they are already considered as threatened species (WCMC, 1998). There is also a possibility of loss of soil micro-organisms as a result of the subsequent erosion (Pimentel & Burgess, 2013). In addition, the result from this study also showed that the land use/cover conversion causes habitat fragmentation. Those larger areas of similar LUCTs were subjected to divisions into small pieces of other LUCTs (Figure 12). This might worsen the biodiversity loss in the area. This idea is in agreement with the idea of Chazal & Rounsevell (2009) who explained the negative impact of land use/cover changes and habitat fragmentation on biodiversity.

5.1.3 Aboveground biomass change (AGBC)

As stated earlier, the evaluation for the change in biomass is based on the assumption that the existing LUCTs would have similar values of AGB with the LUCT of similar type that existed before per unit area. Thus, the changes in area of the LUCTs were directly used to estimate AGB change based on measured values from the present LUCTs.

5.1.3.1 AGB of the existing land use/cover categories

From the sampled forest plot, 38 trees of 10 different species were identified. Of these, *Combretum molle* was the most abundant in the area accounting for 58% of the total tree stem. *Rhus glutinosa* and *Terminalia schimperiana* Hochst. accounted about 13 and 11% of the tree abundance, respectively. The forest cover had an AGB of about 31.2 tons ha^{-1}. This value is smaller compared with studies carried out in different parts Ethiopia (Brown, 1997; Sutcliffe, 2009; Watson et al., 2013; MOA, 2013). This might be related to the degraded nature of the remnant forest due to human interferences. However, most of the studies conducted regarding forest biomass estimation concentrated on high forest areas of Ethiopia. Sutcliffe (2009) found AGB of about 82 tons ha^{-1} in Baro Akobo Basin and Watson et al. (2013) found about 390 tons ha^{-1} of AGB in Bale Mountain area. MOA (2013) also indicated that Ethiopia's biomass stocks are largely concentrated in the Afro-montane cloud forests of the southern and southwestern parts of the country, most notably in south central Oromia National Regional State (ONRS) (Bale Mountains region), northwestern parts of Southern Nations and Nationalities People Region (Kafa-Sheka Zones) and western ONRS (surrounding Yayu Biosphere Reserve) while the lowest AGB stock was found in Amhara and Tigray National Regional States. However, the study carried out by Brown (1997) indicated that the actual AGB of Ethiopian forest was about 52 tons ha^{-1}. Brown (1997) also indicated the actual AGB in Kenya was about 33 tons ha^{-1}. It is not surprising to get lower amount of AGB below the national average with the current status of the forest cover.

On six cropland plots, a total of 47 trees were counted ranging from 5 to 11 trees per plot. *C. macrostachyus* tree species accounted for more than 51% of the total tree abundance on the sampled farmlands followed by *E. camaldulensis* (21.3%) and *C. africana* (15%). The average AGB for the sampled plots were 11.2 tons ha^{-1} ranging from 1.3 to 23.6 tons ha^{-1}. This result is in the range of estimates of 9 to 38 tons ha^{-1} of AGB for different AFPs on croplands from Sub-Saharan Africa reported by Unruh et al. (1993). Croplands showed higher AGB per tree compared with that of the forestlands. The average AGB of the shrubland and grasslands was 24.6 and 9.8 tons ha^{-1}, respectively.

5.3.1.2 Change in AGB

Considering the best case assumption, if one ha of forest land would be changed in to cropland, there would be a loss in AGB of 20 tons (31.2 -11.2 tons) and the same amount of AGB will be gained if there is a change from cropland to forest land. When we considered the worst case, a change in one ha of forest land to cropland would cause a loss of 31.2 tons ha^{-1} of AGB since the croplands are considered as those with no woody AGB. The same procedures were applied for other combination of changes to obtain the AGB changes ha^{-1} (Table 7).

Table 7. Woody AGB gain/loss due to the change in land use/ cover types (LUCTs) using two assumptions.

LUCT changes	Area (ha)	Best case		Worst case	
		AGB gain/loss (tons ha^{-1})	TAGB gain/loss (tons)	AGB gain/loss (tons ha^{-1})	TAGB gain/loss (tons)
CL to FL	69.30	20	1,386.0 (+)	20	1,386 (+)
CL to GL	221.56	1.4	310.2 (-)	No change	
CL to SL	181.71	13.4	2,434.9 (+)	13.4	2,435.9 (+)
FL to CL	73.62	20	1,472.4 (-)	31.2	2,296.9 (-)
FL to GL	1.98	21.4	42.4 (-)	31.2	61.7 (-)
FL to SL	103.68	7.5	777.6 (-)	7.5	777.6 (-)
GL to CL	311.31	1.4	435.8 (+)	No change	
GL to FL	9.99	21.5	214.8 (+)	21.5	214.8 (+)
GL to SL	44.28	14.8	655.3 (+)	14.8	655.3 (+)
SL to CL	317.43	13.4	4,253.6 (-)	24.6	7,808.8 (-)
SL to FL	44.64	7.5	334.8 (+)	7.5	334.8 (+)
SL to GL	48.15	14.8	712.6 (-)	24.6	1,184.5 (-)

+, - represents gain & loss, respectively, in AGB; CL = cropland, FL = forestland, GL = grassland and SL = shrubland. TAGB = total aboveground biomass change for the whole watershed area

Considering the best case assumption, a total of 7,569 tons of AGB was lost due to land use/cover changes from 1986 to 2011 in the watershed. However, the loss in AGB when considering the worst case was about 12,130 tons. The largest proportion of the loss was from forestland and shrubland conversion to other LUCTs, which accounted for about 96% (7,258.6 tons) of the total AGB. The remaining 4% (310.2 tons) was from conversion of cropland to grassland (Table 7) for the best case. For the worst case, all the loss was from forestlands and shrublands.

On the other hand, there was also an increase/gain in AGB from 1986 to 2011 due to changes in land use/cover. A total of 5,462 tons of AGB was gained during this period for the best case. Of this, the conversion of cropland to shrubland and forestland constituted the largest proportion (70%) or 3,821 tons of AGB increase followed by grassland (24%) and shrubland (6%) conversions to other LUCTs for the best case. But in the worst case, the gain in AGB was 5,026 tons (Table 7).

Generally, there was a net loss of about 2,107 tons of AGB in the watershed due to the change in area of the respective LUCTs between 1986 and 2011 in the best case. However, in the worst case, the net loss of AGB was about 7,104 tons, which is 3.4 times greater than that in the best case. The results from these two assumptions indicate that agroforestry trees have paramount significance to increase the AGB if farmers can plant trees on farm plots. Moreover, managing agroforestry trees and shrubs might reduce burden on the remaining natural forest resources that would directly contribute to increase the AGB in the watershed.

The agroforestry trees on croplands and managed grasslands could contribute about 4,997 tons of AGB, which may sequester about 2,499 tons of carbon based on the assumption that the carbon content is about 50% of the AGB (Nair, 2011). This shows the potential of the agricultural land for carbon storage, if farmers can sustain trees on their croplands. There is no doubt that, with the current increasing rate of population, the agroforestry in the agricultural lands may be considered as major potential areas to contribute in reducing the pressure on the of natural forest and shrublands by providing timber and non timber products to the society. This has both direct and indirect contribution to increase the AGB in the area.

5.2 Description of major agroforestry practices

5.2.1 Major agroforestry components

There are various agroforestry practices (AFPs) in the watershed. The household survey result showed that more than half of the respondents (53% of total N = 138) were widely using tree and shrub planting in homegardens followed by alley cropping (27%), scattered tree planting (8.8%), boundary planting (5%) and small-scale woodlots (2.2%). The remaining 4% of the households are not using any of these practices on their farms.

Outside the farm plots, there are also area exclosures on degraded lands in few pocket areas that contain larger number of trees and shrubs than the open grazing lands. The exclosures are kept free from animal interferences as indicated by Aert et al. (2009). These newly protected area exclosures have both naturally regenerated and planted woody species though the overall areal coverage is very small. Abiyu et al (2011) emphasized the importance of area exclosures to conserve the vegetation and improve the soil fertility in northern Ethiopia. There are many degraded grazing lands that could be possibly used for this purpose in the watershed. These areas are degraded, almost with no tree cover and, hence, soil erosion problem are aggravated.

Live fences of euphorbia species surrounding the homegardens and open fields are also common practices in the lower watershed. These are mostly used to protect both annual and perennial crops from animal attack. Moreover, the live fences are also used as wind breaks.

About 41% of the households learned the experiences of tree planting and managing from their parents whereas, 32% of the households indicated that the existing AFPs are results from their own trials. The remaining households (27%) said that extension workers helped them to use AFPs on their farm plots. Key informant interviews also indicated that some of the fruit trees and other tree species, such as *Sesbania sesban (*L.) Merr. were introduced in the area through agricultural extension service. However, they also pointed out that the technical support from the extension service was very limited. There is one big nursery site, located close to the watershed, managed by the Hulet Eju Enessie District Agriculture and Development Office (HEEDADO), which is providing new seedlings of tree and shrub species in the area. However, during the workshop with different stakeholders in the district, it was pointed out that the seedlings produced in one area are not appropriate to the other area leading to lower survival rate of the seedlings on the farm plots. On the other hand, the problem of low survival rate may also related to management during transporting the bare rooted seedlings since farmers are not well trained how to manage the bare rooted seedlings.

5.2.1.1 The homegardens

General characteristics

As stated earlier, planting in homegardens is major AFPs pointed out by farmers in the watershed. The term homegarden locally known as '*'ye guaro ersha*'' in Amharic language indicates the cultivation of land close to the residential area. Most of the sampled households (92%, N = 138) had homegarden plots and this constituted about 24.8% of the total number of farm plots (N = 512) owned by the studied households. Only 11 farm households had no homegardens, though they had other farm plots in the watershed. These households were living in rented houses and engaged in small scale business activities on road sides from Motta Town to the regional capital, Bahirdar. The size of the homegardens varied depending on the total farmland that the households possess. The average size of homegarden plots was about 0.32 ha though the range is very wide with minimum and maximum size of 0.06 and 1 ha, respectively. The homegardens are relatively larger in area than other field plots though there is no significant ($p > 0.05$) difference in mean size of these plots. Farmers prefer to build their houses on relatively larger farm plots for management purpose.

Composition of homegardens

The homegardens of the study area are characterized as multi-layered, and in most cases maize is the dominant annual food crop, which is grown when the rainfalls start at the normal period during April and May. With late rainfalls, farmers usually cultivated other crops, such as wheat and tef, which require relatively short rainy season. The upper layer in homegardens is mostly dominated by widely spaced different trees of acacia species, *C. macrostachyus* and *C. africana*. Fruit trees and cash crops, such as coffee and *R. prinoides*, take the middle strata. Recently, farmers started to adapt avocado, mango and guava fruit trees in the upper watershed; where as in the lower watershed, banana and papaya are dominant fruits in homegardens. Vegetables, spices, tubers, such as potatoes and carrot, are also grown in homegarden integrated with maize. The red hot pepper spice is widely cultivated in the lower watershed in homegardens. These days, few farmers are also attracted to cultivate *Catha edulis* (Vahl) Forssk. ex Endl. locally known as 'Chat' in homegardens as a cash crop. *Catha edulis* is a stimulant plant chewed by people. Farmers recognized very high return of this plant since the products can be harvested 2-3 times a year for sale. But in the watershed, the habit of chewing 'Chat' is not socially acceptable and is considered as an addictive plant.

Domestic animals are also integral parts of the homegardens that are managed by farm households. Cattle, equines, sheep and goats are the major animals in the study area. Two types of interactions were observed in homegardens with animal husbandry. Some farmers totally abandon the entry of livestock except for ploughing in homegardens. They usually use the cut and carry system of green grasses and other edible tree leaf and branches during the rainy season and crop residues after harvest to feed their animals. Such kind of system is mostly used for those gardens with multi-layer perennials that can be browsed by animals (see Figure 15A). Others used seasonal restriction of animal entrance during the annual cropping season and allowed animal grazing in the farms after the annual crop is harvested (Figure 15B). The homegardens in the area are generally considered as food crop-based prototypes as described by Tiruneh (2008). The food crops are the major components in most of the homegardens in the watershed with various types of woody species.

The pattern of tree and shrub planting varies among homegardens. Most of the farmers plant trees and shrubs without row (Figure 15B) using irregular spacing while others used row planting, like that of alley cropping, with irregular spacing between rows and mixing of different species (Figure 15A).

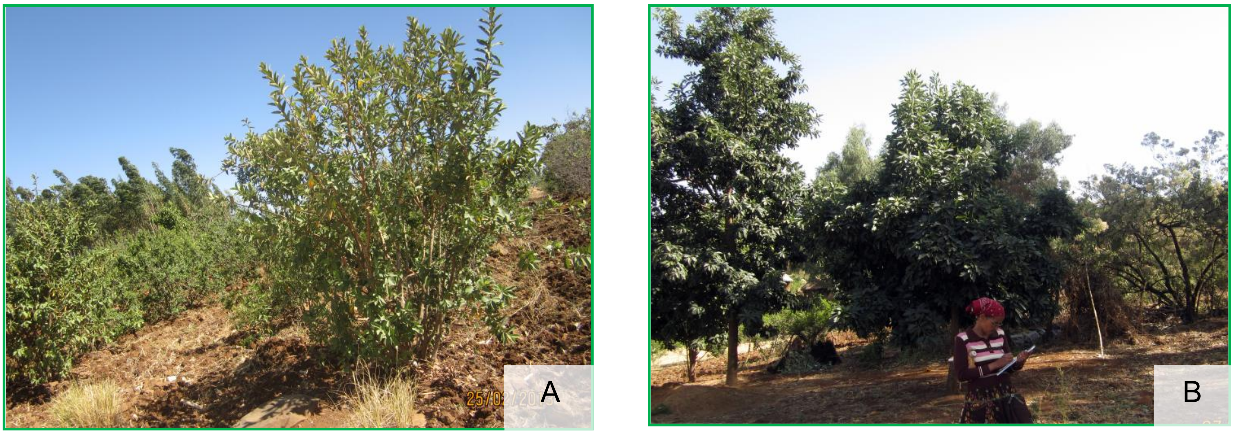


Figure 15. Row planting (A) and scattered tree planting (B) in homegardens

5.2.1.2 Alley cropping

Alley cropping indicates the planting of trees or shrubs in rows between annual crops. In the study area, alley cropping with *R. prinoides* is a very common practice, especially in the upper part of the watershed on red nitosols (Figure 16). In the lower watershed, the vertisols soil type is not suitable for the growth of *R. prinoides*. As it was observed in the field, most of the land, which is used for *R. prinoides* alley cropping is located in relatively lower slope areas as opposed to the idea given by Bishaw (2001) who explained alley cropping is commonly practiced on unproductive steeper slope areas in Ethiopia.


Figure 16. Alley cropping practiced with *R. prinoides* shrubs.

In the past, farmers used to plant *R. prinoides* in separate fields from annual croplands, mostly close to farm boundaries. Now, farmers have changed this type of planting and have shifted to plant the shrubs in alleys. This practice is based on farmers' knowledge and experience. Supporting this idea, Asefa & Worku (2014) also explained that the alley cropping in south Gondar area is a newly introduced practice by the local farmers.

The spacing between rows of the woody plant varies from place to place. However, the recommended spacing by the Federal Environmental Protection Authority (FEPA) for all types of alley cropping is 5 m in between rows (MOA, 2004). This specification may not be applied everywhere since farmers consider their farm size, when they decide to use the practice. It is observed that farmers used larger spacing than the recommended spacing by FEPA, ranging from 5 to 12 m wide. They believed that wider spacing may help to produce more food crops for household consumption. Currently, farmers are planting *R. prinoides* on soil bunds in the upper watershed, which is also used to stabilize the bund and sustain the soil and water conservation activities in the area.

The main purpose of planting *R. prinoides* in alleys is its economic importance for farmers and the possibility to produce annual crops in between the rows of these shrubs since farm size has diminished over time. On average, farmers can collect the products three times a year per shrub so that they can generate all year-round income from rows of *R. prinoides*. Farmers are also using the products for household consumption to prepare local alcoholic beverages, known locally as ‘Tella’ and ‘Araki’. In addition, alleys on which the shrub is planted gradually accumulate soils and form a natural bund like structure that is useful to prevent soil erosion (Figure 16).

Alley cropping practice using *S. sesban* (Figure 17) is a newly introduced practice by the agricultural extension service on soil bunds. The spacing between rows of the woody plant varies from place to place depending on the slope of the farm plots that determines the spacing of the soil bunds. The main objective of planting *S. sesban* on soil bunds is to stabilize the bunds and to increase the nitrogen content of the soil through nitrogen fixation.

Figure 17. Alley cropping practice with *S. sesban*.

In well managed situations, the products from *S. sesban* are also used for animal feed by the cut and carry system. But, in most cases, the seedlings are browsed by animals since free grazing is the common practice in the watershed. Though the feed value and soil fertility improving power of the species is very high, as indicated by Oosting et al. (2011), farmers are not giving much attention to the species compared with *R. prinoides.* Only few areas with *S. sesban* trees have shown the potential of the area for this multipurpose tree species. Recently, farmers have started to plant fruit trees in alleys. Citrus, avocado, casimiroa and guava are grown in alleys in some areas close to homes (Figure 15A).

5.2.1.3 Small-scale woodlots

Small-scale woodlots represent farmland plantations on a piece of land for the provision of, mainly, the wood products for fuel and construction material (Figure 4). In Maytemeko Watershed, eucalypt woodlots are becoming very common. The size of the woodlots is not more than 0.25 ha. The two common species used for small-scale woodlots are *E. camaldulensis* and *Eucalyptus globulus* Labill. Key informant interviews with elder people indicated that, before 25 years, eucalypt plantations were not very common in the area. The fast growing nature of the species to solve fuelwood problems encouraged farmers to plant these trees in woodlots. Farmers are using farm edges for eucalypt woodlots regardless of the fertility of the farm plots, but they are not planting eucalypts in the middle of their farm plots mainly due to the recognition of the negative effect of the tree on the crops as a shade and nutrient competition. Farmers also confirmed this idea in the preference ranking of trees for soil fertility management, which will be discussed on section 5.5. There is no specific rule for the management activities on these woodlots. In addition to using the wood products for both household consumption of fuel and construction wood, the woodlots are also used to increase household income by selling the products. The rotation period for small scale eucalypt woodlots vary depending on the purpose of the wood product whether farmers need the wood for 'mager[4]', pole or split wood. *Mager* can be harvested three years after plantation, where as the poles are usually harvested four to five years after planting (personal communication with farmers).

Figure 18. Small-scale woodlot established at the edge of farms in the watershed.

Establishment of small-scale woodlots, as an agroforestry practice, showed interaction with the crop and animal husbandry components since they are planted at the edges of other farm plots (Figure 18). The results from the focus group discussions indicated that farmers recognize the shading effects of trees on annual crops cultivated near the woodlots. However, they still want to expand the plantation due to its economic return and wood production in relatively short period of time. Supporting this idea, Kidanu et al. (2005) pointed out that though eucalypt plantations along annual crops reduced the crop yield, the economic return from the sale of eucalypts is still attractive and can compensate for the loss in crop yield. Farmers also used the grasses at the boundary and sometimes from inside the woodlots with low density of trees and after coppicing to feed their animals.

5.2.1.4 Scattered trees on farm

Scattered trees on farmlands are sources of various wood and non wood products outside the forest land and provide several ecological services, such as carbon sequestration and improving the micro-climate and the soil (Zomer et al., 2009; FAO, 2013b).

[4] Wood that is smaller in size than poles and used for small-scale construction.

In Maytemeko Watershed, a number of scattered indigenous tree species, which are also found in natural forests are commonly observed on farmlands (Figure 19). The most common tree species found scattered on farmlands are *C. macrostachyus* in the upper watershed and *A. abyssinica* in the lower watershed. Farmers maintain these trees on their farms to improve soil fertility. The branches of these trees are also used for fuelwood and fencing of the annual crop during the cropping season. Farmers also use matured branches of *C. macrostachyus* for the preparation of farm equipments. Moreover, in the lower watershed, farmers plant and manage *C. africana* trees to produce timber for its market value. The wood obtained from *C. africana* is considered as the best wood for household and office furniture compared with other species in the area.

Figure 19. Scattered trees on farmlands

5.2.2 Woody plant species richness and diversity in farmlands and homegardens

5.2.2.1 Farmlands

Out of 32 sampled plots, 25 and seven were found with and without woody plant species, respectively. A total of 1560 woody plant stems were recorded, which accounted for an average density of about 49 woody plants ha^{-1}. These woody plants represented 43 species belonging to 25 families. Of these, 67.4% were trees and the remaining 32.6% were shrubs. Woody plants with height greater or equal to 5 m and one erected stem from the base were considered as trees, while those lower than 5 m in height with multiple stems were considered as shrubs. In agreement with this study, Negash (2013) also reported that the largest proportion of woody plant species was covered by trees compared with shrub species within agroforestry practices in the south eastern Rift Valley of Ethiopia. Ten woody species that belong to the Fabaceae family accounted for 23.3% of all the species. Similar result was reported in north Ethiopia where the Fabaceae family dominated the farmlands compared with other families (Tefera et al., 2014).

The calculated Shannon diversity and evenness indices were 1.23 and 0.597, respectively for farmland woody plant species. Shannon diversity index in this study is relatively higher than the result found in northern Ethiopia by Tefera et al. (2014) who reported a Shannon diversity index of 0.58. However, the value of the Shannon diversity index in this study is lower than the studies reported from the forest areas of Ethiopia for woody species by Yirdaw (2001) and Zegeye et al. (2011) who found the Shannon diversity index of 3.0 and 2.98, respectively. Similarly, Alelign et al. (2007) reported a Shannon diversity index of 3.72 in Zegie Peninsula, northwest Ethiopia. However, farmlands might have their own contribution to conserve different tree and shrub species and could be used as habitats for other organisms since the forest cover is reducing over time. The Shannon diversity index showed positive significant correlation with altitude ($r = 0.376$, $p = 0.034$). This indicates that both the evenness and abundance of woody species increase with an increasing altitude. However the correlation with slope was not significant ($r = 0.346$, $p = 0.052$).

The highest and lowest numbers of woody species recorded in the different farmlands were 14 and three, respectively, while the average number of woody species was about five. The four most abundant woody species, namely *C. macrostachyus, R. prinoides, Vernonia amygdalina* Del., and *Rumex nervosus* Vahl accounted for 19.6, 16.2, 8.5 and 8.2% of the total stems on the farmlands, respectively.

On the other hand, six of the woody species were the rarest on farmlands represented by only a single stem, accounting for 0.38% of the stems of all the species together (Appendix 2). These are *Dombeya torrida* (J.F. Gmel.) P Bamps, *Ficus vasta* Forssk, *Ricinus communis* L., *Ficus thonningii* Blume, *Juniperus procera* Hochst.ex Endl and *Polyscias fulva* J.R. Forst & G. Forst. A very similar result was also reported by Tefera et al. (2014) who reported that tree species such as *J. procera* are becoming rare in the farmlands of northern Ethiopia.

Alebachew (2012) also reported that *D. torrida* and *F. vasta* are the most endangered tree species in central Ethiopia. This can be attributed to the preferences of farmers for different tree species to sustain and manage on their farmlands. Trees, like *F. vasta,* are not preferred on the farmlands because of its extensive canopy and its shading effect on annual crops. Instead, the farmers leave these trees outside the farmlands so that they can use them for shade during meetings as indicated by Muller-Hohenstein & Abate (2004). On the other hand, the regeneration and survival rates of the tree species, which are affected by both natural and human-induced factors, may also limit the presence of indigenous tree species in the area.

5.2.2.2 Homegardens

A total of 6,047 woody plant stems were recorded, which accounted for a density of about 275 woody plants ha^{-1} (Appendix 3). These woody plants represent 51 species belonging to 29 families. Of these, 29 species (53%) were trees and the remaining 22 species (47%) were shrubs. Nine woody species that accounted for 17.6% of the total species recorded belonged to the Fabaceae family.

The calculated Shannon diversity and evenness indices for homegardens were about 1.34 and 0.60, respectively. The value of Shannon diversity index is lower than another study carried out by Mekonnen et al. (2014) who reported a Shannon diversity index of 3.01 to 3.28 for different homegardens in Holeta, central Ethiopia. This might be related to ethnicity differences for the preferences of the species in homegardens. However, the result from the present study had better Shannon diversity index than the study conducted by Duguma & Hager (2010) in central Ethiopia.

Significant positive correlation was found between the number of trees in homegardens and altitude ($r = 0.464$, $p = 0.03$). More woody plants were found in the higher altitude ranges compared with the lower altitudes in the watershed. However, the correlation with slope was not significant ($r = - 0.205$, $p = 0.365$).

The highest and lowest numbers of woody species recorded in the different homegardens were 23 and seven, respectively, while the average number of woody species was about 12. The most abundant woody species in homegardens were *R. prinoides*, *E. camaldulensis, E. globulus* and *C. macrostachyus*, which accounted for about 37, 24.8, 16.2 and 4.3% of the total stems recoded in homegardens, respectively (Appendix 3). However, ten of the species recorded in the homegardens were represented by only a single stem (Appendix 3). Two stems of B*aphia abyssinica* Brummit were found in homegardens. This species is the most treated in the world, and, hence, already registered in the red lists of species (WCMC, 1998).

The relatively higher abundance of *R. prinoides* in homegardens may be attributed to its economic significance to the local farmers. The short rotation period of eucalypt species compared with other indigenous tree species may also increase the interest of farmers in the area to improve household income and satisfy their wood demand. Farmers are usually using the edges of homegardens for eucalypt plantations as it was observed on other farm plots as stated earlier. Similar results were also reported by Duguma & Hager (2010) who found exotic tree species and indigenous shrub species were most abundant woody plants in central Ethiopia. Tefera et al. (2014) also pointed out that exotic tree species of eucalypts are expanding at the expense of indigenous species in northern Ethiopia.

5.2.2.3 Similarity between farmlands and homegardens in woody species richness

The overall similarity between the farmlands and homegardens in woody species richness was about 0.4, which suggests substantial differences. This can be explained by the fact that the homegardens had 16 woody species, which were not found in other farmlands. Also, the farmlands contained eight species, which were not found in homegardens. Most fruit trees, such as citrus and papaya were observed only in homegardens. Most of the trees found in farmlands but not in homegardens were remnants from forest clearing, such as *Rhus glutinosa* A. Rich and *Terminalia schimperiana* Hochst (Appendices 2 & 3).

The woody plants are used for different purposes by the local farmers. Fire wood, construction materials, medicine, income generation, farm implements, bee forages, shade, animal fodder and soil fertility amendments were frequently pointed out as uses of the woody species by farmers in the study area **(**Appendices 2 & 3).

5.3 The role of agroforestry in soil nutrient improvement

Soil nutrient improvement is one of the most important issues that can address the problem of low productivity since most of the soils of Ethiopia are nutrient deficient. One of the ways to improve the soil nutrient status is using appropriate land use practices and integrating soil improving woody species with annual crops.

5.3.1 Soil chemical properties in agroforested and non-agroforested land use types

5.3.1.1 Soil pH

Soil pH is an indicator for soil reaction and determines the availability of nutrients in the soil that can influence the growth of plants. The result showed that soil pH values for the different land use types (LUTs) in the watershed vary significantly, ranging from 5.9 to 7.0. This range is the optimum range for most plant and microorganism (Lemenih et al., 2005; FAO, 2006). Multiple comparison of using THSDT indicated significant[5] difference in pH values among the five LUTs both in the upper (0-15 cm) and lower (15-30 cm) layers of the soil. The highest pH value was recorded in soils sampled from the *C. macrostachyus* fields (CMF) compared with those of other LUTs and the lowest value was recorded from farms cultivated with single cereal crops (SCC) (Table 8). Different results were reported in various parts of Ethiopia. For example, in agreement with the present study, Anteneh (2010) found that farm plots without tree species showed lower pH than farm plots with tree species in Gelda watershed. Haile et al. (2014) also reported that higher pH values in soils from Enset agroforestry than soils from cereal farm plots. Ndlovu et al. (2013) also reported the highest pH values from soils taken under the *C. macrostachyus* farm plots compared with the controlled open farm plots in Kenya. However, Gindaba et al. (2005) reported non-significant differences between soils from *C. macrostachyus* and open farmlands in eastern Ethiopia though the value in open farmlands was lower.

The low pH in SCC is attributed to the depletion of major soil nutrients by crops and removal of crop residues from farmlands for different purposes (animal feed, fuel and construction material). Exchangeable cations were also significantly lower in SCC than those in other LUTs, and this may contribute to the low pH values (Table 9). If less basic cations are available in the soil exchange complex, significant portion of the soil colloid is occupied by H^+ and/or Al^{+3} that might lead to lower pH values in the soil (Brady & Weil, 2002). On the other hand, higher basic cations content was recorded in CMF than in other LUTs (Table 9), which could result in higher pH value. The high basic cations in CMF might be also attributed to the nutrient pumping ability of the trees from the deeper horizon and litter decomposition and mineralization.

The pH values by soil depth classes indicated partly a decreasing trend from upper to lower soil layers except soils from alley cropping in between rows (ACR) and homegarden (HG)

[5] Hereafter, significance and non-significance levels refer to $p < 0.05$ and $p > 0.05$, respectively, unless otherwise specified.

LUTs that exhibited slightly higher pH values at the lower layer of the soil though the variation was not significant (Table 8).

In general, according to the rates used by Tekalign (1991), SCC can be categorized as moderately acidic, whereas, ACS (alley cropping within the row of shrubs), HG and ACR are slightly acidic and CMF is considered as neutral. The highest Al value was observed in SCC; hence, its potential for acidification in SCC is higher than in other LUTs. This can be aggravated by continuous nutrient removal through harvesting.

5.3.1.2 Organic carbon (OC), total nitrogen (N) and C: N ratio

Significant differences were observed in soil OC content among the different LUTs. The highest content of OC was recorded in CMF followed by ACS, HG, ACR and SCC both in the upper and lower layers of the soil (Table 8). In the upper layer of the soil, OC was more than 80% greater in CMF than in SCC. Similar results were reported in different studies conducted in various parts of Ethiopia. For example, Gelaw et al. (2014) indicated that agroforestry LUTs exhibited higher OC than open farmlands in northern Ethiopia. Duguma et al. (2010) also reported that cereal farmlands showed lower OC than agroforestry LUTs in central highlands of Ethiopia.

Soil N showed the same trend like that of OC. Significantly higher value of N was observed in the CMF than the other LUTs and the lowest was recorded from SCC in both the upper and lower layers of the soil (Table 8). Similar to the present result, Gindaba et al. (2005) found higher N near *C. Macrostachyus* than cereal fields in eastern Ethiopia. Manjur et al. (2014) also reported similar result that soil from *C. macrostachyus* farmlands exhibited relatively higher level of OC and N than open farmlands in south Ethiopia.

Table 8. Mean ± SE of soil parameters for land use types (LUTs) in both soil layers

LUT	pH (H_2O)	OC (mg g^{-1})	N (mg g^{-1})	C:N
		Depth = 0-15 cm		
CMF	7.0 ± 0.2b	38.4 ± 4.6a	3.8 ± 0.4a	10.2 ± 0.2a
SCC	5.9 ± 0.1a	17.9 ± 2.3b	1.9 ± 0.1b	9.4 ± 0.6a
ACS	6.4 ± 0.2a	34.6 ± 8.2ab	3.1 ± 0.5ab	10.7 ± 1.0a
ACR	6.0 ± 0.1a	21.6 ± 2.1ab	2.0 ± 0.1ab	10.8 ± 0.3a
HG	6.4 ± 0.1ab	29.7 ± 1.1ab	2.7 ± 0.1ab	10.6 ± 0.1a
		Depth = 15-30 cm		
CMF	6.9 ± 0.3 a	27.6 ± 4.5a	2.9 ± 0.4a	9.4 ± 0.6b
SCC	5.9 ± 0.1b	13.5 ± 2.2b	1.7 ± 0.2b	8.2 ± 0.9b
ACS	6.2 ± 0.1ab	23.3 ± 1.6ab	2.4 ± 0.2ab	9.6 ± 0.1b
ACR	6.1 ± 0.1b	19.4 ± 2.8ab	2.0 ± 0.2ab	9.6 ± 0.4b
HG	6.5 ± 0.2ab	23.1 ± 2.4ab	2.3 ± 0.1ab	9.7 ± 0.3b

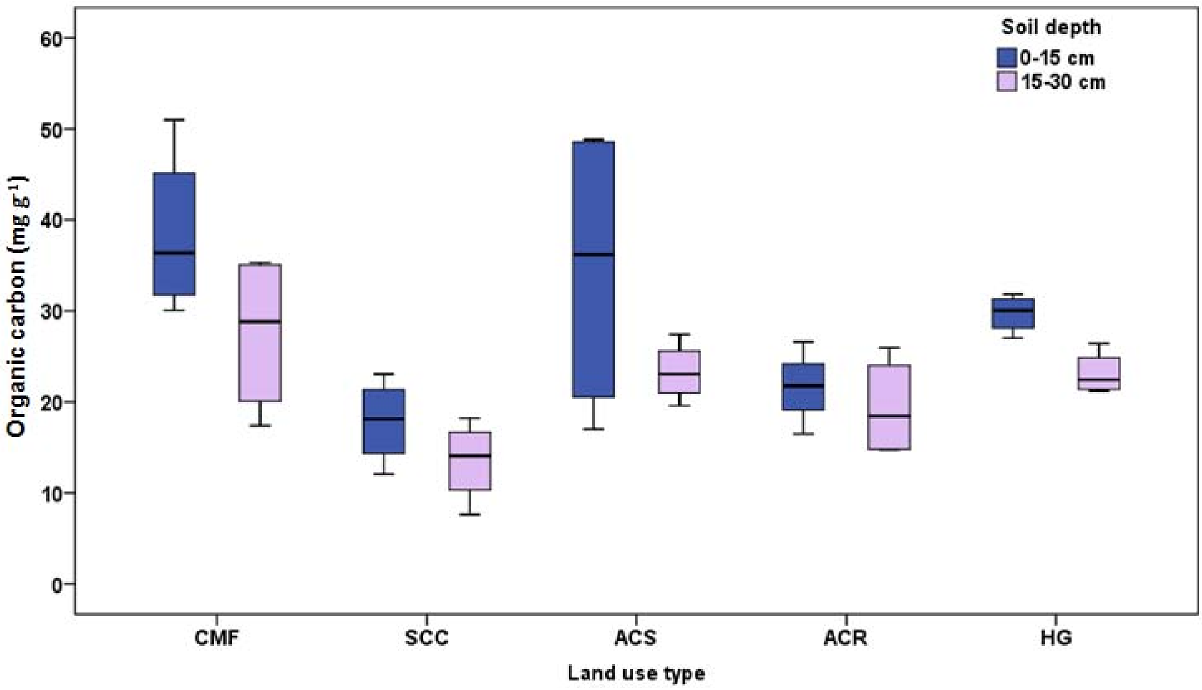
Mean values in a columns labelled by similar letter with in the same depth classes do not show significant variation at $p < 0.05$. CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden).

Relatively lower content of OC and N in SCC is attributed to long years of cultivation and biomass removal without the addition of crop residues or organic fertilizers. FAO (2006) also pointed out that the removal of N with crop harvest is very high. Tolessa et al. (2014) indicated that crop residue removal from agricultural lands significantly reduced soil OC and N contents. Bakht et al. (2009) pointed out that removal of crop residue resulted in the decline of soil N and OC in Pakistan.

On the other hand, it is evident that the highest amount of OC and N in CMF might be related to the litter accumulation and decomposition from the tree. The amount of OC in the soil is directly related to the amount of leaf litter accumulated on the soil surface (Salako & Tian, 2005; Iloyanomon & Ogunlade, 2011). Malo et al. (2005) also explained that lower levels of N and OC in cultivated fields implies the fact that fertilizer additions have not replaced the total N loss due to harvest removal, leaching and humus losses associated with cultivation. In addition, erosion may also deplete soil N and OC from the top soil (Anteneh, 2010).

Compared to SCC, soil from ACS contained nearly two fold OC. This might be due to the capacity of alley cropping to form a natural bund like structures along the alleys which are used to reduce soil erosion and increase the accumulation of soil nutrients compared with bare lands. In addition, despite of the harvesting of *R. prinoides* leaves, some litter from the shrubs, especially from lower ground root biomass, may also contribute to amend the OC and N contents.

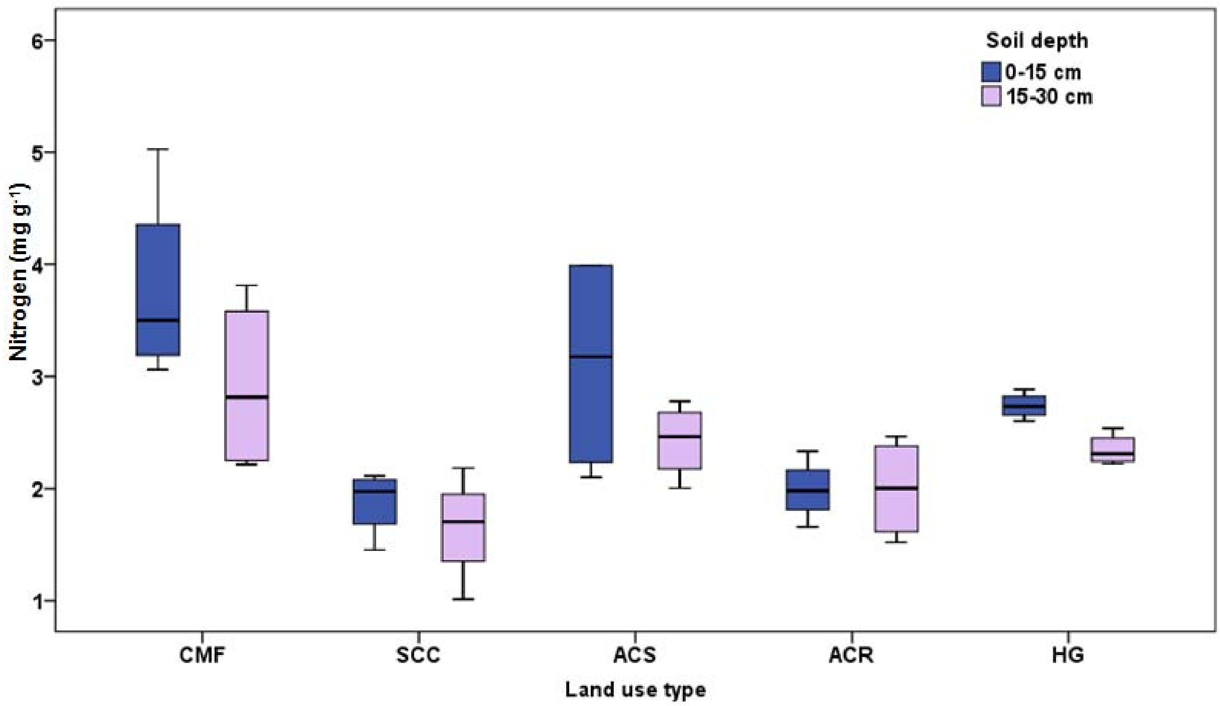
OC and N showed a decreasing trend from the upper to lower soil layers for all LUTs (Figure 20 & Figure 21). Relatively lower content of OC and N in the lower layer of the soil is attributed to the accumulation of the decomposing litter in the upper layer compared with the lower one. This result agrees with different studies documented in various parts of Ethiopia (Lemenih et al., 2005; Anteneh, 2010; Abera & Belachew, 2011; Gelaw et al., 2014). Similarly, Malo et al. (2005) reported similar result in northern Great Plains of the United State of America.



CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 20. Soil OC in different LUTs of the two soil depth classes

The mean values of OC and N in HG plots showed relatively the lowest deviation. This shows that soil nutrient variability in HG was lower than those in other LUTs. The composition of different tree species in homegardens may play a significant role for this.



CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 21. Soil nitrogen content of LUTs (0-30 cm depth).

The C: N ratio did not show significant variation among LUTs. Similar result was also documented by Anteneh (2010).

Comparing the results of this study with already established critical values by Tekalign (1991), regardless of the LUTs, the soils of the study area are considered as moderate in soil OC content containing 2.6%. However, soil from SCC can be categorized as having low level of OC (1.5%) whereas, CMF can be categorized as having high level of OC since the average value of OC is greater than 3%.

5.3.1.3 Soil exchangeable cations

Exchangeable Ca^{2+} and Mg^{2+} did not show significant differences among the different LUTs in both the upper and lower layers of the soil (Table 9). Similarly, Duguma et al. (2010) reported non-significant differences among different LUTs in both exchangeable Ca^{2+} and Mg^{2+} in central Ethiopia. However, the highest and lowest values of exchangeable Ca^{2+} were observed in soils from CMF and SCC, respectively. Similarly, Anteneh (2010) found that farmlands with trees exhibited relatively higher exchangeable Ca^{2+} than the land without trees. Contradictory to this result, Duguma et al. (2010) reported higher value of exchangeable Ca^{2+} in cereal farms than other agroforestry LUTs. The higher content of exchangeable Ca^{2+} in his study might be related to the back history of the land use types. There might have been an application of lime in the area to improve the soil pH.

Table 9. Soil exchangeable cations (cmol$_c$ kg^{-1}) of land use types (LUTs) in both soil layers.

LUT	Ca^{2+}	K^+	Mg^{2+}	Na^+	Mn^{2+}
			Depth = 0-15 cm		
CMF	11.9 ± 3.5a	2.6 ± 1.6b	3.7 ± 0.7a	0.06 ± 0.01a	0.2 ± 0.10a
SCC	7.9 ± 1.5a	0.3 ± 0.1a	3.2 ± 1.7a	0.05 ± 0.01a	0.6 ± 0.20b
ACS	11.1 ± 2.2a	0.6 ± 0.4a	3.6 ± 1.2a	0.06 ± 0.01a	0.2 ± 0.20a
ACR	8.3 ± 1.6a	0.4 ± 0.2a	3.1 ± 1.4a	0.04 ± 0.00a	0.5 ± 0.10b
HG	9.6 ± 1.0a	1.1 ± 0.4ab	3.7 ± 0.6a	0.10 ± 0.04b	0.1 ± 0.04a
			Depth = 15-30 cm		
CMF	10.0 ± 3.1b	1.7 ± 0.8b	3.0 ± 0.8b	0.06 ± 0.01a	0.1 ± 0.04a
SCC	7.6 ± 1.6b	0.2 ± 0.1a	3.1 ± 1.5b	0.05 ± 0.02a	0.2 ± 0.10a
ACS	8.5 ± 1.0b	0.4 ± 0.3a	3.3 ± 0.9b	0.05 ± 0.01a	0.2 ± 0.10a
ACR	7.7 ± 0.8b	0.3 ± 0.3a	2.9 ± 1.0b	0.05 ± 0.01a	0.2 ± 0.06a
HG	8.5 ± 0.9b	0.8 ± 0.3a	3.5 ± 0.6b	0.10 ± 0.04b	0.1 ± 0.05a

Mean values in a column labelled by similar letter with in the same depth classes do not show significant variation at $p < 0.05$. CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Higher exchangeable K^+ was observed in CMF than in other LUTs and the lowest value was found in SCC in both the upper and lower layers of the soil (Table 9). This result agrees with another study conducted by Manjur et al. (2014) who reported higher content of exchangeable K^+ in soils near *C. macrostachyus* trees than in open fields. All the three exchangeable basic cations showed decreasing trends with increasing depth in all LUTs though the variation was not significant.

Significantly higher value of exchangeable Na^+ was found in soils sampled from HG in both the upper and lower layers of the soil. Other pairs of comparisons did not show significant variation. High values of exchangeable Na^+ in HG might be attributed to the enrichment by human and animal wastes since this land use type is located near the residential area. Contrary to this result, Duguma et al. (2010) found lowest content of exchangeable Na^+ in HG compared with other land use types though the variation was not significant. The difference might be related to the preference of the households to put excretes outside homesteads in his study area. He emphasised that the homesteads are mostly used for the production of vegetables and *C. edulis* which are normally grown in relatively clean gardens.

Significant variation in exchangeable Mn^{2+} was also observed in the upper layer of the soil among the LUTs. The highest value of exchangeable Mn^{2+} was observed in SCC followed by ACR. This might be related to lower pH values of these LUTs than other LUTs (Table 8). At lower pH values, the solubility and availability of soil micronutrients for plants increased (Brady & Weil, 2002) and higher pH causes a decrease in solubility and availability of the micronutrients. Negative relationship was observed between soil pH and Mn^{2+} in the upper layer of the soil (Figure 22). In the lower layer of the soil, there was no significant difference in the content of exchangeable Mn^{2+} among the LUTs.

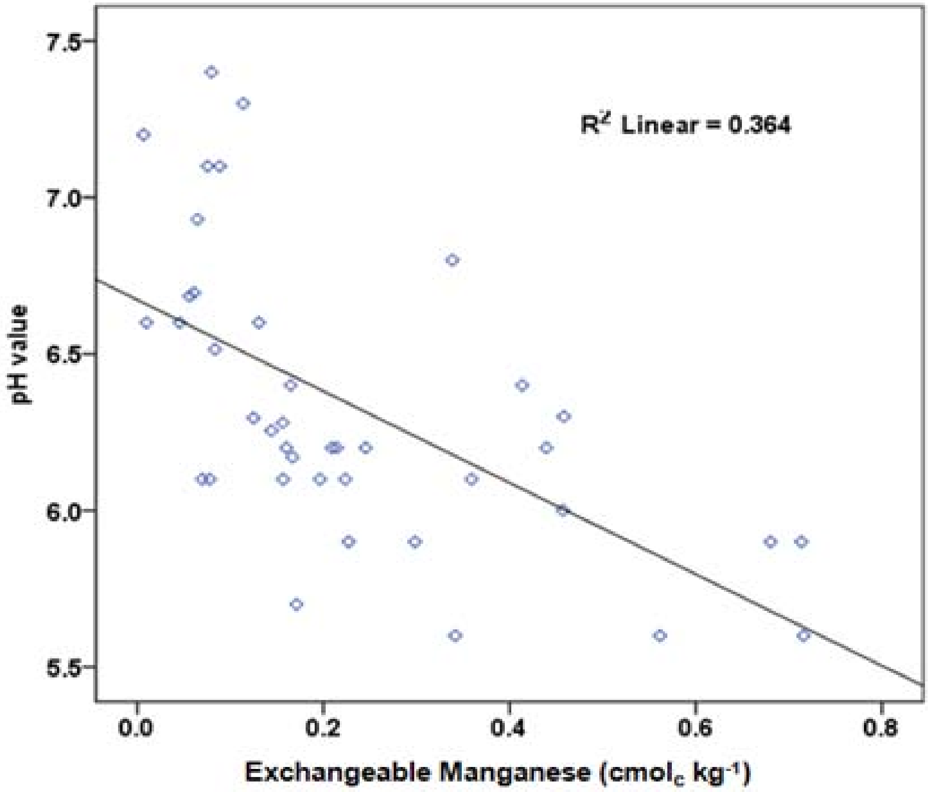


Figure 22. Relationship between exchangeable Mn^{2+} and pH values in the upper layer of the soil.

According to the rating of FAO (2006), most of the LUTs showed relatively optimum contents of exchangeable basic cations. However, there is variation in the contents of these basic cations among the different LUTs. Accordingly, soils in CMF can be categorized as having very high level of exchangeable K^+, high values of exchangeable Ca^{2+} and Mg^{2+} and very low level of exchangeable Na^+. All other LUTs exhibited medium to high level of other exchangeable cations and very low to low level of exchangeable Na^+ in the upper and lower layers of the soil.

5.3.1.4 Soil ''total'' nutrients and available phosphorus (Ava P)

Soil ''total'' nutrients here indicates the acid extractable nutrients using nitric and hydrochloric acids as indicated earlier, not the real total. Overall, significant variation in soil total Ca was observed among the LUTs in the upper layer of the soil. The mean value of total Ca in CMF was more than 40% higher than the soils from SCC in the upper layer of the soil. The pair-wise comparison also showed that total Ca in CMF land use type was significantly higher than in other LUTs except in HG. But in the lower layer non-significant difference in total Ca was observed among the LUTs.

Table 10. Mean ± SE of soil total nutrients and available phosphorus (Ava P) in different land use types (LUTs)

LUT	Ca (mg g^{-1})	K (mg g^{-1})	Mg (mg g^{-1})	Na (mg g^{-1})	P (mg g^{-1})	Ava P (µg g^{-1})	Al (mg g^{-1})
				Depth = 0-15 cm			
CMF	4.4 ± 0.8a	5.1 ± 0.4a	3.3 ± 0.1a	0.14 ± 0.01a	0.7 ± 0.09a	59.2 ± 10.3a	66.5 ± 2.6a
SCC	2.5 ± 0.2b	3.4 ± 0.6ab	4.1 ± 0.9a	0.15 ± 0.01a	0.4 ± 0.06b	27.8 ± 2.8b	78.8 ± 2.7b
ACS	3.8 ± 0.4ab	2.9 ± 0.4b	3.5 ± 0.4a	0.12 ± 0. 00a	0.4 ± 0.09b	40.0 ± 7.9a	70.6 ± 2.2b
ACR	2.6 ± 0.1b	2.3 ± 0.4b	3.3 ± 0.4a	0.13 ± 0.00a	0.3 ± 0.05b	32.0 ± 2.3a	70.7 ± 1.0b
HG	3.8 ± 0.3ab	3.0 ± 0.3b	3.7 ± 0.3a	0.16 ± 0.00a	0.5 ± 0.06ab	46.5 ± 6.1a	69.6 ± 0.7b
				Depth = 15-30 cm			
CMF	3.6 ± 0.6a	5.0 ± 0.4a	3.3 ± 0.1b	0.12 ± 0.00a	0.5 ± 0.03a	37.7 ± 6.8ab	74.2 ± 2.6ab
SCC	2.5 ± 0.2a	3.5 ± 0.7ab	4.1 ± 0.9b	0.18 ± 0.02b	0.3 ± 0.07ab	17.5 ± 1.5a	82.1 ± 2.3b
ACS	2.7 ± 0.2a	2.9 ± 0.4b	3.2 ± 0.4b	0.12 ± 0.00a	0.3 ± 0.06ab	29.3 ± 2.7ab	75.6 ± 1.8ab
ACR	2.6 ± 0.2a	2.1 ± 0.3b	3.2 ± 0.5b	0.13 ± 0.01ab	0.2 ± 0.05b	29.5 ± 6.3ab	70.0 ± 1.7a
HG	3.3 ± 0.1a	2.7 ± 0.3b	3.7 ± 0.3b	0.10 ± 0.00ab	0.4 ± 0.05ab	42.0 ± 4.1b	68.3 ± 1.0a

Mean values in a column labelled by similar letter with in the same depth classes do not show significant variation at $p < 0.05$. CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

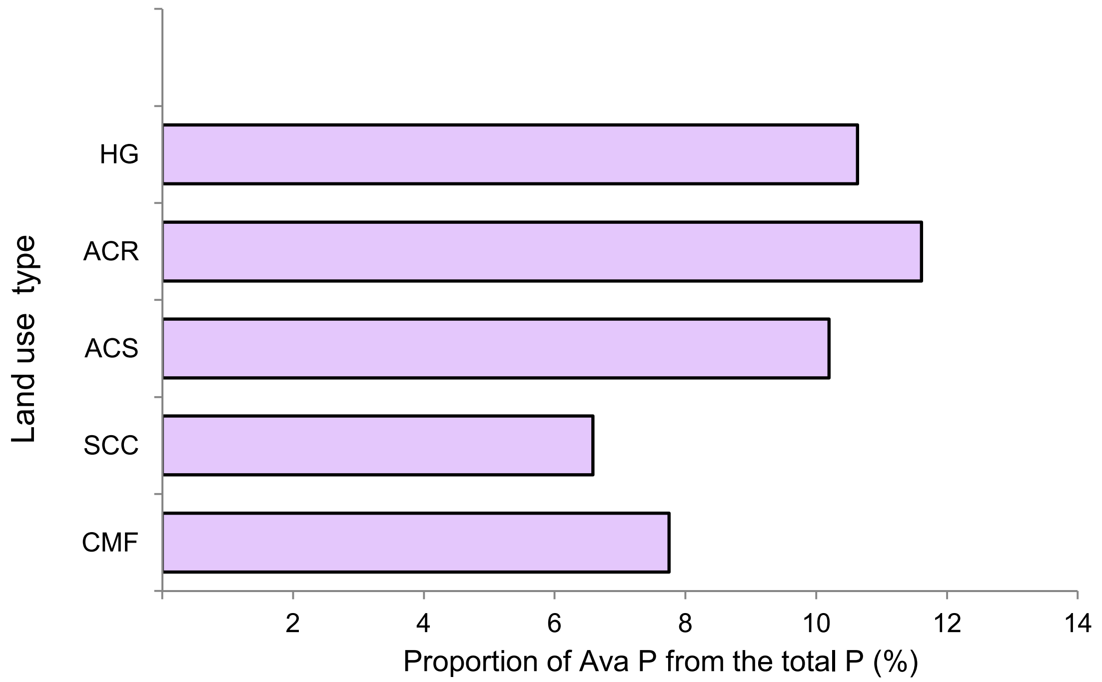
Significant differences in total K were observed among the LUTs for both soil layers. The highest and lowest values of total K were observed in soils sampled from CMF and ACR, respectively, for both layers of the soil. Following the CMF, SCC also showed relatively higher total K though the difference was not significant (Table 10).

The pair-wise comparison indicated that there was no significant difference in total Mg content between the different LUTs in the upper and lower layers of the soil. Similar result was reported by Anteneh (2010) who found that LUTs did not show significant variation in total Mg in the upper layer of the soil. However, the highest value of total Mg was recorded in SCC followed by HG in both soil layers. The remaining LUTs showed close results in total Mg in the respective soil layers (Table 10).

Significant differences in total P were observed among LUTs. The highest value of total P was recorded in CMF followed by HG, whereas the lowest level was recorded in ACR. The pair-wise comparison also showed significantly higher total P in CMF than in other LUTs except in HG in the upper layer of the soil. In the lower layer of the soil, CMF showed significant difference in total P compared with ACR, but not with other LUTs.

Ava P was also the highest in CMF, whereas the lowest value was recorded in SCC in the upper layer of the soil. In the lower layer of the soil, the highest value of Ava P was recorded in HG followed by CMF and the lowest was recorded in SCC. In the upper layer of the soil, the mean value of Ava P of CMF showed significant difference compared with SCC but not with other LUTs. However, in the lower layer, Ava P showed significant difference between pairs of HG and SCC but not among others. Averaged across the depth classes, Ava P follows the decreasing order of CMF, HG, ACS, ACR and SCC. In agreement with this study, highest value of Ava P was also reported near *C. macrostachyus* trees in other parts of Ethiopia (Gindaba et al., 2005; Manjur et al., 2014). Lowest Ava P in SCC is attributed to the removal of the entire crop component from the land. In line with this idea, Brady & Weil (2002) explained that the major pathway through which phosphorus is lost from the soil system is through plant removal followed by removal of soil particles containing phosphorus by erosion and phosphorus dissolved in surface runoff water. Soils of SCC are exposed to all these losses so that the Ava P was lower than in the other LUTs.

Even though the highest values of total P and Ava P were found in CMF, the proportion of Ava P from the total P did not show the same order (Figure 23). The highest value of Ava P proportion was in ACR LUT and others follow the decreasing order of HG, ACS, CM and SCC. Relatively lower proportion of Ava P from the total P in SCC and CMF might be attributed to the lowest and highest pH values, respectively, compared with other LUTs. At low and high pH values, phosphorus fixation may occur that results in the formation of insoluble complex compounds (Brady & Weil, 2002). The results also showed that CMF exhibited relatively the highest values of total Ca that might lead to the formation of stable Ca compound with phosphorus. In SCC, the highest value of Al was found in both upper and lower soil layers (Table 10). This may contribute to lower proportion of Ava P by forming complex compounds with phosphorus.



CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 23. Proportion of available P from the total P in different land use types.

The bivariate correlation also showed strong and negative correlation between soil Ava P and total Al in the upper layer of the soil (r = - 0.7, p = 0.01) (Table 12). The correlation is also negative but not significant in the lower layer of the soil.

5.3.1.5 Cation exchange capacity and base saturation

CEC did not show significant differences among the LUTs in both the upper and lower layers of the soil (Table 11). Similar to the present study, non-significant difference in CEC was also reported by Duguma et al. (2010) in different land use types in central Ethiopia.

Table 11. Mean ± SE of soil cation exchange capacity (CEC) and base saturation % (BSP) among different land use types.

Soil parameters	Soil depth (cm)	CMF	SCC	ACS	ACR	HG
CEC ($cmol_c\ kg^{-1}$)	0-15	18.4 ± 2.8a	12.0 ± 1.5a	15.5 ± 1.7a	12.4 ± 1.4a	14.6 ± 0.9a
	15-30	14.9 ± 2.3a	11.2 ± 1.6a	12.4 ± 0.9a	11.1 ± 0.7a	13.0 ± 0.8a
BSP	0-15	99.1 ± 0.4a	94.8 ± 1.2b	98.6 ± 0.5a	95.3 ± 1.0b	99.0 ± 0.3a
	15-30	99.4 ± 0.2a	98.0 ± 0.6a	98.5 ± 0.5a	97.9 ± 0.4a	98.9 ± 0.4a

Mean values labelled by similar letter with in a row do not show significant variation at $p < 0.05$. (CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden).

However, CMF exhibited the highest value of CEC in both soil depth classes, while the lowest value was recorded in SCC in the upper layer of the soil and in ACR in the lower layer of the soil. Regardless of the soil layers, the magnitude of CEC content follows the order of CMF > ACS > HG > ACR > SCC. A very similar result was also documented by Manjur et al. (2014) who reported that the highest value of CEC was recorded from soils under *C. macrostachyus* compared with the open fields in south Ethiopia. All the exchangeable basic cations are also higher in CMF than in other LUTs, which are responsible for the highest CEC since CEC is the sum of the exchangeable cations (Table 9). This might be due to the accumulation of organic matter from the tree canopy that may result in the release of cations to the soil through mineralization. This study also confirmed that the OC content of CMF is the highest compared with other LUTs (Table 8). The highest correlation of CEC and OC was also reported by many other authors in Ethiopia (Yimer et al., 2008, Anteneh, 2010; Duguma et al., 2010).

Generally, based on the rating given by FAO (2006) for CEC, the soils of the studied LUTs can be considered as medium ranging from 12 to 18.6 $cmol_c\ kg^{-1}$.

BSP showed significant difference among LUTs in the upper layer of the soil. But variation in BSP is not significant in the lower layer of the soil among the different LUTs. BSP showed an increasing trend from the upper to the lower layers of the soil for all the LUTs except HG and ACS that showed almost similar values of BSP in the two soil layers. This might be attributed to the leaching of cations to the lower layer. In the upper layer of the soil, the highest and lowest values of BSP were observed in CMF and SCC LUTs, respectively. For all depth classes, the trend of BSP followed the same order as CEC among the LUTs. The BSP recorded in the study area is relatively higher compared with other studies. This is mainly due to the lower contribution of acidic cations, such as Al^{3+} and H^{+} to CEC that most of the exchangeable site is occupied by basic cations.

5.3.1.6 Correlation of soil nutrients within the land use types

Soil OC had a positive and significant correlation with N, pH, C: N ratio, Ca, P and Ava P, Mn and S. But it had a negative and significant correlation with Al, while its correlation with Na, Mg and Fe was also negative but not significant in the upper layer of the soil (Table 12). In the lower layer of the soil, positive significant correlation of OC with N, C: N ratio, pH, Ca and Ava P was found, whereas, negative significant correlation of OC was observed with total Na and total Al. The remaining correlation in the lower layer was similar with that of the upper layer of the soil (Table 13).

The pH value of the soil showed significant positive correlation with N, C: N ratio, Ca, K, P, Mn, S and Ava P (Table 12) whereas the correlation with Al was negative and significant (r =

- 0.643, p = 0.01). Ava P was also negatively correlated with Al (r = - 0.662, p = 0.01) showing that high level of Al limits the availability of P for plants. However, significantly strong positive correlation of Ava P was observed with N and OC. Total P also showed moderate and significant correlation with OC and N in the upper layer of the soil (Table 12), whereas the correlation in the lower layer was not significant (Table 13). Similar result was also recorded by Duguma et al. (2010) that total P showed significant correlation with OC and N in different land use types.

Table 12. Correlation of soil parameters (mg g^{-1}) in the upper soil layer (0-15 cm).

	N	OC	C: N	pH (H_2O)	Ca	K	Mg	Na	P	Ava P	Al	Fe	Mn	S
N	1	0.971**	0.464*	0.783**	0.788**	0.549*	- 0.092	- 0.220	0.653**	0.900**	- 0.644**	- 0.067	0.538*	0.736**
OC		1	0.647**	0.703**	0.712**	0.408	- 0.080	- 0.202	0.549*	0.868**	- 0.613**	- 0.031	0.444*	0.623**
C:N			1	0.173	0.124	- 0.088	- 0.180	- 0.144	0.062	0.441	- 0.394	- 0.038	0.069	0.061
pH (H_2O)				1	0.789**	0.616**	- 0.091	0.073	0.775**	0.785**	- 0.643**	- 0.027	0.755**	0.748**
Ca					1	0.416	0.083	- 0.045	0.718**	0.799**	- 0.667**	0.179	0.566**	0.831**
K)						1	- 0.394	- 0.030	0.829**	0.558*	- 0.395	- 0.514*	0.477*	0.686**
Mg							1	0.331	- 0.146	- 0.067	0.492*	0.770**	- 0.106	- 0.361
Na								1	0.189	- 0.152	0.280	0.143	- 0.217	- 0.222
P									1	0.705**	- 0.585**	- 0.197	0.591**	0.804**
Ava P										1	- 0.662**	0.055	0.572**	0.765**
Al											1	0.274	- 0.596**	- 0.788**
Fe												1	- 0.071	- 0.210
Mn													1	0.636**

**. Correlation is significant at 0.01 significant level, *. Correlation is significant at 0.05 significant level.

Table 13. Correlation of soil parameters (mg g^{-1}) in lower layer of the soil (15-30 cm).

	N	OC	C:N	pH (H_2O)	Ca	K	Mg	Na	P	Ava P	Al	Fe	Mn	S
N	1	0.949**	0.348	0.549*	0.622**	0.431	- 0.320	- 0.536*	0.382	0.687**	- 0.372	- 0.130	0.542*	0.266
OC		1	0.615**	0.489*	0.579**	0.252	- 0.332	- 0.609**	0.239	0.807**	- 0.501*	0.054	0.632**	0.323
C:N			1	0.037	0.084	- 0.244	- 0.330	- 0.587**	- 0.281	0.620**	- 0.621**	0.384	0.500*	0.342
pH (H_2O)				1	0.782**	0.453*	- 0.022	- 0.158	0.724**	0.398	- 0.294	0.028	0.367	0.106
Ca					1	0.225	0.279	- 0.013	0.581**	0.458*	- 0.357	0.249	0.458*	- 0.011
K						1	- 0.371	- 0.181	0.697**	- 0.078	0.235	- 0.698**	- 0.064	0.348
Mg							1	0.509*	0.026	- 0.224	0.266	0.513*	- 0.183	- 0.337
Na								1	0.062	- 0.376	0.422	0.141	- 0.496*	- 0.403
P									1	0.060	- 0.020	- 0.295	0.258	0.369
Ava P										1	- 0.533*	0.343	0.522*	0.312
Al											1	- 0.332	- 0.737**	- 0.278
Fe												1	0.105	- 0.063
Mn													1	0.345

**. Correlation was significant at 0.01 significant level, *. Correlation was significant at 0.05 significant level.

5.3.1.7 Major components of soil parameters in the different land use types.

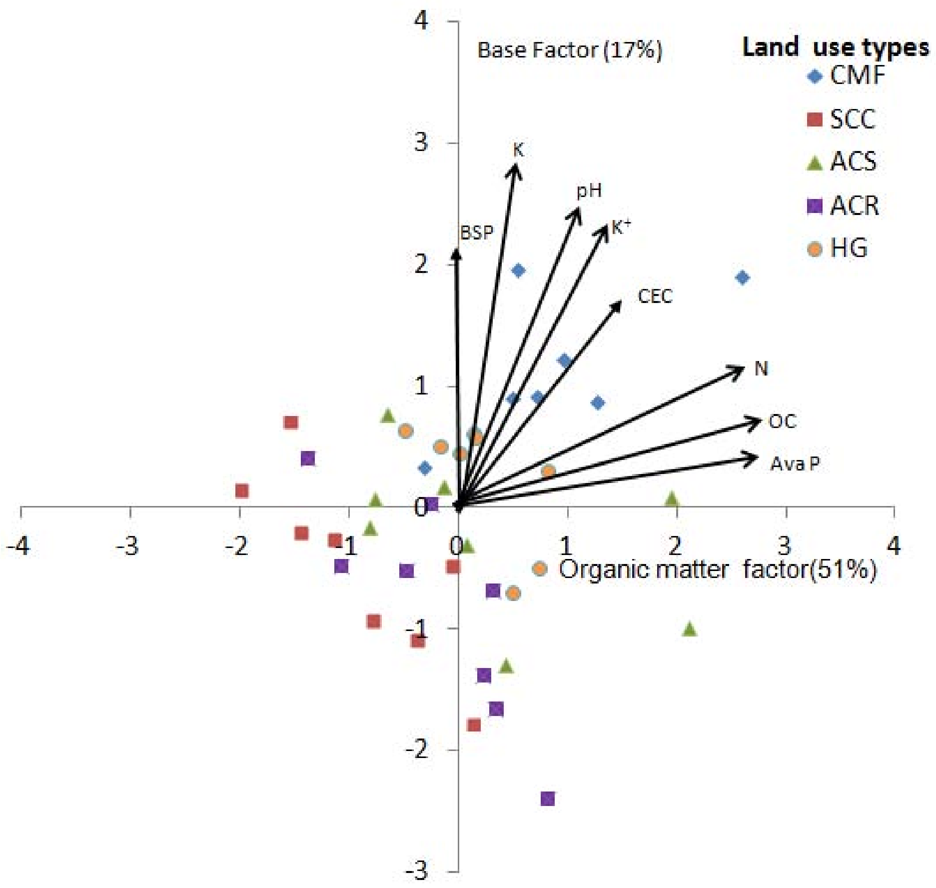
Three principal components (PCs) were produces from the whole soil parameters (Table 14). The first component (PC1) had high loading factor on OC, N, Ava P and, it could be considered as *organic matter factor* since all these parameters are related to organic matter additions. Ava P had also strong correlation with N and OC. The second component (PC2) had high loading factor on pH, exchangeable K^+, BSP, total K and CEC, and it could be considered as *base factor* as all the factors are related to the contents of basic elements in the soil. The third component (PC3) had high loading factor on total Mg and exchangeable Na^+ and, it could be considered as *enrichment factor* since both soil parameters are related to inorganic salts from human and animal waste enrichments**.**

Table 14. Principal components (PCs), Eigen values, variance and Eigen vectors of soil parameters in different LUTs (0-30 cm soil depth).

Principal components	Organic matter factor	Base factor	Enrichment factor
Eigen value	5.1	1.7	1.2
Variance %	51.2	17.34	11.8
Cumulative variance %	51.2	68.6	80.4
Eigen vectors			
OC	**0.945**	0.244	
Ava P	**0.925**	0.149	
N	**0.881**	0.391	
pH	0.397	**0.841**	
Exchangeable K^+	0.472	**0.792**	
BSP		**0.754**	0.282
Total K	0.166	**0.693**	- 0.467
CEC	0.490	**0.592**	0.373
Total Mg			**0.886**
Exchangeable Na^+		0.357	**0.717**

Figures in bold indicate the highest loading factors for the respective components

The three components altogether explained 80.4% of the total variance. The largest proportion of the variation (51.2%) was explained by the first PC (organic matter factor) followed by the base factor (17.3%) and enrichment factor (11.8%) (Table 14). A very similar result was reported by Beyene (2012) that the humus and base factor contributed to 39.9, 22.19% of the total variation in soils of northwestern Ethiopia.

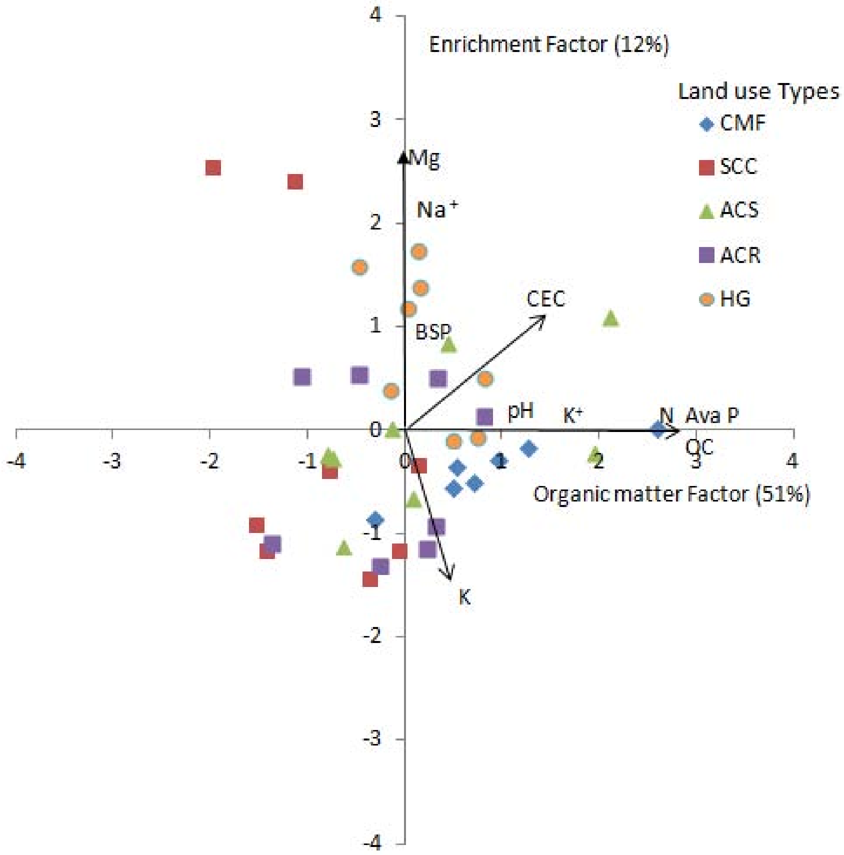


To make the factors loading visible on the graph, all values were multiplied by the factor three. CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 24. Relationship of land use types with PC1 and PC2

Most of the soil samples from CMF and HG were concentrated in both high organic matter and base factors compared with the other land use types. But almost all values of the SCC and ACR concentrated in lower organic matter factor as well as base factor (Figure 24). Pair-wise comparison of soil parameters also showed that the SCC and ACR LUTs exhibited the lowest contents of soil OC, N (Table 8) and Ava P (Table 10). Soils from ACS did not show distinct components they are located in the intermediate positions. But they concentrated in lower organic matter factor and base factor compared with the CMF. Compared with the

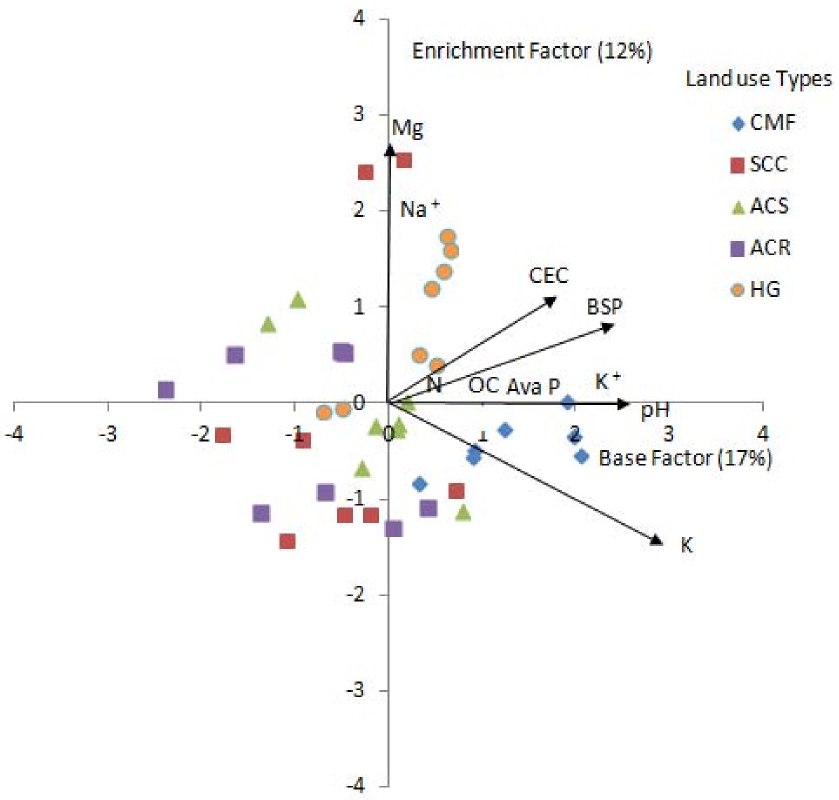
SCC and ACR plots, most of the samples in ACS are located on better organic matter and base factor.



To make the factors loading visible on the graph, all values were multiplied by the factor three; CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 25. Relationship of land use types with PC1 and PC3.

Soils from HG showed relatively higher loadings in the enrichment factor than other LUTs (Figure 25). This might be related to human and animal waste additions since the HGs are located near residential areas. Stevenson (1986) also indicated that animal wastes and sewage sludge contain inorganic salts of Na and Mg that might contribute to the highest enrichment factor in HGs compared with other LUTs. Since most of the households in rural areas are not using toilets, the addition of human excretes may lead to an increase in inorganic salts in HG. All soil samples collected from CMF concentrated in the lower part of the enrichment factor loadings compared with other LUTs.



To make the factors loading visible on the graph, all values were multiplied by the factor three; CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

Figure 26. Relationship of land use types with PC2 and PC3.

Considering the base factor against the enrichment factor, the CMF land use type exhibited distinct lower loadings for the enrichment factor and higher loadings for the base factor than the other LUTs (Figure 26). Most of the samples from HG showed relatively higher loadings in enrichment factors compared with other LUTs though there were also plots that showed high loadings for this factor from SCC.

5.3.1.8 Variation of major soil nutrients in land use types

The SCC LUT was considered as reference for comparison purposes since it serves as a control with no tree or shrub species. In all the soil parameters, the agroforestry LUTs showed better status than SCC plots evidenced from the positive values of the variation percentage of soil nutrients (Table 15).

Table 15. Variation percentage (%) and relative soil improvement index (RSII) in major soil nutrients of the land use types from 0-30 cm in relation to SCC

Soil parameters	Variation (%)			
	CMF	ACS	ACR	HG
OC (mg g^{-1})	110.7	84.6	31.0	68.7
N (mg g^{-1})	89.4	57.0	12.9	43.9
Ava P (µg g^{-1})	114	53.0	36.1	95.8
Exchangeable K^+ ($cmol_c$ kg^{-1})	794.8	97.9	60.2	279.8
RSII	1108.9	292.5	140.2	488.2

CMF = *C. macrostachyus* on farm; SCC = single cereal crop; ACS = alley cropping within the row of shrubs; ACR = alley cropping in between rows; and HG = homegarden.

In terms of RSII, the CMF LUTs were the best concerning soil chemical properties followed by the HG and ACS. Still, soils sampled from ACR were better than the SCC farm plots in all major soil parameters. Very similar result was also reported by Duguma et al. (2010) who reported that AFPs showed relatively higher RSII than the cereal farms in central Ethiopia. This might be related to the removal of soil nutrients through harvesting crops and crop residues in SCC. Moreover, SCC is relatively more vulnerable to erosion than the other LUTs due to cultivation and lack of tree cover as indicated earlier. Generally, in terms of RSII, the major soil nutrients follow the order of CMF > HG > ACS > ACR > SCC.

5.3.2 Variability of soil chemical properties in homegardens under different tree species

As it was stated earlier, five dominant tree species, namely: *Cordia africana* Lam., *Croton macrostachyus* Del. and *Acacia abyssinica* Hochst. ex Benth. *Sesbania sesban* (Jacq) W. Wight and *Eucalyptus camaldulensis* Dehnh. were considered to see variability in soil chemical properties under the canopies of these tree species and outside the canopies (interspaces) in homegarden LUT.

5.3.2.1 Soil pH

The pH value (H_2O) in homegarden plots showed slightly acidic condition, ranging from 6.1 to 6.8 under and outside the canopies of different tree species. Significant difference was observed in the pH values between soil samples under the tree canopies and outside the tree canopies in homegardens in both the upper and lower layers of the soil. The multiple comparisons showed significant difference in soil pH values in between soils under the canopies of *C. africana* and outside the canopies of the tree in both depth classes, whereas all other pairs of comparisons did not show significant difference (Table 16). Soils sampled under the canopies of other tree species also showed relatively higher pH values than soils collected from outside the canopies of the tree species. This might be attributed to the addition of decomposing litter that can contribute to increase basic cations under the canopies of the tree species.

Similar result was reported by Mekonnen et al. (2009) for different tree species in homegardens. They found that soils under the canopies of indigenous tree species exhibited relatively higher pH values than those away from the tree canopies in the central highlands of Ethiopia. Contradictory to the current study, Manjur et al. (2014) reported slightly higher soil pH values on open agricultural lands than soils under the canopies of the tree species though the variation was not significant in southern Ethiopia. This might be related to the difference in crop types cultivated before soil samples. In the current study, the fine grain Teff might cause nutrient mining compared with maize fields where the former study was carried out. Haile et al. (2014) also indicated that soil nutrient depletion is higher for Teff and wheat than other crop types. Gindaba et al. (2005) found non-significant difference in soil pH between soils under and outside the canopies of *C. africana*.

When all the tree species are compared, soils under the canopies of *S. sesban* and *E.camaldulensis* showed relatively lower pH values in both soil depth classes though the variation was not significant. Thus, indigenous trees showed relatively higher pH values than the exotic tree species. The study carried out by Mekonnen et al. (2009) also agrees with the present result that indigenous trees and shrubs showed relatively higher pH values than exotic species in the highland areas of central Ethiopia. This may be attributed to the leaf litter of eucalypt may be hard to decompose compared with the indigenous tree species considered. But slightly higher values of pH were found in soils sampled under the canopies of *S. sesban* and *E. camaldulensis* than those collected outside the canopies of all the tree species. In contrast, Hailu (2002) found slightly higher pH values on agricultural lands than eucalypt plantations in the highlands of Ethiopia. He emphasised that litter raking is a major problem in his study area that could probably result lower pH value under the canopy of eucalypt plantations. However, litter raking is not common in the present study area.

The pH value did not show significant variation between the two soil layers both under the canopies of the tree species and outside the canopy. However, a decreasing trend of soil pH was observed from the upper to the lower soil layers both under the canopies of the tree species and outside the tree canopies except for soils under the canopy of *C. africana*, which showed slightly higher pH value in the lower layer of the soil. The high pH value in the lower layer under the canopy of *C. africana* might be higher root litter input and turnover in the lower layer compared with other tree species.

5.3.2.2 Organic carbon, nitrogen and carbon: nitrogen ratio

The generalized linear model (GLM) and multiple comparisons showed significant difference in the values of soil OC under the tree canopies and outside the canopy in HG in the upper layer of the soil. But in the lower soil layer, there was no significant difference between soils under the tree canopies and outside. Soils under the canopies of trees of *A. abyssinica* showed the highest value of OC in the upper layer of the soil. But in the lower layer, the highest value of OC was found under the canopies of *C. africana*. Soil samples taken from outside the canopies also exhibited the lowest amount of soil OC than soils under the tree canopies. However, the difference is significant only compared with soils sampled under the canopies of *C. africana* and *A. abyssinica* in the upper layer of the soil. But other relation of soil OC among the tree species and outside the canopies in the upper soil layer did not show significant difference (Table 16). The magnitude of OC follows the order of: *A. abyssinica* > *C. africana* > *C. macrostachyus* > *S. sesban* > *E. camaldulensis* > outside canopy in the upper layer of the soil.

Table 16. Mean ± SE of soil pH, OC, N and C: N ratio under and outside the tree canopies of tree species in homegardens.

Species	**pH H_2O**	**OC (mg g^{-1})**	**N (mg g^{-1})**	**C:N**
		Depth = 0-15 cm		
C. africana	6.8 ± 0.17a	36.1 ± 3.0a	3.2 ± 0.20a	11.0 ± 0.29a
C. macrostachyus	6.5 ± 0.12ab	30.3 ± 3.3ab	2.7 ± 0.22ab	11.1 ±.36a
A. abyssinica	6.7 ± 0.16ab	38.3 ± 3.6a	3.3 ± 0.24a	11.5 ± 0.29a
S. sesban	6.3 ± 0.26ab	29.6 ± 3.3ab	2.8 ± 0.19ab	10.3 ± 0.51ab
E. camaldulensis	6.3 ± 0.14ab	28.1 ± 2.2ab	2.6 ± 0.18ab	10.7 ± 0.36ab
Outside canopy	6.2 ± 0.10b	20.2 ± 1.0b	2.1 ± 0.08b	9.5 ± 0.31b
		Depth = 15-30 cm		
C. africana	6.8 ± 0.17a	28.7 ± 2.7a	2.7 ± 0.18a	10.5 ± 0.38a
C. macrostachyus	6.4 ± 0.15ab	25.3 ± 1.8a	2.5 ± 0.17a	10.1 ± 0.28a
A. abyssinica	6.7 ± 0.22ab	23.5 ± 2.3a	2.4 ± 0.19a	9.9 ± 0.46a
S. sesban	6.3 ± 0.19ab	21.1 ± 3.9a	2.3 ± 0.24a	8.6 ± 0.67a
E. camaldulensis	6.3 ± 0.13ab	21.3 ± 1.3a	2.2 ± 0.10a	9.6 ± 0.36a
Outside canopy	6.1 ± 0.06b	18.0 ± 0.9a	2.0 ± 0.07a	9.1 ± 0.26a

Same letters in a column in the same soil depth class did not show significant difference at $p < 0.05$ significance level.

When the tree species are considered, *E. camaldulensis* and *S. sesban* showed relatively lower value of OC. In line with this study, Hailu (2002) found lower OC under the canopies of *E. camaldulensis* even compared to open agricultural fields in the same type of soil with the current study area. Relatively lower amount of OC in *S. sesban* in both layers of the soil might be related to the removal of the green biomass from the trees for animal feed. Edible plants can be easily browsed by livestock as free grazing is very common after crop harvest. On the other hand, farmers also use the cut and carry system to feed their animals from fenced in plots, which are protected from animal grazing in the vicinity of homes. In accord with these observations, Oosting et al. (2011) also indicated that farmers used the same system to feed their animals from *S.sesban* trees both in northwestern and southern parts of Ethiopia.

Significant difference in soil N was observed between soils under the canopies of different tree species and outside the tree canopies in both the upper and lower layers of the soil. When values of the two soil layers were pooled and averaged, the highest and lowest values of N were recorded in soils under the tree canopies of *C. africana* and outside the tree canopies, respectively. The order of N content followed: *C. africana* > *A. abyssinica* > *C. macrostachyus* > *S. sesban* > *E. camaldulensis* > outside the canopies. However, in the upper layer of the soil, *A. abyssinica* exhibited the highest values of N. Though S.sesban is a nitrogen fixing tree, it did not show high value of N. This might be attributed to its fodder value and browsing of animals, which may reduce the return of N to the soil. Considering the multiple comparisons, soils from outside the canopies of the tree species showed significantly lower N compared with soils under the canopies of *C. africana* and *A. abyssinica* (Table 16) in the upper layer of the soil. Other combinations of mean comparisons did not show significant differences in both soil layers. A very similar result was reported by Gindaba et al. (2005) who reported that soils under the canopies of *C. africana* and *C. macrostachyus* exhibited significantly higher values of N compared with outside the canopies of these tree species.

The C: N ratio also showed significant difference among soil samples taken under the canopies of the different tree species and outside the canopies. Regardless of the soil depth classes, highest and lowest values of C: N ratios were observed under the canopies of *A. abyssinica* tree and outside canopies, respectively. There was also significant difference in C: N ratio between soils collected under the canopies of trees of *C. africana* and *C. macrostachyus* compared with soils sampled from outside the canopies of these tree species in the upper layer of the soil. All the other pairs of comparisons in both soil layers did not show significant difference in C: N ratio (Table 16).

In all the tree species and outside the canopies, significantly lower values of soil N and OC were recorded in the lower layer of the soil than the upper layer. This result is consistent with many of the studies carried out in different parts of Ethiopia. Gindaba et al. (2005) reported that the surface soil OC under *C. macrostachyus* and *C. africana* tree species was significantly higher than that of the subsurface. Manjur et al. (2014) also reported significantly higher N in the surface soil compared with the subsurface soil in southern Ethiopia. This can be related to the availability of decomposing litter from the tree in the upper layers of the soil.

5.3.2.3 Soil "total" nutrients and available phosphorus (Ava P)

Regardless of soil depth layers, significant difference in the value of total Ca was observed under and outside the canopies of different tree species. The highest and lowest values of total Ca was observed in soils sampled under the canopies of *C. africana* and outside the canopies (Figure 27).

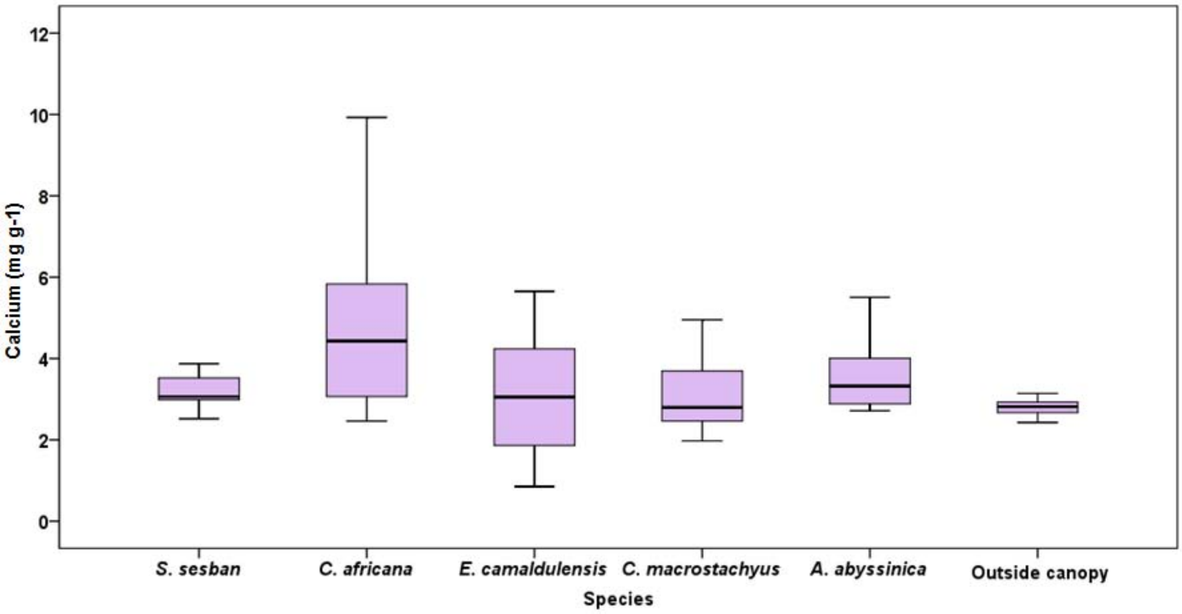


Figure 27. Soil total Ca under and outside the canopies of different tree species from 0-30 cm soil depth.

Considering the depth classes and multiple comparisons, significant difference in soil total Ca was observed only between soils sampled under tree canopies of *C. africana* and outside the canopy in the upper layer of the soil. All other combinations in both soil layers did not show significant differences (Table 17).

Table 17. Mean + SE of soil parameters under and outside the canopies of the different tree species.

Species	Ca (mg g^{-1})	K (mg g^{-1})	Mg (mg g^{-1})	Na (mg g^{-1})	P (mg g^{-1})	Ava P (µg g^{-1})	Al (mg g^{-1})
				Depth = 0-15 cm			
C. africana	4.6 ± 0.5a	4.1 ± 0.2a	4.0 ± 0.3a	0.18 ± 0.02bc	0.8 ± 0.1a	59.8 ± 7.9b	69.4 ± 1.3a
C. macrostachyus	3.8 ± 0.5ab	2.6 ± 0.2b	3.4 ± 0.2a	0.14 ± 0.01a	0.4 ± 0.1ab	52.5 ± 14.9b	67.4 ± 1.0a
A. abyssinica	4.0 ± 0.3ab	2.8 ± 0.4ab	3.5 ± 0.2b	0.20 ± 0.04b	0.5 ± 0.1ab	46.6 ± 4.6b	66.2 ± 3.1a
S. sesban	4.3 ± 0.8ab	3.7 ± 0.1ab	4.1 ± 0.4a	0.15 ± 0.01abc	0.5 ± 0.1ab	37.1 ± 6.6b	70.0 ± 1.0a
E. camaldulensis	3.7 ± 0.5ab	3.2 ± 0.4ab	4.1 ± 0.4a	0.18 ± 0.01bc	0.4 ± 0.1ab	43.1 ± 5.5b	67.4 ± 1.5a
Outside canopies	2.7 ± 0.1b	2.6 ± 0.2b	3.4 ± 0.2a	0.12 ± 0.00a	0.3 ± 0.0b	35.2 ± 3.3b	69.3 ± 0.9a
				Depth = 15-30 cm			
C. africana	4.4 ± 0.4b	4.2 ± 0.4b	4.0 ± 0.3b	0.20 ± 0.02a	0.6 ± 0.10a	48.3 ± 6.5a	71.7 ± 1.4b
C. macrostachyus	2.8 ± 0.2b	2.6 ± 0.4a	3.2 ± 0.1b	0.13 ± 0.01c	0.2 ± 0.05b	34.5 ± 3.2a	69.6 ± 1.4b
A. abyssinica	3.1 ± 0.2b	2.3 ± 0.3a	4.3 ± 0.3b	0.20 ± 0.03ab	0.3 ± 0.04b	76.0 ± 12.1b	68.6 ± 3.1b
S. sesban	3.6 ± 0.6b	3.2 ± 0.1ab	4.1 ± 0.3b	0.16 ± 0.01ac	0.3 ± 0.10ab	42.8 ± 9.2a	70.4 ± 1.3b
E. camaldulensis	2.8 ± 0.3b	2.6 ± 0.4a	3.6 ± 0.3b	0.16 ± 0.01abc	0.3 ± 0.10ab	35.0 ± 2.6a	68.0 ± 0.9b
Outside canopies	3.0 ± 0.2b	2.2 ± 0.2a	3.8 ± 0.3b	0.12 ± 0.00c	0.2 ± 0.10b	32.9 ± 1.7a	79.4 ± 8.4b

Same letters across a column in the same soil depth class do not show significant difference at $p < 0.05$ significance level.

Averaged across the two soil layers, significant variation in soil total K ($p < 0.01$) and Mg ($p < 0.05$) among soils under and outside the canopies of the different tree species were found. The magnitude of the content of total K in the soil samples followed the following order: *C. africana* > *S. sesban* > *E. camaldulensis* > *C. macrostachyus* > *A. abyssinica* > outside the canopies. In the upper layer of the soil, *C. africana* showed significantly higher total K than soils from *C. macrostachyus* and outside the canopies, whereas, the other combinations did not show significant difference in soil total K. But in the lower layer, soils from *C. africana* showed significantly higher difference in total K compared with all other tree species and outside the canopies except with *S. sesban (*Table 17). Soils sampled under the canopies of *C. africana* also exhibited the highest content of total Mg than the other tree species and the lowest total Mg was recorded from soil samples collected from outside the canopy of the tree species, though the multiple comparison of soil Mg did not show significant difference in both soil layers (Table 17).

Total Na also showed significant difference among soils sampled under the canopies of different tree species and outside the canopies. Averaged to the two soil layers, the highest and lowest values of total Na were recorded under the canopy of *A. abyssinica* and outside the canopies, respectively both in the upper and lower layers of the soil (Table 17).

Overall significant difference in total P ($p < 0.001$) and Ava P ($p < 0.05$) were observed in soils under the canopies of different tree species and outside the canopies in homegardens. Soils sampled under tree canopies of *C. Africana* showed significantly higher value of total P compared with soils sampled outside of the canopies in the upper layer of the soil. However, no significant difference was observed between other combinations (Table 17). In the lower layer, soils collected under trees of *C. africana* also exhibited significant difference compared with soils sampled under tree canopies of *C. macrostachyus, A. abyssinica* and outside the canopies of the tree species. Averaged across the soil depth layers, the magnitude of total P followed the following order: *C. africana* > *S. sesban* > *A. abyssinica* > *E. camaldulensis* > *C. macrostachyus* > outside the canopies.

In the upper layer of the soil, Ava P did not show significant variation between different tree species as well as soils from outside the canopies of the tree species. But in the lower layer of the soil, *A. abyssinica* showed significantly higher values of Ava P than all other tree species and outside the canopies of the tree species. All other comparisons did not show significant difference. This result is in agreement with other studies carried out in Ethiopia. Manjur et al. (2014) reported significantly higher contents of Ava P between soils under the canopies of the tree species compared with outside the canopies of the tree species. He also reported that Ava P from soils collected under *Faidherbia albida* (Delile) A. Chev. trees was higher than those collected under *C. macrostachyus.* Asfaw and Agren (2007) also reported higher values of Ava P in soils sampled under trees of *C. africana* than those collected under *E. camaldulensis*.

Though the lowest value of Ava P was observed in soils collected from outside the canopies of the tree species (Table 17), the proportion of Ava P from the total P was the lowest under the tree canopies of *C. africana* (8%), whereas, the highest was observed in soils collected under the tree canopies of *A. abyssinica* (14.4%) followed by those sampled outside the canopies of the tree species (Figure 28).

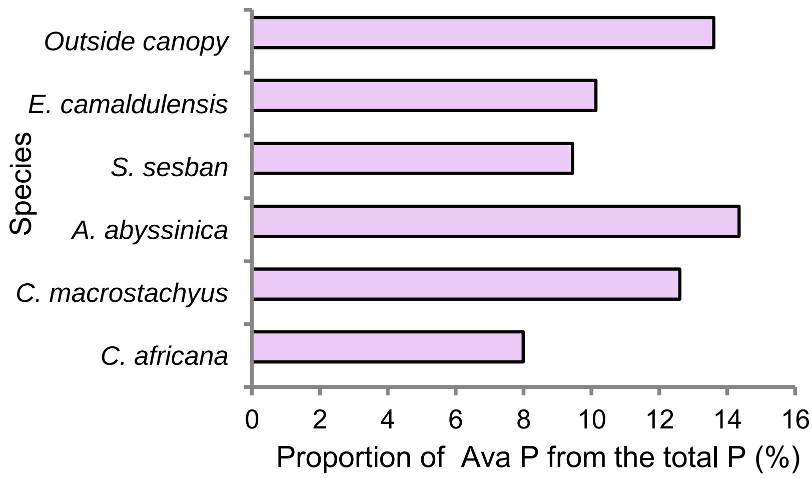


Figure 28. Proportion of Ava P from the total P under the canopies of the different tree species and outside the canopy.

The lowest proportion of Ava P under the tree canopies of *C. africana* might be related to the highest level of soil total Ca under these tree species compared with soils under the canopy of other tree species and outside of the canopy. The lowest content of Al was also observed in *A. abyssinica* compared with the other species that might be responsible for the highest proportion of Ava P (Table 17). As explained earlier, high level of total Ca and Al may lead to the formation of stable compounds with P and may limit the availability of P for plants (Stevenson, 1986; Brady & Weil, 2002).

5.3.2.4 Exchangeable basic cations, cation exchange capacity and base saturation

There was significant difference in exchangeable Ca^{2+} among soils under the canopies of different tree species and outside the canopies in both soil layers (Table 18). The highest and lowest levels of exchangeable Ca^{2+} were observed under the tree canopies of *C.*

africana and outside the canopies, respectively in both soil layers. Averaged across the two depth layers, the magnitude of exchangeable Ca^{2+} followed the order: *C. africana* > *S. sesban* > *A. abyssinica* > *C. macrostachyus* > *E. camaldulensis* > outside the canopies of the tree species. A very similar result was reported by Mekonnen et al. (2009) who found that soils under different tree species showed significant difference in exchangeable Ca^{2+} and Mg^{2+}. Asfaw and Agren (2007) also reported that significantly higher levels of exchangeable Ca^{2+} and Mg^{2+} were observed in the top soil under *C. africana* than in *E. camaldulensis*.

Significant difference in exchangeable K^+ was also observed in the upper layer of the soil between soils collected under the canopies of the different tree species and outside the tree canopies. However, soils sampled in the lower layer did not show significant difference in exchangeable K^+. The highest value of exchangeable K^+ was observed in soils sampled under tree canopies of *A. abyssinica* followed by *C. africana*, *S. sesban*, *C. macrostachyus*, *E. camaldulensis* and outside the canopies of the tree species. This result agrees with the study conducted by Gindaba et al. (2005) who reported lower values of exchangeable K^+ in soils outside than under the canopies of trees of *C. africana* and *C. macrostachyus*. Similarly, Manjur et al. (2014) reported highest value of soil exchangeable K^+ under the tree canopies compared with soils far away from the canopy.

Non-significant difference was observed in exchangeable Na^+ and Mg^{2+} among soils under the canopies of the tree species and outside the canopies in both soil layers. However, the highest value of both exchangeable Mg^{2+} and Na^+ was observed under *A. abyssinica* and *S. sesban* in the upper layer of the soil and the lowest exchangeable Mg^{2+} content was observed outside the canopies in the upper layer, whereas, the lowest exchangeable Na^+ was recorded in *C. macrostachyus* in both the upper and lower layers of the soil.

Table 18. Mean± SE of soil exchangeable cations, CEC and BSP under and outside the canopies of tree species

Species	Ca^{2+} $cmol_c\ kg^{-1}$	K^+ $cmol_c\ kg^{-1}$	Mg^{2+} $cmol_c\ kg^{-1}$	Na^+ $cmol_c\ kg^{-1}$	Mn^{2+} $cmol_c\ kg^{-1}$	CEC $cmol_c\ kg^{-1}$	BSP
				Depth = 0-15 cm			
C. africana	11.7 ± 0.8a	1.6 ± 0.4a	3.9 ± 0.3a	0.12 ± 0.04a	0.07 ± 0.02a	17.5±1.2a	99.5 ± 0.1b
C. macrostachyus	8.7 ± 0.4ab	1.0 ± 0.3ab	3.7 ± 0.2a	0.07 ± 0.01a	0.07 ± 0.02a	13.6±0.7ab	99.4 ± 0.2b
A. abyssinica	10.0 ± 0.6ab	1.8 ± 0.3a	4.0 ± 0.2a	0.20 ± 0.10a	0.05 ± 0.02a	16.0±0.9ab	99.7 ± 0.1b
S. sesban	11.0 ± 1.3ab	1.2 ± 0.2ab	4.0 ± 0.2a	0.20 ± 0.10a	0.12 ± 0.05ab	16.4±1.6ab	99.0 ± 0.5ab
E. camaldulensis	9.0 ± 1.2ab	1.0 ± 0.2ab	3.8 ± 0.3a	0.16 ± 0.03a	0.21 ± 0.04b	14.2±1.6ab	98.0 ± 0.5a
Outside canopies	7.8 ± 0.3b	0.4 ± 0.1b	3.1 ± 0.2a	0.10 ± 0.01a	0.09 ± 0.01a	11.5±0.6a	99.0 ± 0.2ab
				Depth = 15-30 cm			
C. africana	10.6 ± 0.5a	1.3 ± 0.3b	3.8 ± 0.3b	0.12 ± 0.02b	0.07 ± 0.02b	15.8 ± 1.0b	99.4 ± 0.2b
C. macrostachyus	7.6 ± 0.3b	0.6 ± 0.3b	3.2 ± 0.2b	0.07 ± 0.01b	0.07 ± 0.02b	11.6 ± 0.7a	99.2 ± 0.7b
A. abyssinica	7.8 ± 0.1ab	1.3 ± 0.4b	3.5 ± 0.1b	0.14 ± 0.10b	0.03 ± 0.01b	12.8 ± 0.5ab	99.7 ± 0.1b
S. sesban	9.9 ± 1.2ab	0.6 ± 0.1b	3.9 ± 0.2b	0.16 ± 0.10b	0.10 ± 0.04b	14.6 ± 1.4ab	99.3 ± 0.3a
E. camaldulensis	7.4 ± 0.8ab	0.6 ± 0.1b	3.4 ± 0.3b	0.14 ± 0.03b	0.25 ± 0.04a	11.8 ± 1.2a	97.1 ± 0.7b
Outside canopies	8.1 ± 0.4b	0.4 ± 0.1b	3.3 ± 0.2b	0.10 ± 0.01b	0.09 ± 0.01b	12.0 ± 0.6a	99.2 ± 0.1b

Similar letters across a column in the same soil depth class do not show significant difference at $p < 0.05$.

Exchangeable Mn^{2+} showed significant variation between soils under and outside the canopies of the tree species in both soil layers. The lowest level of exchangeable Mn^{2+} was recorded from soils under the canopies of *A. abyssinica*. *Eucalyptus camaldulensis* exhibited the highest value of exchangeable Mn^{2+} compared with all other tree species and soils from outside the canopies of the tree species (Figure 29). The mean value of exchangeable Mn^{2+} in *E. camaldulensis* was even higher than the maximum values in the other tree species. Following *E. camaldulensis*, the level of exchangeable Mn^{2+} was also higher in *S. sesban* than the other tree species (Figure 29).

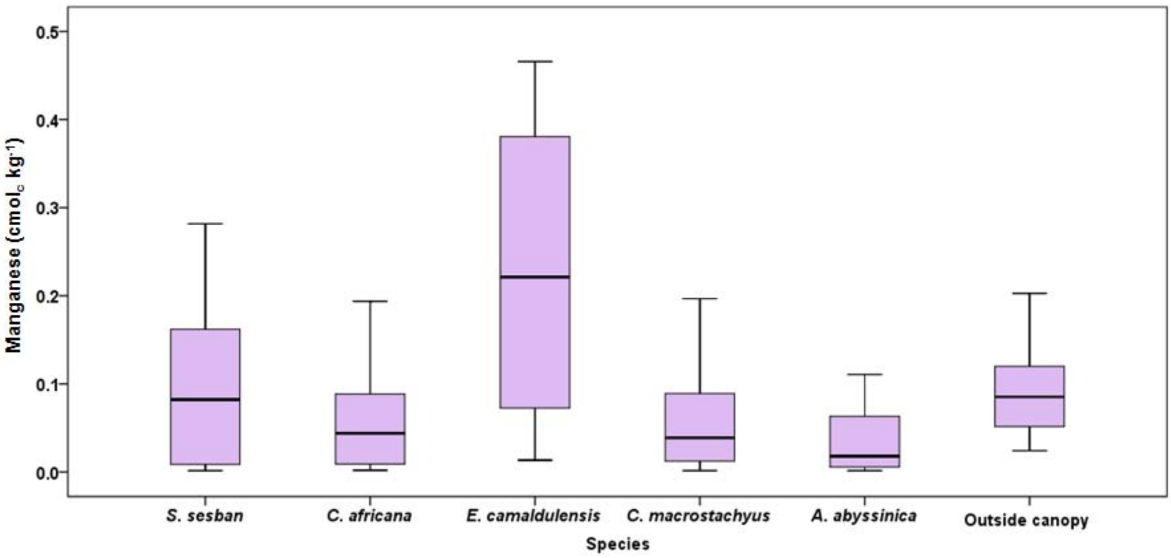


Figure 29. Exchangeable soil Mn^{2+} content under and outside the canopies of different tree species (0-30 cm).

The relatively higher content of Mn^{2+} in *E. camaldulensis* might be related to lower pH values of soils under this tree species than the other species (see Table 16). Negative significant correlation ($r = -0.48$, $p = 0.01$) was also found between soil pH and exchangeable Mn^{2+} under and outside the canopies of the studied species (Table 19). Supporting this idea, Brady and Weil (2002) indicated that this micronutrient cation is most soluble and available to plants under acidic conditions, and if pH values are increased, the availability of this micronutrient is also decreased. There are also results that showed an increase in exchangeable Mn^{2+} due to *E. camaldulensis* plantation in other countries. In Iran, Khanmirzaeia et al. (2011) found that soils under the canopies of *E. camaldulensis* plantations exhibited significantly higher content of exchangeable Mn^{2+} than areas in between the rows of the plantations. In addition, Wadt (2004) found that exchangeable Mn^{2+} in eucalypt plantations increased with increasing age of the trees, implying that this temporal dynamic effect upon exchangeable Mn^{2+} could lead to toxicity in the soil.

Significant differences in CEC were observed among soils under the canopies of the tree species and outside the canopies in homegardens. Averaged across the two soil depth layers, the highest and lowest values of CEC were recorded under the canopies of *C. africana* trees and outside the canopies, respectively. Similarly, significant variation in soil BSP was observed among the tree species and outside the canopies of the tree species in both soil layers. The highest and lowest values of BSP were observed in soils under the tree canopies of *A. abyssinica* and *E. camaldulensis*, respectively, in both soil layers. The lowest BSP in *E. camaldulensis* might be related to the highest level of acidic cations that may occupy significant portion of CEC compared with the other tree species. Both exchangeable Mn^{2+} (Figure 29) and H^{+} (Figure 30) are significantly the highest in *E. camaldulensis* than other tree species which may contribute to low BSP. Though the content Al^{3+} is very trace for comparison in other tree species, its value was high in soils under the canopy of *E. camaldulensis.* Thus, high proportion of the acidic cations may lower the BSP in *E. camaldulensis* than other tree species and outside the canopies.

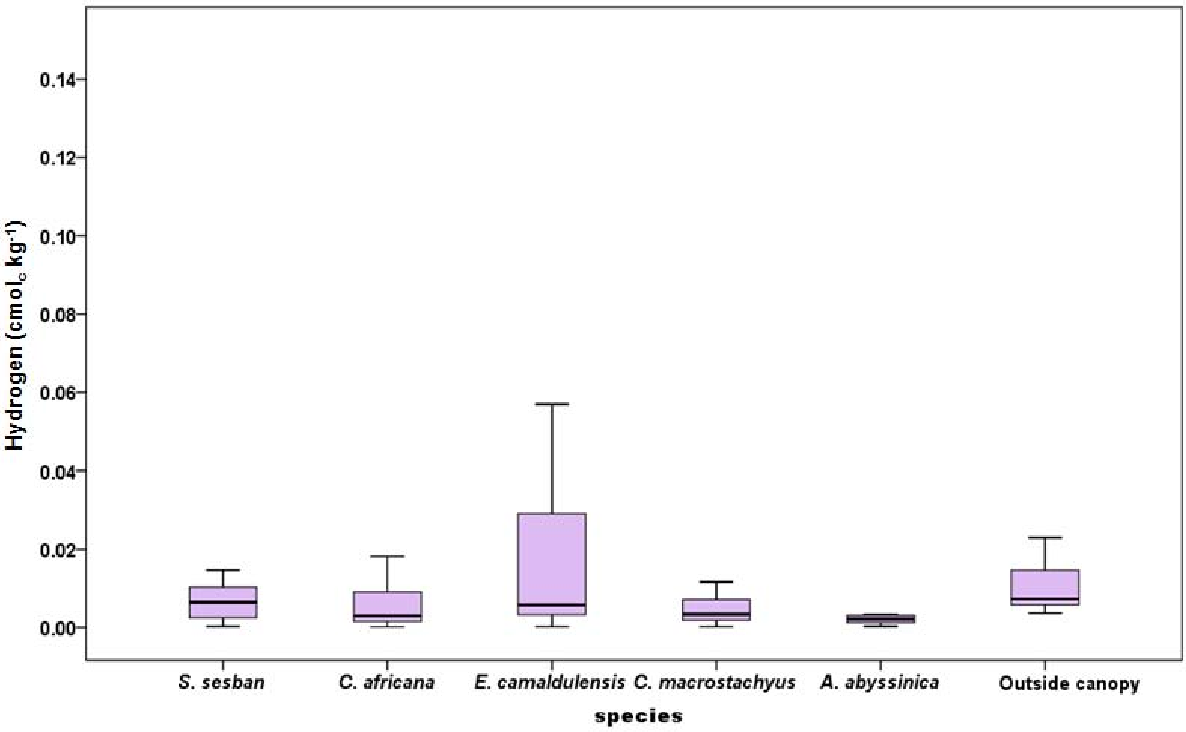


Figure 30. Exchangeable H^{+} under the canopies of different tree species and outside the canopy.

Generally, higher level of exchangeable basic cations and CEC under the tree canopies than outside the canopies might be related to the deficiency in organic matter outside the canopies of the tree species as most of the basic cations and CEC have positive significant correlation with OC (Table 19).

5.3.2.5 Correlation of soil chemical parameters under tree canopies and outside canopy in homegarden

Total N showed positive and significant correlation with most of the soil nutrients except with total Al and Mg. The correlation with total Al was negative and significant ($r = -0.297$, $p < 0.01$) (Table 19). This indicates addition of organic matter can improve other soil nutrients. The correlation of N with OC was significantly high compared to other soil parameters (Figure 31). Nitrogen showed negative non-significant correlation with total Mg.

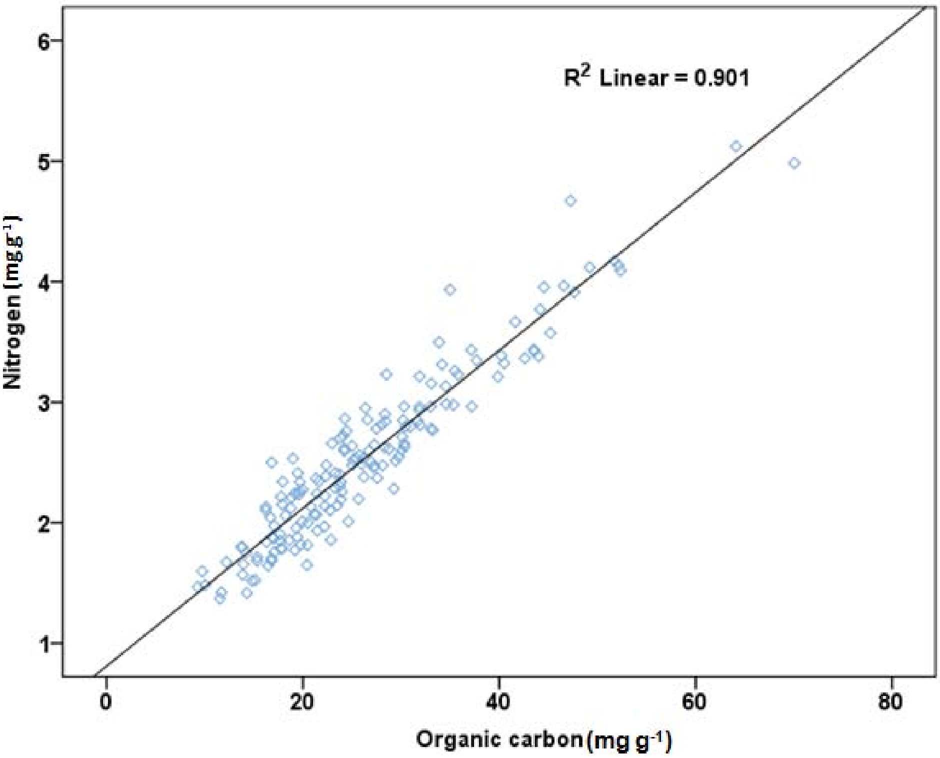


Figure 31. Relationship between soil N and OC for soils from 0-30 cm soil depth.

Soil pH also showed positive significant correlation with many of the soil total nutrients except total Al and K. The correlation with total Al was negative but not significant ($p > 0.05$). It also showed significant positive correlation with all other exchangeable cations except with exchangeable Mn^{2+}. Negative significant correlation was observed between pH and exchangeable Mn^{2+} (Table 19).

Table 19. Overall correlation of soil nutrients in the upper layer of the soil for homegardens.

Nutrient	**N**	**OC**	**pH**	**Total nutrients and Ava P (mg g^{-1})**							**Exchangeable cation and CEC ($cmol_c$ kg^{-1})**						**BSP**
				Ca	**K**	**Mg**	**Na**	**P**	**Ava P**	**Al**	**Ca^{2+}**	**K^+**	**Mg^{2+}**	**Na^+**	**Mn^{2+}**	**CEC**	
N	1	0.959**	0.362**	0.322**	0.302**	- 0.036	0.360**	0.396**	0.192	- 0.297**	0.369**	0.658**	0.203	0.403**	- 0.006	0.447**	0.074
OC		1	0.375**	0.327**	0.291**	- 0.076	0.359**	0.406**	0.168	- 0.261*	0.342**	0.679**	0.194	0.396**	- 0.006	0.432**	0.047
pH			1	0.565**	0.116	0.225*	0.346**	0.422**	0.424**	- 0.008	0.606**	0.606**	0.335**	0.239*	- 0.480**	0.607**	0.441**
Ca				1	0.243*	0.537**	0.581**	0.788**	0.164	- 0.062	0.738**	0.381**	0.495**	0.233*	- 0.322**	.0683**	0.401**
K					1	0.212	0.301**	0.386**	0.175	0.061	0.433**	0.213	0.069	0.177	0.213	0.364**	- 0.232*
Mg						1	0.444**	0.338**	0.072	0.261*	0.695**	0.252*	0.793**	0.305**	- 0.058	0.701**	0.282*
Na							1	0.536**	0.133	0.035	0.479**	0.393**	0.462**	0.514**	0.023	0.526**	0.092
P								1	0.168	- 0.108	0.574**	0.402**	0.301**	0.148	- 0.203	0.540**	0.277*
Ava P									1	- 0.056	0.290**	0.299**	0.093	- 0.031	- 0.086	0.281*	0.097
Al										1	0.035	- 0.011	0.127	- 0.078	- 0.082	0.045	0.065
Ca^{2+}											1	0.612**	0.723**	0.399**	- 0.305**	0.965**	0.465**
K^+												1	0.547**	0.518**	- 0.350**	0.755**	0.401**
Mg^{2+}													1	0.436**	-0.202	0.829**	0.455**
Na^+														1	0.043	0.500**	0.040
Mn^{2+}															1	- 0.297**	- 0.912**
CEC																1	0.476**

**. Correlation was significant at the 0.01 significance level, *. Correlation was significant at the 0.05 significance level.

Generally, the highest values of soil nutrients in homegardens were observed under the tree canopies compared with soils sampled outside the canopies.

This indicates that regardless of other soil management activities in homegardens, the influence of trees was significant. However, Duguma et al. (2010) explained that the high values of soil nutrients in homegardens is mainly due to soil management practices, such as addition of human and animal wastes, wood ash, dung and other decomposable materials. Based on the present results, it can be argued that if the soil improving power of other management activities in homegardens are higher than that of the influence of the tree species, it would be true that soils outside the canopies of the tree species in homegardens would not show significant variation in soil chemical parameters compared with those under the canopies of different tree species. This result is also supported by the findings of Mekonnen et al. (2009) who reported relatively higher values of soil nutrients under the canopies of tree species than outside the canopies in homegardens.

Thus, the contribution of tree litter as well as dead roots had significant influence on soil parameters in the study area. Various literatures in nutrient content analysis of leaf litter reported different results that may explain the variation in soil nutrients (Table 20).

Table 20. Major nutrient contents of leaves of different tree species

Species	**N (mg g^{-1})**	**P (mg g^{-1})**	**K (mg g^{-1})**
C. africana	18.10[a], 11.1[b],12.8[c]	2.23[a], 2.54[b], 1.9[c]	26.03[a], 11.5[c]
A. abyssinica	31.6[a]	2.37[a]	12.5[a]
C. macrostachyus	12.9, 11.36, 12.9	2.4[a], 2.54[b], 2.4[c]	8.7[a], 8.7[c]
S. sesban	38.2[a]	3.4[a]	21.23[a]
E. camaldulensis	16.6[d]	0.98[d]	7.04[d]

[a]Mekonnen et al. (2006) on experimental site, Mahari (2014) on cropland, [c]Gindaba et al. (2005) with no tillage site, [d]Mengist (2011) on plantation.

Almost all the results in this study also followed the same order with leaf nutrient content of tree species from past studies except the contents in *S. sesban*. The difference with *S. sesban* might be also related to the management factor since the leaves were taken from the experimental controlled plots with no interference of animal grazing or fodder harvesting (Mekonnen et al., 2006). However, in the current study area, the *S. sesban* trees are mostly used for animal feed that may reduce its potential for soil nutrient improvement.

5.4 Other benefits of agroforestry practices

5.4.1 Reducing wood demands from the natural forest and shrubland areas

As stated earlier, the woody vegetation cover of Maytemeko Watershed showed a decline through time. The gradual degradation of the forest due to high dependency of the population on the woody vegetation cover for forest products, e.g. for fuel and construction wood, and/or expansion of agricultural land at the expense of woody vegetation cover are the main driving forces for deforestation.

5.4.1.1 Agroforestry systems as major sources of energy

Households obtained their energy for cooking and heating from four major sources during the year 2012/13 (Figure 32). Nearby natural forests and shrublands, own farms (like boundary plants, homegardens, small-scale woodlots and scattered trees on farm), animal dung, crop residues and very small amount from other sources like charcoal and kerosene. This was observed by Damte et al. (2012) indicated that Ethiopian households used various sources of fuel for cooking and but most of it comes from bio fuel.

The mean annual fuel consumption of the sampled households in Maytemeko Watershed was 3015.5 kg, ranging from 771 to 5871 kg from all types of sources, while the per capita fuel consumption was about 541 kg. Comparable result was also reported by Bewket (2003) in Chemoga Watershed, northwest Ethiopia, who found per capita fuel consumption of 511 kg yr^{-1}. Of the total fuel consumption (416.1 tons), the largest fuelwood amount (40.3%) was obtained from agroforestry trees and shrubs. This result is in agreement with studies reported by Damte & Koch (2011) who reported the largest proportion of the households in rural Ethiopia obtained their fuel from trees and shrubs on the farm. In this study, natural forests and shrublands, animal dung, crop residues and other sources followed in decreasing order of contribution to the fuel needs of sampled households (Figure 32).

Overall, this result is very similar with the national level estimates of fuel from different sources, which indicated that about 68.5% of the energy comes from wood based sources and around 27.7% comes from crop residues and animal dung (Geissler et al., 2013). Bekele et al. (2013) also found similar result in Mukehantuta Watershed with about 62.2% and 29.3% of wood and dung biomass fuel consumption, respectively.

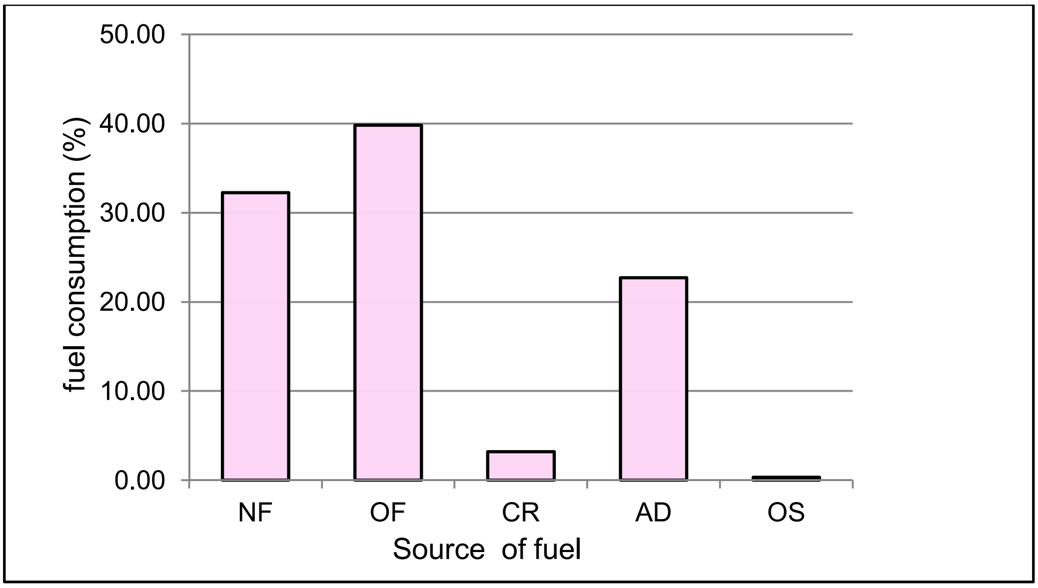


Figure 32. Proportion of fuel consumption by households from different sources in 2012/2013. NF = nearby natural forest and shrubland areas, OF= own farm, CR = crop residues, AD = animal dung and OS = other sources

Comparing the two wood sources of fuel (natural forests and shrublands and own farm agroforestry trees and shrubs) at the household level, the majority (46%, N = 138) of the households used both sources for their fuel demand during the study year. About 37% of the households relied on only agroforestry trees and shrubs, while the remaining 17% of the households were totally using the nearby natural forests and shrublands for their fuelwood demands. From this, we can understand that the main source of fuel for farmers in the watershed was trees and shrubs from different components of agroforestry.

Fuel consumption from dung has an implication on soil nutrients as nutrients would be lost with the burning of dung. The mean annual consumption of animal dung in the watershed was about 685 kg HH^{-1}. This result was lower than the study carried out by Anteneh (2010) in northwestern Ethiopia who reported consumption of 1.23 tons of animal dung HH^{-1} yr^{-1} for fuel. This might be due to the replacement of other sources instead of animal dung in the present study area since the per capita fuel consumption is even higher than other studies (Bewket, 2003). On the other hand, this might be related to smaller number of animals (3.8 TLU[6]) since the dung is produced from these animals compared with the previous study by Anteneh (2010) who found 4.6 TLU in his study area. However, the current result showed slightly higher proportion of fuel consumption from animal dung compared with national level studies (15%) (Geissler et al., 2013) .

[6] TLU is a unit used to describe livestock numbers of various species as a single figure that expresses the total amount of livestock present. One TLU = 250 kg livestock body weight.

Owing to the considerable amounts of nutrients it contains, the dung, which is used for fuel could add significant amounts the soil if farmers could use it for soil fertility management. According to Lupwayi et al. (2000), animal dung contains 18.3, 4.5 and 21.3 g kg^{-1} of N, P and K, respectively, on dry mass basis. Therefore, a household in Maytemeko Watershed could waste on average 12.5, 3.1 and 14.6 kg yr^{-1} of N, P and K, respectively through the burning of animal dung. Taking the total households in the watershed, i.e. 3,229, the nutrient loss through the burning of dung would be 40.3, 10 and 47.1 tons yr^{-1} of N, P and K, respectively. This could match to a fertilizer equivalence of 18 and 49.7 tons of urea and Di-ammonium phosphate (DAP), respectively. On the bases of blanket recommendation of fertilizer for *teff* (Gebretsadik et al., 2009), this would have a potential of fertilizing about 180 and 497 ha of land using urea and DAP, respectively. Since farmers in Ethiopia are the lowest users of inorganic fertilizer, the potential of animal dung use would have a significant contribution for soil fertility management and increase food production per household (Duguma, 2010; Tefera, 2012; Bekele et al., 2013).

Usually, it was found that the amount and source of fuel consumption is affected by the wealth status of households (Duguma, 2010; Nath et al., 2013). In this study, the amount of total and per capita fuel consumption did not show significant difference ($p > 0.05$) among the three wealth classes (Table 21). In agreement with the present result, Bekele et al. (2013) reported non-significant difference in fuel consumption among wealth classes. The amount of fuel consumption from the natural forests and shrublands showed significant difference among the three wealth classes of the households. However, the poor households consumed significantly higher ($p < 0.05$) amount of fuel from the natural forests and shrublands compared with the rich households. On the other hand, significant ($p < 0.05$) difference in the amount of fuel consumption from agroforestry trees and shrubs was found among the wealth classes Thus, the rich households consumed the highest amount of fuel from their own farm, where as the poor consumed the lowest amount. This might be related to the number of trees and shrubs that existed on their farms since the rich farmers had the highest number of trees and shrubs on their farms (see section 5.6).

Significant ($p < 0.05$) variation was observed among the three groups of households in fuel consumption from animal dung. The poor households consumed relatively lower amount of fuel from animal dung than the two groups. This might be related to the number of livestock a household possessed since the poor and rich households had on average 2.3 and 4.6 TLU, respectively. This indicates that the use of dung for soil fertility management is not related to the amount produced at household level; the rich, who are producing more, consume more dung for fuel. However, if farmers can substitute the dung with other sources of energy, the rich would have higher potential of using the dung for soil fertility improvement.

Table 21. Mean ± SD of annual fuel consumption per household from different sources for wealth categories.

Wealth classes	Amount of consumption (kg) from different sources					
	Natural forests and shrublands	Own farm	Crop residues	Animal dung	Other sources	All sources
Poor	1343.0 ± 980a	583.8± 910.7a	71.0 ± 38.9a	497.4 ± 450.8a	2.6 ± 8.3a	2735.7 ± 209.6a
Medium	1053.3± 998.6a	1114.3 ± 962.3a	103.8 ± 53.7b	688.5 ± 416.6ab	9.0 ± 39.8a	3081.8 ± 1229a
Rich	720.3 ± 909.6b	1557.6 ± 855.8b	97.5 ± 54.7ab	755.9 ± 480.3b	15.4 ± 57.3a	3045.6 ± 136.6a

Means in a column labelled with similar letters are not significantly different at $p < 0.05$

The amount of consumption of crop residues for fuel showed significant ($p < 0.05$) difference among the wealth classes. The poor households consumed relatively a lower amount of crop residues compared with the rich and medium households. This may be related to the resource availability. Households who produce more crops would have higher amounts of residues that could be used as an energy source. Slightly lower consumption of crop residues by the rich compared with the medium households could explain the fact that the rich households may satisfy their needs from other sources and the crop residues could be left on the farm for soil fertility improvement.

Variation in annual fuel consumption from different sources among households living in different distance ranges from the natural forests and shrublands was observed in the watershed. The highest (1,437 kg) and lowest (454 kg) amounts of fuelwood were consumed from these natural forests and shrublands by households living closer and relatively far away distances, respectively. This result is in agreement with the study carried out by (Duguma, 2010) in central Ethiopia. He reported that households living close to the state forest consumed more fuel from the state forest than the households living far away from the state forest. On the other hand, significant differences in fuelwood consumption from their own farms were also observed among distance ranges from the natural forests and shrublands. Households who are living in relatively far distances from the natural forests and shrublands consumed higher amounts of wood from their own farms than those who are living closer to the natural wood sources (Table 23). The Pearson bi-variant correlation also showed that as distance from the natural forests and shrublands increases, farmers consume lesser amount of fuelwood from the natural forests and shrublands area ($r = - 0.360$, $p < 0.01$). However, the correlation of distance from the natural forests and shrublands and amount of fuelwood consumption from own farm was positive and significant ($r = 0.357$, $p < 0.01$) (Table 22). This implies that larger distances from the natural forest and shrubland sources encourages farmers to plant and use their own trees and shrubs for their fuel demands since fuel collection could consume significant amount of time and energy with increasing distance.

Table 22. Correlation of total number of trees and shrubs on farm and fuelwood consumption from different sources.

Source	NF	OF	CR	AD	OS	D	number of wood plants
NF	1	- 0.615**	- 0.153	- 0.096	- 0.124	- 0.360**	- 0.202*
OF		1	0.139	0.166	0.018	0.357**	0.147
CR			1	0.255**	0.024	- 0.027	- 0.029
AD				1	0.031	0.262**	- 0.062
OS					1	0.075	0.045
D						1	0.253**

** Correlation is significant at p < 0.01 significant level and * correlation is significant at p < 0.05. NF = natural forests and shrublands, OF= own farm, CR = crop residue, AD = animal dung, OS = other sources, D =distance of home from the natural forests and shrublands.

Non-significant differences were observed between distance ranges in fuel consumption from crop residues. However, animal dung consumption showed significant difference ($p < 0.01$) among distance ranges. The highest and lowest amounts were consumed by households who are living relatively far from and close to the natural forests and shrublands, respectively. This might be related to the choice of fuel for households that could be possibly affected by the availability of open access forest for fuel collection in the nearby area. Those households who have easier access to the natural forests and shrublands might give greater attention for wood-based fuel consumption than those who are living away from these sources since dung collection and processing is laborious and it is relatively smoky when burning compared with wood.

Table 23. Mean ± SD of fuel consumption per household from different sources at various distance ranges from the natural forests and shrubland areas.

Distance range	Amount of annual fuel consumption (kg)					
	Natural forests and shrublands	Own farms	Crop residues	Animal dung	Other sources	Total
≤ 2 km	1437.4 ± 893a	714.6 ± 743.0a	97.8 ± 56.0a	596.9 ± 429.1a	3.1 ± 22.3a	2868.5 ± 980.5a
2-4 km	704.8 ± 891.6b	1511.0 ± 983.1b	98.8 ± 52.9a	619.2 ± 395.0a	14.7 ± 56.8a	3165.9 ± 1041.0a
4-6 km	790.6 ± 1044.6ab	1254.5 ± 1019.7ab	97.0 ± 56.1a	1021.1 ± 448.1b	12.5 ± 47.2a	3096.6 ± 876.9a
> 6 km	454.3 ± 914.1b	1796.4 ± 833.4b	81.5 ± 38.9a	833.6 ± 544.5ab	19.6 ± 53.0a	2898.6 ± 862.7a

Means in a column labelled by similar letters are not significantly different at $p < 0.05$.

It was also found that the higher the number of trees and shrubs on the farm is, the less is dependency of farmers for other sources of energy, such as crop residues and animal dung, though the correlation was not significant (Table 22). At the same time, there was significant negative correlation ($r = -0.615$, $p < 0.01$) between fuelwood consumption from their own land and from natural forests and shrublands due to replacements.

It was also tried to assess the current wood demand and supply from the two major sources (natural forest and shrublands and agroforestry trees and shrubs). The result showed that mean annual increment of the AGB[7] of the natural forests and the shrublands was about 3 and 2.4 tonnes $ha^{-1}yr^{-1}$, respectively. As indicated earlier in section 5.1.2.2, the areas of forests and shrublands were about 222 and 513 ha, which could provide about 700 and 1,230 tons of biomass per annum, respectively. However, having the total of 3,229 households living in the watershed and considering current consumption of fuel from these sources (0.97 ton HH^{-1}), about 3,138.3 tons of fuelwood from the existing natural forest and shrubland areas was consumed. This estimate shows that wood harvest is more than 1.7 times the allowable harvest from these sources. This value is lower than the estimate of a similar study in south western part of Ethiopia by Haile et al. (2009) who found out three times more fuel consumption from the forest compared with the allowable harvest. This might be related to replacement of other sources of fuel in the current study as the forest and shrub areas contributed only 33% of the total consumption.

[7]Mean annual increment in AGB is calculated based on mean annual volume increment (MAIV) and biomass expansion factor (BEF) data (Moges et al., 2010) for woodland forests (MAVI = 0.79 m^3 $ha^{-1}yr^{-1}$, BEF= 6.9) and shrubs (MAVI = 0.5 m^3 $ha^{-1}yr^{-1}$, BEF= 8.2) using wood density of 0.58 as used by Brown et al. (1989).

On the other hand, the estimated fuel consumption from agroforestry trees and shrubs for all households was about 3,879 tons (1.2 tons HH^{-1}). Considering the six sample cropland plots with trees, which were used for the biomass estimation, the calculated mean annual increment of biomass was 0.48 ton ha^{-1} yr^{-1}, and the total area of the cropland that could be covered with agroforestry trees was 1,690 ha as indicated earlier in section 5.1.2.2. This could have a potential of producing 811.2 tons yr^{-1}. This value could be the lowest estimate since the shrub and smaller trees below 5 cm diameter were not considered. The result showed that there is a gap between allowable harvest and the potential of these sources to satisfy the current demands of fuel in the watershed. The harvest is about 4.8 times greater than the allowable harvest of wood from the agroforestry practices. However, in most cases, the fuel used from agroforestry trees and shrubs does not lead to overall loss of AGB. Farmers usually employ lopping and pollarding of trees and shrubs for their fuel demands so that the wood biomass remains for a long time. Supporting this idea, Unruh et al. (1993) explained that AGB in fuel wood agroforestry trees and shrubs does not vary through time compared with clear cut in plantations.

Generally, even if the contribution of agroforestry trees and shrubs for fuel is higher than those obtained from the natural forest and shrubland areas, the current demands for fuel by all the households are not being satisfied in a sustainable way both from the natural and agroforestry trees and shrubs. However, if farmers in Maytemeko Watershed could not use agroforestry trees and shrubs for their fuel demand, the estimated harvest from the natural forests and shrublands would increase to 3.6 times the allowable harvest. Exploitation of the growing stock through over-harvesting of the fuel may also reduce the future annual increments. This, finally, will result in further depletion of the forest resources. At national level, Bekele (2011) indicated that the potential of the forest resources to supply fuelwood on a sustainable yield basis is very low and there is an imbalance between required rural energy and the supply capacity of the forest resources. The demand therefore, is fulfilled through over exploitation of the woody vegetation. Moreover, the vegetation cover of the watershed is also threatened by the expansion of agricultural land even towards steep slopes as it was indicated earlier.

5.4.1.2 Agroforestry trees as source of construction wood

Two major types of houses were observed in the watershed. Most of the households (72.3%) constructed two houses each, one with Iron roof and the other with thatched grass roof. About 75% (N = 138) of the households had constructed their houses two times, one before 20 years ago and the other within the last 20 years. But, the remaining of the households had no house before 20 years ago but constructed their houses within the last 20 years. 20 years is considered as the life time of houses in the watershed based on the information from elder people.

The main sources of construction pole wood for households were agroforestry trees, open access natural forests, buying from others and gift from relatives both before 20 years ago and within the last 20 years (Figure 33). Before 20 years ago, the sampled households consumed larger proportions of poles for house construction from the natural forest compared with their consumption within the last 20 years. On the other hand, households consumed smaller proportion of poles from their own farms (agroforestry trees) before 20 years ago than within the last 20 years. This indicates that there was replacement of wood from the natural forests by that from agroforestry practices through time (Figure 33).

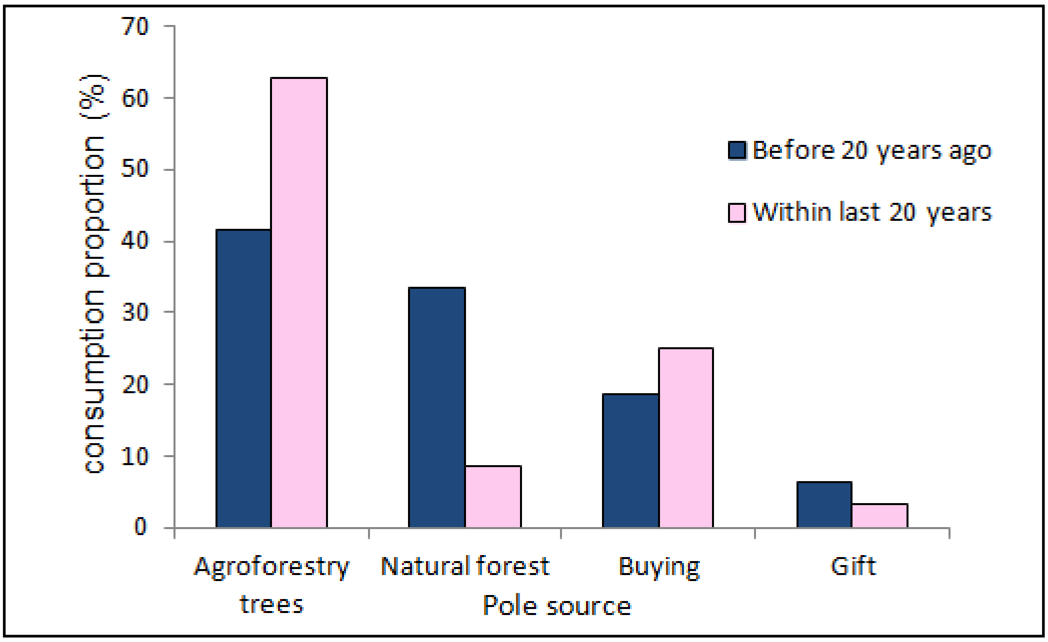


Figure 33. Construction pole wood consumption proportion (%) from different sources before 20 years ago and within the last 20 years.

The mean number of poles used for construction by households from their own farms and from natural forests varied significantly before 20 years ago and within the last 20 years (Table 24). From own farms, the mean number of poles used for house construction was significantly ($t = -6.3$, $p < 001$) lower before 20 years ago (about 147) than within the last 20 years (about 283).

On the other hand, the mean number of poles for house construction, used by the households from natural forests before and in the last 20 years was about 107 and 44, respectively. The result of paired sample t-test also showed a significant difference of consumption of construction wood from forests in these two time periods ($t = 5.5$, $p < 0.001$)

(Table 24). This might be related to the decline of quality wood in the forests that was used for the construction of the houses over time, as a result, farmers have started to use their own trees for house construction as alternative sources. The result from focus group discussions also indicated that before 20 years ago, it was easier to get suitable wood for construction from forests. They also pointed out that though they prefer to use wood from forest for construction due to its strength. However, these days because of over exploitation, it is rather seldom to find suitable poles.

Table 24. Mean consumption of construction poles in two different periods from agroforestry and natural forests.

Consumption of pole from two sources	Number of HH	Mean number of poles	Std. Error (Mean)	t-value
Agroforestry				
Before 20 years ago	103	147.2	25.0	-6.3***
Within the last 20 years	136	283.4	32.7	
Natural forest				
Before 20 years ago	103	107.0	12.0	
Within the last 20 years	136	44.2	6.5	5.5***

*** Significant at $p < 0.001$ level. HH = household

5.4.2 Agroforestry in reducing burden of women and time of collection of fuel

More than 56% of the respondents (N = 87) confirmed that mothers and daughters are responsible for fuelwood collection from the nearby forest and shrublands. Among household members, the burden of fuelwood collection is higher for daughters than the sons (Figure 34). Even little girls (Figure 35) are told by their parents to practice fuelwood collection with their elder sisters. Similar result was also reported by Beyene et al. (2014) who indicated that the fuel and other resource collection burden is less likely for the boys than the girls in the Amhara National Regional State (ANRS). Kituyi (2004) also pointed out that the task of fuelwood collection was disproportionately left for women and children that had significant impact on their education and other development activities. While, in contrast to this result, Gebru & Bezu (2012) found that fathers and sons are more responsible to collect firewood from forests in the northern part of Tigray National Regional State (TNRS). They explained that the forest area is very far away from home, which may take up to 7 hours to travel and the area is adjacent to Afar National Regional State where other ethnic groups are living. Therefore, households fear risks of rape of their daughters and wives. Such kinds of cases are not common in the current study area. Focus group discussions also confirmed that fuelwood collection from the forests and shrubs is left for females.

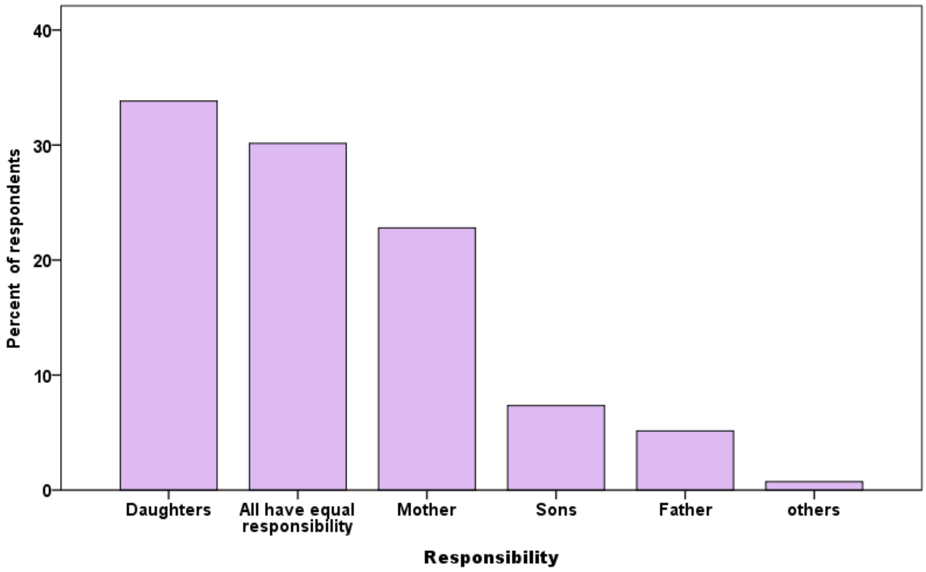


Figure 34. Responsibility of household members for fuelwood collection from natural forests and shrublands.

The burden on females may be exacerbated with increasing deforestation since the forest cover will be pushed up to the marginal areas and farther away from home, which increases the fuelwood collection time. Consequently, children become essential for their parents with high work demand at the expense of schooling (Winkler-Dworak, 2004). Winkler-Dworak (2004) also explained that such phenomenon subsequently worsens the process of human competence formation by reducing the time used for education.

Female children who are attending their education in the nearby schools usually collect the fire wood before or after school so that they will not have enough time to concentrate on their education outside the school. Sometimes, they are obliged by their parents to cancel their normal schooling time and collect fuelwood.

Figure 35. Female fuelwood collectors in Maytemeko Watershed.

In contrast, 91% of the households (N = 51) confirmed that preparation and collection of fuelwood from agroforestry trees and shrubs is mostly carried out by men than women. This might be actually related to the ownership/property right for planted trees and shrubs. As it was identified from the discussions, though the management for AFPs is left for women, the ownership is overtaken by men so that women have no saying on the planted trees and shrubs. Forty one percent of the respondents confirmed that the responsibility of managing trees is mostly left for females compared with 33% of the respondents who said males are mostly responsible for managing trees and shrubs on the farm. The management activities include planting seedlings, watering, weeding and harvesting of the products. However, the use and decision right on the products of AFPs was more often given to men than women. Supporting other persons who are building new houses by donating wood is very common in the area. This mandate of allowing the gift is decided by the husband without communicating to the wife unless the female is a household head.

The household survey also indicated that the average time needed to collect 30 kg (one bundle) of fuelwood from natural forests and shrublands sources was about four hours where as for those households who used their own trees and shrubs, it was about one hour to collect and prepare the same amount of fuelwood. The average fuelwood amount from the natural forest and shrub was about 1542 kg (for households who depend on these sources only). This needs about 206 hours for collection. Assuming the annual working hours at the national level is about 1,520 hours[8] based on civil servants (eight hours/day) work load excluding public holidays and annual allowable leave, the fuelwood collection would amount to approximately 9% of a person. This illustrates that significant time is consumed by fuelwood collection from the forests. A very similar result was reported by Gebru & Bezu (2012) in the northern part of TNRS. They found that on average, the time spent to collect fire wood from the forest is about 9 hours, which is even greater than the current study. The difference might be related to the distance of the forest area from home. Thus, an increase in time for collecting firewood is due to shortages in the nearby area. This fact was also confirmed by Damte et al. (2012). On the other hand, for those households who are using their own trees and shrubs for fuel, the annual time spent was about 32.4 hours instead of 130 hours to collect and prepare the same amount of fuel. This means that collecting fuelwood from the natural forests took more than four times longer than collecting firewood from agroforestry trees and shrubs. Almost the same result was reported by Mugo (1999)in Kenya who found that the annual time spent to collect fire wood from far away forests was about 130 hours compared with 36 hours for collecting from their own farms.

This shows that trees and shrubs grown in agroforestry practices can play a significant role not only to conserve the natural forests but also to minimize the work load of women through labour division among the household members for fuel collection and reduce the time spent for collection. This, in turn, could have impact on other sectors of development. In line with this idea, recently FAO (2013b) pointed out that combining agricultural crop and fuelwood production through AFPs saves woodland trees and frees up labour, especially for women, who traditionally collect wood.

5.4.3 Economic contribution of AFPs

5.4.3.1 Income from fruits and vegetables from agroforestry practices

Farmers in the study area integrate fruit trees and vegetables in homegardens as it was stated earlier. In addition to household consumption, the products are used for additional income generation. The results from the household survey indicated that around 65% of the households (N = 138) generated income from the sale of fruits and vegetables grown in homegardens. The mean income of a household from the sale of fruits and vegetables was about 2,515 ETB during the year 2012/2013. The remaining households had no income from these sources. The income generated also varied among different wealth classes of the households (Table 25).

[8] Calculated using 39 working hours per week with14 and 30 days of public holidays and annual leave, respectively in a year (Addis Negari Gazeta, 2008).

Table 25. Mean ± SE income of the households from the sale of fruits and vegetables grown in agroforestry practices for the year 2012/13.

Wealth classes	Number HH	Income (ETB)
Poor	6	955.0 ± 421a
Medium	39	1501.0 ± 247a
Rich	44	3,626.6 ± 555b
Total	89	2515.0 ± 317

Mean values labeled by similar letter did not show significant difference at $p < 0.05$.

Significant ($p < 0.05$) difference in income from the sale of fruits and vegetables was observed among the three wealth classes. The poor farmers had the lowest income from the sale of fruits and vegetables, where as the rich had the highest income. The rich farmers earned 3.8 times more money than the poor. Key informant interviews with elder people indicated that in earlier times, the sale of fruits used to be left for the poor. Rich farmers did not engage in these activities since this was socially unacceptable. But these days, widespread fruit tree growing in homegardens has changed the attitude of farmers. Moreover, there is also an increase in demand of fruits in the urban areas where most of these products are consumed. These trends made the fruit selling more attractive for farmers. In Motta town, the nearby town to the watershed, micro-finances organizations are encouraging fruit producer farmers. Farmers were given small container shops in the town to sell their fresh fruit and vegetable products directly to the consumers. This is a good incentive for other farmers in the area to start fruit and vegetable production in the future.

5.4.3.2 Profitability of agroforestry practices

As stated earlier, to evaluate the profitability of land use types, three land use types namely, alley cropping with *R. prinoides*, small-scale woodlot and the conventional mono-cropping practices were considered.

The result indicated that throughout the 15 years periods under consideration in the study, the average cost invested ha^{-1} for the alley cropping with *R. prinoides* was the highest. The aggregated average cost for alley cropping with *R. prinoides* was 17.9 and 1.4 times higher than small-scale woodlots and mono-cropping land use types, respectively (Table 26). However, the average cost for the small-scale woodlots was high only during establishment period and declined after wards since all the harvesting and transporting costs were covered by the buyers. The highest investment cost in alley cropping throughout the study period is attributed to the labour costs needed to collect the products throughout the year. For mono-cropping plots, the cost invested ha^{-1} has shown an increasing trend, mainly, due to an increase in fertilizer costs.

Though the net profit of the alley cropping is negative at the beginning due to establishment cost, the loss in income is lower compared with the small-scale woodlots. This is due to the fact that planting *R. prinoides* does not take large space at the beginning, and it is less difficult to plough between the rows to cultivate the annual crops. When *R. prinoides* starts to grow and occupies a relatively large area, farmers can collect leaves and young branches for household consumption and for sale. This leads to positive revenues during the lifecycle. The net profit from the small-scale woodlot depends on the harvesting year due to irregular harvesting time of the woodlots. This leads to higher net income when more farmers harvest their products in the same year and no income in other years with no harvest.

The mono-cropping farms exhibited negative net profit for eight years at the beginning, until 2007 (Figure 36C). A very similar result was also reported in Tanzania that showed negative profits for the conventional cropping system (Bullock et al., 2011) compared with agroforestry land use types. However the net profit showed an increasing trend after this time. This might be due to a dramatic increase in food crop prices starting from 2007 (Appendix 4). At national level Durevall et al.(2010) indicated that the food crop price increased more than double following the Ethiopian Millennium due to high inflations rates in the country. The national level price of food crops might be also related to global markets where the food price increased between 2007 and 2008 (Piesse & Thirtle, 2009). The net profit from mono-cropping is still very low compared with those of the alley cropping with *R. prinoides* and small-scale woodlot agroforestry practices (Figure 36).

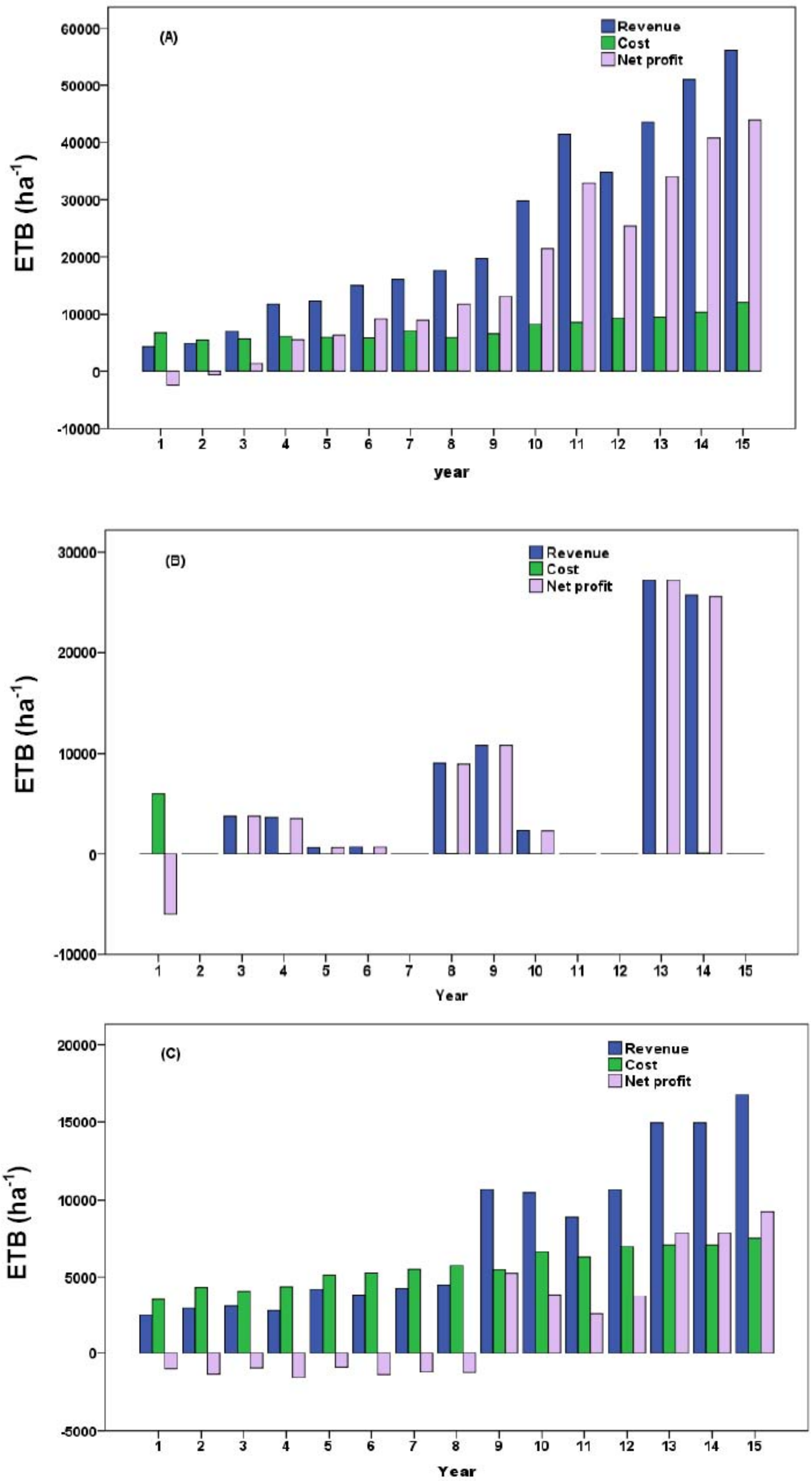


Figure 36. Cash flow of alley cropping with *R. prinoides* (A), small-scale woodlots (B) and mono-cropping (C) plots.

The annual average crop yield harvested per unit area between rows of *R. prinoides* was slightly higher than the crop yield harvested from mono-cropping fields. The data of crop yield for the 15 years period showed irregular pattern in comparison of these practices (Figure 37). This might be due to variation in the crop type that farmers cultivate in rotation and the corresponding yield variation per unit area. The 15 years aggregated average crop yield for alley cropping was 2.1 tons ha^{-1}, while for the mono-cropping, it was about two tons ha^{-1}.

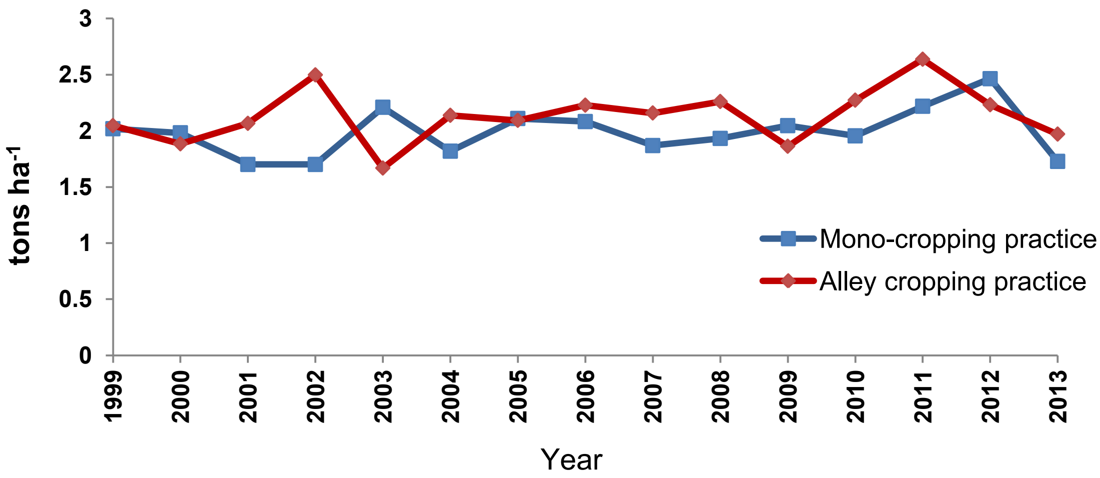


Figure 37. Average annual field crop yield of mono-cropping and alley cropping with *R. Prinoides.*

The slightly higher yield in the alley cropping might be related to the positive contribution of the shrubs in improving the soil fertility. In agreement with this study, results in other parts of Africa indicated that, intercropping increases the yield per unit area of land. For example, Pre-Smith (2008) pointed out that using fertilizer trees, such as *Tephrosia vogelii* Hook. *f.* and *Gliricidia sepium* (Jacq.) Kunth. ex Walp.*,* resulted in average maize yields of 3.7 tons ha^{-1} compared with one ton ha^{-1} in plots without fertilizer trees in Malawi. FAO (2013b) also pointed out that extensive integration of rows of poplar trees into wheat and barley farms by smallholders significantly increased income without any loss of crop production in northwestern India. Another review by Jose (2009) pointed out that AFPs in nutrient-depleted soils have demonstrated the ability of trees to absorb nutrients that have leached below the rooting zone of annual crops, and to recycle these nutrients through leaf litter and fine root turnover, thus, improving the nutrient supply for annual crops. The result from the soil analyses in this study also indicated that soils from alley cropping with *R. prinoides* exhibited better major soil nutrients compared with soils from single cereal farm plots (Section 5.3.1).

Small-scale woodlots showed the lowest aggregated average revenue and cost in 15 years of life span, whereas alley cropping with *R. prinoides* exhibited the highest values for both aggregated average revenue and cost. The aggregated average revenue in alley cropping with *R. prinoides* was about 4.4 and 3.5 times higher than that of small-scale woodlots and mono-cropping land use types, respectively. The lowest aggregated average revenue of small-scale woodlots might be related to lower prices due to poor transport networks and an impeded access to the profitable markets in the regional capital, Bahirdar, and other towns. Thus, the products are mostly marketed at the local level. But the aggregated net profit of woodlots (5151 ETB ha^{-1} yr^{-1}) is still better than that of the mono-cropping land use types (1381 ETB ha^{-1} yr^{-1}) due to lower investment costs.

Table 26. Total and aggregated average revenues and costs of different land use types.

Land use type	Revenue		Cost	
	Total (ETB ha^{-1})	Average (ETB ha^{-1} yr^{-1})	Total (ETB ha^{-1})	Average (ETB ha^{-1} yr^{-1})
Alley cropping with *R. prinoides*	365,541.5	24,369.4	113,679.9	7,578.7
Small-scale woodlots	83,624.7	5,575.0	6,363.5	424.2
Mono-cropping plots	104,846.7	6,989.8	82,639.1 [a]	5,509.3[a]
			61,944.14 [b]	4,129.7[b]

[a] considers all the labour costs, [b] without considering the labour cost for the first eight years.

When the labour costs were not considered for the mono-cropping (for the first eight years) by assuming that farmers could not pay with such kind of negative return for a long time, the net return from the unit of land showed relative improvement (positive net profits) as shown on figure 38. The aggregated average cost was reduced by 1,379.6 ETB ha^{-1} yr^{-1}.

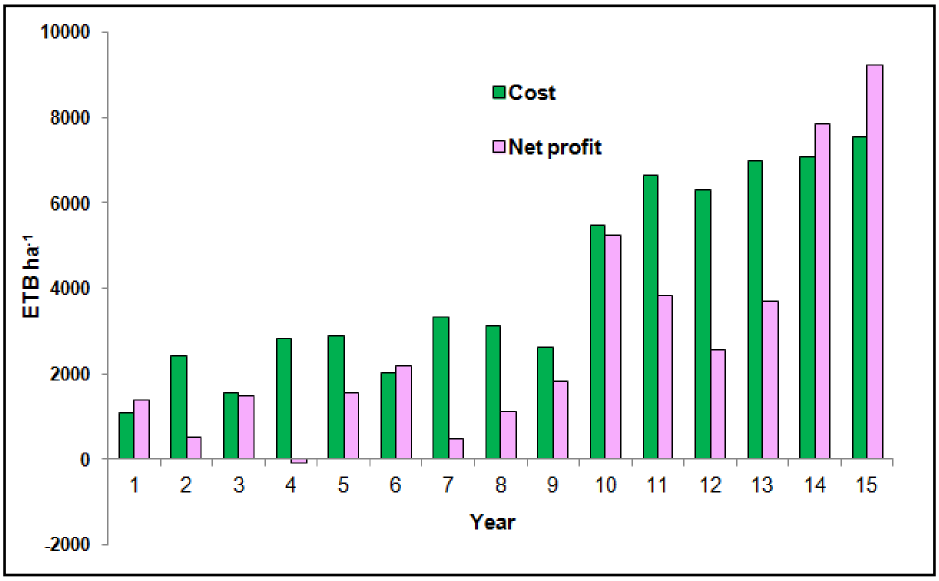


Figure 38. Cost and net profit of mono-cropping without labour cost (for the first eight years).

Generally, though the cost invested in the alley cropping with *R. prinoides* was the highest compared with the other two land use types, the return from this land use type per unit area was better than the others. This shows that diversification of the product through agroforestry with high input of labour might be one option for the improvement of smallholder farmers livelihoods in the area.

5.5 Farmers' perception

5.5.1 Farmers' perception of deforestation and land productivity

As it was indicated in section 5.1, the land use/cover showed the loss in forests and shrublands due to the expansion of agricultural land in the area. Moreover, exploitation of woody species for energy demand was also another threat for the forest and shrub cover in the area. How farmers perceive this situation and the possible consequences may have significant impact on sustainable management of the remaining forests and shrublands. Taye (2006) pointed out that efforts to minimize natural resource degradation partly depend on how farmers perceived the problem in their daily lives.

In this study, the majority of the sampled households (71%, N = 138) realized that the forest cover of Maytemeko Watershed is declining over time. Contrary to the majority, 27% of the households realized that the forest cover of the area is increasing through time, and the remaining households (2%) pointed out that the forest cover has not shown significant change through time.

The former households listed population increase, lack of awareness, fuelwood shortage and lack of legal protection for local rules as the main reason for forest resource decline in the area. Workshop participants indicated that there are local rules to protect the forest area, but these rules are not institutionalized and have no legal protection. On the other hand, respondents who indicated an increase in the area of forest pointed out that tree planting in the area contributed for the observed forest cover increase. As it was stated earlier, tree planting in small-scale woodlots and around boundaries have been practiced in the area after the villagization program of the former Socialist Government.

Farmers also presumed that major consequences have resulted from the decline of forest cover. Scarcity of fodder and fuel, drying of streams, lack of wild edible fruits, emigration of wild animals, warming of climate of the area were the major consequences they observed due to the decline of forest cover.

Similarly, the majority of the households (61%) realized that the productivity of the land was declining through time. In contrast, 32.6% of the respondents realized that productivity of the farmland is increasing through time. The former gave many reasons for the decline in land productivity (Figure 39). More than half of the sampled households indicated that soil fertility decline was the major cause for low productivity of land in the watershed. The others indicated change in rainfall pattern, reduced fallowing periods and decline in fertilizer use due to price increases as the main reasons for land productivity decline in the area.

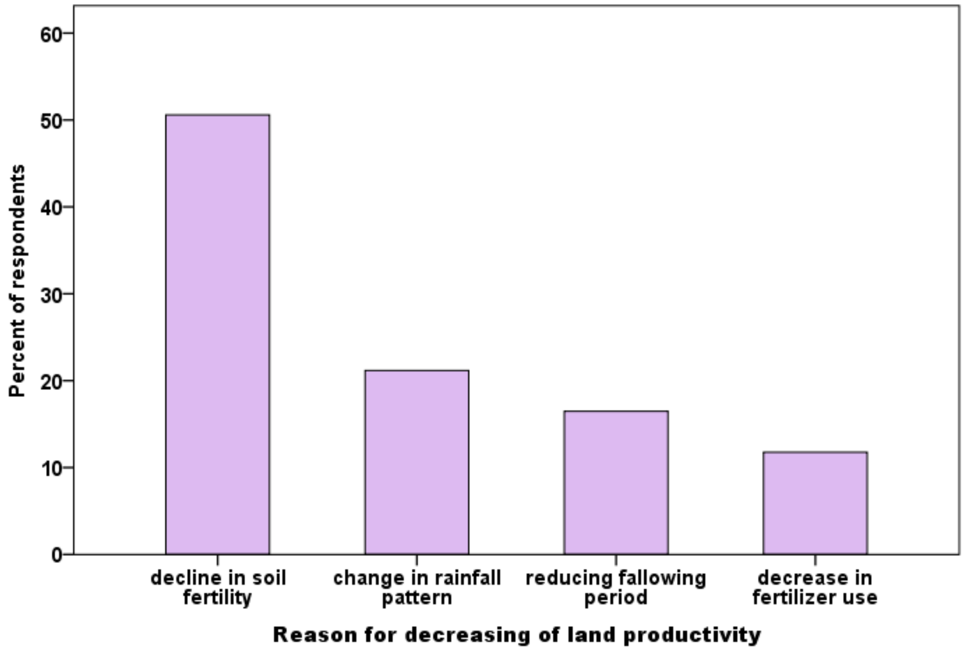


Figure 39. Reasons given by farmers for land productivity decline

The other opinion group pointed out that an increase in land productivity was due to the use of improved seed varieties and the recommended amount of inorganic mineral fertilizers on their farm plots. However, since most farmers are using the lowest level of fertilizer, the productivity of their farm plots may provide low yield per unit area. Plot-level fertility rating by farmers in this study also showed that the majority of the farm plots were considered as infertile (see section 5.5.3).

5.5.2 Farmers' perception of impacts of trees and shrubs on soil fertility

The majority of farmers (87.7%) realized that though most trees are important for soil fertility management, there are also trees that are not preferred for fertility improvement. Eucalypt trees and *Dodonea angustifolia* L.*f*. shrubs are most frequently listed as least preferred for soil fertility management. *Croton macrostachyus* Del. and acacia tree species were considered as most preferred for fertility management in the area (see section 5.5.4). The result from soil laboratory analysis also supported farmers' rating, since soils under the canopy of *E. camaldulensis* showed lower soil nutrients compared with other tree species as indicated in section 5.3.2. However, 6.5% of the respondents said that all trees and shrubs are equally important for soil fertility management. Only 2.9% of the respondents had an opinion that trees on farm are not important for fertility management. The remaining, 2.9% of the respondents did not realize the impact of trees on soil fertility at all.

5.5.3 Soil fertility rating by farmers and the number of trees and shrubs on farms

Land fragmentation is very common in the study area. The mean number of farm plots was about 3.7 HH^{-1}. The fertility level of these farm plots also vary due to site and management factors. One of the management practices might be planting trees and shrubs on the farms. Based on their own experience, farmers in the study area classified their farm plots as very fertile, fertile, medium and infertile. The major criteria used for this classification were soil depth, soil colour and amount of mineral fertilizer needed. On the basis of this, it was found out that of the 512 plots, more than half (57%) were labelled as infertile plots. Medium, fertile and very fertile plots accounted for 21, 16 and 6%, respectively.

The number of trees and shrubs on each plot varied among soil fertility classes. The mean number of trees and shrubs by fertility classes followed an increasing order from infertile, medium, very fertile and fertile plots. Multiple comparisons using ANOVA showed that the number of trees and shrubs among the fertility classes was significant differences ($p < 0.01$). The number of both naturally growing and planted trees and shrubs was lowest on infertile plots compared with the other plots (Table 27).

Table 27. Mean ± SE of trees and shrubs on different plots of different fertility classes.

Fertility classes	Number of plots	Trees and shrubs		
		Naturally growing	Planted	Total
Infertile	290	1.7 ± 0.3a	24.2 ± 12.0a	25.9 ± 12.0a
Medium	110	4.5 ± 0.7b	161.1 ± 95.2a	165.8 ± 95.2a
fertile	83	9.0 ± 1.9c	444.3 ± 133.3b	443.5 ± 133.0b
Very fertile	29	6.4 ± 1.4bc	366.5 ± 64.3ab	372.9 ± 64.7ab

Similar letters in a column do not show significant difference at $p < 0.05$ level.

As stated earlier, the number of eucalypt tree species is very high around homegardens. Here, unlike Tigray Region, where a ban was imposed on eucalyptus plantation on fertile agricultural lands starting from 1997 (Jagger & Pender, 2000), there is no any restriction for eucalypt tree planting related to the fertility of land in Amhara Region. Likewise, the fertile land is used for tree planting in Maytemeko Watershed instead of the infertile lands.

On the other hand, it takes special consideration that the total number of trees and shrubs on very fertile soil classes was lower than on fertile ones. This might be related to farmers' decision to use this very fertile land predominantly for annual crop production purpose, because they may believe that trees on farm take away significant land from crop production and they prefer to use very fertile plots for annual crop production.

5.5.4 Comparison of tree preference rank by farmers and the rank by major soil parameters

It is interesting to compare farmers' ratings of trees for soil fertility management and the related major soil chemical parameters under the canopies of these tree species from soil analysis. This comparison may yield interesting result for sustainable soil fertility management. Based on farmers' preferences, *C. macrostachyus* was considered as the best tree species for soil fertility management followed by *A. abyssinica* and *C. africana*. The lowest rank for fertility management was given to *E. camaldulensis* (Table 28).

Table 28. Farmers' ranking of tree species for soil fertility management.

Group	**Scores***				
	C. macrostachyus	***A. abyssinica***	***C. africana***	***S. sesban***	***E. camaldulensis***
1	5	3	4	2	1
2	5	4	3	2	1
3	5	4	2	3	1
4	4	5	3	2	1
Total	19	16	10	9	4
Rank	1	2	3	4	5

*Score values of 1 to 5 indicate from least to most preferred trees.

Based on the results of the soil analysis, *C. africana* and *A. abyssinica* had the highest scores followed by *C. macrostachyus*. The lowest score was for *E. camaldulensis* (Table 29).

Table 29. Ranking of tree species based on major soil chemical parameters (0-30 cm).

Soil parameters	***C. macrostachyus***	***A. abyssinica***	***C. africana***	***S. sesban***	***E. camaldulensis***
OC (mg g^{-1})	27.8 (3)	30.9 (4)	32.4 (5)	24.4 (1)	24.7 (2)
N(mg g^{-1})	2.6 (3)	2.8 (4)	3.0 (5)	2.6 (3)	2.4 (1)
Ava P (μg g^{-1})	43.5 (3)	61.3 (5)	54.1(4)	39.4 (2)	39.1 (1)
K^+ $cmol_c$ kg^{-1}	0.8 (1)	1.6 (5)	1.5 (4)	0.9 (3)	0.8 (1)
Sum scores	10	18	18	9	5
Rank	3	1	1	4	5

Numbers in parenthesis indicate the relative scores given, based on the mean values of soil parameters

Despite of the fact that the method of ranking soil chemical variables only by magnitude and without weighting may be taken as one limitation, it is interesting that these summed up rankings corresponds to a major extent with farmers ratings. At least the first three tree species in the ranking by the analysis results were the same as in farmers' rankings though the order showed deviations. Moreover, *S. sesban* and *E. camaldulensis* were given the lowest scores, which were also confirmed by the soil laboratory test results. The results of the soil analysis showed that *C. africana* had relatively higher soil nutrients compared with other tree species though farmers ranked it as the third important species. Mekonnen et al. (2006) also indicated that the N and K contents of the leaf of *C. africana* were higher than that of *C. macrostachyus* (Table 20).

Farmers explained that the canopy shade of *C. africana* is not good for undergrowth of plants, and the shoots are not sprouting very fast after pruning. The main explanation they used for their preference of *C. macrostachyus* among other tree species was that its leaves decompose very easily. This idea was also supported by Mahari (2014) who found that the decomposition rate of the leaves of *C. macrostachyus* is much faster than leaves of *C. africana*. Moreover, farmers also pointed out that the branches of the tree have the ability to sprout very fast after pruning so that they produce litter continuously. The lower score for *S. sesban* by farmers may be related to management practice to this tree in the fields. As it was stated earlier, the biomass of *S. sesban* was under continuous extraction for animal fodder and, hence, could not show significant contribution towards soil nutrient improvement. By this way, farmers may not realize its contribution to soil fertility compared with the other tree species.

5.6 Constraints of tree and shrub planting for AFPs

Promising AFPs are observed in the watershed as described earlier. These practices contributed to reduce deforestation by providing wood products, improve the soil fertility, conserve woody vegetation diversity and generate relatively better income for farmers. Moreover, farmers in the study area were aware about the importance of trees on soil quality improvement. However, there are major constraints that are challenging farmers when they want to plant and maintain trees and shrubs in their farm plots.

5.6.1 Household characteristics

5.6.1.1 Landholding, labour and distance of home from the forest

The average landholding size of the household was about 1.1 ha though there was variation among households ranging from 0.25 to 2.5 ha. The household survey results indicated that trees and shrubs on the farm had positive significant correlation ($r = 0.214$, $p = 0.01$) with landholding size (Table 30). At the same time, when farmers were asked to point out the major constraints for tree planting on their farmlands, they considered farmland shortage as the main problem (Figure 40). Since most of the farmers are smallholders and rely on subsistence farming, their inclination towards long-term investments like tree planting might be low on small farm sizes. Their main focus is to satisfy their immediate food needs from annual crops than to grow trees for long-term benefits. Similar results were reported from different parts of Ethiopia, which indicated farmers with relatively larger farm sizes planted more trees than those with smaller farm sizes (Gebreegziabher et al., 2010; Zeleke & Bliss, 2010; Mekonnen & Damte, 2011; Sisay & Mekonnen, 2013). Oeba et al. (2012) also pointed out that tree planting on farmlands had positive correlation with farmland size in Kenya.

The average family size of the households in Maytemeko Watershed was about six ranging from two to eleven. However, the average number of active labour (excluding children below 15 and old people above the age of 64) was about three ranging from zero to six. The number of trees and shrubs showed positive and significant correlation ($r = 0.210$, $p = 0.05$) with the number of active labour in the household (Table 30). This might be attributed to the high labour demand of planting and managing trees and shrubs on the farm. Labour may not have significant impact on tree planting at large scale in highly populated areas as it was stated by Dewees & Saxena (1997). However, at household level with a large number of dependants, it may affect tree planting and other farming activities. The non-significant correlation ($r = 0.164$, $p = 0.08$) of family size and number of trees and shrubs on the farm also confirmed this fact. Even with large area of farmland, farmers used to rent-out their land to others if there is not enough labour to manage the farm. Thus, the rented-out land is usually used for annual crop cultivation. In agreement with results from this study, Holden et al. (2003) also pointed out that households with relatively higher labour planted more trees on their farm plots than others.

Table 30. Correlation of trees and shrubs on the farm with household variables.

	Age	FS	NAL	LHS	NP	NL	DS
Age	1						
FS	0.025	1					
NAL	- 0.158	0.698**	1				
LHS	0.354**	0.420**	0.248**	1			
NP	0.097	0.262**	0.164	0.506**	1		
NL	0.048	0.357**	0.265**	0.192*	0.132	1	
DS	0.050	0.259**	0.169*	0.308**	0.011	0.103	1
NTS	- 0.041	0.164	0.210*	0.214*	0.020	- 0.027	0.253**

** Correlation is significant at the 0.01 level and * Correlation is significant at the 0.05 level. FS = family size, NAL = number of active labour, LHS = land holding size, NP = number of plots, NL= number of livestock in TLU, DS = distance of the house from forest and shrub area and NTS = number of trees and shrubs on the farm plot.

Tree planting had positive and significant correlation ($r = 0.253$, $p = 0.003$) with distance of the house from the natural forest and shrublands. This indicates that households who are situated very far from the remnant natural forests and shrublands planted more trees compared with those who are living close to the remnant forest and shrublands. This could be attributed to a restricted access to the forest products, which forces the farmers to plant and sustain trees and shrubs on their farm plots. Duguma et al. (2009) also pointed out that farmers living near the state forest consumed more fuelwood from the state forest compared with farmers living outside the state forest. This implies that farmers living far from the state forest had their own trees and shrubs to satisfy their fuel demands.

5.6.1.2 Influence of wealth status on tree and shrub planting

The number of trees and shrubs on farm plots showed significant difference ($p < 0.05$) among different wealth classes (Table 31). The rich farmers had the largest number of trees and shrubs on their farm plots, while the poor had the smallest. This might be related to the resource availability to plant and manage trees on their farm plots. The resource availability could be also related to the farm size since there was significant difference ($p < 0.05$) in farm size among the three wealth classes (Table 31). The poor farmers had an average farm size below one hectare. For such households and subsistence farmers, long-term benefits from trees and shrubs are not their main concern. While, the rich farmers with relatively larger farm sizes use tree planting as a living bank account to increase their income in the future.

The use of trees, especially eucalypts, as a living bank account (Turnbull, 1999), to be harvested when there is a need for cash, is widespread in Ethiopia (Teketay, 2000).

Table 31. Mean ± SE of trees and shrubs in relation to wealth classes of the households.

Wealth classes	Number of HH	Trees and shrubs	Farm size (ha)
Poor	20	65.5 ± 30.0a	0.8 ± 0.07a
Medium	62	208.1 ± 26.4a	1.1 ± 0.04b
Rich	52	2,665 ± 668.6b	1.3 ± 0.40c

Means in a column labelled by similar letters do not show significant difference at $p < 0.05$. HH = household.

5.6.2 Plot characteristics and their relation to the number of trees and shrubs

As stated earlier, farmers in Maytemeko Watershed had fragmented farm plots. At individual plot level, tree and shrub planting was affected by the number of years the household farmed on a specific plot, distance of the farm plot from home, the size of individual farm plots, soil fertility level and slope of the farm plots.

The number of years that the plot was owned by the farmer showed significant correlation ($r = 0.126$, $p = 0.012$) with the number of trees and shrubs on the farmlands (Table 32). Positive correlation indicates those plots owned by farmers for longer periods had more trees and shrubs on them than plots farmed for shorter periods. This might be related to tenure security issues. If the plot of land stays with the farmers for a long period of time, they may feel more secure and invest for long-term benefits from the land, such as tree planting.
Distance of the farm plots from home had negative and significant correlation ($r = - 0.106$, $p = 0.03$) with total number of trees and shrubs.

Table 32. Relationship between number of trees and shrubs and some plot level variables

Parameter	Plot size (ha)	Ownership years	Distance from home (km)	Naturally growing trees & shrubs	Planted trees & shrubs
Plot size	1				
Ownership	0.160**	1			
Distance from home	- 0.029	- 0.054	1		
Naturally growing trees &shrubs	0.021	0.104*	- 0.097*	1	
Planted trees & shrubs	0.106*	0.174**	- 0.105*	0.055	1
Total trees and shrub	0.023	0.126*	- 0.106*	0.033	0.999**

**significant at $p < 0.01$ and *significance at $p < 0.05$ level.

As distance increases, farmers' willingness to plant and protect trees and shrubs decreased. This is mainly due to management problems on the farm since trees and shrubs need special attention and close management. One of the major challenges to plant trees and shrubs on relatively distant farm plots might be free grazing, which is common in the study area that could damage the planted trees and shrubs on the farm. In the nearby plots, it is easier to manage and grow trees and shrubs since household members can prohibit animals from browsing after crop harvest. It was observed that trees and shrubs that are grown far from homes are not palatable to animals. In addition, the result from focus group discussion also showed that there is widespread problem of theft of fruits as well as other tree products, when they are planted far away from home. In agreement with this result, Predo & Francisco (2012) also found that distance from home negatively influences tree planting behaviour of farmers in the Philippines.

There was significant and positive correlation ($r = 0.106$, $p = 0.03$) between individual plot size and number of trees and shrubs planted on the farm plots, while the correlation of plot size with the number of naturally growing trees and shrubs was not significant (Table 32).

The fertility level of farm plots may also affect tree planting behaviour of framers. As indicated in section 5.5, according to the ratings given to individual plots, farmers had larger number of trees and shrubs on relatively fertile lands compared with the medium and infertile plots. This may exacerbate the problem of low productivity of less fertile plots due to lacking of the beneficial effect of tree planting in mitigating soil erosion. If farmers would use these infertile plots for tree and shrub planting, they may also increase the productivity of the land due to the contribution of the tree components towards soil nutrient improvement. Nair (2011) pointed out that trees and shrubs in nutrient-depleted soils have demonstrated the ability of trees to absorb nutrients that have leached below the rooting zone of annual crops and to recycle these nutrients through leaf litter and fine root turnover, thus, improving the nutrient status in the system as a whole.

In addition, the slope of the farm plots also varied in the watershed. Of the total farm plots, 34.2% were considered as very steep by farmers. Steep, moderate and gentle slopes accounted for 34.6, 20.3 and 10.9% of the total farm plots (Table 33). The number of trees and shrubs on the farm plots showed significant differences ($p < 0.01$) among different slope classes rated by farmers. The highest and lowest number of trees and shrubs were found on gentle and very steep slope positions, respectively.

Table 33. Mean ± SE of trees and shrubs at different levels of slope positions on farm plots.

Slope	Number of plots	Naturally growing trees and shrubs	Planted trees and shrubs	Total number of trees and shrubs
Very steep	175	1.9 ± 0 .2a	3.83 ± 1.4a	5.7 ± 1.5a
Steep	177	2.8 ± 0.5a	17.95 ± 4.4a	20.8 ± 4.3a
Moderate	104	6.1 ± 0.9b	130.0 ± 18.8a	136.1 ± 18.9a
Gentle	56	7.9 ± 2.7b	980.2 ± 260.0b	973.8 ± 260.2b

Mean values in a column labelled by similar letters do not significant difference at $p < 0.05$ level.

This shows that farmers are using the fertile farm plots with gentle slope more often for tree and shrub planting than the infertile steeper slope areas. The steep slope areas are left for further degradation through erosion. One of the main reasons for lower number of trees and shrubs on steep slope areas might be related to transport problem to harvest the products. The poor transport network and low level of technology to harvest the products may make small-scale woodlots less attractive in steep slope areas. On the other hand, tree and shrub planting is very common around the residential areas than other plots. The result from this study showed that the mean number of trees and shrubs in homegardens (273.6) is significantly higher ($F = 5.7$, $p < 0.01$) than the other plots (100). Thus, farmers also prefer to construct their houses on relatively gentle slope areas than steep slope farm plots.

5.6.3 Farmers direct judgment of major constraints for tree and shrub planting

In addition to relating household and plot level variables with tree and shrub planting, it was also important to see farmers' direct judgement on the constraints of tree and shrub planting on farm plots. Similar to the relation found earlier, some farmers (41.5%) in the study area also pointed out that shortage of farmland is the limiting factor for tree planting and maintaining (Figure 40).

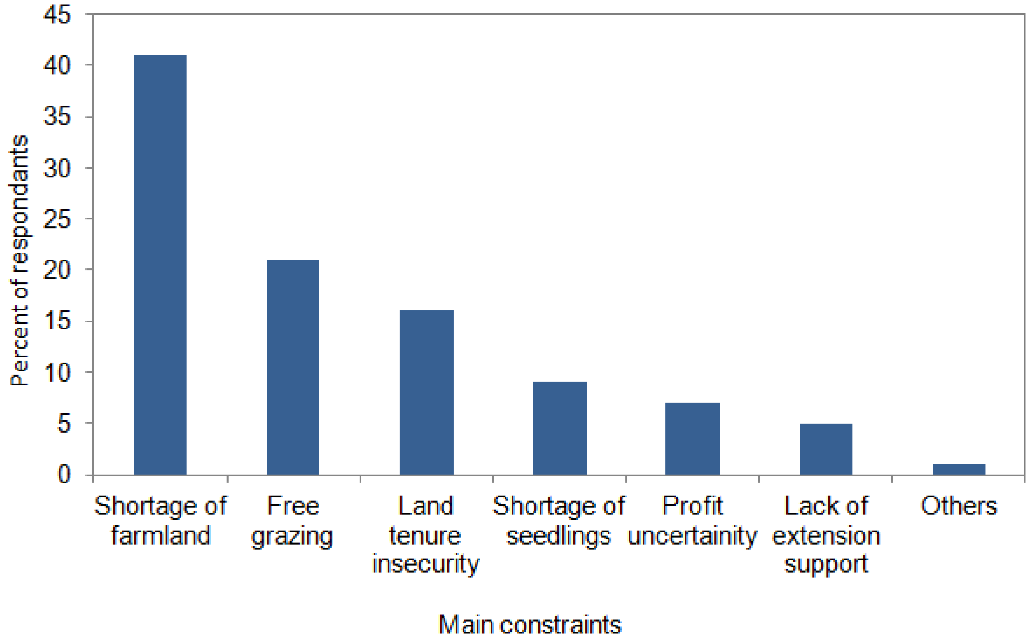


Figure 40. Major constraints pointed out by farmers for tree and shrub planting on farm.

Free grazing was pointed out as the second major problem by the studied households for tree planting and protection. Crop production and animal husbandry are complementary activities in the highlands of Ethiopia. Cattle are used as sources of power for drafting and the crop residues are used for animal feeds. However, free grazing, which is a common practice in many areas in both open forests and agricultural lands, is becoming a major problem for sustainable land management. One of these problems is the grazing and browsing of animals on farmlands after crop harvest. Edible trees and shrubs might be browsed by the roaming cattle, and in this way farmers can be discouraged to plant again. This finding was also supported by Mekonnen et al. (2008), who found that free grazing on agricultural landscape is the major constraint for tree planting and maintenance in central Ethiopia. Key informant interviews also confirmed that free grazing on croplands is destroying the trees/shrubs planted on soil bunds. As a counter measure, experts suggested to the farmers to keep animals around their homes and to use a cut and carry system to feed their animals.

The third major problem pointed out by the studied households was land tenure insecurity. The experience that farmers had with land tenure policies left them insecure about their land property rights. As a consequence, they do not want to employ long-term investments, such as tree planting on their farmlands. Though the government gave the use right of land through certification, farmers still have the feeling of insecurity since they have a belief that the government may transfer their land to other people when there is a need. This discourages them from planting and protecting trees and shrubs on their farm plots. They do not want to invest more if they are not sure that the plot of land will stay under their control throughout their life and pass it over to their descendants. This result is also in agreement with the findings from other studies conducted in Ethiopia. Alelign et al. (2011) pointed out that farmers in Zegie Peninsula, northwest Ethiopia, have no plan to plant trees in the future due to tenure insecurity. Gebreegziabher et al. (2010) also reported similar result in northern Ethiopia. The results from Cameroon also showed that land tenure security made a positive contribution for the implementation of AFPs (Nkamleu & Manyong 2005). Oino & Mugure (2013) also reported similar results in Kenya.

The remaining households mentioned seedling supply problems, uncertainty about the profitability of tree growing and lack of extension support as major problems. Participants of the workshop also pointed out that despite the fact that there are two nursery sites in the district, the supply of seedlings is not fulfilling the current demand. Sisay and Mekonnen (2013) reported similar problems on seedling supply for agroforestry in central Ethiopia. Moreover, the low survival rate of seedlings was also pointed out by farmers as a problem as stated earlier. On the other hand, uncertainty of profitability was considered as a factor, which discourages tree planting in the Watershed. If farmers are not sure that the trees and shrubs planted on their farm plots can produce more profits for the household than the annual crops, they may do business as usual and produce annual crops. In line with this idea, Franzel et al. (2001) stated that profitability is one of the determinants for the potential adoption of agroforestry practices, and if farmers are uncertain, they will not use it. This is also related to the limited capacity of farmers to take the risks of losing out, since most of the farmers are leading subsistence life without ample resources.

6.CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main focus of this study was to evaluate the land use/cover dynamism, to assess major contributions of AFPs for minimizing forest degradation, improving soil nutrients and their contribution in improving the livelihoods of smallholder farmers in Maytemeko Watershed. Moreover, farmers' perception and major constraints of tree and shrub planting in AFPs were assessed in order to find possible solutions for sustainable management of the watershed.

The land use/cover change investigation from satellite images of 1986 and 2011 showed that the vegetation cover in Maytemeko Watershed declined between the two years. The cropland area increased at the expense of the forest, shrubland and grassland areas. Clearing the vegetation cover, even, in steep slope areas and replacing it with cultivated lands is very common. Moreover, significant amounts of fuelwood were also exploited from the surrounding forests and shrublands, which exacerbates deforestation and forest degradation. The annual allowable harvest for fuel from natural forest and shrubland areas was estimated to be unsustainable that may lead to further degradation of the remaining forests and shrublands. Consequently, considerable amounts of AGB were lost in the area over the 25 years considered in the study.

Tree planting in homegardens, alley cropping, small-scale woodlot and scattered trees on farmlands are promising AFPs identified in the watershed. These AFPs are contributing to ecological benefits, such as woody plant species conservation, soil nutrient improvement and reducing pressure on natural forest through provision of wood and non-wood products. Moreover, improving income of farmers and reducing burden of women for fuel collection were major benefits of agroforestry trees and shrubs identified in the area.

Tree species composition of homegardens indicated that the two exotic species of eucalypt trees and indigenous *R. prinoides* shrub are dominating other tree and shrub species because of their economic significance. Significant numbers of indigenous tree species are becoming rare in the farm plots of the study area. Some of them are already registered in the red data lists of conservation agencies, which indicates the need for greater attention to conserve the diversified woody species by AFPs.

Comparison of soil nutrient status of different land use types indicated that soils from agroforestry land use types showed relatively higher nutrient status compared with the SCC land use types. Both the principal component analysis and RSII revealed that the soils from

CMF land use types exhibited the highest soil nutrient status compared with others. Soil OC, N, Ava P and exchangeable K^+ were significantly higher in agroforestry land use types than the SCC land use types. The order of availability of these soil nutrients followed CMF > HG > ACS > ACR > SCC.

For the choice of tree species in agroforestry for sustainable soil fertility management, it was also important to assess the contribution of individual tree species for soil fertility improvement under the same land use type. Generally, it was found that the soil nutrients under the canopies of different tree species were significantly higher compared with outside the tree canopies. Moreover, there was also variation in major soil nutrients among the tree species. Soils under the canopies of indigenous tree species showed relatively better nutrient status compared with exotic tree species, e.g. *Cordia africana, A. abyssinica* and *C. macrostachyus* were higher in soil nutrients than *S. sesban* and *E. camaldulensis*.

Agroforestry played a significant role in reducing pressure on the natural forests and shrublands by providing fuel and construction wood as well as other forest products. In this study, the proportion of consumption of fuelwood obtained from AFPs was significantly higher compared with that obtained from the natural forests and shrublands for the year 2012/2013. Generally, the study showed that about 166 tons of fuelwood was saved from the natural forests and shrublands due to the replacement of fuelwood from the trees and shrubs growing in the different AFPs. Estimation of AGB loss in this study also indicated that trees from AFPs contribute to the accumulation of significant amounts of AGB in the watershed. Though the total fuelwood demand by households in the watershed was above the amount that could be obtained sustainably from the natural forests, shrublands and agroforestry, the fuelwood harvested from agroforestry trees and shrubs has helped to minimize over-exploitation of the natural forests and shrublands. The demand from the natural forests and shrublands is about 1.7 times higher than the allowable harvest. If agroforestry trees and shrubs were not used, this value would have been 3.6 times higher than the allowable harvest from the natural forest and shrubland areas.

In addition, before 20 years ago, the proportion of pole wood extracted from the natural forest was higher than that from agroforestry trees. However, the proportion has been reversed within the last 20 years, and agroforestry trees are contributing now higher proportion of poles than the natural forest. This shows that there is a shift of supply from the natural forests and shrublands towards agroforestry trees and shrubs for house construction through time.

On the other hand, animal dung for fuel accounted for about 23% of the total consumption, thus the potential of animal dung to improve soil nutrient in fields is greatly lost.

Fuelwood harvested from agroforestry also reduced the burden of women (mothers and daughters) by reducing significantly the time spent and efforts required to collect fuelwood from the natural forest and shrubland areas. Moreover, collecting fuelwood from agroforestry trees and shrubs also helped the households to share the responsibility of fuelwood collection among household members more evenly between men and women.

With regard to financial benefits, the net return per unit area of land was the highest for the alley cropping with *R. prinoides* though the aggregated cost invested was very high due to the labour cost additions to collect and transport the products. The average aggregated cost associated with the alley cropping practice was 17.9 and 1.4 times higher than the small-scale woodlot and the mono-cropping land use types, respectively. However, the average aggregated revenue was 4.4 and 3.5 times higher than for these two land use types, respectively.

The analysis of farmers' perceptions showed that the majority of the households in the study area realised a decline in forest cover and land productivity through time. Decline in soil fertility was emphasized as the major threat for land productivity reduction. Based on randomly selected plot level analyses, farmers rated farm plots with relatively higher number of trees as fertile plots than those with lower number of trees. Also, the majority of farmers realized that the presence of selected tree species on farmlands can improve the fertility of the land. The tree preferences of farmers for soil fertility management was also in agreement with results from the scientific soil laboratory tests, i.e. trees with relatively higher contents of major soil nutrients were also given higher scores by farmers than those with lower contents of major soil nutrients.

Despite tremendous benefits from trees and shrubs in agroforestry, major constraints were also identified for the implementation and wider expansion of trees and shrubs planting as part of AFPs. At household level, farm size, number of active labour, distance of the house from the natural remnant forests and shrublands and wealth of the households showed positive relations with the number of trees and shrubs on the farm plots. At individual plot level, the number of years the households cultivated a plot of land, individual plot size and soil fertility level had positive significant effects on planting of trees and shrubs, while distance of the farm plots from houses and slope of the farm plots influenced the number of trees and shrubs on the farm lands negatively. Farmers also pointed out free grazing, land tenure insecurity, lack of seedling provision and lack of extension support as major constraints for the expansion of AFPs in the watershed.

6.2 Recommendations

Generally, based on the results of this study the following recommendations are forwarded to improve the forest cover and livelihoods of smallholder farmers in the watershed.

- To improve the forest cover of the area, realistic community-based forest management strategies should be developed with the participation of the farmers. This needs initiating farmers as they are already aware of the deforestation problems.
- The existing forest and shrubland areas are degraded, which requires actions to improve the regeneration and stocking. Especially, exclosures and plantations on the degraded lands on hill slopes may be taken as one option for restoration and future supply of timber and non-timber products to the local farmers.
- Since the poor farmers are relatively high consumers of fuelwood from the remnant forests and shrublands because of the low number of trees and shrubs on their farms, these farmers should be encouraged to plant trees through incentive mechanisms, such as providing seedlings at moderate prices and special land grants from degraded common lands to do plantations and restoration.
- High dependency on biomass fuel (wood, animal dung and crop residues) may lead to further degradation of forests and shrublands as well as soil resources. Hence, introduction and promotion of energy saving stoves should be given greater attention.
- The SCC land use types showed the lowest soil nutrients due to continuous harvest and nutrient removal, this needs greater attention to improve the productivity of these lands through such means as compost and green manure application.
- Though indigenous trees have better soil nutrient improving characteristics than exotic tree species, farmers are inclined to grow eucalypts on their farm plots for economic reasons. Instead of using the fertile land for eucalypt plantation, the degraded lands on steep slopes should be considered as potential areas. Policy attention should also focus on the reallocation of degraded hill slopes under communal use to individual farmers.
- Integration of fast growing multipurpose trees such as *Faidherbia albida* (Delile) A.Chev. may be taken as another option on farm lands to improve soil fertility and satisfy wood and fodder demands.
- Integration of indigenous knowledge of farmers for the choice of tree species for soil fertility management should be given greater priority, since farmers are well aware of the function of trees for fertility management.

- Most of the farmers pointed out farmland shortage as the main limiting factor for tree planting and managing. On the other hand, the result in this study showed that the net return from a unit of land is higher for agroforestry plots than the mono-cropping fields. This proves that creating awareness on the multiple benefits of agroforestry practices through experience sharing is of utmost importance.
- Extension support should be given to farmers on the technical aspects of tree planting on farm lands.
- The issue of free grazing should be addressed to protect and maintain trees and shrubs planted on farmlands. This could be achieved through ensuring the participation of farmers during the planning and implementation.
- Land tenure insecurity feelings of farmers had significant impact on planting of trees and shrubs in agroforestry practices. Hence, it needs the appropriate policy attention.

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Web page

http://glovis.usgs.gov

Proclamation

Addis Negari Gazeta (2008). 1st year No.1. Addis Ababa, Ethiopia, July 2008.

8.Appendices

Appendix 1. Sample cropland plots considered for AGB estimation

Plots	Altitude	No of trees	AGB(kg)	AGB(ton)
1	2420	9	23629	23.6286
2	2151	5	4164	4.164
3	2395	9	18458	18.4582
4	2243	6	14576	14.5757
5	2025	12	1307	1.307
6	1945	7	5108	5.108
Total		48	67241	67.2415
average		8	11207	11.2069

Appendix 2. Woody plant species, their family name, local name, primary uses and their number in farmlands

Species name	Family	Local name	Habit	Primary uses	Number
Croton macrostachyus Del.	Euphorbiaceae	Bisana	tree	SF,FW, MD	305
Rhamnus prinoides L'Hér.	Rhamnaceae	Gesho	tree/shrub	IN, AL	252
Vernonia amygdalina Del.	Asteraceae	Girawa	tree	CL, FO, MD	133
Rumex nervosus vahl	Polygonaceae	Embuacho	shrub	FB,OR	128
Lippia adoensis (Hochst. ex Walp.)	Verbenaceae	Kesey	shrub	CL, FO, MD	109
Calpurnia aurea (Ait.) Benth	Fabaceae	Ligta	shrub	CL, FW,MD	102
Solanum incanum L.	Solanaceae	Embuay	shrub	MD	96
Dodonea anguistifolia L.*f.*	Sapindaceae	kitkta	shrub	FO,FW	68
Euphorbia tirucalli L.	Euphorbiaceae	Qnchib	tree/shrub	FB, OR	52
Maytenus arbutifolia (Hochst. ex A.Rich.) R.Wilczek	Celastraceae	Atat	shrub	FO,FW	50
Acacia abyssinica Hochst. ex Benth	Fabaceae	Bazira girar	tree	SF,SH,FO,FW	39
Senna singueana Del	Fabaceae.	Gufia	shrub	CL, FO, FW	29
Sesbania sesban (L.) Merr	Fabaceae	---------	tree	SF, FO	21
Otostegia integrifolia Benth.	Lamiaceae	Tunjit	shrub	CL,OR	18
Acacia seyal Delile	Fabaceae	Neche girar	tree	CM, FW,	16
Flueggea virosa (Roxb. ex Willd.)	Euphorbiaceae	Wonahi	tree	FW,CM	16
Acacia nilotica (L.) Del.	Fabaceae	Cheba	tree	FW,SH	15
Baphia abyssinica Brummitt	Fabaceae	---------	tree	FW	14
Mangifera indica L.	Anacardiaceae	Mango	tree	FT	13
Combretum molle R.Br. ex G.Don	Combretaceae	Avalo	tree	FW, CL, MD	12
Coffee arabica L.	Rubiaceae	Buna	Tree/shrub	IN	12
Cordia africana Lam.	Boraginaceae	wanza	tree	CW, FW	8
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Key bahir zaf	tree	CW, FW, MD	5
Carissa spinarum L	Apocynaceae	Agam	tree	FW, CM	4
Albizia gummifera (J.F.Gmel.) C.A.Sm.	Fabaceae	Sesa	tree	FW, SF, CM	4
Olea Europaea L.	Oleaceae	Woira	tree	FW, CM, CL	4
Stereospermum kunthianum Cham.	Bignoniaceae	--------	tree	FW, OR	4
Terminalia schimperiana Hochst	Combretaceae	---------	tree	FW	3
Buddleja polystachya Fresen.	Loganiaceae	Anfar	shrub	CL, OR, MD	3
Faidherbia albida (Delile) A.Chev	Fabaceae	Bazira girar	tree	SF, FW, CW	3
Premna schimperi Engl	Verbenaceae	Checho	tree	CM	3
Rosa abyssinica R. Br. ex Lindl	Rosaceae	qega	shrub	FT, FW	3
Rhus glutinosa A.Rich	Anacardiaceae	Abar	tree	CL, OR,	2
Clerodendrum myricoides (Hochst.)	Lamiaceae	Misrch	tree	FW, CW, MD	2
Erythrina abyssinica Lam. ex DC	Fabaceae	Korch	tree	FW, CM	2

Species name	Family	Local name	Habit	Primary uses	Number
Gardenia ternifolia Schumach. & Thonn	Rubiaceae	Gobil	tree	FO, FW	2
Psidium guajava L.	Myrtaceae	Zeitun	tree/shrub	FT, IN	2
Polyscias fulva J.R.Forst.& G.Forst	Sapotaceae	Yeznjero wenber	tree	FW, CM	1
Dombeya torrida (J.F. Gmel.) P. Bamps	Sterculiaceae	Wulkfa	shrub	FW, CM	1
Ficus vasta Forssk	Moraceae	Warka	tree	SH, FW	1
Ricinus communis L.	Euphorbiaceae	Chakma	tree	FW, OP, FO	1
Juniperus procera Hochst. ex Endl	Cupressaceae	Tid	tree	CM, FW, OR	1
Ficus thonningii Blume	Moraceae	Chibeha	tree	FO, SH	1

SF = soil fertility, FW = fire wood, MD = medicine, FI = farm implements, IN = income generation, AI = alcohol preparation, CL= cleaning, FO = fodder LF = live fence, *OR = ornamentals SH = shade, CM = construction material, FT = fruit and OP = oil plant.*

Appendix 3. Woody plant species, their family name, local name, primary uses and their number in homegardens

Species name	Family	Local name	type	Primary use	Number stems
Rhamnus prinoides L'Hér.	Rhamnaceae	Gesho	shrub	IN, FI,	2236
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Key Bahirzaf	tree	CM, FW, MD	1502
Eucalyptus globulus Labill.	Myrtaceae	Nech Bahirzaf	tree	CM, FW, MD	979
Croton macrostachyus Del.	Euphorbiaceae	Bisana	tree	SF, FW, MD, FI	261
Vernonia amygdalina Del.	Asteraceae	Girawa	tree/shrub	CL, FO, MD	192
Catha Edulis (Vahl) Forssk. ex Endl.	Celastraceae	Chat	shrub	IN	170
Cordia africana Lam.	Boraginaceae	wanza	tree	CM, FW, SF	105
Sesbania Sesban (L.) Merr.	Fabaceae	----------	shrub	SF	83
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Bazira girar	tree	SF, FW, SH	61
Dombeya torrida (J.F. Gmel.) P. Bamps	Sterculiaceae	Wulkfa	shrub	CL	44
Ruta chalepensis L.	Rutaceae	tenadam	shrub	MD, OR	42
Ricinus communis L.	Euphorbiaceae	Chakma	shrub	OP, SF	41
Acacia nilotica (L.) Del.	Fabaceae	Cheba	tree	FW, CW, SF	30
Dodonea anguistifolia L.*f*.	Sapindaceae	kitkta	shrub	FW, FO	30
Lippia adoensis Hochst. ex Walp.	Verbenaceae	Kesy	Shrub	OR, CL, MD, BK	24
Carica papaya L.	Caricaceae	papaya	tree	FT, MD	20
Solanum incanum L.	Solanaceae	embuay	shrub	MD	19
Rumex nervosus Vahl	Polygonaceae	Embuacho	tree	OR, BK	18
Senna singueana Del.	Fabaceae	Gufia	Shrub	CL, MD, FW	16
Citrus aurantiifolia (Christm.) Swingle	Rutaceae	Lomi	shrub	FT, IN	15
Olea Europae L.	Oleaceae	Woira	tree	CW, FW	15
Carissa spinarum L.	Apocynaceae	Agam	tree	FW, MD	14

Species name	Family	Local name	type	Primary use	Number stems
Euphorbia tirucalli L.	Euphorbiaceae	Qinchb	shrub	LF, FB	13
Ficus thonningii Blume	Moraceae	Chibeha	tree	FO, FW, CW	11
Acacia mearnsii de Wild.	Fabaceae	Mimosa	shrub	FW, SF	11
Citrus sinensis (L.) Osbeck	Rutaceae	Birtukan	shrub	FT, MD	9
Clausena anisata (Willd.) Hook.f. ex Benth.	Rutaceae	limch	shrub	CL, FW,	9
Albizia gummifera (J.F. Gmel.) C.A. Sm.	Fabaceae	Sesa	tree	CW, SF, FW	9
Juniperus procera Hochst. ex Endl.	Cupressaceae	Tid	tree	CW, FW, OR	8
Mangifera indica L.	Anacardiaceae	Mango	tree	FT, IN	7
Calpurnia aurea (Ait.) Benth.	Fabaceae	ligta	shrub	CL, FW	7
Schinus molle L.	Anacardiaceae		tree	CM, FW, MD	6
Psidium guajava L.	Myrtaceae	Zeitun	tree	FT, IN	5
Rosa abyssinica R. Br. ex Lindl.	Rosaceae	qega	shrub	FT, IN	5
Berberis holstii Ahrendt	Berberidaceae	Yeset af	shrub	MD, FW	4
Maytenus arbutifolia (Hochst. ex A.Rich.) R. Wilczek	Celastraceae	Atat	shrub	FW, CW	3
Clerodendrum myricoides (Hochst.) Vatke	Lamiaceae	Misrch	shrub	FW, CW	3
Coffea arabica L.	Rubiaceae	Buna	shrub	FI, MD	2
Baphia abyssinica Brummitt	Fabaceae	--------	shrub		2
Persea americana Mill.	Lauraceae	Avocado	tree	FT, IN	2
Combretum molle R. Br. ex G. Don	Combretaceae	Avalo	tree	FW, CL, CW, FO	2
Rhus vulgaris Meikle	Acanthaceae	Qamo	shrub	FT, FW	2
Dracaena steudneri Schweinf. ex Engl.	Dracaenaceae	Merko	Shrub	OR, FO	1
Faidherbia albida (Del.) A. Chev.	Fabaceae	Girar	tree	SF,FW,CW	1
Prunus africana (Hook. f.) Kalkman	Rosaceae	Tikur enchet	tree	CW, FW, MD	1
Gardenia ternifolia Schumach. & Thonn.	Rubiaceae	gobil	tree	FO, FW	1
Buddleja polystachya Fresen.	Scrophulariaceae	-------	tree	FO,	1
Ficus vasta Forssk.	Moraceae	warka	tree	SH, FW, CW	1
Jasminum grandiflorum L.	Oleaceae	Tembelel	tree	FW, CW	1
Grewia villosa Willd.	Tiliaceae	Lenquata	shrub	MD, CL, FW, SF	1
Premna schimperi Engl.	Verbenaceae	Checho	tree	CW, MD	1
Grevillea robusta A. Cunn. ex R. Br.	Proteaceae	------	tree	FW, CW	1

SF = soil fertility, FW = fire wood, MD = medicine, FI = farm implements, IN = income generation, Al = alcohol preparation, CL= cleaning, FO = fodder LF = live fence, *OR = ornamentals SH = shade, CM = construction material, FT = fruit and OP = oil plant.*

Appendix 4. Prices of common crops from 1999 to 2013 (ETB/quintal)

	Year														
Major crops	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Teff	185.7	198.0	200.0	241.8	212.0	215.0	220.0	280.0	900.0	800.0	592.0	648.0	966.0	1200.0	1400
Maize	100.0	100.0	101.0	114.5	114.5	134.3	150.0	190.0	500.0	380.0	310.0	330.1	700.0	700.0	750
Wheat	112.0	115.0	110.0	130.0	145.0	145.0	150.0	180.0	400.0	380.0	370.0	502.5	640.0	820.0	900
Barely	160.0	90.0	95.0	100.0	103.0	105.0	110.0	400.0	320.0	480.0	320.0	392.8	392.8	700.0	750
Bean	160.0	187.5	180.0	220.0	315.0	200.0	250.0	300.0	375.0	266.5	450.0	450.0	750.0	750.0	825
Pea	285.0	300.0	380.0	372.0	345.0	360.0	380.0	400.0	600.0	600.0	475.0	620.0	840.0	980.0	1100

Source: Hulet Eju Enessie District Micro Finance Office

Appendix 5. Household survey questionnaire

Code Number_____
Name of the enumerator ________

I. Personal Information

1. Name of the respondent ______________________
2. Age of the respondent ___________________
3. Kebele administration________________________
4. *Got*[1]_____________________________
5. sex _______________
6. marital status ____________
7. Education level/ completed
   a. illiterate
   b. can read and write only
   c. church education
   d. elementary school (1- 8 grades)
   e. secondary school (9- 10 grades)
   f. preparatory school
   g. college/ university

II. Socio-economic indicators

1. Family size: Total ______ 0 to 15 years_____, 16 to 30 years____, 31 to 45 years____, > 45 years _____
2. How many *timad*[2] of land do you have? ____________
3. In how many plots are your land holdings distributed? ___________
4. For how long do you possess your farm plots? __________
5. Have you been experienced with land redistribution done by the government? a. yes b. no If yes, how many times? ______
6. Are you feeling that your land is subjected to future redistribution? a. Yes b. no
7. If your answer for question 6 is yes, do you think this will have negative impact on tree planting activity on your farm? a. yes b. no
8. if you said yes in Q 7, please explain the reason____________________________
9. Number of animals: cows _____, oxen _______,sheep ______, goats _______, horses ______, mule ______, donkey _________ others ,specify ________________
10. Do you participate in additional income generating off farm activities?
    a. Yes b. No
11. If your answer for Q 10 is yes, would you please specify on what type of activities you are participating? _________________________________

12. Sources of energy for cooking and heating

sources	Amount used for cooking and heating for the year 2012/2013	Estimated mass in k	remarks
Natural forest/ shrub in the surrounding (in bundles)			
Animal dung (basket)			
Crop resides (bundles)			
Own trees planted on farm (bundles)			
Others			

13. How far your house is from the natural forest (km)? ____________
14. How many hours do you need to collect a bundle of fuelwood from the natural forest/shrub area? _________
15. Who is responsible for fuelwood collection among family members?
    a. mostly female children
    b. mostly male children
    c. the mother
    d. the father
    e. others, specify ____
    f. all have equal responsibilities
16. If you are using your own sources, how many hours you need to prepare a bundle of fuelwood? ________
17. Sources of construction wood: write the most used sources for construction material in different times.

Source of construction wood	Estimated number of poles and small poles		Duration of the house constructed without maintenance	Remarks
	Before 20 years ago	Within the last 20 years		
Natural forest in the area				
Own woodlots				
Gifts from relatives				
Buy from markets				
others				

18. Type and number of houses:

Iron-roofed number _______ size______, _______, _______

Thatched-roofed number _______Size ______, ______, ______

III. Deforestation, soil fertility and AFPs

1. Do you think that the forest cover in the watershed was changing over time? a. Yes b. no
2. If your answer for Q1 is yes, in what way?
   a. decreasing in time b. Increasing in time c. I have not realized the change
3. If you said decreasing in time, what are the possible causes for the decrease? Please list them
   ____
4. Please list the possible consequences of deforestation which you observe in your area
   ____
5. What possible measures should be taken to minimize deforestation problems in the area? Please list them.____
6. If you said increasing for Q 2, please specify the possible reason for this.
   ____
7. How do you judge the productivity of your farm plot through time?
   a. Increasing
   b. Decreasing
   c. I do not realize
8. If your answer for Q 7 is decreasing, what would be the most possible reason?
   a. Decline in soil fertility
   b. Climatic variability
   c. A reduction in fertilizer use
   d. Reducing fallowing period
   e. Others, specify _______________________________________
9. If your answer for Q 7 is increasing, please specify your suggested reason for the increase____
10. List other types of soil fertility management activities you are using on your farm plots
    ____
11. Which types of AFPs you are widely using on your farm plots?
    a. Tree on farms
    b. homegardens
    c. trees on boundaries
    d. small-scale woodlots
    e. alley cropping
    f. None of these
    g. others (list them)_________________________
12. Who introduce these practices to you?
    a. My own trial
    b. Extension works
    c. Inherited from my family
    d. Others Specify___________________________
13. Do you think that trees on the farmland can improve the fertility of the soil?
    a. Yes, all trees b. No c. yes, but not all trees d. I do not realize
14. If your answer for Q13 is yes, but not all trees (c), please list those trees you know which are preferred and not preferred for soil fertility improvement

Preferred   not preferred

---------------------------------------   ---------------------------------------

---------------------------------------   --

15. Farm plots, tree planting and soil fertility status

Plot	Area in *Timad*	Years owned	Distance from home (km)	Number of trees/shrub planted	Number of trees/shrubs naturally exist	soil fertility status (1...4)[a]	Slope (1..4)[b]	Remark
1								
2								
3								
4								
5								

[a] *1-very fertile 2-fertile 3 moderate 4-Infertile ;* [b] *1-Very steep 2-Steep 3-moderate 4-gentle*

16. Do you have fruit trees and vegetables in your homegarden?
   a. Yes   b. No
17. If yes for Q 16, please specify the type of fruits and vegetables you have in your garden
   ____
18. If yes for Q 16, for what purpose you are using the fruits and vegetables?
   a. for household consumption b. additional income generation c. for both d. Others, specify___________

19. Estimated amount of money from the sale of fruit in the year 2012/2013 (ETB)?
   ____
20. If your answer is no for Q19, would you please specify your reason?
   ____
21. Who is mostly taking care of the home garden fruits and other plants (such as weeding, pruning, collecting etc. activities) in your family? a. husband b. wife
   c. children d. we all equally
22. List other tree/shrub plant species you are using for additional income generation.____
23. What are the major problems you are facing to plant trees on your farm? List them in order of the severity of the problem?
   ____
   ____
   ____
24. Please point out your suggested solutions to these problems in improving tree planting activities on your farm. ____

9. Table of Abbreviations

ACR	Alley cropping between rows
ACS	Alley cropping within the rows of shrubs
ADO	Agriculture Development Office
AFPs	Agroforestry Practices
AGB	Aboveground biomass
AGBC	Aboveground biomass Change
ANRS	Amhara National Regional State
Ava P	Available Phosphorus
CMF	*Croton macrostachyus* on farmlands
CSA	Central Statistical Authority
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
FEPA	Federal Environment Protection Authority
GCPs	Ground Control Points
GPS	Global Positioning System
HEED	Hulet Eju Enessie District
IPCC	Intergovernmental Panel on Climate Change
HG	Homegarden
LUCT	Land use/cover type
LUT	Land use type
MEA	Millennium Ecosystem Assessment
MOA	Ministry of Agriculture
RSII	Relative Soil Improvement Index
SCC	Single cereal cropland
SD	Standard Deviation
SE	Standard Error
SLUF	Sustainable Land Use Forum
TLU	Tropical Livestock Unit
WCMC	World Conservation Monitoring Centre

Curriculum vitae

Personal data	
Name	Meseret Kassie Desta
Date of Birth	20.01.1981
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University	University of Natural Resources and Life Sciences (BOKU), Vienna, Austria
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