Jimma University

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Woody Species Diversity and Aboveground Live Carbon Storage in Agroforestry Systems of Sokoru District, Jimma Zone, Southwest Ethiopia

By

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A Research Paper Submitted to Department of Biology, College of Natural Sciences, Jimma University, in Partial Fulfillment of the Requirement for the Degree of Master of Biology in Botanical Sciences

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Acronyms

TRW = tree ring width

IPCC = Intergovernmental Panel on Climate Change

Pg = petagram = 10^{15} g = 1 billion metric tones

tC ha^{-1} = Carbon amount per hectareper unit of time

GHG = Green House Gas

C ha^{-1} yr^{-1} = Carbon produced by hectare per year

Mg C ha^{-1} yr^{-1} = megagram of Carbon produced by hectare per year

IGFRI = Indian Grassland and Fodder Research Institute

FAO = Food, and Agriculture Organization

ICRAF = International Center for Research in Agroforestry

MoME = Ministry of Mines and Energy

CSA = Central Statistics Agency

GLC = Global Land Cover

WB = World Bank

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Abstract

There is a growing interest in the role of different types of land use systems in stabilizing the atmospheric CO_2 concentration, reducing the CO_2 emissions and on increasing the carbon sink of forestry and agroforestry systems. Agroforestry has potential to mitigate climate change and help farmers to adapt the impacts of climate change. Different types of agroforestry systems such as homegarden, cropland and pastureland have great role in storing carbon and stabilizing the climate change by absorbing CO_2 from the atmosphere. The main objective of this study was to investigate woody species diversity and aboveground live carbon storage in Sokoru *District, Jimma Zone. The study was conducted from February to May, 2018. Descriptive statistics and one way ANOVA were used to analyze the population density, above ground live biomass, carbon storage, tree height and diameter at breast height and basal area for each tree was calculated. Aboveground live biomass of each tree was determined by using the revised non destructive equation. The amount of carbon stored in each tree was estimated at 50% of the aboveground live biomass hence 5.54 t, and in homegarden, 9 t in cropland and 3.47 t pastureland carbon was stored. The result of the study showed that woody species diversity were higher in homegarden (2.79) followed by pastureland(2.77) and cropland (2.1).Moreover, the higher similarity in woody species composition were found between homegarden and cropland(65.7%)whereas homegarden and pastureland showed higher difference with similarity of 38.8%..From three land use types the highest amount of carbon was stored in cropland followed by homegarden and pastureland. Eventually, the study revealed that the woody species found in different agroforestry system of the study area have great role in carbon storage and CO_2 sequestration. Thus all stakeholders should focus on conservation of trees and shrubs found agricultural landscapes.*

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Key words: agro-forestry, land use types, carbon storage, woody species, homegarden, cropland, pastureland and carbon storage

1. Introduction

Global emissions of carbon dioxide to atmosphere have been increasing for about 140 years since the beginning of the industrial revolution (Odum, 1994). Concentration of carbon dioxide in the atmosphere has increased and approached 360ppm by the end of year 2000. It is estimated that the future doubling of CO_2 in atmosphere to about 700ppm will risk an accompanying greenhouse effect rise of 1.5 – 4.0^{o}Cin mean global surface temperature (Scott *et al.,* 1999).

The woodlands of Africa cover about 54% of the continent and support some 64% of its population (CIFOR, 2011). At this time, these woodlands are under serious threats mostly by human activities (Poorter *et al*., 2004) and the impact of climate change (Unmubig and Cramer, 2008). In face of this significant concern, the main concrete solution suggested were forest plantation (Brockerhoff *et al.,* 2008), the effectiveness of protected sites in biodiversity conservation.

As forests are converted to agricultural fields and urban areas, the amount of carbon dioxide in the atmosphere become increased. The concentration of carbon dioxide is increasing and a trend believed to impact the earth's climate (Houghton, 1999). It is thought that land use change is responsible for 20-30% of the net increase of carbon emission (Bach, 1998).

Agroforestry systems are amongst the most important processes that determine the terrestrial ecosystem carbon balance ((Bouriaud *et al*., 2004). The magnitude and dynamics of the forest carbon sink depend on carbon allocation to many storage pools (Litton *et al.*, 2007). Agroforestry systems play an important role in various goods and services including enhancement of carbon storage and organic matter conservation of above and below ground biodiversity and improvement of soil fertility and structure (Sanchez *et al.,* 1997).

Silvopastoral systems have been promoted as new technologies to increase productivity and environmental services (Gobbi and Ibrahim, 2004). Most farmers permit natural regeneration of woody species in pastures because it is a cost effective way to introduce woody species into the grassland dominated landscape (Kuptz *et al*., 2011).

Agroforestry has played an important role in increasing land productivity and enhancing livelihoods in developed and developing countries(Schroth *et al*., 2004). Although carbon sequestration and afforestation and reforestation of degraded natural resource have long been considered significant in climate change mitigation, agroforestry offers distinct advantages (Dawson *et al*., 2009). The planting of trees along with crops on cropland improves soil fertility, controls and prevents soil erosion, controls water logging, checks acidification and eutrophication of streams and rivers enhances local biodiversity by decreasing pressure on forests for fuel and provides fodder for livestock (Makundi and Sathaye, 2004).

The geographical location of Ethiopia covers wide agro-climatic zones and very significant biodiversity (Dawson *et al*., 2009). This wide geographical condition of Ethiopia has created diverse and convenience environments for the survival and development of a variety of flora (Dawson *et al*., 2009). There are about 6000 species of higher plant taxa in Ethiopia, of which about 10% are endemic (Ensermu Kelbessa and Sebsebe Demisew, 2014).

Agroforestry is dynamic and involves the integration of trees on farms (Makundi and Sathaye, 2004). Agroforestry diversifies and sustains production for increased social, economic and environmental benefits for land users (ICRAF, 2002). There are several types of traditional agroforestry practices in Ethiopia. They include coffee shade tree systems, scattered trees on farmland, homegardens, woodlots, farm boundary practices and trees on grazing lands (Zemede Asfaw, 2003). In addition to support native species plants and animals, agroforestry areas contribute to the conservation of biodiversity by increasing the connections of populations, communities, and fragmented landscapes (Havey and Haber, 1998). Agroforestry systems can serve as *in-situ* conservation areas for many woody species like *Eucalyptus camaldulensis, Mangifera indica and Malus pumila* that farmers value and wish to conserve(Dawson *et al*., 2013).

Homegarden is among the agroforestry systems with a potential to harbor biodiversity(Schroth *et al*., 2004). Homegarden agroforestry in Ethiopian highlands consist higher woody species diversity than other nearby woodlands. This high woody species diversity ecosystem provides significant services such as nutrient recycling, soil and water conservation, and minimizes environmental deterioration (Tolera Motuma*et al*., 2008).

Agriculture is the main backbone of the economy and also is the major occupation of Ethiopian population (MoMe, 2003). The increment of population growth has changed the land cover systems and caused environmental degradation in many developing countries including Ethiopia (Feoli *et al.,* 2002). Cropland agroforestry is the integration of trees on farms that diversifies agricultural landscapes and sustains production for improved social, economic and environmental benefits (ICRAF, 2002). Agroforestry systems bring about changes in edaphic, microclimatic, floral, faunal, and other components of the ecosystem through biorecycling of mineral elements, environmental modifications, and changes in floral and faunal composition (Shukla, 2009).

1.2 Statement of the problem

Although the possible benefits of agroforestry in carbon sequestration have been conceptually discussed and field measurements to validate these concepts have been undertaken to significant extent, there is no any report on the potential of agroforestry in carbon storage from Sokoru district. Therefore; this study was designed to fill this knowledge gap.

Research questions

1. Which agroforestry system has more woody species diversity?
2. How much carbon is stored in aboveground live woody species biomass in Agroforestry systems of Sokoru district?
3. Which agroforestry system stores more carbon in aboveground live biomass?

1.3 Objective of the study

1.3 .1 General objective

To investigate woody species diversity and aboveground live carbon storage in different agroforestry systems of Sokoru district, Jimma Zone, Southwest Ethiopia.

1.3.2 Specific objectives

- To assess woody species diversity in homegarden, cropland and pastureland agroforestry systems of the study area;
- To estimate aboveground live carbon storage in agro-ecosystems of Sokoru District; and
- To assess the variation in carbon storage among the three land use types such as homegarden, cropland and pastureland agroforestry systems in Sokoru District..

1.4 Significance of the study

The outcome of this study could be used to show the variation among different land uses in aboveground live carbon storage. The result might also be used as a spring board for other researchers in the area of agroforestry and carbon storage.

2. Review of related literature

2.1 Ways in which woody species can store carbon

Carbon is stored in pools of aboveground biomass like timber, branches and belowground biomass like roots, soil microorganisms and organic carbon in soil (Thomson, 2007). Trees have greater capacity to store carbon than annual crops and grasses on pastures. Agroforestry systems, therefore present better option for carbon sequestration (Kirby and Potvin, 2007**)**.

2.2 Measurement of Carbon dioxide in the atmosphere

Since pioneer measurements of turbulent fluxes over tall vegetation, eddy-covariance (EC) has been widely used as a standard method for the estimation of seasonal fluctuations in carbon exchange between forest ecosystems and the atmosphere (Baldocchi, 2003). In conjunction with forest inventories (Etzold *et al*., 2011), data have greatly improved the understanding of the terrestrial carbon budget and its climate sensitivity at local to global scales (Baldocchi, 2003; Reichstein *et al*., 2007).

Flux towers, however, essentially provide integral measurements above the canopy and leave uncertainties concerning the magnitude and inter-annual variability of carbon allocation within the respective ecosystems. Furthermore, the fraction of CO_2 entering different long-term storage pools is challenging to quantify (Litton *et al*., 2007; Luyssaert *et al*., 2007) and may not be constant in time (Campioli *et al*., 2011) or across ecosystems.

There is a growing interest of different types of land use systems in sequestering the atmospheric CO_2 concentration or on increasing the carbon sink of forestry and agroforestry systems. Agro-forestry has been recognized as a means to reduce CO_2 emissions as well as enhancing carbon sinks. The role agroforestry in carbon cycles is well recognized and forests are large sinks of carbon (Brown, 1996). There is considerable interest to increase the carbon storage capacity of agroforestry land-use practices such as afforestation, reforestation, and natural regeneration of forests, silvicultural systems and agro forestry (Garrity, 2004).

Agroforestry systems are very important, the number of people who depend on land for their livelihoods, and the need for integrating food production with environmental services (Soto-

Pinto *et al.,* 2001). In addition to existing indigenous agroforestry systems, improved practices and technologies are now being expanded into dry regions for perceived benefits such as arresting desertification, decreasing water and wind erosion hazards, and improving biodiversity (Gordon *et al*., 2003).

Forests occupy one third of the world's land area and control the carbon transfers and influence nitrogen content in the atmosphere through photosynthesis, respiration, and specific organic matter turnover, with representing important Carbon and Nitrogen pools (Brown and Lugo, 1990). Forest ecosystems can store more than 80% of all terrestrial aboveground live carbon and over 70% of all soil organic carbon (SOC) (Six *et al.,* 2002). Land use change causes disturbance of the ecosystems and can influence the carbon and nitrogen stocks and fluxes (Brown, 1996).

Agroforestry systems of different land use types make an important contribution to climate change mitigation, but are not systematically accounted for in either global carbon budgets or national carbon accounting (Kauppi *et al.,* 1996). The remote sensing data show that in 2010, 43% of all agricultural land globally had at least 10% tree cover and that this has increased by 2% over the previous ten years. Combining geographically and bio climatically stratified Intergovernmental Panel on Climate Change (IPCC) default estimates of carbon storage with agroforestry cover analysis, 45.3 Pg C on agricultural land has been estimated globally, with agroforestry trees contributing >75% (Nair, 2012). Between 2000 and 2010 agroforestry increased by 3.7%, resulting in an increase of >2 Pg C (or 4.6%) of biomass carbon. On average, globally, the biomass carbon stored increased from 20.4 to 21.4 $tCha^{-1}$. Regional and country-level variation in stocks and trends were mapped and tabulated globally, and for all countries. Brazil, Indonesia, China and India had the largest increases in biomass carbon stored on agroforestry, while Argentina, Myanmar, and Sierra Leone had the largest decreases (Foley, 2005).

Agro-forestry- a diversified set of agricultural production systems that integrate trees in the agricultural landscape is discussed as a strategy that can be used for mitigation (IPCC, 2014). It is extensively practiced throughout tropical and developing countries, with an estimated 1.2 billion people around the world dependent upon agro-forestry systems (WB, 2004). While the significance of biomass carbon in agro-forestry is widely recognized (Houghton, 2005) the biomass carbon pool in agricultural land is seen as arguably negligible compared to the soil organic carbon (SOC) pool (Lal, 2004). However, given the vast scale of available agricultural land, estimates of tree cover on agricultural land globally, and the role of woody biomass in the global carbon pool and agroforestry can significantly contribute to global carbon budgets (Nair, 2012).

Carbon sequestration with best reliable and mass scale option is the need of today to doge the GHG emission (Ahmed and Hazarika, 2007). Different biological systems from aquatic to terrestrial are found to be potential with mass adoption lies in forestry and agro forestry. The potential of agro forestry to mitigate climate change and help farmers to adapt the impacts of climate change are a strong driving force behind India's new agro forestry policy (Albrecht and Kandji, 2003).

Climate change has increasingly gained the momentum as a major threat against the survival of biotic environment. To balance the atmospheric carbon and their storage in the terrestrial agroforestry is a vital way to compensate the emission of green house gases. Agro forestry systems have higher potential to sequester carbon than pastures (Sanchez, 2000; Kirby and Potvin, 2007). Global warming is mainly the result of CO_2 rising in the Earth’s atmosphere and we have a few years, not decades, to stabilize CO_2 and other greenhouse gases as the present global atmospheric CO_2 level has already touched 406.81ppm in June, 2016 (https://www.co2.earth). Therefore to sequester the increasing amount of CO_2, agroforestry can play a pivotal role. Agroforestry is known to have the potential to sequester high amount of CO_2.

Avery significant proportion of carbon in the form of above and below ground biomass, thus agro forestry systems play a vital role in regulating carbon cycle to meet out the challenges of climate change. The estimates of carbon sequestration potential in agro forestry systems are highly variable, ranging from 0.29 to 15.21 t C/ha/y (Nair *et al.*, 2009).

According to Brown and Lugo (1982), 50% of dry biomass of plants is estimated to be carbon. It is also observed that if agro forestry practices include fertilizer to maximize crop production then that can easily increase carbon sequestration of many woody species such as *Ficus sur* and *Eucalyptus camaldulensis* (Koskela *et al*, 2000). In an agro forestry study by

Sharma (1995, 2003) in Sikkim found that cardamom based agro forestry system with different tree species like *Albizia-cardamom*, *Alnus-cardamom*, forest-cardamom and integrated crops restore the carbon. In this manner agro-forestry provides environmental services like biodiversity conservation, fertility of the soil, temperature regulation, carbon storage, soil moisture conservation, maintenance of water quality-quantity and consequently restores the environment. Shamsudheen *et al.* (2014) reviewed that silvipastoral system sequestered 36.3% to 60.0% more total soil.

However, agroforestry systems play significant role in forming active carbon pool accounting about 60% of terrestrial aboveground carbon storage (Wilson and Daff, 2003). Long rotation systems such as agroforestry and homegardens can sequester significant amount of carbon in the wood. Newaj and Shabir (2009) also reviewed the carbon sequestration potential in different land uses with special reference to agro forestry.

Global carbon, water and nutrient cycles have been profoundly impacted by the historical and ongoing increment of agricultural production as international level (Johnson, 2014). Both land use change to agriculture and agricultural production have contributed significantly to the impacts of global warming (IAASTD, 2008).

Tree cover on agricultural land has the potential in climate change mitigation (Albrecht and Kandji, 2003). The global role of agroforestry-based carbon sequestration on agricultural land is thus far poorly understood and possibly has been significantly underestimated. Agricultural production and ongoing land use change contribute significantly to greenhouse gas emissions, accounting for 24% globally.

2.3 Biomass carbon on agricultural land globally

Overall, the amount of area classed as agricultural is approximately 22.2 million km^2 (GLC, 2000). Using the IPCC Tier 1 default value, the world stores an estimated 11.1 Pg C in above- and below-ground biomass carbon in agro-forestry. However, in 2000 >40% of this area had ≥10% woody species cover, corresponding to the FAO definition of forest. Combining the IPCC Tier 1 values with estimates of carbon storage in the hitherto ignored tree component, we produce a revised estimate of 45.3 Pg C (with trees contributing >75% (34.2 Pg C)) to this global total. Between 2000 and 2010 there was an increment of 2% tree cover, resulting in an increase of >2 Pg C (or 4.6%) biomass carbon (Bartholomé and Belward, 2005).

2.4 Carbon sequestration potential of agroforestry systems

Agroforestry, the practice of introducing trees and shrubs in farming has played an important role in increasing land productivity and improving livelihoods in many countries. Although carbon sequestration through agroforestry has long been considered useful in climate change mitigation, agroforestry offers some distinct advantages. The planting of trees along with crops improves soil fertility, controls and prevents soil erosion, controls water logging, checks acidification and eutrophication of streams and rivers, increases local biodiversity, decreases pressure on natural forests for fuel and provides fodder for livestock (Makundi and Sathaye, 2004).

Lal (2004) estimation of the potential of agroforestry in sequestering carbon wasbetween 0.05 – 0.3 Mg C ha^{-1} yr^{-1}. The estimate, however, included a variety of uncertainties related to future shifts in global climate, land-use and land cover, as well as poor performance of trees and crops on poor soils in the region.

2.4.1 Conversion and estimation

For aboveground biomass, trees are divided by compartments: leaves, branches and trunks, and measured in dry weight (Albrecht and Kandji, 2003). Each compartment has unique carbon content and decomposition rate. Although this is the most accurate method, these inventories are often too time-consuming and costly (Schroeder, 1993). Alternatively, biomass expansion factors or allometric biomass equations are often used, because they require only stem wood information such as diameter at breast height (DBH). These equations exist for practically all forests types of the world, especially in the temperate zone (Sharrow and Ismail, 2003).

2.4.2 Estimating biomass production

Allometric equations are the most commonly used methods in estimating biomass production by trees in agroforestry systems. However, they are often derived from forest grown trees that are different in their growth form from those open-grown trees in agroforestry. This can introduce errors in estimating not only biomass production potential, but also carbon sequestration. It is imperative that species specific allometric equations for different agroforestry practices must be developed in order to overcome this serious weakness in agroforestry research (Nair *et al*., 2010).

Jamal *et al*. (2006) conducted a study in Florida, USA, to develop biomass equations for cadaghi (*Corymbia torelliana*) trees in various aged windbreaks. Trees were destructively sampled based on diameter at breast height and grown biomass was estimated using randomized branch sampling (RBS) while trunk biomass was measured by taking disks every 1.5 m along the stem. Separate nonlinear equations were developed for crown, trunk and whole tree biomass estimation using DBH and height. The study found that DBH alone was sufficient to predict aboveground live biomass while the inclusion of height provided more accurate results. Using their equation the authors recorded a total biomass per 100 m windbreak length to be between 166 and 26,605 kg. Kumar *et al*. (1994) on the other hand, developed new allometric equations using remotely sensed crown area and/or tree height as predictor of aboveground biomass. These equations corresponded well with the data obtained from destructive sampling with about 85 % of the observed variation in aboveground biomass explained by crown area. Addition of height and wood density as second predictor variables improved model fit by 6 and 2 % and lowered the relative error by 7 and 2 %, respectively. Total estimated aboveground biomass carbon was measured at 20.8 t C/ha, which was about 19 % more than the amount estimated using DBH as predictor. These results confirm that the new allometric equations using crown area could be a better predictor of aboveground biomass and can be used as an important tool for predicting carbon stock in such like systems.

2.5 Woodlands of Ethiopia

Woodlands globally constitute about 41% of the landmass (Safriel and Adeel, 2005). Their Proportion out of the landmass of Ethiopia is estimated to be around 70% (Yeo, 2014). In the Central Rift Valley within the East Shewa Zone, the natural vegetation is mainly made up of *Acacia*-dominated woodland, a highly fragile ecosystem adapted to semi-arid conditions with erratic rainfall, growing on a complex and vulnerable hydrological system (Hengsdijk and Jansen, 2006). As it stands, most of the farmlands in the landscape have some level of remnant and naturally regenerating trees, and the landscape may be considered as a mix of homestead and parkland agroforestry system. Important crops such as teff, wheat and maize are produced, and livestock freely roam and graze during the dry season

2.6 Types of agroforestry and their role in carbon sequestration

2.6.1 The role of homegarden trees in carbon storage

All of the technically suitable land areas for forestation cannot be devoted to plantation forestry because they are agricultural lands that support local populations. A more appropriate land use system could be agroforestry, specially, growing trees in conjunction with agricultural crops and pastures. Agroforestry systems in Sri Lanka provide corridors that join distant reserves through the matrix effect on species diversity in landscape mosaics with native tree cover and through the persistence and movement of species across land use type. Agroforestry in the rural area contributes to environmental sustainability and benefits climate change adaptation by storing carbon, halting land degradation, and fixing nitrogen. Homegardens, which are widespread and vary in species composition and tree density, are the best developed agroforestry systems in Sri Lanka. Homegarden agroforestry systems cover 22% of the land area and are considered forest analogues that supply more than 70% of the timber and 80% of the fuel wood outside natural and planted forests in Sri Lanka. Homegardens in Sri Lanka offer great potential for restoring and increasing forest cover and connectivity (Jamal *et al.*, 2006).

Different forms of agroforestry, homegardens and boundary plantings have been well recognized as potential longrotation systems that mitigate CO_2 and sequester sizeable quantities of carbon in plant biomass (Albrecht and Kandji, 2003). Homegardens contain a significant fraction of the total aboveground biomass carbon stock in the terrestrial system, and this was increased from almost one-sixth in 1992 to nearly one-fifth in 2010. Homegardens store significant amount of carbon, with aboveground biomass carbon stocks with a mean value of 35 $MgCha^{-1}$ in dry zone while 87 $MgCha^{-1}$ in wet zone in the terrestrial system in Sri Lanka (Mattsson *et al.*, 2013).

2.6.2 The role of Pasture land trees in carbon storage

A functional relationship of either form between diversity and carbon storage and sequestration could have significance implications for the management of carbon-sink projects. In the former case, the relationship of tree species diversity to carbon sequestration is the greatest concern for managers interested in sequestering the maximum amount of carbon over the short term, though in some cases long term carbon storage may also be of concern. In the later case, understanding the relationship of tree species diversity to carbon storage will be critical to maintaining carbon stocks of protected forests over the long term (Albrecht and Kandji, 2003).

Silvopastoral systems have been promoted as win technologies to increase productivity and provide environmental services (Gobbi and Ibrahim, 2004). Most farmers allow natural regeneration of trees in pastures because it is a cost effective way to introduce trees into the grassland dominated landscape. There is however, a tendency to replace traditional pastures with more aggressive and drought tolerant grass species (Esquivel *et al.*, 2003).

In addition to the agricultural production issues arising from combining trees and pastures, over the past decade or so there has been enhancing the interest in the role of agroforestry, including silvopastoral systems, as a means of sequestering atmospheric carbon to mitigate the effects of greenhouse gas (Albrecht and Kandji, 2003; Montagnini and Nair, 2004; Oelbermann *et al*., 2004). The advantage of agroforestry systems compared to forests is that the land can remain in agricultural use whilst sustaining a greater phytomass than pastoral system. Many Previous literatures suggest tree on pasture land have high potential for carbon sequestration (Veldkamp, 1994).

2.6.3 Cropland agroforestry

Agroforestry is a treebased activity there by requiring forestry knowledge, it does not qualify as ‘‘forest’’ by definition of size (Perry *et al*., 2008). On the other hand, even though these tree-based practices leave the land in agricultural land use, those managing these lands for agriculture will not likely be looking to agroforestry land use activities to glean their ‘‘agricultural’’ opportunities. There are agroforestry practices that integrate with the tree/crop component throughout the whole farm, like silvopasture and alley cropping, which, despite their excellent carbon sequestering/production capabilities may not be picked up by either group (Nair and Nair, 2003).

2.7 The major benefits of maintaining agroforestry systems

2.7.1 Improved soil fertility

Enhancing and maintaining soil fertility is very important for food security, reducing poverty, preserving environment and for sustainability. Agroforestry land use systems like agrohorticulture, agro-pastoral system, agri-silvipastoral system, etc., are efficient methods of restoring soil organic matter. Studies have also shown that yield is higher with improved crop rotation than with continuous cropping (Jama *et al.*, 2006). The leaf litter from agroforestry practices, forms humus after decomposition and improves various soil properties. Agroforestry can control runoff and soil erosion, thereby reducing losses of water, soil material, organic matter and nutrients. It can check development of soil toxicities, both soil acidification and salinization and trees can be employed in the reclamation of polluted soils (ICAR, 2006).

2.7.2 Increased income

The diverse component of agroforestry system in different land use type provides multiple harvests at different times of the year. It increases food production, improves supply of fodder for fish and livestock, improves soil fertility and water supply, increases supply of fuel wood and habitats. Thus it reduces the risk of crop failure and ensures alternate income for the farmers (Pandey, 2007).

2.7.3 Increased carbon stock

Agroforestry has a huge potential as mitigation strategy to climate change because of its potential to sequester carbon in its many plant species and soil. The average carbon sequestered by these practices has been estimated to be 9, 21, 50, and 63 MgCha-1 in semiarid, sub-humid, humid, and temperate regions. In tropics, for small agroforestry systems, it has been found to be ranging from 1.5 to 3.5MgCha^{-1}yr^{-1} and thus can be a viable strategy for carbon storage. In degraded soils of the sub-humid tropics, agroforestry practices have been found to increase top soil carbon stocks up to to1.6 MgCha^{-1}yr^{-1} (Mutuo *et al.*, 2005). Thus, proper designing and managing of agroforests can make them effective carbon sinks.

2.7.4 Reduced vulnerability

Agro forestry enhances the resilience of farming systems by buffering against various risks, both biophysically (hydraulic lift, soil fertility) and financially (diversification, income risk).

Other advantages of agroforestry include reducing seasonal labor peaks, earn income throughout the year and ensure benefits over the short, medium and long term ((Roshetko *et al.*, 2007).

2.7.5 Increased productivity

Studies show that forest influenced soils give higher yields than ordinary soils. Taungya cultivators got higher yields than from pure agriculture in Tarai region of Uttar Pradesh. IGFRI, Jhansi conducted experiments that indicated increased yield of fodder when fodder grasses were intercropped with fodder trees as compared to mono cropping of fodder grass. In South India, and states like Punjab, Haryana, Uttar Pradesh and Gujarat, intercropping agroforestry food crops was found to be more productive (Garrity, 2004).

2.7.6 Aesthetic value

Agroforestry can create a healthy environment-interaction to living things. Agroforestry practices may use only 5% of the farming land area, yet account for over 50% of the biodiversity, improving wildlife habitat and harboring birds and beneficial insects which feed on crop pests. Tree biodiversity adds variety to the landscape and improves aesthetics (Droppelmann *et al.*, 2000).

2.7.7 Wind break

Windbreaks are plantings of single or multiple rows of trees, shrubs or grass that protect crops, livestock, wildlife or people from wind's harmful consequences (Mattsson *et al.*, 2013).

3. Methods and Materials

3.1 The study area and period

This study was conducted in Sokoru district of Jimma Zone from February – May, 2018. Sokoru district is found in Oromia Regional State, Jimma Zone (Figure1) at about100 km East of Jimma town and 156 km southwest of Addis Ababa. The altitude of the district lies in the range of 900-2,300 m above sea level. The district is located between 7° 55' -7°.92' N latitude and 37° 25' -37°.42' E longitude(CSA, 2010).

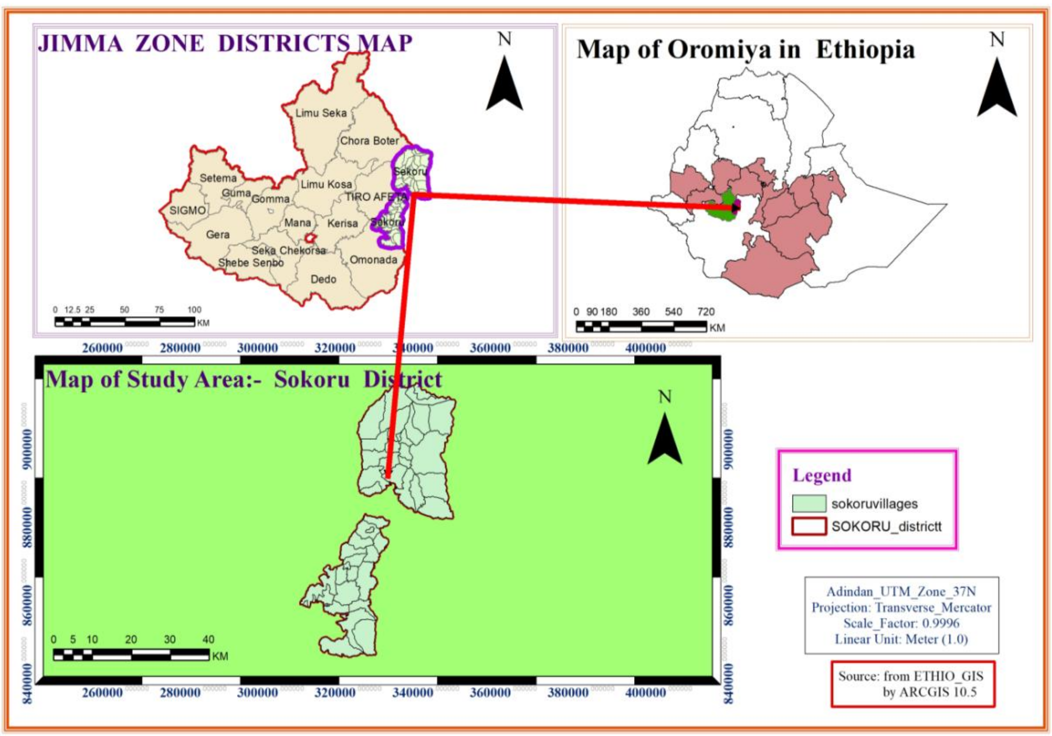

Figure 1:Location map of the study area (Source: from ETHIO-GIS)

3.2 Population and their Religion

A total population of Sokoru district up to 2016 was 136,320 (male = 68,469; female = 67,851). Of the total population, 12,724 or 9.33% were urban dwellers. The majority of inhabitants were Muslim (91.63%), while 6.99% of the populations are followers of Ethiopian Orthodox Christianity, and 1.19% was Protestant (CSA, 2010).

3.3 Climate and agro-economy of the study area

Maximum and minimum temperature of the district was 28.3 ºC and 12.1ºC respectively while the average annual rainfall was 1, 458 mm. The current crops grown in the area include maize, sorghum, teff, sesame (selit), nug (niger seed), fruit crops like mango, orange, papaya, avocado, apple and the main cash crop is coffee. Among the animals: cattle, sheep, goat, mule, horse, donkey, chickens are common. There is also beekeeping activities in the area using modern and traditional beehives. In addition, there were also vegetables grown in different kebeles like green peppers, potatoes, tomatoes, sweet potatoes, yam, beet roots, and carrots (CSA, 2010).

3.4Methods

3.4.1. Sampling design

A transect line of 24 km long with 2 km buffer (1km on the left and 1km on the right of the transect) was established across different land use types (homegarden, pasture and cropland). The elevation of the study area ranges from 1679 – 1934 m above sea level. Of 42 total sample plots, 14 sample plots of 100 m × 100 m were established in cropland and 14 sample plots of 100 m × 100 m were established in cropland while 14 plots of 20 m × 20 m were put in the homegardens (the homegarden was standardized to hectare for later comparison with the two land use types).

3.4.2 Data collection

Stem count of woody species in pasture and cropland has been taken from each one hectare plot (100 m × 100 m) whereas the stem count from homegarden agroforestry was taken from 20 m × 20 m plot (this was later converted to hectare in order to compare with cropland and pastureland). The circumference of each stem with diameter at breast height (DBH) ≥ 5cm, height ≥ 1.3 m was recorded from each plot (Mac, 1997).The height of all individuals was also recorded using Clinometers. For the stem abnormalities, RAINFOR protocol was followed (Phillips *et al*., 2009). All woody species (trees and shrubs) were recorded from all plots. Latitude, longitude and altitude of the study site were recorded by using Global Positioning System (GPS). Samples of woody species (including their local names) were recorded. All woody specific gravity of each tree species was taken from global wood density data base developed by Chave *et al*. (2009). The samples were transported to Jimma University herbarium for identification. Flora of Ethiopia and Eritrea were used for the identification of species in the herbarium.

3.5 Data analysis

3.5.1 Density

The density of woody species was one of the most important structural parameters considered during data analysis. The density per hectare of trees and shrubs were calculated by summing up all stems across all sample plots and converted into hectare.

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Sampled area in hectare}}$$

$$\text{Relative Density} = \frac{\text{Number of individuals of species}}{\text{Total number of all individuals}} \text{ x } 100$$

3.5.2 Basal area

Basal area of the woody species in the three land use types was calculated on Microsoft office excel 2007 using the following equation

$$BA = \pi\left(\frac{D}{2}\right)^2$$

Where, BA = basal area

D = diameter at breast height

3.5.3 Frequency

The number of plots in which a given species found in the study area is referred to as frequency. Relative frequency for each woody species was taken using the following formula.

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a woody species}}{\text{Frequency of all woody species}} \text{ X } 100$$

3.5.4 Species diversity

Woody species diversity of the study site was calculated using Shannon-Wiener diversity Index

$$H' = -\sum_{i=1}^{S} Pi \ln Pi$$

Where, Pi is the proportion of individuals found in the i^{th} species and ln is the natural logarithm.

3.5.5 Shannon's Equitability (E)

Evenness was calculated the ratio of observed diversity to the maximum diversity using the following equation.

E = H'/H'max, H'max = lnS

Where, H' = Shannon-Wiener diversity Index

S = total number of species in the sample

ln = natural logarithm

3.5.6 Similarity in species composition

Similarity among the three land use types in woody species composition was calculated by using Sorenson's similarity index.

$$SSI = \frac{2a}{2a + b + c}$$

Where, a = number of common species

b = number of species unique to the first site

c = number of species unique to the second site

3.5.7 Carbon storage

Aboveground live biomass of each tree was calculated by using the revised non destructive allometric equation (Chave *et al*., 2014).

$$AGB = 0.0673(\rho D^2 H)^{0.976}$$

Where, ρ = wood specific gravity, D = diameter at breast height, H = height. The amount of carbon stored in aboveground live biomass of each woody species was estimated at 50% of the aboveground live biomass (AGB). The amount of CO_2 sequestered by the tree was calculated by multiplying the amount of carbon in the biomass by 3.67 (which is the ratio of the atomic mass of CO_2 (44.01) to the atomic mass of carbon (12)) (Chave *et al*., 2014).

Analysis of Variance (one way ANOVA) of SPSS version 20 was used to determine the variation among different agroforestry systems in carbon storage and woody species density. The data were log transformed as to maintain the normal distribution.

4. Results and Discussions

4.1 Results

4.1.1 Woody species richness, evenness and diversity

Woody species richness

Overall, 58 woody species belonging to 52 genera and 35 families were recorded from the three agroforestry systems along the study transect, of which 14 (ca. 24%) were shrubs and 44 (ca. 76%) were trees. Of the woody species families recorded in the study area, Fabaceae was the most species rich family with 6 (10.34%) species followed by Euphorbiaceae 5 (8.6%) and Rutaceae, with 5(8.6%) species each, whereas, Moraceae and Merytaceae were the thirdwith3 (5.17%) species each. The other families such as Annonaceae, Asteraceae, Boraginaceae, Celasteraceae, Meliaceae and Rosaceae each of them contain 2 (3.44%) species.

From the homegarden, 33 woody species belonging to 32 genera and 23 families were recorded. Similarly, 37 woody species belonging to 33 genera, 22 families from the cropland and 37 woody species belonging to 33 genera and 23 families were recorded from Pastureland.

Table 1: The list of families with $\geq$ 2 species in descending recorded from Sokoru District; April, 2018

Family name	Number of species	%
Fabaceae	6	10.34
Euphorbiaceae	5	8.6
Rutaceae	5	8.6
Moraceae	3	5.17
Myrtaceae	3	5.17
Annonaceae	2	3.44
Asteraceae	2	3.44
Boraginaceae	2	3.44
Celastraceae	2	3.44
Meliaceae	2	3.44
Rhamnaceae	2	3.44
Rosaceae	2	3.44
Total	36	61.96

Woody species life form

Majority of the woody species recorded were found into the form of trees while few species belong to shrub and Furthermore shrubs were more common habit type in homegarden while trees were more recorded both in cropland and pastureland (Table 2).

Table 2: Growth form and distribution of woody species across the three land use types of Sokoru District; April 2018.

Land use types	Habit		
	tree	Shrubs	Total
Homegarden	21	12	33
Cropland	29	8	37
Pasture land	29	8	37

4.1.2 Woody species diversity and evenness

Although crop and pasturelands have high and equal number of woody plant species. homegarden showed the highest diversity of species (Table 3).

Table 3: Woody species diversity across the three agroforestry of Sokoru District; April, 2018

Land use type	Species richness	Diversity index (H')	H'max (lnS)	Equitability(J)
Homegarden	33	2.791	3.49	0.799
Cropland	37	2.1	3.6	0.58
Pastureland	37	2.77	3.6	0.77

4.1.3Similarity in species composition

Homegardens and croplands showed high similarity in woody species composition where as the least similarity was observed between homegarden and pastureland (Table 4).

Table 4: Similarity of the three agroforestry in woody species composition of Sokoru District; April, 2018

Land use types	Homegarden	Cropland	Pastureland
Homegarden	1	0.657	0.388
Cropland		1	0.64
Pastureland			1

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4.1.4 Basal Area

From the individual stem count recorded from homegarden, *Cordia africana* has relatively the highest BA (9.84) followed by *Mangifera indica* (BA = 2.2) (Table 5).

Table 5: Basal area for ten most important woody species in homegardenof Sokoru District; April, 2018

Species name	BA	BA/ha
Cordia africana	137.8	9.84
Mangifera indica	30.84	2.2
Persea americana	30.68	2.19
Azadirachta indica	21.69	1.5
Albizia gummifera	20.36	1.45
Grevillea robusta	20.29	1.44
Croton macrostachyus	19.62	1.4
Cupressus lusitanica	17.06	1.21
Carica papaya	14.81	1.05
Erythrina bureccei	13.32	0.95

Relatively, the highest basal area was calculated for *E.camaldulensis* followed by *C.africana* in the Cropland (Table 6).

Table 6: Basal area of ten most important woody species in crop-land of Sokoru District; April, 2018

Species name	BA	BA/ha
Eucalyptus Camaldulensis	155.5	11
Cordia africana	145.53	10.3
Ficus vasta	142.86	10.2
Ficus sur	82.37	5.88
Croton macrostachyus	38.18	2.72
Albizia gummifera	32.67	2.33
Syzygium guineense	16.54	1.18
Acacia abyssinica	15.34	1.09
Azadirachta indica	9.38	0.67
Coffea arabica	8.78	0.62

Table 7: Basal area of ten most important woody species in Pasturelandof Sokoru District; April, 2018

Species name	BA	BA/ha
Ficus vasta	115.99	8.28
Cordia africana	33.57	2.39
Albizia gummifera	22	1.57
Eucalyptus camaldulensis	11.6	0.82
Croton macrostachyus	10.87	0.77
Syzygium guineense	10.64	0.76
Acacia abyssinica	9.91	0.7
Ficus sur	6.59	0.47
Ekebergia capensis	4.60	0.32
Combretum paniculatum	4.36	0.31

4.1.5 Density and frequency of woody species

About 688 individuals of 58 woody species with ≥ 5 DBH were recorded from three agroforestry (homegarden, cropland and pastureland). Trees were with higher density when compared to shrubs of woody species recorded from the three land-use types. The result also indicated that, cropland was found to be with the highest woody species density when compared to paturelands and homegardens (Figure 2; Table 8).

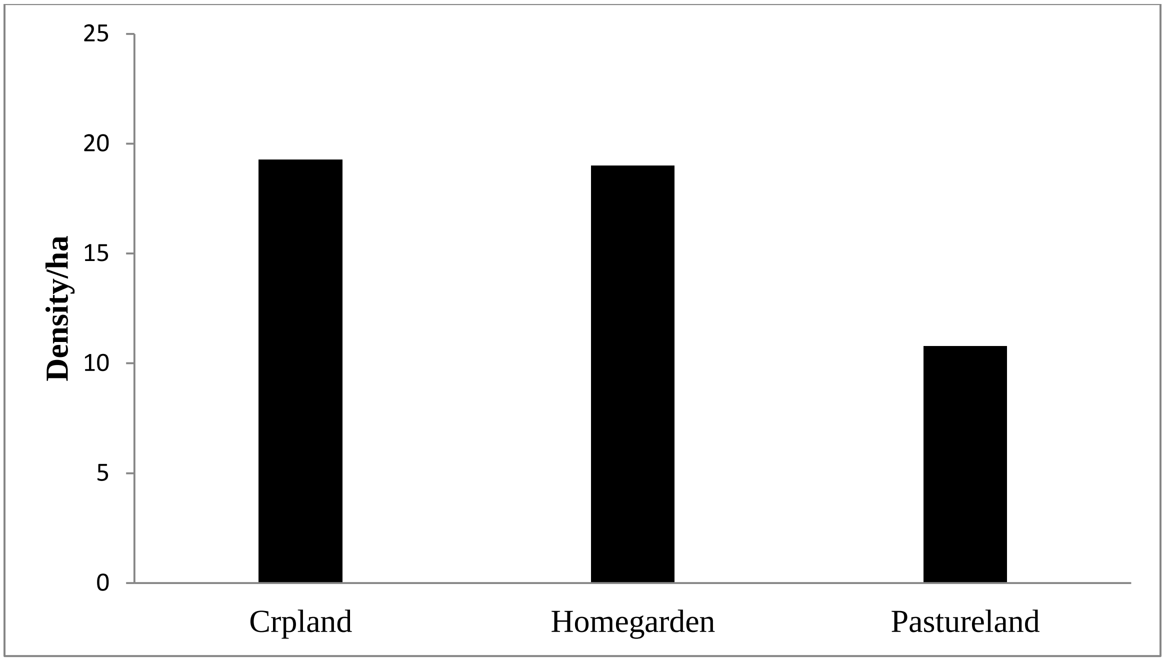

Figure 2:Woody species density of the three land use types of Sokoru District; April, 2018

Table 8: The number and percentage of all individual tree and shrubs recorded from three land use types of Sokoru District; April, 2018

Land use type	Tree		Shrub		Total	
	Number	%	Number	%	Number	%
Homegarden	197	28.6	70	10.17	267	38.81
Cropland	225	32.7	45	6.54	270	39.2
Pastureland	124	18	27	3.9	151	21.9
Total	552	80.16	136	19.65	688	100

Table 9: Abundant and rare woody species of Sokoru District; April, 2018

Habit	AbundantSpecies		Rare species	
	Scientific name	No	Scientific name	No
Tree	*Cordia africana*	127	*Citrus aurantifolia*	2
	Eucalyptus Camaldulensis	59	*Ehretia cymosa*	2
	Persea americana	40	*Grewia ferruginea*	2
	Croton macrostachyus	39	*Moringa oleifera*	2
	Croton macrostachyus	39	*Moringa oleifera*	2
Shrub	*Coffea arabica*	66	*Clausena anisata*	4
	Euphorbia trucalli	43	*Justicia schimperiana*	3
	Catha edulis	22	*Acacia etbaica*	2
	Vernonia auriculifera	14	*Phytolacca dodecandra*	2
	Psidium guajava	5	*Gossypium arboretum*	1

4.1.6Frequency

The most commonly sampled woody species from the three land use types was *Cordia Africana*. Whereas, *Coffea arabica* was the most frequently observed species in homegarden and cropland. Similarly woody species such as *Albizia gummifera*, *Eucalyptus camaldulensis* and *Croton macrostachyus* were frequently recorded from cropland and pastureland (Table 10).

Table 10: Frequency (F), Density (D) and Relative density (RD) of species recorded from homegarden, cropland and pasture land of Sokoru District; April, 2018

Species name in homegarden	**F**	**D**	**RD**
Cordia africana	12	54	20.2
Persea americana	12	21	7.86
Coffea arabica	9	27	10
Mangifera indica	9	23	8.6
Euphorbia trucalli	8	18	6.7
Species name (in Cropland)	**F**	**D**	**RD**
Cordia africana.	10	52	19.2
Eucalyptus camaldulensis	9	48	17.78
Croton macrostachyus	7	22	8.1
Albizia gummifera	6	15	5.56
Coffea arabica	6	26	9.6
Spceis name in Pastureland	**F**	**D**	**RD**
Cordia africana	7	21	13.9
Cordia africana	7	21	13.9
Albizia gummifera	5	10	6.6
Eucalyptus camaldulensis	5	11	7.28
Combretum paniculatum	4	7	4.63
Croton macrostachyus	4	10	6.6

4.1.7 Variations in woody species density and Aboveground live Carbon storage

Analysis of variance (ANOVA) showed that there is significant variation (F = 6.544, P = 0.004) among the three agroforestry in woody species density and the variation was mainly (Table 13). Between cropland and pastureland (P= 0.008); and between pastureland and homegarden (P = 0.01) (Table 14).

Table 11: The summary of significant value for one-way ANOVA between the three land use types of the study area for density

Density/ha	Sum of Squares	Df	Mean Square	F	P.
Between Groups	657.762	2	328.881	6.544	0.004
Within Groups	1960.143	39	50.260		
Total	2617.905	41			

Table 12: Summary of ANOVA for the density of the three land use types (HG = Homegarden)

group	(J) group	Mean D.(I-J)	Std.Error	Sig	95% Confidence Interval	
					L. bound	U.bound
HG	Cropland	-.21429	2.67955	.996	-6.7425	6.3139
Cropland	Pasture	8.50000	2.67955	.008	1.9718	15.0282
Pasture	HG	-8.28571	2.67955	.010	-14.8139	-1.7575

4.1.8Carbon stored and sequestered

Of total calculated from the study area, about 20.331 t, 33.123 t and 12.7 t was stored in homegarden, cropland and pastureland respectively. Totally 66.17 t CO_2 were estimated from the three land uses and croplands stored sequestered high amount of carbon dioxide and followed by homegardens and pasturelands (Table 13).

Table 13: Summary of AGC and $AGCO_2$ in three land use types of Sokoru District; April, 2018

Land use type	AGC t/ha	CO_2 t/ha
Homegarden	5.539	20.331
Cropland	9.025	33.123
Pastureland	3.465	12.7
Total	18.03	66.17

Totally 18.03 tones/ha AGC were estimated from the three land uses and croplands stored high amount of carbon and followed by homegardens and pasturelands (Figure 3).

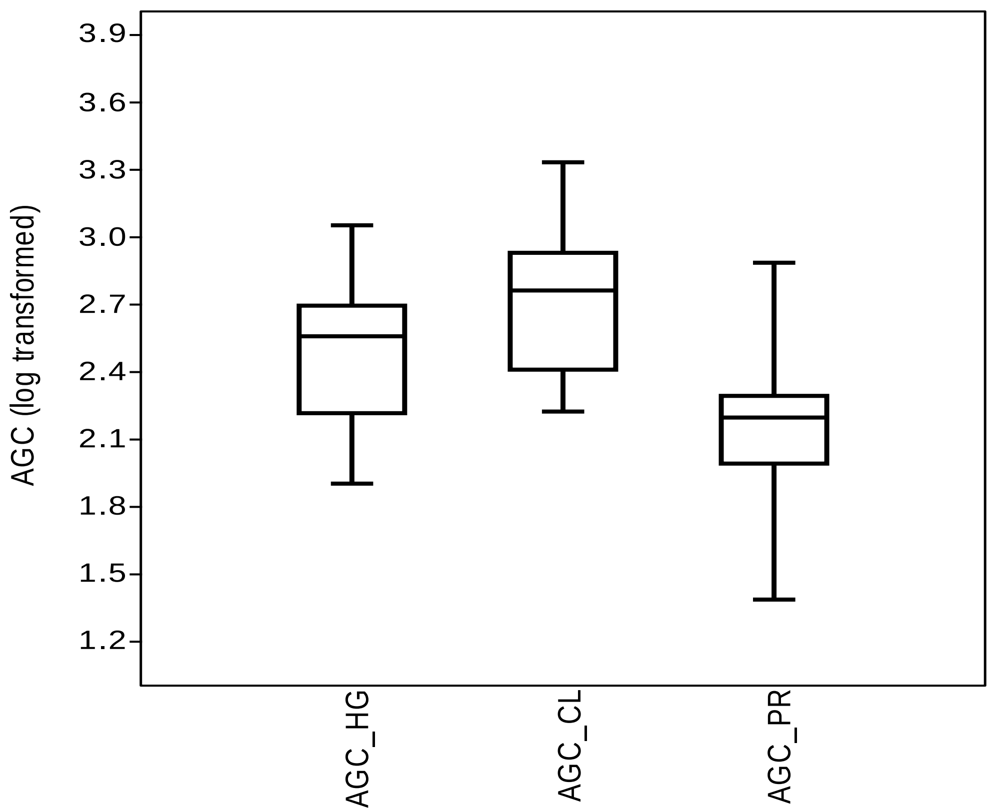

Figure 3: Box plot showing AGC storage in each land use type (cropland, pastureland and homegarden) of Sokoru District; April, 2018

There was a significance difference in AGC storage amongst the three land use types of the study area (F = 6.129, P = 0.005) (Table 14). Tuky's multiple comparison showed that there was significant variation (P = 0.003) between Crop and Pastureland in carbon storage (Table 15).

Table 14: Analysis of variance (ANOVA) showing variation in aboveground live carbon storage among the three agroforestry of Sokoru District; April, 2018

	SS	df	MS	F	P
Between groups:	1.695	2	0.847502	6.129	0.005
Within groups:	5.39298	39	0.138281		
Total:	7.08798	41			

Table 15: Summary of one way ANOVA for comparison of AGC of the three land use types (HG = Homegarden, CL = Cropland, PR = Pastureland) of Sokoru District; April, 2018

	AGC of HG	AGC of CL	AGC of PR
AGC of HG		0.3221	0.1191
AGC of CL	2.062		0.003
AGC of PR	2.868	4.929	

4.1.8.1 Aboveground live carbon storage in different land use types

The top seven known species by storing carbon and sequestering CO_2 in homegarden were C.*africana*, *A.indica*, *M.indica*, *C.macrostachyus*, *G.robusta*, *C.lusitanica* and *E.bureccei*. Comparatively, C.*africana*, and *A.indica* played very important role than any other woody species found in homegarden (Figure 4).

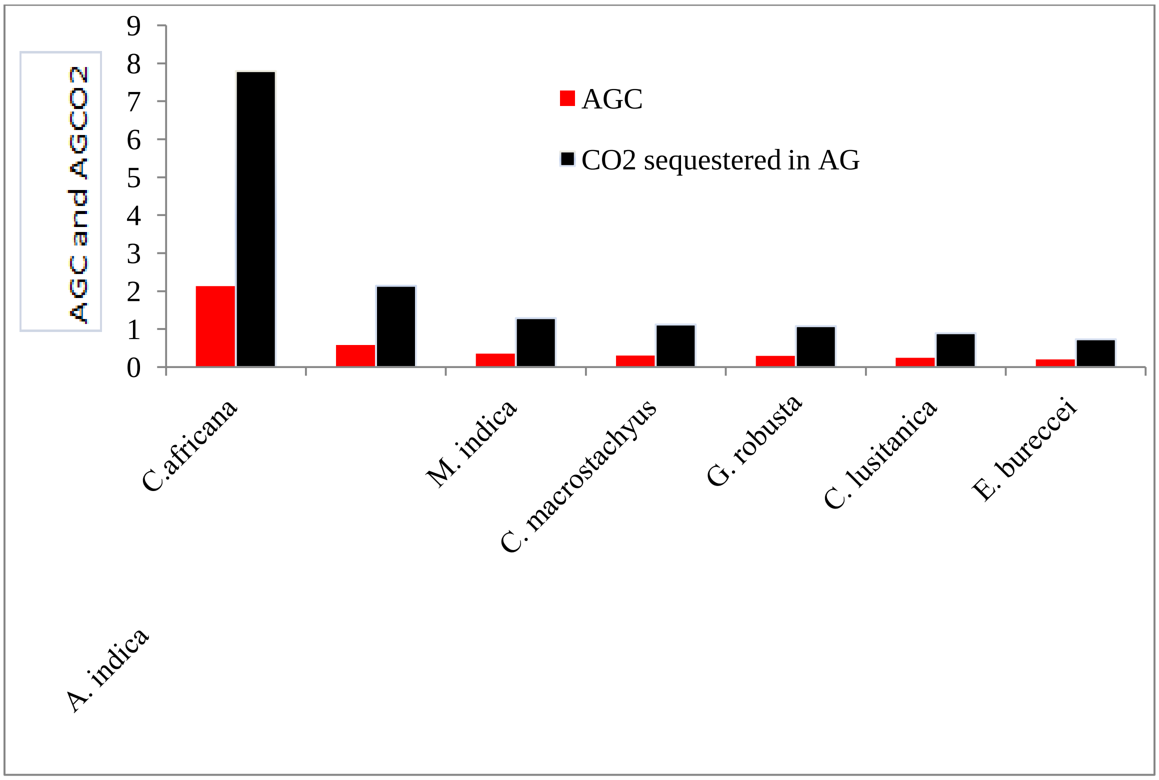

Figure 4: AGC and CO_2stored in seven top important woody species of Homegarden of Sokoru District; April, 2018

The top seven species in carbon storage in cropland were *C.africana*, *E.camaldulensis*, *F.vasta*, *F.sur*, *A.gummifera*, *C.macrostachyus and S.guineense.* Comparatively, *C.africana*, and *E.camaldulensis* played very important role than any other woody species found in cropland (Figure 5).

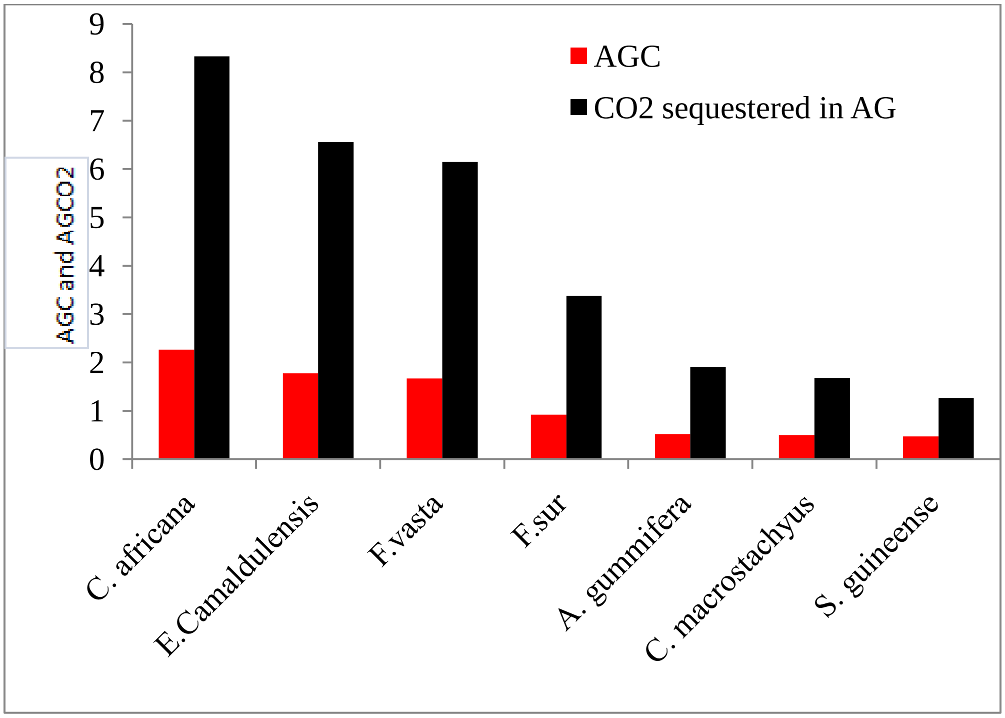

Figure 5: AGC and CO_2 in seven top important woody species of cropland land of Sokoru District; April, 2018

The top seven known species by storing carbon and sequestering CO_2 in cropland were: *F.vasta, C.africana, E.camaldulensis, A.gummifera, A.abyssinica, C.macrostachyus* and *S.guineense.* Comparatively, *F.vasta* and *C.africana*,played very important role in carbon storage and CO_2 sequestration than any other woody species found in pastureland (Figure 6).

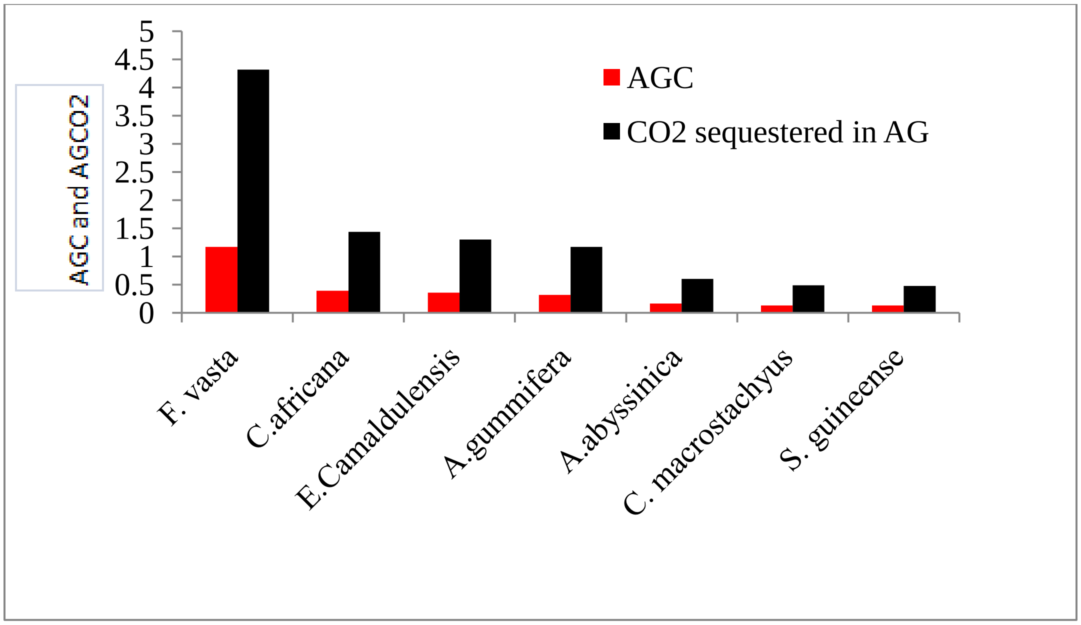

Figure 6: AGC and CO_2 in seven top important woody species of pastureland of Sokoru District; April, 2018

4.2 Discussions

Woody species richness and diversity

Fabaceae was the most species rich family (6 species) followed by Euphorbiaceae (5 species) and Rutaceae (5 species). Moraceae and Myrtaceae each of them contain 3 species. Seven families namely: Annonaceae, Asteraceae, Boraginaceae, Celastraceae, Meliaceae, Rhamnaceae and Rosaceae each contain two woody species. But, majority of the families (23 families) were represented by single species. Similar result has been reported from Gunono district, wolayta zone by Aklilu Bajigo and Mesfin Tadesse (2015). Accordingly, Euphorbiaceae was 13%(4 species) which was commonly observed family among woody species. However, many of the families were represented by single species. The result of the study indicated that the highest number of woody species was recorded from cropland and pastureland as compared to the homegarden. The possible explanation for this difference of species richness among the land use types is that, farmers may conserve plants purposely depending on the economic importance of those plants. They might prefer to conserve large trees with high canopy in order to form favorable environment for coffee shade, to get timber and to conserve soil and. For example, the most frequent woody species recorded from cropland were trees with high basal area and large canopy. These are *Cordia africana, Eucalyptus camaldulensis, Croton macrostachyus, Albizia gummifera, Coffea arabica* and *Ficus sur.* This result is supported by Kitessa Hunderra *et al.* (2013) the regeneration of six late-successional tree species (*S. guineense, Afrocarpus falcatus O. welwitschii, P. africana, Ilex mitis and Pouteria adolfi-friederici*) were consistently greater in the forest coffee than in the semiforest coffee and semi plantation coffee agroforestry system. Also similar with the study reported by Dereje Denu *et al.* (2016) in which farmers preferred trees with flat and wider canopy under which they expect better coffee yield. *Cordia africana* was also reported as an important shade tree and was preferred by some farmers due to its valuable timber. The farmers' preference for coffee shade trees was in line with the abundance of tree species in the coffee plots: *Albizia gummifera* (abundance = 15.4 stems ha^{-1}), *A. abyssinica* (4.29 stems ha^{-1}), *M. ferruginea* (11.14 stems ha^{-1}), and *C. africana* (14.43 stems ha−1).

The explanation for this study about cropland is similar with study conducted by Aklilu Bajigo and Mesfin Tadesse (2015) the dominancy of fruit and timber trees is related to farmers' tree species preference. Consequently, the woody species, plantation crops and agricultural crops are chosen due to their shade, soil fertility improvement, less competitive effect to middle and lower story, and income generation such as timber production. Fruit tree such as (*Persea americana*) and timber tree (*Cordia africana*) were also reported

The result of the study revealed that homegarden and cropland showed more similarity in woody species composition, while the least similarity was observed between homegarden and pastureland. This might be due to human preference to conserve woody species in cropland and homegarden than pasture land for different purposes. For example: to get timber, to get fruit and fertile soil. This is similar with the study conducted by Makundi and Sathaye (2004); the planting of trees along with crops on cropland improves soil fertility, controls and prevents soil erosion and controls water logging.

Density of Woody plant species and variation among the three agroforestry systems

The reason why the variation of species richness among three land use types of the study area could be due to unequal management practice, socio-economic factors such as preference of timber trees, edible fruit trees and the ability of woody species to fertile the soil.

The result of the study investigated that cropland was hosted highest stem density when compared to homegarden and pastureland. This might be due to deliberately retained trees and plant other trees in their farmland for different purposes such as for improving soil fertility and reduce the impact of soil erosion. Similar studies reported high stem density in croplands. This is similar with the study reported by Makundi and Sathaye (2004); the planting of trees along with crops on cropland improves soil fertility, controls and prevents soil erosion, controls water logging, checks acidification and eutrophication of streams and rivers, enhances local biodiversity, reduces pressure on forests for fuel and provides fodder for livestock. Agroforestry influenced soils give higher yields than ordinary soils. Taungya cultivators got higher yields than from pure agriculture in Tarai region of Uttar Pradesh. IGFRI, Jhansi conducted experiments that indicated increased yield of fodder when fodder grasses were intercropped with fodder trees as compared to mono cropping of fodder grass. In South India, and states like

Punjab, Haryana, Uttar Pradesh and Gujarat, intercropping agroforestry food crops was found to be more productive (Garitty, 2004).

The result also indicated that homegarden was the second land use type with high stem density. This might be due to people's preference of woody trees for timber, their fruits and wind break. This is similar with the study reported from Sri Lanka by Jamal *et al.* (2006); homegardens, which are widespread and vary in species composition and tree density, are the best developed agroforestry systems in Sri Lanka. The home garden systems of Sri Lanka covers 22% of the land area and are considered forest analogues that supply more than 70% of the timber and 80% of the fuel wood outside natural and planted forests. However, pastureland showed small stem count. This could be, due to people preference the land use type for pasture than trees. This is in line with the study conducted by Esquivel *et al.* (2003) which says most farmers do not permit natural regeneration of trees in pastures because it is a cost effective way to introduce trees into the grassland dominated landscape.

Frequency and Abundance of woody species

The topknownwoody species found in the study area having the greatest basal area (1.6m^2/ha) was *Cordia africana* followed by *Ficus vasta.* The main reason why these two species had large basal area was that they had high DBH value. Amongst the three land use types, cropland woody had the largest basal area followed by homegarden. The least value of basal area was calculated from pastureland agroforestry. This might be influenced by the density of each stem count in each land use type. This is similar with the study conducted by Wassie (2004); particularly, in northern Ethiopia, *C. africana* has been pushed out of its wild habitat and conserved in protected areas such as monasteries and in the agricultural lands. People preference for different purposes like household furniture made of *C. africana* highly threatened its population density in the wild and now days are confined to the farm lands and homegarden in south west Ethiopia (Behailu Etana, 2010).

This is in line with the study conducted by Diriba Muleta *et al.* (2011) in the Yayu Hurumu and Bonga forests, the fourth most preferred shade species was *Cordia africana.* This is a multi-purpose tree, providing good shade for coffee and also high-quality timber. It is widely used for making doors and window frames, cabinets, mortars and beds. The farmers stressed the importance of *Cordia africana* as an alternative source of income, which explains its relative abundance even in cropland.

This result is different from the result of study conducted by Duguma Lalisa and Hager (2010) significant difference in species richness and abundance among land use practices in the central highlands of Ethiopia. The highest diversity in homesteads and line plantings may be due to the short distance from home (and consequently better care) and to a more active tree management than in crop lands. The difference could be due to majority of woody species in homegarden of this study area may be under or < 5 DBH those were excluded in this investigation.

The most frequent woody species in the three land use types of the study area were *Cordia africana* followed by *Croton macrostachyus.* Others were found at medium and lower class frequency. This showed that most of the woody species of the study area were found in lower class frequency and small numbers of woody species were found in higher frequency. The reason why the frequency of woody species differ from one land use type to the other and from species to species might be either unequal conservation by human being or the difference in soil types. There was similar study reported from Bangladesh by Kibria and Anik (2010) most of the stem count recorded from the study area were categorized in lower class frequency.

Carbon storage, sequestration and variation among the three agroforestry systems

The result of the study indicated that the highest amount of AGC was calculated from the woody species recorded from the cropland followed by homegarden and the least AGC was calculated from pastureland. The most probable reason behind the variation of AGC among the three land use types could be the difference in density (stem count) and DBH, height, and ways of conservation and utilization by the society. This is in line with the study conducted by Albrecht and Kandji (2003); Montagnini and Nair (2004) indicating that the agricultural production issues arising from combining trees and pastures, over the past decade or so there has been increasing interest in the role of agroforestry, including silvopastoral systems, as a means of sequestering atmospheric carbon to mitigate the effects of greenhouse gas. The advantage of agroforestry systems compared to forests is that the land can remain in agricultural use whilst sustaining a greater phytomass than a purely arable or pastoral system. This result disagrees with (Reference) the study conducted on Silvopastoral system or woody species in pasture land showing high potential for carbon sequestration.

Cordia africana was the most important woody species in carbon storage. They are the most densely populated woody species in cropland followed by homegarden. This showed that *Cordia africana* in cropland had high density, high DBH and height. Similar study was reported from Jimma by Desalegn Raga and Dereje Denu (2017) in which cropland with least stem density has got larger biomass following the SFC system, mainly due to the tree DBH. This is an indication that old trees with larger DBH classes are found in the croplands. Almost all the *C. africana* trees in cropland are matured trees with larger diameter that contributed to the biomass of the trees in the cropland.

From the total AGC (18.03 t/ha) stored in three land use types of the study area, about 17.595 t/ha or 97.56 % of this carbon was stored in trees. While only 0.438 t/ha or 2.44 % of the AGC was stored in shrubs. This could be due to the lower DBH, richness, density and height of the shrubs, since larger basal area, DBH and height stores large amount of AGC; the trees of the study area could store large amount of AGC than shrubs. Similar study was reported by Talemos and Sebsibe Demisew (2014) the larger diameter woody species stored high amount of AGB, while small amount of AGB has been stored in small diameter class woody species.

The top seven known species by storing carbon and sequestering CO_2 in homegarden were C.*africana, A.indica, M.indica, C.macrostachyus, G.robusta, C.lusitanica* and *E.bureccei.* Comparatively, C.*africana,* and *A.indica* played very important role than any other woody species found in homegarden. The possible explanation for this result could be due to the higher DBH and BA of these plant species than any other woody species of the study area. Similar result was reported from Wanago district of Ethiopia by Talemos and Sebsibe Demisew (2014) the larger diameter woody species stored high amount of AGB, while small amount of AGB has been stored in small diameter class woody species.

The top seven known species by storing carbon and sequestering CO_2 in cropland were, C.*africana*, *E.camaldulensis*, *F.vasta*, *F.sur*, *A.gummifera*, *C.macrostachyus and S.guineense.* Comparatively, C.*africana*, and *E.camaldulensis* played very important role than any other woody species found in cropland. This might be due to the higher DBH, height and BA of these species than the others. Since the higher DBH, height, BA and density can store high AGB, these plant species could store high amount of AGB than the lower one.This idea could be supported by the result reported by Talemos and Sebsibe Demisew (2014) the larger diameter woody species stored high amount of AGB, while small amount of AGB has been stored in small diameter class woody species

The top seven known species by storing carbon and sequestering CO_2 in cropland were *F.vasta*, C.*africana*, *E.camaldulensis*, *A.gummifera*, *A.abyssinica*, *C.macrostachyus* and *S.guineense.* Comparatively, *F.vasta* and C.*africana,* played very important role in carbon storage and CO_2 sequestration than any other woody species found in pastureland. The possible explanation for this might be due to the variation of factors like DBH, height and BA among different woody species recorded from the study site.

Table 16: Comparison of carbon storage in current study with others related results

Study site	Source	AGCt/ ha
Central closed public park in Addis Abeba	Mareshet Tefera,	29.1
Selected church forest in Addis Ababa	Tulu Tolla, 2011	128.86
Wenago District, Ethiopia	Talemos Seta and Sebsibe Demisew, 2014	16.66
Sub-Saharan Africa	Unru *et al*., 1993	4.5 to 19
Sokoru District, Ethiopia	Current study	18.03

5. Conclusion and Recommendation

5.1 Conclusion

About 58 woody species were collected from Sokoru district of which 44 were trees while 14 were shrubs. Most of the AGC calculated from the aboveground biomass was stored in trees mainly due to their high DBH than shrubs.

Of all woody species recorded from the three agroforestry systems, *Cordia africana* was the most frequent and abundant species with highest basal area. This species also stored the highest aboveground live carbon in its biomass. The woody species of the study area could play an important role in climate change mitigation via photosynthesis. Cropland was the highest land use type in woody species density followed by homegarden.

5.2 Recommendation

- The woody species found in the study area have great role in carbon storage and CO_2sequestration hence all stakeholders should pay attention for the conservation of trees and shrubs.
- People of the study area are conserving woody species found in cropland and homegarden very well than pastureland which indicates, there were over exploitation and lack of conservation in pastureland. Bearing this in mind any concerned body including the local people of the study area should work for the conservation and plantation of the woody species in pasture land
- There should be awareness among the people of the study area regarding the direct and indirect significance of the woody species in the agroforestry systems of the study area.
- This study was about woody species diversity and aboveground live carbon storage of the three land use types (homegarden, cropland and pasture land) and did not include riverine, natural forest and others. Therefore, we recommend further study to fill the above mentioned gaps.

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Appendixes

Appendix 1: List of woody species recorded from the study area (L. name= local name, ha= habit, A/O= Afan Oromo)

No		L.name in A/O	Family	ha
1	*Acacia abyssinica* Hochst ex Bench.	Lafto	Fabaceae	T
2	*Acacia etbaica*Schweinf.	Doddota	Fabaceae	S
3	*Albizia gummifera* (J. f. Gmel.) *C.A.Sm*	Hambabessa	Fabaceae	T
4	*Annona reticulata* L.	Gishxa	Annonaceae	T
5	*Apodytes dimidiata*E.Mey. ex Arn.	Wendabiyo	Metteniusaceae	T
6	*Azadirachta indica* A. Juss	Nimi	Meliaceae	T
7	*Bersama abyssinica* Fresen.	Lolchisa	Melianthaceae	T
8	*Calpurnia auria* (Lam.)Benth.	Chekata	Fabaceae	T
9	*Carica papaya* L.	Papaya	Caricaceae	T
10	*Carissa spinarum* (Forssk.) Vahl	Hagamsa	Apocynaceae	S
11	*Casimiroa edulis*(La.) Liave and lex.	Kasmira	Rutaceae	T
12	*Casuarina equisetifolia* L.	Shuwashuwe	Casuarinaceae	T
13	*Catha edulis* (Vahl) Frossk. ex End/.	Caatii	Celastraceae	S
14	*Celtis africana*Burm. f.	Matakoma	Ulmaceae	T
15	*Citrus aurantifolia* (Christm.)Swingle	Lomi	Rutaceae	T
16	*Citrus sinensis* (L.) Osbeck.	Burtukana	Rutaceae	T
17	*Clausena anisata* (Wild.) Hook. F. ex. Benth	Ulmayi	Rutaceae	S
18	*Coffea arabica* L.	Buna	Rubiaceae	S
19	*Combretum paniculatum* Vent	Dhandheessa	Combretaceae	T
20	*Cordia africana* Lam.	Waddessa	Boraginaceae	T
21	*Croton macrostachyus* Hochst.ex Del.	Makanisa	Euphorbiaceae	T
22	*Cupressus lusitanica* Mill.	Gattira	Cupressaceae	T
23	*Dodonaea angustirolia*L. f.	Etacha	Sapindaceae	T
24	*Dracaena afromontana* Mildbr.	Rukessa	Agavaceae	T
25	*Ehretia cymosa* Thonn.	Ulaga	Boraginaceae	T

26	*Ekebergia capensis* Sparm.	Sombo	Meliaceae	T
27	*Erythrina burecei* Schweinf.	Walensu	Fabaceae	T
28	*Eucalyptus camaldulensis* Dehnk.	Bargamo dima	Myrtaceae	T
29	*Euphorbia abyssinica* Gmel.	Adami	Euphorbiaceae	T
30	*Euphorbia trucalli* L.	Cadaa	Euphorbiaceae	S
31	*Ficus sur* Forssk.	Harbu	Moraceae	T
32	*Ficus thonningii* Blume	Dambi	Moraceae	T
33	*Ficus vasta* Frossk.	Qilxu	Moraceae	T
34	*Flacourtiaindica*(Brm.f.)Merr	Akukkuu	Flacourtiaceae	T
35	*Gossypium arboream*L.	Jirbi	Manaceae	S
36	*Grevillea robusta*A. Cunn.	Giravila	Proteaceae	T
37	*Grewia ferruginea* Hochst. exA. Rich.	Dhoqonu	Tiliaceae	T
38	*Justicia schimperiana* (Hochst. ex A. Nees) T. Anders	Dhumuga	Acanthaceae	S
39	*Maesa lanceolata* Forssk	Abbayyi	Myrsinaceae	S
40	*Malus pumila*Mill.	Appili	Rosaceae	S
41	*Mangifera indica* L.	Mango	Anacardiaceae	T
42	*Millettia ferruginea (*Hockst.) Bak	Askira/Sotelo	Fabaceae	T
43	*Moringa oleifera* Lam.	Moringa	Moringaceae	T
44	*Maytenus arbutifolia* (A. Rich.) Wilczek	Kombolcha	Celastraceae	S
45	*Olea europea ssp.* Cuspidata	Ejersa	Oleaceae	T
46	*Persea americana* Mill.	Avokado	Lauraceae	T
47	*Phoenix reclinata* Jacq.	Mexxii	Arecaceae	T
48	*Phytolacca dodecandra* L. Herit	Andode	Phytolaccaceae	S
49	*Prunus persica*(L.) Batsch	Kookii	Rosaceae	T
50	*Psidium guajava* L.	Zayituna	Myrtaceae	T
51	*Rhamnus Prinoides*L. Her.	Gesho	Rhamnaceae	S
52	*Ricinus communis* L.	Qobboo	Euphorbiaceae	T
53	*Sapium ellipticum* (Krauss) Pax	Bosoqa	Euphorbiaceae	T
54	*Spathodea campanulata* P. Beanv	Annonobo	Bignoniaceae	T

55	*Syzygium guineense* (Wild.) Dc.	Baddessa	Myrtaceae	T
56	*Vernonia amygdalina* Del.	Dhebicha	Asteraceae	S
57	*Vernonia auriculifera* Hiern	Rejji	Asteraceae	S
58	*Ziziphus mauritiana* Lam.	Qurqura	Rhamnaceae	T

Appendix 2: Family and Genera of the study area

N<u>o</u>	Family	N<u>o</u> of Genera	N<u>o</u> ofSpecies
1	Acanthaceae	1	1
2	Agavaceae	1	1
3	Anacardiaceae	1	1
4	Annonaceae	1	1
5	Apocynaceae	1	1
6	Arecaceae	1	1
7	Asteraceae	2	2
8	Bignoniaceae	3	3
9	Caricaceae	1	1
10	Casuarinaceae	1	1
11	Celastraceae	1	1
12	Combretaceae	1	1
13	Cupressaceae	1	1
14	Euphorbiaceae	4	5
15	Fabaceae	5	6
16	Flacourtiaceae	1	1
17	Lauraceae	1	1
18	Manaceae	1	1
19	Meliaceae	2	2
20	Melianthaceae	1	1
21	Metteniusaceae	1	1

22	Moraceae	1	3
23	Moringaceae	1	1
24	Myrsinaceae	1	1
25	Myrtaceae	3	3
26	Oleaceae	1	1
27	Phytolaccaceae	1	1
28	Proteaceae	1	1
39	Rhamnaceae	2	2
30	Rosaceae	2	2
31	Rubiaceae	1	1
32	Rutaceae	3	5
33	Sapindaceae	1	1
34	Tiliaceae	1	1
35	Ulmaceae	1	1

Appendix 3:AGC and density of woody species in Homegarden

Pilots	Altitude	AGC(kg/ha)	Density
P1	1787	480.7407108	18
P2	1786	849.9912348	26
P3	1718	253.4249708	17
P4	1689	132.8347891	14
P5	1759	303.0131156	17
P6	1756	107.0651749	15
P7	1829	79.31518281	6
P8	1845	491.1308156	27
P9	1901	190.090618	15
P10	1893	358.57251	12
P11	1879	598.5155736	23
P12	1872	1117.983206	33
P13	1886	414.033813	24
P14	1904	163.2092391	20
Total		5539.920954	267

Appendix 4:AGC and density of woody species in Cropland

Pilots	Altitude	AGC(kg /ha)	Density
P1	1790	573.2435282	22
P2	1772	998.0579641	27
P3	1730	581.3155669	20
P4	1697	437.8105591	14
P5	1801	245.8416511	20
P6	1734	1377.661379	24
P7	1798	271.7386618	18
P8	1840	2132.068118	40
P9	1872	843.8013698	25
P10	1882	634.664565	15
P11	1851	312.984981	15
P12	1872	195.6848794	14
P13	1931	254.6856387	9
P14	1912	165.9730152	7
Total		9025.531878	270

Appendix 5: AGC and density of woody species in Pastureland

Pilots	Altitude	AGC (kg/ha)	Density
P1	1784	747.9101928	8
P2	1778	24.15448154	5
P3	1679	155.9983287	7
P4	1701	190.9339785	9
P5	1774	97.29002146	6
P6	1750	41.27071766	7
P7	1796	173.8573164	10
P8	1855	761.8719298	12
P9	1925	194.7788975	10
P10	1879	126.2312075	7
P11	1861	114.1444968	11
P12	1870	93.5121423	14
P13	1917	116.5756527	19
P14	1934	626.6045133	26
Total		3465.133877	151

Appendix 6: List of woody species commonly found in three land use types

*Grevillea robusta*A. Cunn.	Giravila	proteaceae
Cordia africana Lam.	Waddessa	Boraginaceae
Croton macrostachyus Hochst.ex Del.	Makanisa	Euphorbiaceae
Erythrina burecei Schweinf.	Walensu	Papilionoideae
Calpurnia auria (Lam.)Benth.	Chekata	Fabaceae
Vernonia auriculifera Hiern	Rejji	Asteraceae
Albizia gummifera (J. f. Gmel.) C.A.Sm	Hambabessa	Fabaceae
Ekebergia capensis Sparm.	Sombo	Meliaceae
Cupressus lusitanica Mill.	Gattira	Cupressaceae
Eucalyptus camaldulensis Dehnk.	Bargamo dima	Myrtaceae
Euphorbia trucalli L.	Cadaa	Euphorbiaceae
Maesa lanceolata Forssk	Abbayyi	Myrsinaceae