Jimma University

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Woody Species Diversity and Aboveground Live Carbon Storage in Different Land use types of Yem Special District, Southwest Ethiopia

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Certificate

This is to certify that the thesis paper entitled as the *"Woody Species Diversity and Aboveground Live Carbon Storage in Different Land use types of Yem Special District, Southwest Ethiopia"* submitted to Jimma University for the award of the degree of Master of science (Msc.) and is a record of genuine research paper work carried out by Dibora Aklile Nigatu, under our guidance and supervision.

Therefore, we here declare that no part of this research has been submitted to any other university or institutions for the award of any degree or Diploma.

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Table of contents

Contents pages

List of Tables

List of Figures

Lists of Appendixes

Acronyms

IPCC = Intergovernmental Panel on Climate Change

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

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

GHG = Green House Gas

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

FAO = Food, and Agriculture Organization

ICRAF = International Center for Research in Agroforestry

UNFCCC=United Nations framework convention on climate change

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Abstract

Agroforestry principles and practices have long been recognized and applied in tropical countries, temperate countries have lagged behind in this regard. The desire for more environmentally responsible agricultural practices and systems has provided an ideal context for developing and implementing agroforestry in temperate regions. Agroforestry is a system in which trees and different crops are grown together in the same area for net economic returns to farmers. Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter, or income from products, including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services). Agroforestry has been identified as a potential greenhouse gas mitigation and afforestation approach under the Kyoto Protocol. The main objective of this study is to investigate Woody Species Diversity and Aboveground live Carbon Storage in Different Land uses of Yem Special district, Southwest Ethiopia. This study was conducted from January – June, 2020. A transect line has been established across different land use types (homegarden, pastureland and cropland). Stem count of woody species in three land use types was recorded. The circumference of each stem with diameter at breast height (DBH) ≥ 5cm, height ≥ 1.3 m were recorded from the 39 total sample plots. Woody species diversity was calculated using Shannon-Wiener diversity index and woody species in pastureland was highly diversified (3.37). The similarity of woody species composition among the three land use types was calculated by using Sorenson's similarity index. As a result cropland and pasture land showed the highest similarity when compared to the others. Aboveground live biomass of each tree was calculated by using the revised nondestructive allometric equation $AGB = 0.0673(\rho D^2 H)^{0.976}$*. As a result Cropland stored the highest amount AGC (11.52 t/ha). As a whole 20.11 t/ha of AGC was stored in the three land use types. Depending on the result of this study I recommend for further investigation on other components to fully understand the contribution of agroforestry systems in biodiversity conservation and carbon storage.*

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

1. Introduction

1.1 Background of the study

Agroforestry principles and practices have long been recognized and applied in tropical countries, temperate countries have lagged behind in this regard. The desire for more environmentally responsible agricultural practices and systems has provided an ideal context for developing and implementing agroforestry in temperate regions. Agroforestry offers many benefits, including the protection of crops, livestock, soil and water resources. It also permits diversification of agricultural revenues through the production of timber and non-timber forest products. Agroforestry practices also enhance landscapes by promoting biodiversity and carbon sequestration. In short, agroforestry provides an array of environmental goods and services that support integrated management of farmland and rural spaces.

Agroforestry is a system in which trees and different crops are merged together in the same area for net economic returns to farmers (Alao and Shuaibu, 2013).There are various definitions of agroforestry. International Center for Research in Agroforestry(ICRAF) defines agroforestry as “the interaction of agriculture and trees, including the agricultural use of trees”. This includes trees on farms and contained in agricultural landscapes, farming in forests and along forest margins and tree-crop production, including cocoa, coffee, rubber and oil palm (Lovric *et al.*, 2018). Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter, or income from products, including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services) (Aleixandre-Benavent *et al.*, 2014). FAO (2004) defines agroforestry as “a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence.”

Farmers plant, protect and promote woody species within and around their homegardens, fields and communal pasturelands to derive a range of benefits, including provisions of food, fodder, construction materials, farm equipment, fuel wood and medicines (Tabuti, 2012). The retention of trees and shrubs in agricultural landscapes depends on local ecological knowledge regarding the use and conservation of species, the values of plants within subsistence and market economies, land and other resource tenure systems that determine access, spiritual beliefs and traditions associated with plants, as well as changes in socio-cultural structures (Neba, 2009).

Agroforestry systems have the potential to address both food insecurity and carbon mitigation goals (Yasin *et al.,* 2018; Nawaz *et al.,* 2017). Agroforestry has been identified as a potential greenhouse gas mitigation and afforestation approach under the Kyoto Protocol (Makundi and Sathaye, 2004; Nair *et al.,* 2009). Several researchers have determined that planting trees with crops results in higher carbon sequestration compared with croplands depending upon the environmental and socioeconomic conditions of the area (Nair *et al.,* 2009). Around 45.3 PgC of the world's terrestrial carbon is currently stored in agricultural lands, with trees contributing 33.9 PgC (Zomer *et al*., 2016) and the potential could increase up to another 586 Tg year^{-1} by 2040 if 630 million ha of unproductive croplands are converted into agroforestry globally (Smith, 2004).

The average carbon storage by agroforestry worldwide has been assessed to be 9, 21, 50 and 63 Mg C ha^{-1} in semiarid, subhumid, humid and temperate regions, respectively (Chauhan *et al.*, 2010). Agroforestry systems with different trees have a greater capability to cope with climate change and sequester a higher amount of carbon. Trees planted with crops can increase the carbon stock up to many folds when compared with monocrop systems, for example, 34.61 t C ha^{-1} in an agrisilvicultural system (simultinaneously growing crops and trees on the same piece of land) compared with 18.74 t C ha^{-1} in a monocrop system (Kaur *et al*., 2002).

There is a growing interest in the role of different types of land use systems in stabilizing the atmospheric CO_2 concentration and reducing the CO_2 emissions or on increasing the carbon sink of forestry and agroforestry systems. Forestry has been recognized as a means to reduce CO_2 emissions as well as enhancing carbon sinks. The role of forests (or trees) in carbon cycles is well recognized and forests are a large sink of carbon. There is considerable interest to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as afforestation, reforestation, natural regeneration of forests, silvicultural systems and agroforestry (Canadell and Raupach, 2008). Agroforestry systems are very important given the area currently under agriculture, the number of people who depend on land for their livelihoods and the need for integrating food production with environmental services (Smith, 2004).

Globally, climate negotiations have highlighted the importance of land use sectors in mitigating the climate change. Agriculture alone accounts for 10-12% of the total global anthropogenic emissions of GHGs with an estimated non-CO_2 GHG emission of 5120-6116 $MtCO_2eq/yr$ in 2005 (Roshetko *et al*., 2007). Since agricultural lands are often intensively managed, they offer many opportunities to improve agronomic practices, nutrient and water management, land use practices to fit the land manager's objectives of carbon sequestration. Agriculture is the main backbone of the economy but also the major occupation of Ethiopian population (Feoli *et al*., 2002). Rapid population growth and long history of sedentary agriculture have changed the land use/land cover systems and caused environmental degradation in many developing countries including Ethiopia (Bishaw and Asfaw, 2010). They indicated that population growth and environmental degradation on forest ecosystems lead to loss of forest area, habitat fragmentation, soil degradation and biodiversity losses. International concern is to find alternative farming systems that are ecologically and economically sustainable as well as culturally acceptable to local communities (ICRAF, 1997).Different forms of agroforestry, home gardens and boundary plantings have been well recognized as potential long-rotation systems that mitigate CO_2 and sequester sizeable quantities of carbon in plant biomass (Albrecht and Kandji, 2003).

Most farmers permit natural regeneration of trees inpastures 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. There are agroforestry practices that fully integrate the tree/crop component throughout the whole farm, such as silvopasture and alley cropping, which, despite their excellent carbon sequestering/production capabilities may not be picked up by either group (Nair and Nair, 2003).This thesis is designed to assess woody species diversity of different land use types, to estimate aboveground live carbon storage in different agro-ecosystems and to compare and contrast the variation in Woody species diversity and carbon storage among different land use types of Yem special District, Southwest Ethiopia.

1.2 Statement of the Problem

The role of land use systems in capturing atmospheric carbon dioxide (CO_2) and storing the carbon (C) in plant parts and soil became an important area of research during the past decade.

Agroforestry attracted special attention as a carbon sequestration strategy following its recognition as a carbon sequestration activity under the afforestation and reforestation activities of the Kyoto Protocol. This was in recognition of the perceived advantages of the large volume of aboveground biomass (AGB) and deep root systems of trees in accomplishing that task.

Many researches were conducted at different time and places on woody species diversity and carbon storage, but there is no any report on woody species diversity and the potential of agroforestry in carbon storage from Yem Special district. Therefore; this study was designed to fill this knowledge gap.

Research questions

1. Are the different land use types different in woody species richness and diversity?
2. How much carbon is stored in aboveground live woody species biomass in different land use systems of Yem Special district?

1.3 Objective of the study

1.3.1 General objective

The general objective of the study was to assess woody species richness, diversity and carbon storage in different land use types of Yem Special District, Southwest Ethiopia.

1.3.2 Specific objectives

The specific objectives of this study were to:

1. Assess woody species richness and diversity indifferent land use types of the study area.
2. Determine above ground live carbon storage in different land use types of the study area.
3. Determine the variation in Woody species diversity and carbon storage among different land use types of the study area.

1.4 Significance of the study

The result of this study helps to show the variation of woody species diversity and carbon storage among different land uses of Yem Special District. The outcomes of this study showed the contribution of agroforestry systems of Yem special District in Climate mitigation. The result could also be used as a spring board for further study by other researchers.

2. Review of related literature

2.1 Agroforestry systems and their function in Carbon storage

Agroforestry practices are said to be characterized by four “I” words: intentional, intensive, integrated and interactive (Gold and Garrett, 2009). Starting with the definition, agroforestry is not entirely precise or definitive in many of its attributes. Various attributes of integrated and interactive land use systems that are practiced in concert with nature and environment in accordance with the local socio-cultural norms and traditions cannot be expected to be measured in quantitative terms with 100% precision and accuracy because of the multiplicity of factors involved and their complex interactions (Roshetko *et al.*, 2002). This lack of precision may not be a serious problem in managing the systems because they are location-specific and their management is less dependent on machinery than in the case of commercial agriculture and forestry systems.

However, when it comes to quantifying their attributes to lay the foundations for future scientific developments, accurate measurements are important. Thus, measurement of the perceived benefits and advantages of agroforestry is essential; but it is a challenge, indeed a serious one. There is a serious challenge in the efforts made to estimate carbon (C) sequestration in agroforestry systems (AFS) Takimoto *et al.* (2008). The role of land use systems in capturing atmospheric carbon dioxide (CO_2) and storing the C in plant parts and soil became an important area of research during the past decade. Agroforestry attracted special attention as a carbon sequestration strategy following its recognition as a carbon sequestration activity under the afforestation and reforestation activities of the Kyoto Protocol. This was in recognition of the perceived advantages of the large volume of aboveground biomass (AGB) and deep root systems of trees in accomplishing that task. Consequently a large number of estimates and reports on C sequestration potential of various agroforestry systems under different ecological regions have become available since the mid-1990s starting with the reports of Dixon *et al*. (1994), Schroeder (1994) and others. Most of these available reports on carbon sequestration in AFS are estimates of carbon stocks: how much carbon is, or potentially could be, accumulated and stored in above- and belowground compartments of AFS under different conditions of ecology and management. The estimates range from 0.29 to 15.21 Mg ha^{-1} year^{-1} aboveground and 30–300 Mg C ha^{-1} up to 1m depth in the soil (Nair *et al*., 2010). Collecting (or estimating) such C stock data is important in itself for feeding into massive global datasets such as those of the IPCC (Intergovernmental Panel on Climate Change)(www.ipcc.ch) and for other planning and developmental purposes. The methods and procedures adopted in collecting such datasets have to be consistent and standardized, so that development plans for the future are based on rigorous databases of unquestionable value. Therefore, we have the responsibility of stepping up our norms, criteria and standards for reporting carbon sequestration data in AFS. With that in mind, this portion aims to bring together first of all, some basic concepts of C sequestration and then identify some of the common mistakes and pitfalls in carbon sequestration studies in AFS and ways to avoid them. Developing a uniform or standardized set of procedures is a long and arduous task; that is not even attempted here; the hope, however, is that this effort will stimulate some thinking in organizing future efforts in that direction (Gold and Garrett, 2009).

2.1.1 Carbon Sequestration

During the past two decades, there has been a veritable explosion of the literature on carbon sequestration. Internet search engines and abstracting services are virtually flooded with all sorts of literature on all aspects of the process. Unfortunately, considerable variations exist among different user groups about the concept of carbon sequestration and the term is not used or understood uniformly in different contexts. This has led to serious difficulties in consolidating and synthesizing available reports and publications according to a uniform pattern and set of norms (Roshetko *et al.*, 2002).

The United Nations Framework Convention on Climate Change (UNFCCC) defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir. It entails the transfer of atmospheric $CO_2$and its secure storage in long-lived pools (UNFCCC, 2007). From the agroforestry point of view, carbon sequestration primarily involves the uptake of atmospheric CO_2 during photosynthesis and the transfer of fixed carbon into vegetation, detritus and soil pools for "secure" (i.e. long-term) storage (Nair *et al.*, 2010). It occurs in two major segments of the AFS: aboveground and belowground. Each can be partitioned into sub-segments: the former into specific plant parts (stem, leaves, etc., of trees and herbaceous components) and the latter into living biomass such as roots and other belowground plant parts, soil organisms and carbon stored in various soil horizons. The total amount sequestered in each compartment differs greatly depending on a number of factors including the ecoregion, the type of system (and the nature of components and age of perennials such as trees), site quality and previous land use. On average, the aboveground parts and the soil (including roots and other living biomass) are estimated to hold roughly one-thirds and two-thirds, respectively, of the total carbon stored in tree-based land use systems. Based on the notion that tree incorporation in croplands and pastures would result in greater net carbon storage above and belowground (Palm *et al*., 2004; Hale *et al*., 2008), AFS are believed to have a higher potential to sequester carbon than pastures or field crops growing under similar ecological conditions (Roshetko *et al*., 2002; Kirby and Potvin,2007).

2.2 Measurement of Carbon Sequestration in Agro forestry Systems

2.2.1 Aboveground Carbon storage

Aboveground measurements of carbon stock and sequestration are direct derivatives of aboveground biomass (AGB) measurements/estimates, assuming that 50% of the biomass is made up of carbon. The AGB is often derived by summing up the amount of harvested and standing biomass and the measurements are relatively straight-forward compared to those of the belowground compartment. Estimation of tree biomass by whole-tree harvesting is an old approach: it consists of cutting down sample trees, separating various parts (stem, leaves, inflorescence, etc.), digging out and washing the roots, determining their dry weights from samples of each part and adding them up to get the total biomass. After dividing up the harvested representative trees into their various components (branches, dead branches, branchlets, leaves, roots and fine roots) and determining their dry weight, the C content in each is measured (Gold and Garrett, 2009). Using the data, allometric equations are developed as regression models with the measured variables such as diameter at breast height (DBH), total tree height or commercial bole height and sometimes wood density, as the independent variables and total dry weight as the dependent variable. The destructive method of determining tree biomass, though comparatively accurate, is extremely time and labor-intensive, especially for large trees. It is often used to validate other, less invasive and costly methods, such as the estimation of carbon stock using non-destructive in-situ measurements and remote sensing. Such allometric equations developed based on biophysical properties of trees and validated by occasional measurements of destructive sampling are widely used in forestry for estimating standing volumes of forests. With increasing understanding about the role of forests in sequestering carbon, various allometric equations have been developed for different forest types (Brown, 1997; FAO, 2004). Efforts in developing allometric equations for agroforestry situations have generally been slow and researchers trying to use this approach are forced to use broad approximations. For example, for estimating the standing tree biomass in the parkland AFS in the Sahel where species-specific allometric equations were not available for the region, Takimoto *et al.* (2008) followed the recommendation to use the Brown (1997) general equations for parkland trees. In other cases, more simple analyses were used for large-scale estimations. Dixon *et al*. (1993) made estimations by measuring the volume of stem wood and multiplying it with species-specific wood density; that number was then multiplied by 1.6 to get an estimation of whole-tree biomass; C content was assumed as 50% of the estimated whole-tree biomass and root biomass was excluded. This rough estimation was then used for more extensive estimations of global forest biomass.

More recently, databases for tree characteristics such as wood density for agroforestry species (http://www.worldagroforestrycentre.org/sea/Products/AFDbases/WD) developed at the World Agroforestry Centre (www.cgiar-icraf.org) are being used in such allometric calculations. As Kumar *et al*. (1998) noted following their efforts to develop allometric equations for some common agroforestry tree species in Kerala, India, such equations vary greatly with species, age, wood density, bole shape and other factors and could lead to excessive inaccuracies. Besides, such determinations can be difficult for smallholder agroforestry plots that comprise much of the agroforestry in developing countries. These systems involve a multitude of plants of varying growth habits yielding diverse economic products and the species are planted and their products harvested, mostly for household consumption, throughout the year. Variations in tree management can be another issue: trees in AFS may be pruned depending on management practices or may have different growth forms due to differences in spacing compared to natural (forest) systems. Furthermore, no two agroforestry plots are similar: each may be unique in terms of plant composition, planting arrangements and stand densities. Thus, determination of biomass production from indigenous AFS is a challenging task and makes extrapolation from one system to others very difficult.

2.2.2 Belowground Living Biomass

In addition to SOM, belowground biomass is a major carbon pool (Nadelhoffer and Raich, 1992). However, belowground biomass is difficult to measure. The root-to-shoot ratio is therefore commonly used to estimate below ground living biomass. The ratios differ considerably among species (e.g., higher in palms than in dicot trees) and across ecological regions (e.g., higher in cold than in warm climates). In the absence of measured values, many researchers assume that the belowground biomass constitutes a defined portion of the aboveground biomass and the values so assumed range from 25% to 40% depending on such factors as nature of the plant and its root system and ecological conditions (Perry *et al*., 2008).

2.3 Modeling

In order to understand global carbon cycling, models that incorporate rates of terrestrial carbon cycling are used. Such models are based on a set of assumptions that are formed from our understanding of ecological processes including tree growth and decomposition processes in the soil. The century and Roth carbon models are the most widely used soil carbon models. The former models the cycling of carbon and other elements (phosphorus, nitrogen and sulfur) and their interactions, focusing specifically on the effects of species type and management practices such as tillage to model agricultural systems. It accounts for agricultural systems, forests, or savannas but not for integrated tree-crop systems such as agroforestry; adding agroforestry could be interesting and important to this model in order to improve its carbon sequestration estimates in global soils. The Roth carbon model (Rothamsted model), based on the long-term experiments studying organic matter on the Rothamsted sites in England, takes into consideration organic pools in terms of how labile they are (Mattsson *et al*., 2013). Although the parameters of the model are comparatively simple, the model may not be quite appropriate for predictions of tropical agroforestry sites. Numerous mathematical models have been developed to predict the response of SOM to agricultural practices at various scales, from soil profile or small plot scales to larger spatial extents, especially in response to the demand for national inventories of soil C sequestration potential. Discussing such models, Nair *et al*. (2010) have noted that difficulties in obtaining information that is essential for the models could limit the applicability of the models to many tropical AFS. In general, models used in agroforestry research are developed for natural ecosystems and planted forests or agricultural systems; they rely on assumptions that are not fully relevant to AFS and are often hard to incorporate into larger ecosystem models (Lal, 2004).

2.4 Carbon sequestration potential of different land use types

Agroforestry, the practice of introducing trees in farming has played a significant role in enhancing land productivity and improving livelihoods in both developed and developing countries. Although carbon sequestration through afforestation and reforestation of degraded natural forests 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). The potential for sequestering carbon was, fairly low, between 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 and the poor performance of trees and crops on poor soils in the region (Lal, 2004).

2.4.1 The role of home garden 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, specifically, growing trees in conjunction with agricultural crops. Agroforestry systems in Sri Lanka provide corridors that connect 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 landscapes. Agroforestry in the rural landscape 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. Home garden 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. Home gardens in Sri Lanka offer great potential for restoring and increasing forest cover and connectivity (Jamal *et al.*, 2006).Different forms of agro forestry, home gardens and boundary plantings have been well recognized as potential long-rotation systems that mitigate CO_2 and sequester sizeable quantities of carbon in plant biomass (Albrecht and Kandji,2003). Home gardens contain a significant fraction of the total above-ground biomass carbon stock in the terrestrial system and this proportion has increased from almost one-sixth in 1992 to nearly one-fifth in 2010. Home gardens store significant amount of carbon, with above ground biomass carbon stocks with a mean value of 35 Mg C ha^{-1} in dry zone while 87 Mg C ha^{-1} in wet zone in the terrestrial system in Sri Lanka (Mattsson *et al.*, 2013).

2.4.2 The role of Pasture land trees in carbon storage

A functional relationship of either form between diversity and carbon storage and sequestration could have important implications for the management of carbon-sink projects, not only for reforestation and afforestation type projects, which are currently supported under international agreements such as the Kyoto Protocol's clean development mechanism, but also for emissions reductions projects that focus on forest conservation and management. In the former case, the relationship of tree-species diversity to carbon sequestration is likely to be of 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 latter 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 enhance productivity and provide environmental services (Gobbi and Ibrahim, 2004). Most farmers permit natural regeneration of trees inpastures 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. In the Cañas area, estimated that introduced, more productive grasses (*Brachiaria brizantha* and *Brachiaria decumbens*) occupy 72% of the pasture areas and 56% of totalagricultural area. In such dry and seasonally dry areas, the use of drought tolerant and productive grasses improves the overall productivity of pastoral systems.

In addition to 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 this 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 a purely arable or pastoral system. Many Previous literatures suggest tree on pasture land have high potential for carbon sequestration (Veldkamp, 1994).

2.4.3 Crop land agroforestry

In the case of agroforestry where it is applied versus the ‘‘home’’ science base creates confusion in regards to ownership and endorsement. While agroforestry is a tree-based activity thereby requiring forestry knowledge, it generally 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 Forestry Land Use activities to glean their ‘‘agricultural’’ opportunities. And then there are agroforestry practices that fully integrate the tree/crop component throughout the whole farm, such as silvopasture and alley cropping, which despite their excellent carbon sequestering/production capabilities may not be picked up by either group (Nair and Nair, 2003).

3. Methods and Materials

3.1 Description of The study area and period

This study was conducted in Yem Special District from January – June, 2020. Yem is one of the Districts in the Southern Nations, Nationalities and Peoples' Region (SNNPR) of Ethiopia. Yem Special District is found at about 270 km southwest of Addis Ababa. The altitude of the District lies in the range of 950-2506 m above sea level. The district is located between 7°49' to 7°59′ N latitude and 37°29' to 37°59′ E longitude. Yem is not part of any Zone in the SNNPR; it is considered a Special District, an administrative subdivision which is similar to an autonomous area. Yem is bordered on the west and north by Oromia National Region State and separated from Gurage on the northeast and Hadiya on the east by the Omo River. High peaks in Yem include Mount BorAma, Mount Azulu and Mount Toba. The administrative center of Yem is Saja.

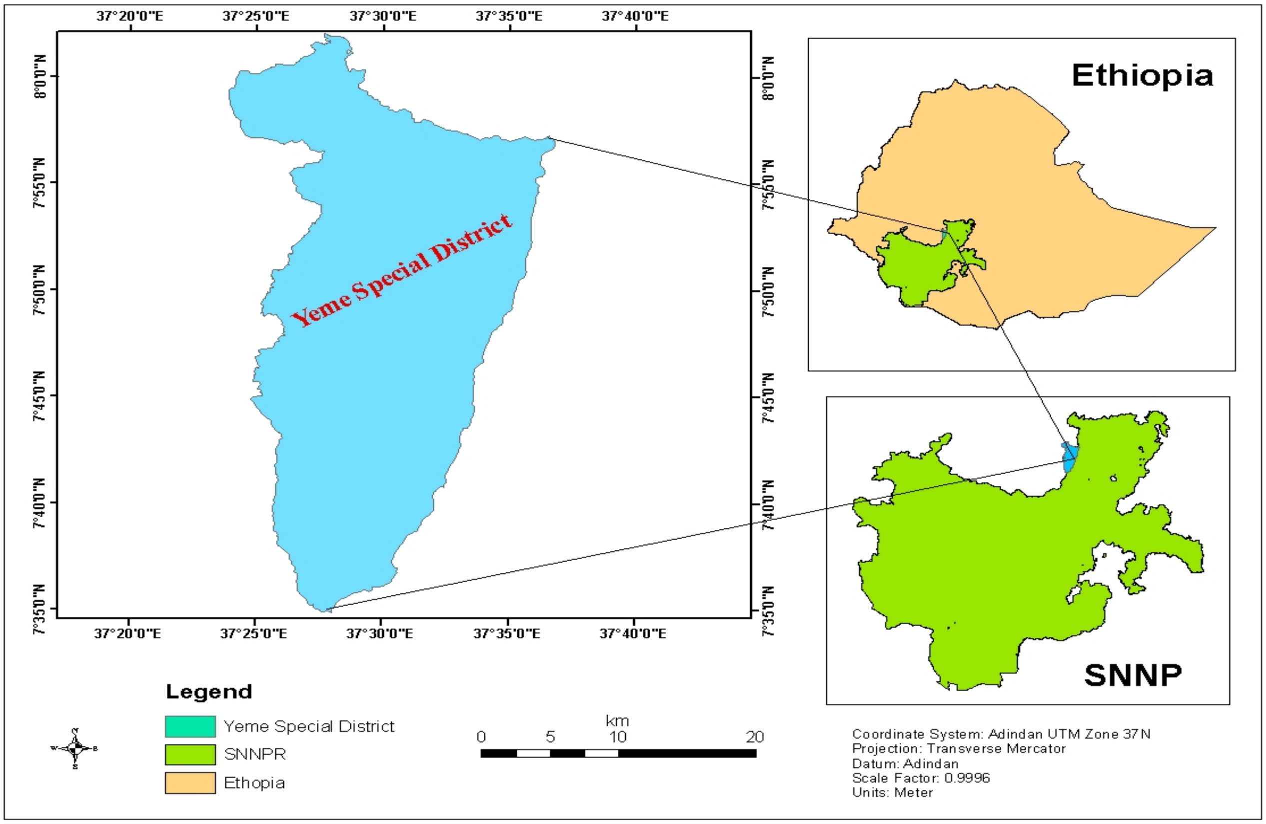

Figure 1: Location map of the study area showing Ethiopia, Southern Nations Nationalities Peoples Region and Yem Special District.

Source=Ethio Arc GIS

3.2 Population

Based on the 2008 Census conducted by the Central Statistical Agency of Ethiopia (CSA, 2008), this district has a total population of 80,687 of whom 40,566 are men and 40,121 are women; with an area of 647.90 square kilometers. A total of 17,632 households were counted in this district, which results in an average of 4.58 persons to household and 17,204 housing units. The three most numerous ethnic groups reported in this district were the Yem (90.57%), the Oromo (5.41%) and the Hadiya (1.27%); all other ethnic groups made up 2.75% of the population.

3.3 Climate, vegetation types and Agro-economy of the study area

The mean annual temperature is in the range of 1230ºC, while the average annual rainfall was 2200 mm in a bimodal pattern, from mid February it April and June to September. The vegetation type of the study area is moist evergreen montane and grass land complex. 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. Subsistence agriculture based on cereal and *Enset* farming is practiced in this district. Important crops include teff, wheat, barley and pulses. Other important non-agricultural sources of income include selling butter and others (SNNPR Livelihood District Reports, 2009).

3.4. Methods

3.4.1. Sampling design

A transect line of 23 km long with 1 km on either side was established across different land use types (homegarden (is the land that combine different physical, social and economic functions on the area of land around the home), pastureland (is the land that used for grazing animals) and cropland (is the land that used for growing crops)). Of 39 total sample plots, 13sample plots of 100m × 100m were laid in cropland, 13 sample plots of 100m × 100m were laid in pasture land and 13 sample plots of 25m × 25m were laid in homegardens (the homegardens were standardized to hectare for comparison with the two land use types). All plots were500m far apart from each other. .

3.4.2 Data collection

Woody species in three land use types were recorded, collected and pressed. The pressed sample specimens were transported to Jimma University Herbarium and have been identified using Flora of Ethiopia and Eritrea. The circumferences of each stem with diameter at breast height (DBH) ≥ 5cm, height ≥ 1.3 m were recorded from each plot (Mac, 1997). 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 have been recorded by using Geographic Positioning System (GPS). Samples of woody species (including their local names) have been recorded. Wood specific gravity of each tree species was also taken from global wood density data base developed by Chave *et al*. (2009).

3.5 Data analysis

3.5.1 Density

The density per hectare of trees and shrubs were calculated by summing up of all stems across all sample plots and converted into hectare.

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

$$\text{Relative Density (\%)} = \frac{\text{Number of individuals of species}}{\text{Total number of all individuals}} \times 100$$

3.5.2 DBH

Diameter at breast height or DBH is a standard method of expressing the diameter of the trunk bole of standing tree. DBH is used in estimating the amount of timber volume in a single tree or stand of trees utilizing the allometric correlation between stem diameter, tree height and timber volume (Mackie and Matthews, 2006).

3.5.3 Basal area

Basal area of the woody species in the three land use types was calculated using the following equation.

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

Where, BA = basal area

D = diameter at breast height

3.5.4 Species diversity

Woody species diversity of the three land use types in the district 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 by the ratio of observed diversity to the maximum diversity using the following equation.

$E = H'/H'max \quad H'max = \ln S$

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 to both land use types

b = number of species unique to the first land use type

c = number of species unique to the second land use type

3.5.7Carbon storage

Aboveground live biomass of each tree was calculated by using the revised non-destructive allometric equation (Chave *et al.*, 2014).Wood specific gravity was taken from Global wood density data base (Chave *et al.*, 2009).

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

Where, ρ = wood specific gravity,

D = diameter at breast height,

H = height.

Analysis of Variance (one way ANOVA) was determined using SPSS Version 20 computer software to show the variation of woody species density and carbon storage among different land use types.

Comparison of different land use types

One way ANOVA was used to compare the degree of similarity among different land use types in plant species richness, abundance and carbon storage. Prior to the use of ANOVA, the data were checked for distribution. Because of the data fail to satisfy the assumption of the normal distribution, an equivalent non-parametric test (Kruskal–Wallis test) was used.

For the analysis of variance (since it is parametric test), the data need to be normally distributed. Shapiro-Wilk normality test was applied to evaluate whether the data were normally distributed or not. The test showed that the data for the three land use types were not normally distributed ($P<0.05$). The normality probability plot also showed that the original data were not normally distributed. As a result the data were transformed using log transformation (look the normality probability plot after transformation) (Figure 2).

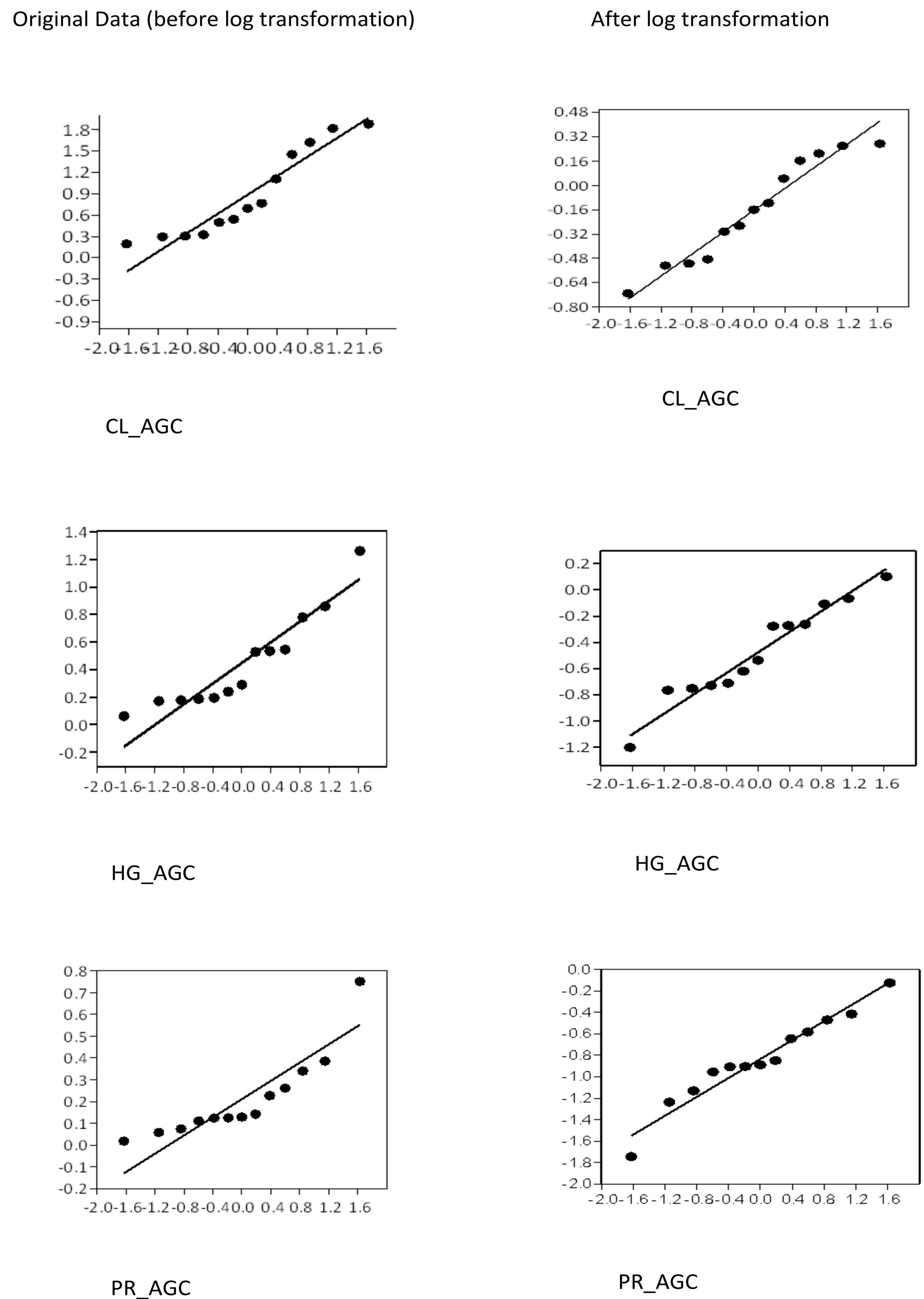

Figure 2: Normal Probability Plot showing the distribution of AGC data in three Land use types (CL = Cropland, HG = homegarden, PR = Pastureland, AGC = aboveground live carbon storage)

4. Results and Discussions

4.1 Results

4.1.1 Woody species richness, evenness and diversity

Woody species richness

Overall, 59 woody species belonging to 49 genera and 34 families were recorded from the three agroforestry systems along the main study transect line, of which 19 were shrubs and 40 were trees. From the all woody species families recorded in the study area, Euphorbiaceae, Fabaceae and Rosaceae were the most species rich families with 5 species each followed by Merytaceae and Rutaceae, with 4 species each. The others Asteraceae, Boraginaceae, Celasteraceae, Cuperessaceae, Meliaceae and Moraceae families composed of 2 species each.

About 35 woody species belonging to 22 families were recorded from homegarden. Similarly, 32 woody species belonging to21 families from the cropland and 34 woody species belonging to 24 families were recorded from cropland and pasture land respectively.

Woody species Habit

Majority of the woody species recorded were found in the form of trees while few species belong to shrub. Shrubs were common in homegarden and pastureland (28.6%) while trees were common in cropland and homegarden(71.4%)(Table 1).

Table 1: Growth form and distribution of woody species across the three land use types of Yem Special district

Land use types	**Habit**		
	Trees	Shrubs	**Total**
Homegarden	25	10	35
Cropland	25	7	32
Pasture land	24	10	34

4.1.2 Woody species diversity and evenness

Homegarden has relatively highest number of individual woody species diversity compared to the remaining two land use types, while Pasture land has the highest Shannon Diversity value (Table 2).

Table 2: Woody species diversity across the three agroforestry of Yem Special district

	Cropland	Home garden	Pasture
Richness	32	35	34
Individuals	236	275	149
Shannon_H	2.87	3.17	3.37
Evenness	0.55	0.68	0.85

4.1.3 Similarity in species composition

Croplands and pastureland showed high similarity in woody species composition whereas the least similarity was observed between homegarden and pastureland (Table 3).

Table 3: Similarity in species composition amongst the three land use types Yem Special district;

Land use types	Homegarden	Cropland	Pastureland
Homegarden	1	0.53	0.37
Cropland		1	0.63
Pastureland			1

4.1.4 Basal Area

From the individual stem count recorded from homegarden, *Persea americana* has relatively the highest BA followed by *Cordia africana* (Table 4).

Table 4: Top 5 woody species by their high Basal Area in Homegarden, Yem Special district

Species name	BA	BA/ha (m^2)
Persea americana	68.89	5.3
Cordia africana	68.79	5.29
Mangifera indica	39.9	3.06

Azadirachta indica	21.74	1.7
Croton macrostachyus	14.45	1.12

From the individual stem count recorded from cropland, *Albizia gummifera* (J. f. Gmel.) C.A.Sm has relatively the highest BA (10.08) followed by *Cordia africana* (BA = 5.24) (Table 5).

Table 5: Top 5 woody species by their high Basal Area in Cropland, Yem Special district

Species name	BA	BA/ha
Albizia gummifera(J. f. Gmel.) C.A.Sm	131.157	10.08
*Cordia africana*Lam.	68.1592	5.24
*Croton macrostachyus*Hochst.ex Del.	54.8559	4.2
*Ficus sur*forssk.	124.727	9.6
*Eucalyptus camaldulensis*Dehnk.	44.4697	3.4

From the individual stem count recorded from pastureland, *Croton macrostachyus* has relatively the highest BA followed by *Cordia africana* (Table 6).

Table 6: Top 5 woody species by their high Basal Area in pastureland, Yem Special district

Species name	BA	BA/ha
*Croton macrostachyus*Hochst.ex Del.	1323.33	101.78
*Cordia africana*Lam.	805.573	61.97
*Acacia abyssinica*Hochst ex Bench.	1419.51	109.2
Syzygium guineense(Wild.) Dc.	1218.23	93.7
*Ficus vasta*Frossk.	1379.62	106.12

4.1.5 Density and frequency of woody species

Overall, 660 individuals of 59 woody species with ≥ 5 DBH were recorded from three agroforestry systems (homegarden, cropland and pastureland). Trees were with higher density when compared to shrubs recorded from the three land-use types. The result also indicated that, homegardens were found to be with the highest woody species density compared to cropland and pasturelands (Figure 3; Table 7).

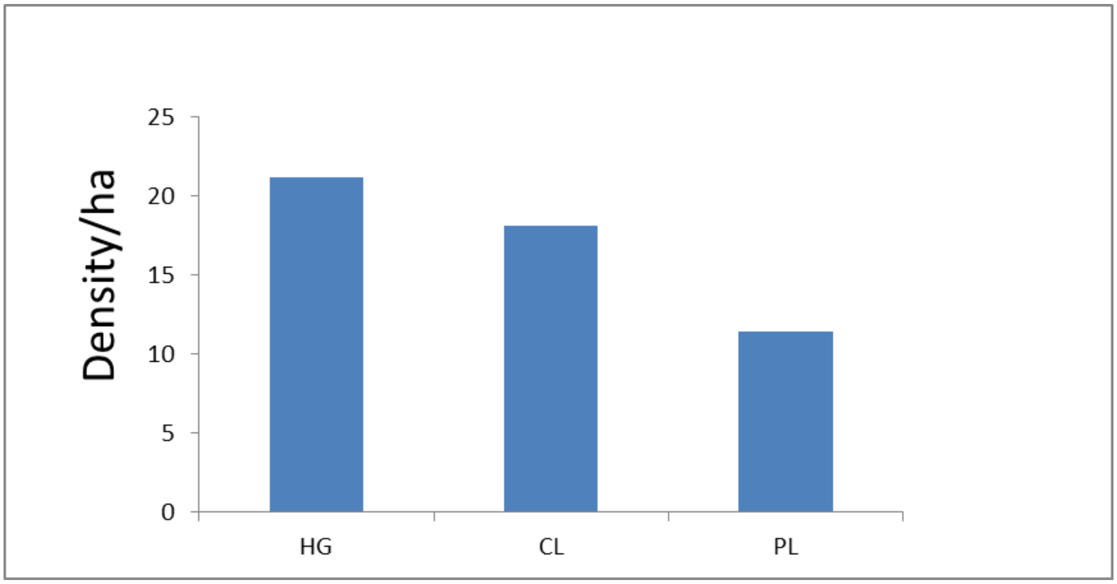

Figure 3: Woody species density of the three land use type of Yem Special District (HG = homegarden, CL = Cropland, PL = Pastureland)

Table 7: Frequency (F), Density (D) and Relative density (RD) of species recorded from homegarden, cropland and pasture land of Yem Special District

Land use type	Species name	F	D	RD
Homegarden	*Persea americana*	11	35	12.7
	Coffea arabica	9	25	9.09
	Cordia africana	8	27	9.8
	Mangifera indica	8	23	8.3
Cropland				
	Cordia africana	9	23	9.75
	Eucalyptus camaldulensis	7	30	12.7
	Croton macrostachyus	8	30	12.7

	Albizia gummifera	8	29	12.3
Pastureland				
	Cordia africana	3	6	4
	Albizia gummifera	4	7	4.7
	Eucalyptus camaldulensis	3	6	4
	Croton macrostachyus	5	8	5.4

Habit, Abundant and rare woody species

Trees were with higher density when compared to shrubs recorded from the three land-use types. The result also indicated that, homegardens were found to be with the highest woody species density compared to cropland and pasturelands. The most abundant tree species is *Cordia africana* and the most rare tree species is *Grewia ferruginea* and also the most abundant shrub species is *Coffea arabica* and the most rare shrub species is *Justicia schimepriana* and *Phytolacca dodecandra* (Table 8).

*Table8: Abundant and rare woody species of Yem Special District

Habit	Scientific name/Trees	No	Scientific name/Shrubs	No
Abundant Species	*Cordia africana*	56	*Coffea arabica*	30
	Eucalyptus camaldulensis	39	*Euphorbia tirucalli*	23
	Persea americana	38	*Catha edulis*	11
	Croton macrostachyus	45	*Carissa spinarum*	9
	Acacia abyssinica	35	*Rhamnus prinoides*	8
	Albizia gummifera	40	*Maytenus arbutifolia*	7
Rare Species	*Citrus aurantifolia*	2	*Osyris quadripartite*	3
	Prunus africana	2	*Justicia schimepriana*	2

	Grewia ferruginea	1	*Phytolacca dodecandra*	2

4.1.6Aboveground live Carbon storage and sequesteration

Different amount of carbon were calculated from three land use types in this study. The total amount of CO_2 sequestered across the three land use types was 73.79 t/ha. The highest amount of CO_2sequestration was calculated for Cropland and the least for Pastureland (Table 9).

Table 9: Summary of AGC and $AGCO_2$ in three land use types of Yem Special District

Land use type	AGC t/ha	CO_2 t/ha
Homegarden	5.84	21.43
Cropland	11.52	42.27
Pastureland	2.75	10.09
Total	20.11	73.79

There was a significance difference in AGC storage amongst the three land use types of the study area (F = 8.42, P <0.05) (Table 12). Tuky's multiple comparison showed that there was significant variation (P <0.05) between Crop and Pastureland in carbon storage (Table 10).

Table 10: Mean and standard deviation of AGC in three land use types of Yem Special District

Land use	Number of plots	Min	Max	Mean ± SD
Crop land_AGC (t)	13	0.195	1.883	0.89±0.61
Home garden_AGC (t)	13	0.063	1.263	0.45±0.35
Pasture land_AGC (t)	13	0.018	0.752	0.21±0.20

Table 11: Analysis of variance (ANOVA) showing variation in aboveground live carbon storage among the three agroforestry of Yem Special district

	Sum of sqrs	Df	Mean square	F	P
Between groups:	2.92807	2	1.46403	10.62	0.000238
Within groups:	4.96515	36	0.137921		
Total:	7.89321	38			

Table 12: Summary of one way ANOVA for comparison of AGC of the three land use types (HG = Homegarden, CL = Cropland, PR = Pastureland) of Yem Special district

	CL-AGC	HG_AGC	PR_AGC
CL-AGC		0.09483	0.0002
HG_AGC	3.035		0.048
PR_AGC	6.511	3.476	

4.1.6.1 Aboveground live carbon storage in different land use types

The highest amount of AGC and $AGCO_2$was calculated from the woody species recorded from the cropland. Homegarden and Pastureland were ranked second and third next to Cropland by AGC storage and $AGCO_2$ sequestration (Figure 4, A and B).

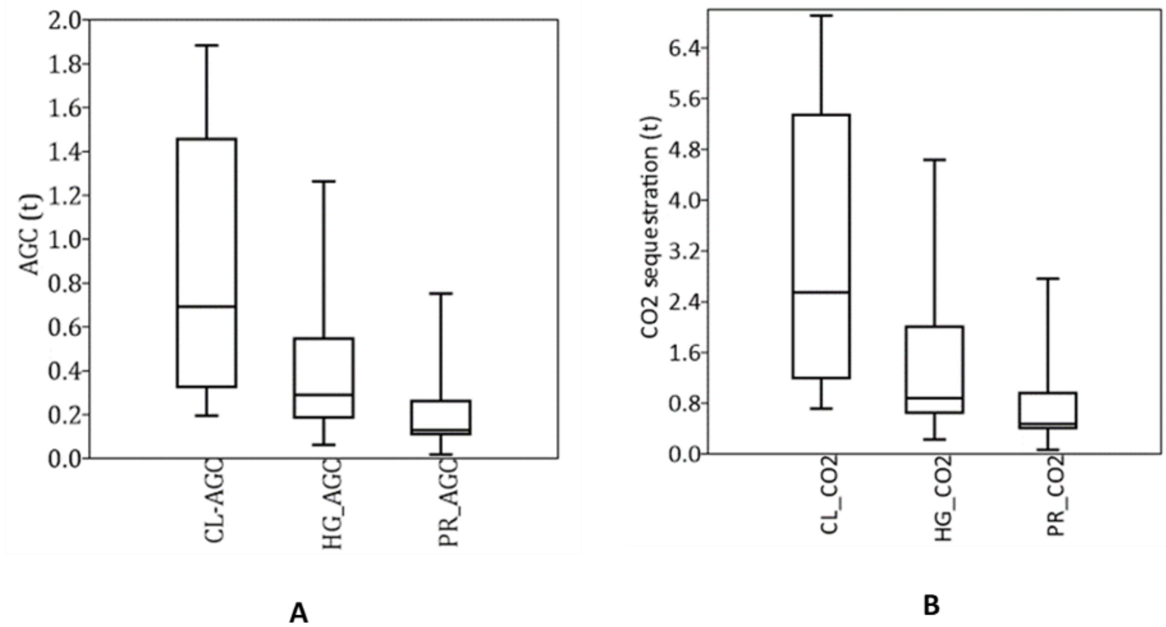

Figure 4: Box plot showing AGC (t/ha) and CO2 sequestration (t/ha) in three land use types of Yem Special District (A = aboveground live carbon storage, B = amount of CO_2 sequestered/ha)

The top five known woody species storing carbon and sequestering CO_2 in homegarden were, *P.americana* and *C.africana*, played very important role compared to any other woody species found in the Homegarden(Figure 5).

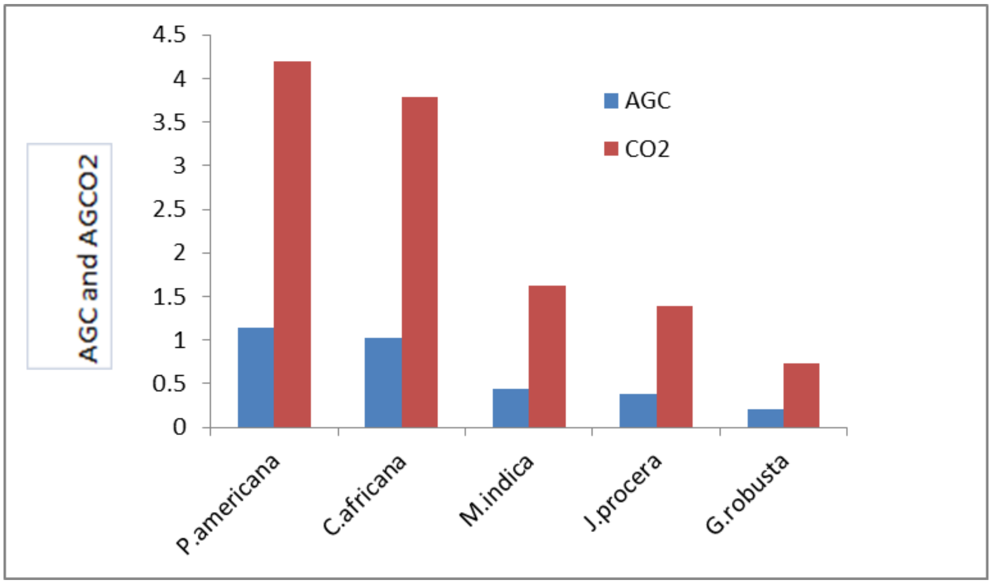

Figure 5: AGC and CO_2 stored in five top important woody species of Homegarden of Yem Special District

The top five species in carbon storage found in cropland were, *A.gummifera*, and *F.sur* played very important role than any other woody species found in cropland (Figure 6).

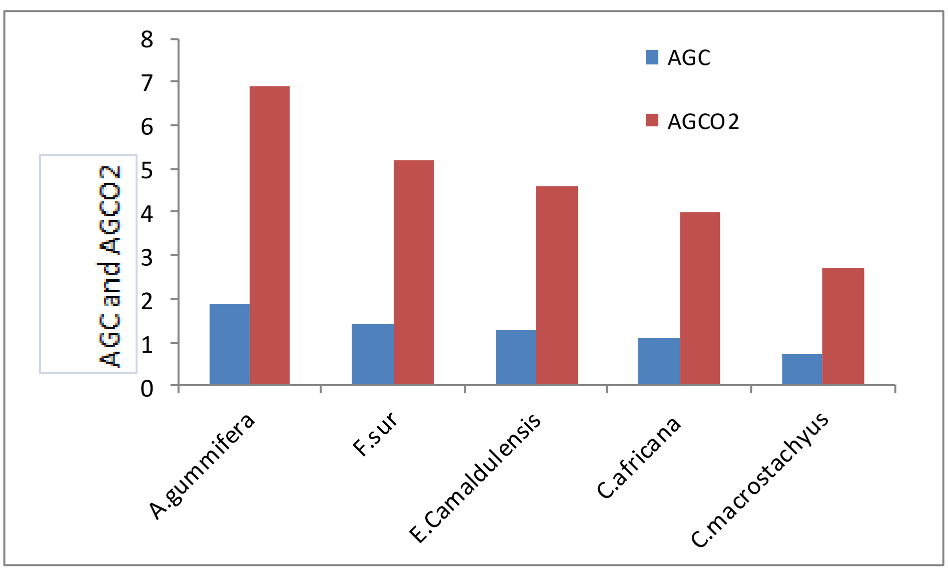

Figure 6: AGC and CO_2 in five top important woody species of cropland of Yem Special District

The top five known woody species instoring carbon and sequestering CO_2 in Pastureland were: *F.vasta* and *A.abyssinica* played very important role in carbon storage and CO_2 sequestration (Figure 7).

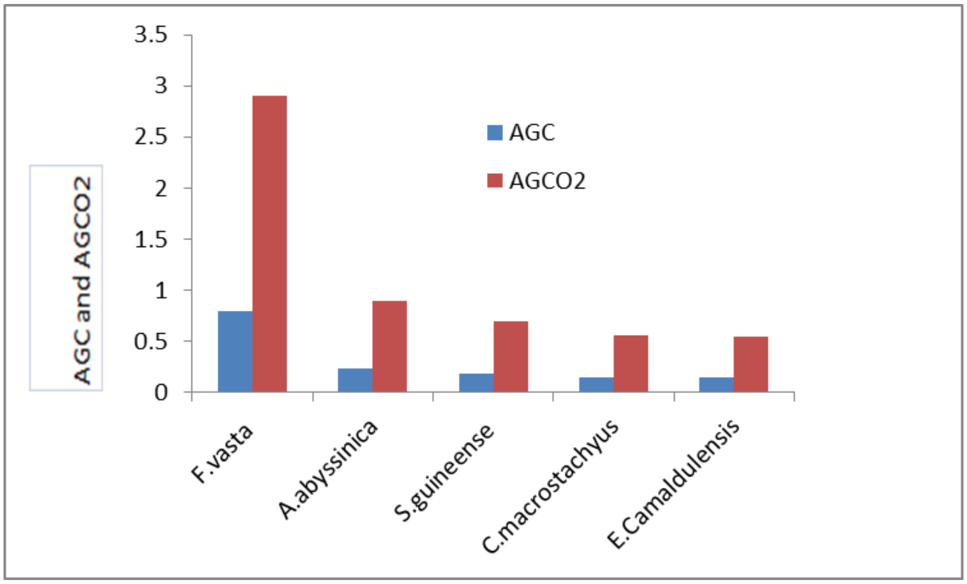

Figure 7: AGC and CO_2 in five top important woody species of pastureland of Yem Special District

4.2 Discussions

The highest number of woody species was recorded from homegarden and cropland as compared to the pastureland. The possible explanation for this difference of species richness among different land use types is that, farmers may conserve plants purposely depending on the economic values of those plants. They might prefer to conserve high canopy woody species in order to create a favorable environment for coffee shade, to get timber and for soil conservation. They might also prefer to conserve plants those produce edible fruits. For example, the most frequent woody species recorded from homegardens were fruit plants such as *P.americana, M.indica* whereas trees with high basal area and large canopy such as *C.africana, F.vasta, F.sur, C.macrostachyus* were recorded from cropland. This is similar with the study result 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}).There is also other similar report from India by Kumar *et al*. (1998) a multitude of plants of varying growth habits yielding diverse economic products and the species are planted and their products harvested, mostly for household consumption, throughout the year. Variations in tree management can be another issue: trees in AFS may be pruned depending on management practices or may have different growth forms due to differences in spacing compared to natural (forest) systems. Furthermore, no two agroforestry plots are similar: each may be unique in terms of plant composition, planting arrangements and stand densities. Thus, determination of biomass production from indigenous AFS is a challenging task and makes extrapolation from one system to others very difficult.

Croplands and Pastureland showed high similarity in woody species composition whereas the least similarity was observed between homegarden and pastureland. The possible explanation for this result is that they might prefer homegarden and pastureland to conserve woody species for different purposes than cropland because they might prefer cropland for farming purposes. There is a similar result reported by Smith (2004) in line with Agroforestry systems are very important given the area currently under agriculture, the number of people who depend on land for their livelihoods and the need for integrating food production with environmental services.

There is a variation of species richness among three land use types of the study area. The result of this study indicates that homegardens were found to be with the highest woody species density when compared to cropland and Pasturelands. Trees were with higher density compared to shrub species recorded from the three land-use types. The reason why the woody species density varies from one land use type to the other could be due to dissimilar management practices amongst different land use types and between plant habits, socio-economic factors such as preference of timber trees, food, fodder, construction materials, farm equipment, fuel wood and medicines. This is similar with the result reported by Mekonnen (2001); Tabuti (2012). According to these authors, farmers protect plant and promote woody species within and around their home gardens, fields and communal pasturelands to derive a range of benefits, including provisions of food, fodder, construction materials, farm equipment, fuel wood and medicines. The retention of trees and shrubs in agricultural landscapes depends on local ecological knowledge regarding the use and conservation of species, the values of plants within subsistence and market economies, land and other resource tenure systems that determine access, spiritual beliefs and traditions associated with plants, as well as changes in sociocultural structures (Neba, 2009).

The result of the study investigated that homegarden hosted highest stem density when compared to cropland and pastureland**.** This might be due to high economic importance of integrated woody species and provisions of ecosystem services and wind breaks around the home. This is in line with the study conducted by Aleixandre *et al*. (2014). According to him interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter, or income from products, including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services)".

The result also indicated that cropland was the second land use type with high stem density. This might be due to farmers' preference to conserve woody plants on their farm land for coffee shade, to reduce soil erosion and others. This result is in agreement with Alao and Shuaibu (2013) in which he indicated merging different crops in the same area benefits the farmers.

Some of the woody species were recorded frequently across the three land use types. Most frequent woody species across the three land use types of the study area was *Cordia africana* followed by *Croton macrostachyus*. Majority of the woody species were found in medium and lower frequency classes. The reason behind the variation of woody species in frequency across land use types might be human influence/unequal conservation, different ecological factors/environmental factors or soil types. This result is similar with the result reported from Bangladesh (Kibria and Anik, 2010) in which most woody species occurred in the lower class frequency.

The top known woody species found in the study area having the highest basal area from the three land use types (8.4 m^2/ha) was *Acacia abyssinica* followed by *Croton macrostachyus* (8.23 m^2/ha). The reason why these two woody species had a large basal area was that they had high DBH value. Of all land use types, woody species in croplands had the largest basal area followed by homegarden. The least value of basal area was calculated from woody species in Pastureland agroforestry. This might be influenced by the density and DBH of each stem count in each land use types. This is similar with the study conducted by Behailu Etana (2010) in northern Ethiopia. According to him, *A. abyssinica* and *C. africana* have been pushed out of their wild habitat and conserved in protected areas such as monasteries and in the agricultural lands. People's preference for different purposes like household furniture made *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).

The highest amount of AGC was calculated from the Cropland while the least was calculated from Pastureland. This result is much related with Perry *et al*. (2008).There are agroforestry practices that fully integrate the tree/crop component throughout the whole farm/alley cropping are excellent in carbon sequestering (Nair and Nair, 2003).

A.gummifera and *Cordia africana* were the most important woody species in carbon storage. They are densely populated woody species mostly found in cropland followed by homegarden. These two woody species could store the greatest amount of carbon. This might be due to their high density and high DBH. 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.

The top five known woody species by storing carbon and sequestering CO_2 in homegarden were *P.americana*, *C.africana*, *M.indica*, *J.procera* and *G.robusta.* Comparatively, *P.americana* and *C.africana* played very important role than any other woody species found in homegarden. The significance of homegarden agroforestry in carbon storage was well indicated in the study conducted by Albrecht and Kandji (2003) in which different forms of agro forestry, home gardens and boundary plantings have been well recognized as potential long-rotation systems that mitigate CO_2 and sequester sizeable quantities of carbon in plant biomass. Home gardens contain a significant fraction of the total above-ground biomass carbon stock in the terrestrial system and this proportion has increased from almost one-sixth in 1992 to nearly one-fifth in 2010. Home gardens store significant amount of carbon, with above ground biomass carbon stocks with a mean value of 35 $Mg \cdot C \cdot ha^{-1}$ in dry zone while 87 $Mg \cdot C \cdot ha^{-1}$ in wet zone in the terrestrial system in Sri Lanka (Mattsson *et al.*, 2013).

The top five species in carbon storage found in cropland were, *A.gummifera, F.sur, E.camaldulensis*, *C.africana* and *C.macrostachyus.* Compared to any woody species in the Cropland, *A.gummifera,* and *F.sur* played very important role in carbon storage. Similar result was reported by Makundi and Sathaye (2004) in which they showed the contribution of planting trees along with crops in cropland to improve soil fertility, soil erosion, water logging, check acidification and eutrophication of streams and rivers, increase carbon dioxide sequestration from the atmosphere, increase local biodiversity, decrease pressure on natural forests for fuel and provide fodder for livestock.

The top five known species in carbon sequestration and storage in pastureland were: *F.vasta, A.abyssinica, S.guineense, C.macrostachyus,* and *E.camaldulensis. Ficus vasta* and *A.abyssinica* were the most important woody species in carbon sequestration and storage in Pastureland.

5. Conclusion and Recommendation

5.1 Conclusion

59 woody species were collected from Yem Special District, of which 40 were trees and 19 were shrubs. Large amount the AGC calculated from the above ground biomass was stored in trees mainly due to their high DBH than shrubs. Homegarden hosted highest stem density compared to cropland and pastureland**.** The top five known woody species in carbon sequestration and storage in the homegarden were *P.americana*, *C.africana, M.indica, J.procera*, and *G.robusta.*The top five species in carbon storage found in cropland were: *A.gummifera, F.sur, E.camaldulensis, C.africana* and *C.macrostachyus.* The top five known species for carbon storage and sequestration in pastureland were: *F.vasta, A.abyssinica, S.guineense, C.macrostachyus* and *E.camaldulensis.*

Cordia africana was the most frequently occurred woody species followed by *Croton macrostachyus* across the three land use types (Homegarden, Cropland and Pasture).*Albizia gummifera* was the most abundant species with highest basal area. This species also stored the highest above ground 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 local community should pay attention for the conservation of themulti dimensionally important woody species found in the three land use systems (Cropland, Homegarden and Pastureland).
- All concerned bodies including government or nongovernment organization and local community should give priority for the conservation of rare or least frequent species in the study area.
- This study was conducted on woody species diversity and above ground live carbon storage in different agroforestry systems of Yem special District. But woody species diversity, above and below ground live carbon storage in natural forest and the rest agroforestry systems were not conducted. Hence we recommend for further study on other land use systems of the District.

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Appendixes

Appendixes 1: List of woody species recorded from the study area (L. name= local name, ha= habit)

No	Scientific name	L.name in Yemegna	Family	ha
1	*Acacia abyssinica* Hochst ex Bench.	Ezu/Gerar	Fabaceae	T
2	*Albizia gummifera* (J. f. Gmel.) C.A.Sm	Sesa	Fabaceae	T
3	*Annona reticulata* L.	Gesheta	Annonaceae	T
4	*Azadirachta indica*	Nimi	Meliaceae	T
5	*Bersama abyssinica* Fresen.	Korbo/Lolchisa	Melianthaceae	T
6	*Calpurnia auria* (Lam.)Benth.	Zimsa/Digita	Fabaceae	T
7	*Carica papaya* L.	Papaya	Caricaceae	T
8	*Carissa edulis* (Forssk.) Vahl	Alelu/Agam	Apocynaceae	Sh
9	*Casmira edulis* (La.) Liave and lex.	Kasmir	Rutaceae	T
10	*Casuarina equisetifolia* L.	Shuwashushe	Casuarinaceae	T
11	*Catha edulis* (Vahl) Frossk. exEnd/.	Jima/Chat	Celastraceae	Sh
12	*Celtis africana*	Kawaya/Kawet	Ulmaceae	T
13	*Citrus aurantifolia* (Christm.)Swingle	Lomiya /Lomi	Rutaceae	T
14	*Citrus sinensis* (L.) Osbeck.	Birtukan	Rutaceae	T
15	*Clausena anisata* (Wild.) Hook. F. ex. Benth	Kamakesa/Lemch	Rutaceae	Sh
16	*Coffea arabica* L.	Ushtefawa/Buna	Rubiaceae	Sh
17	*Combretum paniculatum* Vent	Tult	Combretaceae	T
18	*Cordia africana* Lam.	Waza/Wanza	Boraginaceae	T
19	*Croton macrostachyus* Hochst.ex Del.	Woshkela/Bisana	Euphorbiaceae	T
20	*Cupressus lusitanica* Mill.	Ye Ferenj tid	Cupressaceae	T
21	*Dodonaea angustirolia* L. f.	Titira/Ketketa	Sapindaceae	T
22	*Ehretia cymosa* Thonn.	Karewaza/Ulaga A/o	Boraginaceae	T
23	*Ekebergia capensis* Sparm.	Oroma/Weyba	Meliaceae	T
24	*Erythrina bureccei* Schweinf.	Kocho/Korch	Papilionoideae	T
25	*Eucalyptus camaldulensis* Dehnk.	Shea bahirzafi/Key bahirzaf	Myrtaceae	T
26	*Eucalyptus globulus*	Foro bahirzafiNech Bahirzaf	Myrtaceae	T
27	*Euphorbia abyssinica* J.F. Gmel.	Akema/Kulkual	Euphorbiaceae	T
28	*Euphorbia trucali* L.	Kencheb	Euphorbiaceae	Sh
29	*Ficus sur* Forssk.	Teya/Shola	Moraceae	T

30	*Ficus vasta* Frossk.	Kasha/Warka	Moraceae	T
31	*Gossypium arboretum*	Tiro/Tit	Manaceae	Sh
32	*Grevillea robusta*	Giravila	proteaceae	T
33	*Grewia ferruginea* Hochst. exA. Rich.	Kerero	Tiliaceae	T
34	*Hagenia abyssinica* (Bruce) J.F Gmel.	Offa/Ye Koso zaf	Rosaceae	T
35	*Juniperus procera* Hochst. Ex Endl.	Arkewa/Ye habesha tid	Cupressaceae	T
36	*Justicia schimepriana*	Atabiyo/Sensel	Acanthaceae	Sh
37	*Maesa lanceolata* Forssk	Tegewa/kelewa	Myrsinaceae	Sh
38	*Malus pumila*	Apple	Rosaceae	Sh
39	*Mangifera indica* L.	Mango	Anacardiaceae	T
40	*Milletia ferruginea* (Hockst.) Bak	Zagu/Birbira	Fabaceae	T
41	*Moringa oleifera*	Moringa/Shiferaw	Moringaceae	T
42	*Moytenus arbutifolia* (A. Rich.) Wilczek	Sona/Atat	Celastraceae	Sh
43	*Olea europea* ssp. Cuspidata	Tustefawa buna/Weyra	Oleaceae	T
44	*Osyris quadripartita* Decn.	Keret	Santalaceae	Sh
45	*Persea americana* Mill.	Avocado	Lauraceae	T
46	*Phoenix reclinata* Jacq.	Deya/Zembaba	Arecaceae	T
47	*Phytolacca dodecandra* L. Herit	Andode	Phytolaccaceae	Sh
48	*Prunus africana* (Hook.f.) Kalkm	Wedebiyo/Tikur-zafe	Rosaceae	T
49	*Prunus persica*	Kuko/Kok	Rosaceae	T
50	*Psidium guajava* L.	Zayituna	Myrtaceae	Sh
51	*Rhamnus prinoides*	Geshe/Gesho	Rhamnaceae	Sh
52	*Ricinus communis* L.	Kobo/Gulo	Euphorbiaceae	Sh
53	*Rosa abyssinica* R. Br. Ex Lindl.d	Garona/Kega	Rosaceae	Sh
54	*Sapium ellipticum* (Krauss) Pax	Kerero	Euphorbiaceae	T
55	*Sesbania sesban* L. Merr.	Bunio/Sasbania	Fabaceae	Sh
56	*Spathodea campanulata* P. Beanv	Akuba/Anonobo	Bignoniaceae	T
57	*syzygium guineense* (Wild.) Dc.	Shew/Dokma	Myrtaceae	T
58	*Vernonia amygdalina* Del.	Sukero/Gerawa	Asteraceae	Sh
59	*Vernonia auriulifera* Hiern	Buzo/Gizawa	Asteraceae	Sh

Appendixes 2: AGC, CO_2 stored and density of woody species at Homegarden

Pilots	Altitude	AGC t/ha	CO2 t/ha	Density
P1	1999	0.529	0.529	16
P2	1984	0.535	1.964	24
P3	2023	0.178	0.654	23
P4	2064	0.781	2.865	25
P5	2145	0.172	0.631	17
P6	2163	1.263	4.633	34
P7	2243	0.240	0.879	19
P8	2245	0.547	2.006	16
P9	2276	0.291	1.067	19
P10	2424	0.187	0.687	14
P11	2394	0.195	0.715	23
P12	2465	0.063	0.230	16
P13	2439	0.860	3.157	29
Total		5.839	20.018	275

Appendixes 3: AGC, CO_2 stored and density of woody species at Cropland

Plots	Altitude	AGC t/ha	CO2 t/ha	Density
P1	1980	0.766	2.810	11
P2	2080	0.195	0.716	12
P3	2111	0.497	1.825	12
P4	2133	0.693	2.544	24
P5	2140	0.543	1.992	14
P6	2200	0.327	1.198	13
P7	2213	1.883	6.909	17
P8	2297	0.306	1.122	21
P9	2251	1.456	5.345	21
P10	2287	0.297	1.090	25
P11	2300	1.822	6.685	22
P12	2346	1.110	4.074	23
P13	2430	1.624	5.959	21
Total		11.518	42.270	236

Appendixes 4: AGC, CO_2 stored and density of woody species at Pastureland

Pilots	Altitude	AGC t/ha	CO2 t/ha	Density
P1	2069	0.129	0.473	8
P2	2064	0.386	1.415	15
P3	2113	0.018	0.065	7
P4	2123	0.058	0.214	10
P5	2179	0.074	0.272	9
P6	2221	0.262	0.960	11
P7	2270	0.125	0.459	12
P8	2277	0.752	2.761	14
P9	2304	0.227	0.833	16
P10	2283	0.111	0.408	13
P11	2462	0.124	0.454	9
P12	2456	0.142	0.522	9
P13	2447	0.340	1.249	16
Total		2.748	10.086	149

Appendixes 5: Types of Woody species and families found in Homegarden

Albizia gummifera (J. f. Gmel.) C.A.Sm	Sesa	Fabaceae
Annona reticulata L.	Gesheta	Annonaceae
Azadirachta indica	Nimi	Meliaceae
Calpurnia auria (Lam.)Benth.	Zimsa/Digita	Fabaceae
Carica papaya L.	Papaya	Caricaceae
Casmira edulis (La.) Liave and lex.	Kasmir	Rutaceae
Casuarina equisetifolia L.	Shuwashuwe	Casuarinaceae
Catha edulis (Vahl) Frossk. ex End/.	Jima/Chat	Celastraceae
Citrus sinensis (L.) Osbeck.	Birtukan	Rutaceae
Coffea arabica L.	Ushtefawa/Buna	Rubiaceae
Cordia africana Lam.	Waza/Wanza	Boraginaceae
Croton macrostachyus Hochst.ex Del.	Woshkela/Bisana	Euphorbiaceae
Cupressus lusitanica Mill.	Tid/Ye Ferenj Tid	Cupressaceae
Ekebergia capensis Sparm.	Oroma/Weyba	Meliaceae
Eucalyptus camaldulensis Dehnk.	Shea bahirzafi/Key bahirzaf	Myrtaceae

Euphorbia trucali L.	Kencheb	Euphorbiaceae
Gossypium arboretum	Tiro/Tit	Manaceae
Grevillea robusta	Giravila	proteaceae
Hagenia abyssinica (Bruce) J.F Gmel.	Offa/Ye Koso zaf	Rosaceae
Juniperus procera Hochst. Ex Endl.	Arkewa/Ye habesha tid	Cupressaceae
Maesa lanceolata Forssk	Tegewa/kelewa	Myrsinaceae
Malus pumila	Apple	Rosaceae
Mangifera indica L.	Mango	Anacardiaceae
Moringa oleifera	Moringa/Shiferaw	Moringaceae
Persea americana Mill.	Avocado	Lauraceae
Phytolacca dodecandra L. Herit	Andode	Phytolaccaceae
Prunus africana (Hook.f.) Kalkm	Wedebiyo/Tikur-zafe	Rosaceae
Prunus persica	Kuko/Kok	Rosaceae
Psidium guajava L.	Zayituna	Myrtaceae
Rhamnus Prinoides	Geshe/Gesho	Rhamnaceae
Ricinus communis L.	Kobo/Gulo	Euphorbiaceae
*Sapium ellipticum (*Krauss) Pax	Kerero	Euphorbiaceae
Sesbania sesban L. Merr.	Bunio/Sasbania	Fabaceae
Vernonia amygdalina Del.	Sukero/Gerawa	Asteraceae
Vernonia auriulifera Hiern	Buzo/Gizawa	Asteraceae

Appendixes 6: Types of Woody species and families found in Cropland

Acacia abyssinica Hochst ex Bench.	Ezu/Gerar	Fabaceae
Albizia gummifera (J. f. Gmel.) C.A.Sm	Sesa	Fabaceae
Annona reticulata L.	Gesheta	Annonaceae
Azadirachta indica	Nimi	Meliaceae
Bersama abyssinica Fresen.	Korbo/Lolchisa	Melianthaceae
*Calpurnia auria (*Lam.)Benth.	Zimsa/Digita	Fabaceae
Citrus aurantifolia (Christm.)Swingle	Lomiya /Lomi	Rutaceae
Citrus sinensis (L.) Osbeck.	Birtukan	Rutaceae
Coffea arabica L.	Ushtefawa/Buna	Rubiaceae
Cordia africana Lam.	Waza/Wanza	Boraginaceae
Croton macrostachyus Hochst.ex Del.	Woshkela/Bisana	Euphorbiaceae
Cupr0.3.essus lusitanica Mill.	Ye Ferenj tid	Cupressaceae

Ehretia cymosa Thonn.	Karewaza/Ulaga A/o	Boraginaceae
Ekebergia capensis Sparm.	Oroma/Weyba	Meliaceae
Erythrina bureccei Schweinf.	Kocho/Korch	Papilionoideae
Eucalyptus camaldulensis Dehnk.	Shea bahirzafi/Key bahirzaf	Myrtaceae
Eucalyptus globulus	Foro bahirzafiNech Bahirzaf	Myrtaceae
Euphorbia trucali L.	Kencheb	Euphorbiaceae
Ficus sur Forssk.	Teya/Shola	Moraceae
Ficus vasta Frossk.	Kasha/Warka	Moraceae
Grevillea robusta	Giravila	proteaceae
Grewia ferruginea Hochst. exA. Rich.	Kerero	Tiliaceae
Maesa lanceolata Forssk	Tegewa/kelewa	Myrsinaceae
Mangifera indica L.	Mango	Anacardiaceae
Milletia ferruginea (Hockst.) Bak	Zagu/Birbira	Fabaceae
Moytenus arbutifolia (A. Rich.) Wilczek	Alelu/Agam	Celastraceae
Olea europea ssp. Cuspidata	Tustefawa buna/Weyra	Oleaceae
Persea americana Mill.	Avocado	Lauraceae
Phoenix reclinata Jacq.	Deya/Zembaba	Arecaceae
Ricinus communis L.	Kobo/Gulo	Euphorbiaceae
syzygium guineense (Wild.) Dc.	Shew/Dokma	Myrtaceae
Vernonia amygdalina Del.	Sukero/Gerawa	Asteraceae

Appendixes 7: Types of Woody species and families found in pastureland

Acacia abyssinica Hochst ex Bench.	Ezu/Gerar	Fabaceae
Albizia gummifera (J. f. Gmel.) C.A.Sm	Sesa	Fabaceae
Bersama abyssinica Fresen.	Korbo/Lolchisa	Melianthaceae
Calpurnia auria (Lam.)Benth.	Zimsa/Digita	Fabaceae
Carissa edulis (Forssk.) Vahl	Alelu/Agam	Apocynaceae
Celtis africana	Kawaya/Kawet	Ulmaceae
Clausena anisata (Wild.) Hook. F. ex. Benth	Kamakesa/Lemch	Rutaceae
Combretum paniculatum Vent	Tult	Combretaceae
Cordia africana Lam.	Waza/Wanza	Boraginaceae
Croton macrostachyus Hochst.ex Del.	Woshkela/Bisana	Euphorbiaceae
Cupressus lusitanica Mill.	Ye Ferenj tid	Cupressaceae

Dodonaea angustirolia L. f.	Titira/Ketketa	Sapindaceae
Ehretia cymosa Thonn.	Karewaza/Ulaga A/o	Boraginaceae
Ekebergia capensis Sparm.	Oroma/Weyba	Meliaceae
Erythrina bureccei Schweinf.	Kocho/Korch	Papilionoideae
Eucalyptus camaldulensis Dehnk.	Shea bahirzafi/Key bahirzaf	Myrtaceae
Euphorbia abyssinica J.F. Gmel.	Akema/Kulkual	Euphorbiaceae
Euphorbia trucali L.	Kencheb	Euphorbiaceae
Ficus sur Forssk.	Teya/Shola	Moraceae
Ficus vasta Frossk.	Kasha/Warka	Moraceae
Grevillea robusta	Giravila	proteaceae
Justicia schimepriana	Atabiyo/Sensel	Acanthaceae
Maesa lanceolata Forssk	Tegewa/kelewa	Myrsinaceae
Millettia ferruginea	Zagu/Birbira	Fabaceae
Moytenus arbutifolia (A. Rich.) Wilczek	Sona/Atat	Celastraceae
Olea europea ssp. Cuspidata	Tustefawa /Weyra	Oleaceae
Osyris quadripartita Decn.	Keret	Santalaceae
Phoenix reclinata Jacq.	Deya/Zembaba	Arecaceae
Psidium guajava L.	Zayituna	Myrtaceae
Rosa abyssinica R. Br. Ex Lindl.d	Garona/Kega	Rosaceae
Sapium ellipticum (Krauss) Pax	Kerero	Euphorbiaceae
Spathodea campanulata P. Beanv	Akuba/Anonobo	Bignoniaceae
syzygium guineense (Wild.) Dc.	Shew/Dokma	Myrtaceae
Vernonia auriulifera Hiern	Buzo/Gizawa	Asteraceae