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WOODY PLANT SPECIES DIVERSITY AND CARBON STOCKS POTENTIAL OF HOME GARDEN AGRO-FORESTRY IN EPHRATANA GIDM DISTRICT, CENTRAL ETHIOPIA

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WOODY PLANT SPECIES DIVERSITY AND CARBON STOCKS POTENTIAL OF HOME GARDEN AGRO-FORESTRY IN *EPHRATANA GIDM DISTRICT*, CENTRAL ETHIOPIA

MSc. Thesis

By

Mesafint Minale

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THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr Mesafint Minale** entitled **Woody Plant Species Diversity And Carbon Stocks Potential Of Homegarden Agro-Forestry In *Ephratana Gidm* District, Central Ethiopia**. We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) **In Environment and Climate Change.**

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DECLARATION

This is to certify that the thesis entitled “Woody plant Species Diversity and Carbon Stocks Potential of Homegarden Agro-Forestry in *Ephratana Gidm* District, Central Ethiopia” Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in “**Environment and Climate Change”** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr.Mesafint Minale Fenta (ID No.BDU0906256PR/2016) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of my knowledge and belief.

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ACRONYMS AND ABBREVIATIONS

AFS	Agroforestry System
AGB	Aboveground Biomass
ANRS	Amhara National Regional State
BGB	Belowground Biomass
C	Carbon
CDM	Clean Development Mechanism
DBARC	Debre Birhan Agricultural Research Center
DBH	Diameter at Breast Height
EGWAO	*Ephratana Gidm Wereda* Agriculture Office
FAO	Food and Agricultural Organization
HG	Homegarden
ha	hectare
ICRAF	International Center for Research in Agroforestry
IPCC	Intergovernmental Panel on Climate Change
IVI	Important Value Index
NPP	Net Primary Productivity
Pg	Peta grams (1 Pg=10^{15} grams=1 billion ton)
REDD^{+}	Reducing Emissions from Deforestation and Forest Degradation
SEM	Standard Error of Mean
SHARC	Sheno Agricultuaral Research Center
SLUF	Sustainable Land Use Forum
SOC	Soil Organic Carbon
UNFCCC	United Nations Framework Convention on Climate Change

Woody Plant Species Diversity and Carbon Stocks Potential Of Homegarden Agro-Forestry In *Ephratana Gidm* District, Central Ethiopia.

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ABSTRACT

Homegarden agroforestry is one of the common practices in the Central part of Ethiopia. This is because of the multifunctional ecosystem services, such as food, feed, biodiversity conservation and carbon storage potential. This, in turn is useful for climate change mitigation and adaptation under the current changing environment. But structure, diversity and carbon stock status of homegarden (HG) were not well-studied. This study was carried out to assess the influence of land size on floristic diversity, richness, biomass carbon stock and soil organic carbon (SOC). A total of 30 HGs were surveyed in Ephratana gidm using a stratified random sampling. The homegardens were classified into small (<0.06 ha), medium (0.06–0.1 ha) and large (>0.1 ha). The main parameters were landholding size, species names, floristic composition, height, and diameter at breast height (DBH) of all trees and shrubs (>2.5 cm DBH). Biomass of the HG was computed using allometric equations. Statistical analysis was used to choose the suitable allometric equations among developed for tropical regions. The carbon stock was estimated using a constant 47% of biomass. SOC of the homegarden was estimated at (0-60 cm)). A total of 39 woody species, belonging to 24 families were recorded in all the study HGs. Shannon diversity index (H') was 1.8, 1.6 and 1.9 for small, medium, and large homegardens, respectively. Tree density (625.8 tree ha^{-1}) and basal area (17.3 m^{2} ha^{-1}) were highest for small-sized holdings. However, large homegardens had more species richness (Margalef Index) per garden (12.4) compared to medium and small size HG. Mean biomass C ranged from 9 to 89.3 ton ha^{-1}. Mean biomass carbon stock per unit area was higher in small HG (49.3 ton ha^{-1}) compared to medium (38.4 ton ha^{-1}) and large (35 ton ha^{-1}). Total C stock (biomass C + soil C, 0–60 cm depth) range from 77.2 to 258.3 ton C ha^{-1} with a mean value (164.0 ton C ha^{-1}), indicating that a major portion of the total amount of C in the system is stored in the soil. This result implies that homegarden can serve as both for carbon sequestration and conservation of woody species diversity. However, a specific homegarden management plan is necessary to improve the carbon storage and species diversification to the respective area. The results provide a catalyst the implication of the future potential of HG management in carbon storage thereby for climate change adaptation and mitigation purpose. This helps to start the integration of the Reducing Emissions from Deforestation and Forest Degradation (REDD^{+}) concept as a national program.

Keywords: Agroforestry; Biomass; Carbon stock; Climate Change; Homegardens; Species Diversity

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Chapter One. INTRODUCTION

1.1 Background and Justification

Rising levels of atmospheric carbon dioxide (CO_2) and associated greenhouse gases (GHG) are contributing to the global warming. It is becoming a central point of discussion for climate change (CC) adaption and mitigation (IPCC, 2007). If GHG concentrations continue to increase, it is likely that global average temperature will raise further (IPCC, 2013). The increased atmospheric CO_2 concentration distorts the living standard of the people and makes earth unsuitable for life (Kumar and Nair, 2011). There are signs of climate change in East African countries including Ethiopia. This is revealed by the recurrent drought, floods and famine that have threatened millions of people and livestock (Badege Bishaw *et al*., 2013). Removing atmospheric C and storing it within vegetation and soil pools in terrestrial ecosystems is one of the means to mitigate GHG emissions (IPCC, 2013).

The world needs carbon (C) sequestration techniques that provide social, environmental, and economic benefits while reducing atmospheric CO_2 concentration (Kumar and Nair, 2011). Tree-based farming is believed to be a major potential for carbon sink and could absorb large quantities of C (Kumar and Nair, 2011; Jose and Bardhan, 2012). Agroforestry as a land use system is getting wider recognition not only in terms of agricultural sustainability but also in issues related to CC (Albrecht and Kandji, 2003; Mesele Negash, 2013). Agroforestry systems maximize carbon stocks in the terrestrial biosphere (Verchot *et al.,* 2005) due to diversity and management for biomass (Henry *et al.,* 2009). The assessment report in different parts of the world including tropical regions showed that agroforestry would offer the highest C sequestration (IPCC, 2007; Verchot *et al*., 2007). In Ethiopia, the integration of trees and shrubs into agriculture emerged some 7000 years ago (Edmond *et al*., 2000). Agroforestry systems providing food, source of feed and income for smallholders are practiced in different regions based on the interest of local communities (Kanshie, 2002). The main objective of agroforestry is to improve land productivity through biomass maximization and product diversification. This includes improving the carbon stock for climate change mitigation and adaptation. Hence, long rotation systems such as agroforestry practices, namely; home-gardens and boundary plantings enable to sequester reasonable quantities of carbon in plant biomass and in wood products through photosynthesis process. This enables to sink reasonable amount of carbon in the soil in many agroforestry systems **(**Albrecht and Kandji, 2003).

Agroforestry is the deliberate integration of trees with the other systems mainly crops and livestock to improve agricultural productivity through product diversification, biodiversity and thereby avert risk of crop failure (ICRAF 2006). Agroforestry also ameliorate soil fertility and control erosion. In addition, the diversification of plants in the system is an opportunity to adapt to the changing climate and contribute significantly to greenhouse gas (GHG) emission reductions, from which payment for environmental services (PES) could potentially accrue (Badege Bishaw *et al*., 2013). Agroforestry practices accessed tree resources and forest products that are lost from natural forests and woodlands due to agricultural expansion (FAO, 2010). The empirical estimate of soil carbon sequestration potential of agricultural practices has been argued to be one of the major bottlenecks preventing the introduction of carbon payments to African farmers (Kahiluoto *et al*., 2014).

Different agroforestry practices have different potential to store carbon and depending on species diversity and environmental variables (Kumar and Nair, 2011). In addition, contribution of agroforestry to soil carbon (C) sequestration depends largely on the amount and quality of input provided by tree, non-tree components of the system and properties of the soils (Nair *et al.*, 2009a).

The precise relation between diversity and sustainability is still heavily debated. However, home-gardens are ecologically and socio-economically sustainable due to their species diversity (Tesfaye Abebe *et al*, 2009). A homegarden agroforestry is defined as an intensive land use system that combine diverse farming components such as annual, perennial crops and livestock that can provide environmental services, employment opportunities and household demands (Weerahewa *et al* 2012). In addition, homegarden has a potential for carbon (C) sequestration and thereby maintain a sound and sustainable ecology (Mohan, 2004) mainly for CC mitigation and adaptation under changing environment. This is because of the multifunctional ecosystem services and multiple arrangements of plant and relatively high species diversity compared to other agroforestry practices (Mersha Gebrehiwot, 2013). It is known that the existing climatic change causes adverse effects on food production and the lives of the people. It is also becoming more worsening. The impacts of CC are sensed depend largely on the extent of adaptation and mitigation measures. HG could also play a significant role in adaptation to CC *i.e.* change the microclimate, provide permanent cover, diversify the agricultural systems, improve resource use efficiency, improve soil fertility, reduce carbon emissions and increase carbon stock in the soil and biomass (Rao *et al*, 2007). According to studies conducted in Sub Saharan Africa homegardens is one of the land use practices suggested for CC adaptation and mitigation more than the monoculture practice (Asia Pacific Network for Global Change Research [APN], 2010).

1.2 Statement of the problem

Agroforestry as part of a multifunctional working landscape can play a major role in conserving and enhancing biodiversity from small farms to the landscape level (Jose, 2012). Currently, climate change is becoming a concern because it threatens the survival of live on earth. Trees outside forests (TOF) in the form of agro/farm forestry are an economically feasible and ecologically viable option. However, TOF are an often neglected as carbon pool and little information is available on the potential of carbon stocks in these systems (Hairiah *et al*., 2011 and De Foresta *et al*., 2013) and to evaluate its contribution for carbon stock. The fifth assessment report of the IPCC (2013) estimated that by 2040 agroforestry would offer the highest potential of carbon (C) sequestration in developing countries. Thus, the importance of agroforestry as a sustainable land-use system is receiving wider recognition for agricultural sustainability, biodiversity, and soil and water conservation and eventually to contribute directly and indirectly for CC adaptation and mitigation. Agroforestry in general and homegarden agroforestry particular is recognized during Kyoto Protocol as a C sequestration strategy activity under the afforestation and reforestation programmes (Kumar and Nair, 2011).

If agroforestry/homegarden agroforestry is to be used in carbon sequestration schemes such as the clean development mechanism (CDM) or REDD$^+$, better information is required in several areas (Verchot *et al.*, 2005). Lack of empirical estimates of biomass and soil carbon stock potential of agroforestry practices has been argued to be one of the major bottlenecks preventing the introduction of carbon payments to African farmers (Bryan *et al*., 2010; Kahiluoto *et al*., 2012, 2014).

As a result, estimation of carbon may provide the possibility of promoting traditional tree based farming practices. This, in turn, resulted in an opportunity for improving smallholding farmer's economic benefit through carbon trading (Nair *et al.,* 2009b).

Therefore, the introduction and development of agroforestry practices in farmlands provide multifunctional uses and are best options in the sustainable conservation mainly in agriculture dominated regions like Amhara. Empirical information on carbon stock of agroforestry practices is limited. Specifically, information and documentation on the diversity of woody plants and their relation to carbon stock potential in homegarden agroforestry systems are important both to improve the income and climate change adaptation and mitigation. Farm characteristics, such as farm size, shape, species adaptability, nature of cropping pattern, and management variation also affect the structure and composition in agroforestry (Kumar and Nair, 2004; Rebecca, 2007). Few studies are conducted in relation to HG and carbon stock (Mesele Negash, 20013) and homegarden sizes of the gardeners are other determinants of biomass (Kumar *et al*., 2011) and soil C (Saha *et al.*, 2010) pools.

Most of the reports which are studied in North Shewa zone focus on the plant species diversity of the natural/church forests. Also there are very few studies focusing on the plant diversity potential of agroforestry practices (Abrham Tezera and Haile Sheferaw, 2014). But the status of woody plant species diversity in homegarden agroforestry and their carbon stock potential is not well studied. Therefore, this study designed to show the contribution of homegarden agroforestry of *Epheratana gidm* district for woody species diversity conservation and the potential role of traditional homegarden agroforestry on carbon stock to use as a means for CC mitigation and adaptation strategy.

The study can also be used as baseline information to understand the role of diversity on carbon stock and biomass production.

1.3 Objective of the study

1.3.1 General objective

- The general objective of this study was to assess the contribution of homegarden agroforestry in diversity, biomass and carbon stock in *Epharatana gidm* District.

1.3.2 Specific objectives

- To assess the current structure and composition of woody plant species in homegarden agroforestry
- To estimate the total carbon stock in homegarden agroforestry

1.4 Research Questions

1. How the land size of homegarden affects the diversity, density and composition of woody species in mid-altitude areas of Eastern Amhara?
2. What is the contribution of woody plant species diversity, standing trees and shrubs for biomass and carbon stock in homegarden agroforestry?

Chapter Two. LITERATURE REVIEW

2.1 Concepts of Agroforestry

Agroforestry has been defined as a dynamic, ecologically based natural resources management system that through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (ICRAF, 2002). It is based on the combination of tree, agriculture, pasture and other non-tree crops on the same piece of land and which are arranged spatially and temporally to produce a range of benefits and environmental services (Badege Bishaw and Abdu Abdelkadir, 2003). Agroforestry generally refers to land used system or farming system in which trees or shrubs are grown in association with agricultural crops, pastures or livestock and in which there is an ecological and economic interaction between the trees and other components (Nair, 1993). The main components of agroforestry systems are trees and shrubs, crops, pastures and livestock, together with the environmental factors of climate, soils and landforms. Other components (e.g. bees, fish) occur in specialized systems.

Nowadays, the great challenge in agriculture is to find economically viable and environmentally sustainable farming systems. Agroforestry System (AFS) can be a good land use alternative that not only is sustainably productive but also able to enhance the available resources (Schroth *et al.*, 2004). AFS are practices that integrate trees, annual crops and livestock in the same land unit, sequentially or simultaneously, to improve the benefits of ecologic and economic interactions (FAO, 2010). Indigenous communities have long experience and knowledge on ecosystem management to obtain food, shelter and energy. The survival of life forms on earth is maintained as a result of services obtained from ecosystems (Rossier and Lake, 2014).

Information on both above- and belowground biomass in AFS is generally much higher than that in land use without trees i.e. tree-less croplands (Palm *et al.*, 2004; Haile *et al.*, 2008).Various agroforestry practices such as alley cropping, silvopasture, riparian buffers, parklands, forest farming, homegardens, and woodlots, and other similar land use patterns have thus raised considerable expectations as a C sequestration strategy in both industrialized and developing countries (Kumar and Nair, 2011). Agroforestry, in general, may increase farm profitability through improvement and diversification of output per unit area of tree/crop/livestock, through protection against damaging effects of wind or water flow, and through new products added to the financial diversity and flexibility of the farming enterprise (Molua, 2005).Traditional agroforestry systems are common and major features of land use systems in the tropics. Particularly in the sub Saharan countries farmers consider trees as an integral part of agriculture, which offers solutions for different demands (Nair, 1993). Agroforestry has been an age-old practice in the Ethiopian farming system (Badege Bishaw and Abdu Abdelkadir, 2003) and tropics farming system. There are abundant types of traditional agroforestry practices found in different parts of the country, including southern Ethiopia (Mesele Negash, 2002; Zebene Asfaw, 2003; Tesfaye Abebe *et al.*, 2005).

2.2 Agroforestry and Climate Change Adaptation and Mitigation

Combining adaptation with mitigation has been recognized as a necessity in developing countries; particularly in the AFOLU (agriculture, forestry and other land use) sector (Mbow *et al.*, 2013). Agroforestry in general may increase farm profitability through improvement and diversification of output per unit area of tree/crop/livestock, through protection against damaging effects of wind or water flow, and through new products added to the financial diversity and flexibility of the farming enterprise (Rice, 2008). It can also substantially contribute to climate change mitigation through carbon sequestration (Verchot *et al.*, 2007; Smith and Wollenberg, 2012). The use of multipurpose trees and integrated approaches can enhance the profitability of agroforestry (Nguyen *et al*., 2013), for example, trees can be sources of fodder, which in turn is converted into valuable plant nutrients (Abrham Tezera and Haile Sheferaw, 2014). Trees on farms can provide wild edible fruits (Fentahun Mengistu and Hager, 2010) and non-timber products that serve as alternative food during periods of deficit and primary sources of income for many rural communities (Neufeldt *et al*., 2012).

Agroforestry have the potential to contribute significantly to CC mitigation by sequestering GHG. The global estimated potential of all GHG sequestration in agriculture ranges from 1500 to 4300 Mt $CO_2e\ yr^{-1}$, with about 70% from developing countries; 90% of this potential lies in soil carbon restoration and avoided net soil carbon emission (Smith and Wollenberg, 2012). Performance of mitigation options in agroforestry will depend on the relative influence of tree species selection and management, soil characteristics, topography, rainfall, agricultural practices, priorities for food security, economic development options, among others. In order to improve carbon sequestration, or to reduce carbon emissions, several options are available (objective of AFS), but all are related to development needs of local communities (Mbow *et al.*, 2013). Agroforestry systems have 3–4 times more biomass than traditional treeless cropping systems (IPCC, 2000; Smith and Wollenberg, 2012), and in Africa they constitute the third largest carbon sink after primary forests and long term fallows (Oke and Odebiyi, 2007). For these reasons, agroforestry systems may prove to be very useful component of agricultural adaptation as both an economically feasible adaptation strategy for smallholder farmers vulnerable to climate change as well as a profitable greenhouse gas mitigation opportunity.

2.3 Homegarden agroforestry

Homegarden agroforestry is an integration of tree crop-animal production systems that are established on small parcels of land surrounding homesteads (Badege Bishaw *et al.*, 2013). Managed mixed gardens of trees, shrubs and herbaceous species situated close to the residence can be called as homegardens (Power and Flecker, 2001). Homegarden is an age-old practice that plays an important economic and a cultural role in rural farming community. It is an ensemble of deliberately chosen species of plants of human utility combined so as to mimic a natural climax system. Moreover it is characterized by ensure a sustained availability of multiple products and generate income (Kumar and Nair 2004). Despite their small size (Kumar and Nair, 2006), home gardens fulfill most of the basic food and nutritional needs of the households, while the multi-storied configuration and high species diversity maintain their structure and function in the face of external stress (Kumar and Nair 2004)

Kang and Akinnifesib (2000) described the homegardens as human ecosystems which can be regarded as analogues to natural tropical forest ecosystems. The homegarden in *Ephratana gidm* is shown below (Figure 2.1).

Figure 2.1 The Yimlo homegarden in *Ephratana Gidim*, Ethiopia.

Homegarden agroforestry are intensively managed and exhibit high taxonomic and structural diversity (Power and Flecker, 2001). A study on the structure of homegardens in Basketo and Kafa (Feleke Woldeyes, 2011) suggested that, farmers used existing native forest species as the basic components of their homegarden structure, which are useful for fruit, medicine, or shade. Farmers value the trees grown in their homegardens not only as a source of cash income and subsistence, but also for improving habitat quality, conserving soil and water resources, and for their aesthetic value (Senanayake *et al*., 2009). As forest ecosystems like, homegardens may, therefore be very important as a low-input productive unit that stabilizes the sloping land, the hydrological balance as well as the nutritional supply (APN, 2010).

Homegardens produce an increasingly important supply of food in many countries as population pressure reduces the amount of land available to each household for food crops. They support the cultivation of multipurpose trees and shrubs, often in association with annual and perennial agricultural crops and livestock, within the household compound (Badege Bishaw *et al*., 2013).

In Ethiopia homegarden agroforestry is the most common practices which are familiar to small holder farmers (Yakob Gebre, 2011) .Commonly, multiple perennial and annual crops are grown in homegardens with a certain spatial or temporal arrangement. For instance, Tesfaye Abebe (2005) reported about 120 tree and shrub species from the homegardens in southern Ethiopia. The mixing of different crops and woody species allows niche diversification and some of the combinations complement each other. The fences of gardens are usually reinforced with live plants, which also give some useful products for the family. Large trees are usually left in the open space in the vicinity of the house for their multipurpose use. Farmers usually use such trees for shade and as a facility for social gatherings of the villagers demonstrating the special regard given to trees in the traditional rural life (Tadesse Kippie, 2002).

2.4 Plant diversity and Carbon Stock in homegardens

2.4.1 Biodiversity

Biodiversity is an integrative concept of species composition, structure and function. The structure is the physical organization of objects in an area and includes the tree locations within a landscape (Carlsson, 1998). The composition is the variety of elements in an area including a number of species and a measure of species diversity and genetic diversity (Carlsson, 1998). Ethiopia is one of the richest countries in plant diversity and endowed with more than 7000 different flowering plants, of which about 12% of them are endemic for the country (Khumalo *et al.*, 2012). The rapid expansion of agriculture is becoming a threat to the degradation of forest diversity. The biodiversity losses due to human activity create an interest in protected areas worldwide. However, species and ecosystems are still disappearing at an alarming rate. The key factors contributing to this trend are overexploitation of species, invasion by alien species, environmental pollution and contamination, climate change, alteration of ecosystems, and degradation. It is becoming a challenge that sustainable consumptive use approaches that can combine production and conservation functions in human dominated and fragmented landscapes. However, there are evidences that indicate sustainable farming practices, like agroforestry, utilize and conserve biodiversity, improve environmental quality and limit agricultural expansion into natural forests as well as the negative impacts of agriculture on biodiversity. Agroforestry system, as part of a multifunctional working landscape, can play a major role in conserving and even enhancing biodiversity from farms to the landscape level in both tropical and temperate regions of the world (Jose, 2012).

Homegarden agroforestry practices help to maintain a high number of species outside their native forest habitat. And they are rich in plant diversity have been ranked top among all manmade agro-ecosystems next to natural forest for their high biological diversity (Kang and Akinnifesib 2000). Conservation of woody species on smallholder farms for various traditional uses is an age-old practice, particularly in the tropics. Like for medicinal, spiritual purpose. Agroforestry systems can differ in vegetation structure and compositions which are mainly controlled by traditional management practices, climate and soil conditions and site character (Tadesse Woldemariam *et al.*, 2008).

Homegarden agroforestry practices are among the agroforestry systems practiced by smallholding farmers around their homestead with the potential to harbor native forest biodiversity by a mixture of perennials and annual crops (Kabir and Webb, 2008). In Ethiopia the coffee shade based agroforestry practices also conserve various native woody species (Mesele Negash, 2013). Homegarden agroforestry systems are not only supporting livelihoods of smallholding farmers but also conserving diversity. High biodiversity is an intrinsic property of the homegardens (Kumar and Nair, 2004). (See table 2.1 below).

Table 2.1 Floristic diversity reported in agroforestry systems at different parts of Ethiopia.

Agroforestry system	Place	Vegetation type	No. species	**Reference**
North				
Fruit trees farms	Adiarkay, Debark, Dejen	Edible indigenous fruit trees	17	Fentahun Mengistu and Hager (2010)
Homegarden	Hintalo Wejerat of Tigray	Fruits & fodder trees, vegetables, herbs	40(66)	Tsegazeabe Haileselasie *et al* (2012)
Southwest				
Homegardens	Basketo, Kafa zone	Trees, shrubs, climbers, spices	149-192 (30-32)	Feleke Woldeyes (2011)
Central				
Homegardens	Sebeta-Hawas district	Trees, shrubs, herbs, climbers	114(30	Tefera Mekonen (2010)
Homegardens	Beseku, Arsi Negelle district	Woody species	64	Motuma Tolera *et al*. (2008)
Trees on farms	Three districts, Arsi zone	Woody species	**90**	Birhanu Mengesha (2010)
South				
Coffee-enset system	Four districts, Sidama zone	Woody species + cultivated crops	198 (61)	Tesfaye Abebe *et al.* (2005)
Traditional homegardens	Around Gate Uduma, Gedeo	Trees, shrubs, herbs	165(31)	Debessa (2011)
Indigenous agroforestry	Aleta Wondo district, Gedeo	Trees, shrubs, vegetable crops	50(40)	Mesele Negash (2002)
Various homegardens	Wolayta and Gurage zones	*All floristic species	**60**	Asfaw & Woldu (1997)
Country level				
Agroforestry systems	West, north and south Ethiopia	Trees + shrubs + climbers + herbs	429(27)	Zemede Asfaw (2002)
Homegardens	Central, eastern, western, south Ethiopia	*All floristic species	162	Zemede Asfaw & Ayele Nigatu (1995)

The value in the parenthesis shows that percentage of tree species recorded of the total number of species.

*The share of tree species could not be traced in the report. Source: Mesele Negash, 2013.

2.4.2 Carbon Stock

Homegarden agroforestry and other agroforestry practices systems are assumed to promote Net primary productivity (NPP) and improve the soil and biomass C stock, often doubts are expressed concerning the productive capacities of species mixtures (FAO, 2004). The carbon (C) stock capacity of agroforestry systems have been shown to vary with species composition, age, geographical location of the system (Jose, 2009). While most agroforestry practices (e.g., parkland trees, homegarden, and multipurpose trees) have great potential for C sequestration, homegardens are unique in this respect. This is due to described homegardens as intimate, multistory combinations of various trees and crops around homesteads (Kumar and Nair, 2006) and high diversity is an intrinsic property of the homegardens. It presumably favors higher C stock potential than other agroforestry practices. They not only sequester C in biomass and soil, but also reduce fossil-fuel burning by promoting wood fuel production, and conserve agro biodiversity (Kumar and Nair, 2004). In addition, they help in the conservation of C stocks in existing natural forests by alleviating the pressure on these areas (Kumar and Nair, 2006). Moreover, there is no complete removal of biomass from the homegardens, signifying the permanence of these systems. The homegarden system, thus, is remarkably resilient, which is an added advantage, considering that lack of stability or permanence of the C sequestered is a major concern in C sequestration projects (UNFCCC, 2007).

There are, however, considerable variations in species composition and site characteristics for biomass and C accumulation among the different homegarden regions (Mahmuda Islam *et al*., 2014). Much of the homegardens are also under threat due to urbanization, fragmentation of holdings, and development of mono-cropping production systems (Kumar and Nair, 2004). Due to diversity HG has high biomass and large carbon (C) stocks (Jaman *et al*., 2016). Homegarden agroforestry practices accumulate significant amounts of C, equaling the amount of C stored in some secondary forests of similar age. Their ability to simultaneously address smallholders' livelihood needs and store large amounts of C makes homegarden agroforestry systems viable project types under the Clean Development Mechanism (CDM) of the Kyoto Protocol, with its dual objective of emissions reduction and sustainable development (Roshetko *et al*., 2002). Carbon pools are components of the ecosystem that can either accumulate or release carbon and have classically been split into two main categories (1) biomass carbon stocks; aboveground

Biomass (AGB) and belowground biomass (BGB) and (2) soil carbon stocks. These categories, in the context of homegarden agroforestry are discussed below.

Biomass Carbon

Biomass carbon stock is the summation of aboveground biomass and belowground biomass carbon stock. AGB carbon stock is in all living biomass above the soil, including; stem, stump, biomass branches, bark, seeds and foliage (FAO, 2010). AGB represents the most easily and reliably pool in agroforestry practices and captures the majority of carbon stock by the system (Schoeneberger, 2009). BGB is a major C pool in live root biomass (Nadelhoffer and Raich 1992). Fine roots of less than 2 mm biomass diameter are excluded, because these often cannot be distinguished empirically from soil organic matter or litter (FAO, 2010). There is tremendous difficulty assessing belowground woody biomass, even in relatively uniform conditions, such as managed plantations (Schoeneberger, 2009). BGB is used for fine-root production, which therefore is a major input to soil organic matter (SOM) pool (Nair *et al*., 1999).The average biomass C storage potential of agroforestry systems in semiarid, sub-humid, humid and temperate regions has been estimated to be 9, 21, 50 and 63 ton C ha^{-1}, respectively (Montagnini and Nair, 2004). The biomass C in homegardens is an equivalence with the C stocks reported for similar-aged secondary forests e.g., Jensen, 1993 (Javanese homegarden= 63 ton ha^{-1}); but lower than that accumulated by the Natural forests (cited from Roshetko *et al*., 2002) 114 to 500 ton aboveground C ha^{-1}.

Soil carbon stock

The soil is the largest carbon pool in the terrestrial ecosystem. Soil organic carbon (SOC) as a potential sink for atmospheric carbon dioxide (CO_2) has increased considerably in recent years (IPCC, 2000). Global carbon storage in soil is 3-4 times greater than that in vegetation (Takahashi *et al*., 2010). More than half of the C assimilated by woody perennials is eventually transported belowground via root growth and organic matter turnover processes (e.g., fine root dynamics and litter dynamics), making SOC a significant pool of terrestrial C (>2500 Pg C globally; Lal, 2004); which is 3.3 times the atmospheric pool (770 Pg. C) and 4.5 times the vegetation pool (610 Pg. C) (Nair *et al.* 2009). In agro ecosystems, organic C stocks in the soil often represent the largest C sink (Henry *et al*., 2009).

Soil organic carbon is recognized as a strategy for carbon sequestration under the CDM of the Kyoto Protocol (Nair *et al*., 2009b). The soil carbon sequestration potential of agroforestry systems ranges 30 to 300 ton C ha^{-1} up to 1 m depth in the soil (Nair *et al*. 2010). The impact of any agroforestry system on soil C sequestration depends largely on the amount and quality of input provided by tree and non-tree components of the system and on properties of the soils themselves, such as soil structure and their aggregations (Nair *et al*., 2009a). The soil organic carbon concentration and pools were higher in soils under better species composition agroforestry and increased with tree age (Jose, 2009). Russell (2002) noted that total SOC may increase directly with basal area of the trees included in the system. In view of the great diversity and abundance of woody perennial components, homegarden agroforestry is reasonable to assume that the magnitude of such processes will be greater in homegardens compared to other systems (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004). Careful management of plant residues as it is often practiced in homegardens also can contribute to increases in soil organic matter content (Montagnini, 2006).If tree management practices on existing agroforestry systems are improved, they could sequester an additional 12000 ton C y^{-1} at present and 17000 ton C y^{-1} by 2040 (IPCC, 2000).

Chapter Three. MATERIAL AND METHOD

3.1 Study Site Description

3.1.1 Location and topography

The study was carried out in *Ephratana Gidim* district, North Shewa Zone in ANRS. This district is located 289 km north-east of Addis Ababa, the capital of Ethiopia (Figure 3.1). It has total area coverage of 449.47 km^{2}, composed of 20 administrative *Kebeles*. It is geographically located between 9^{0}45’N to 10^{0}11’N and 39^{0}43’ E to 40^{0}06’E. The altitude of the district ranges from 1200 to 2500 m.a.s.l. and the district is characterized by rugged topography where 26% of the land is plain, 38% is mountainous, 17% gorge and 19% undulating (SHARC, 2002). The study area is specifically located in *Yilmo Kebele*.

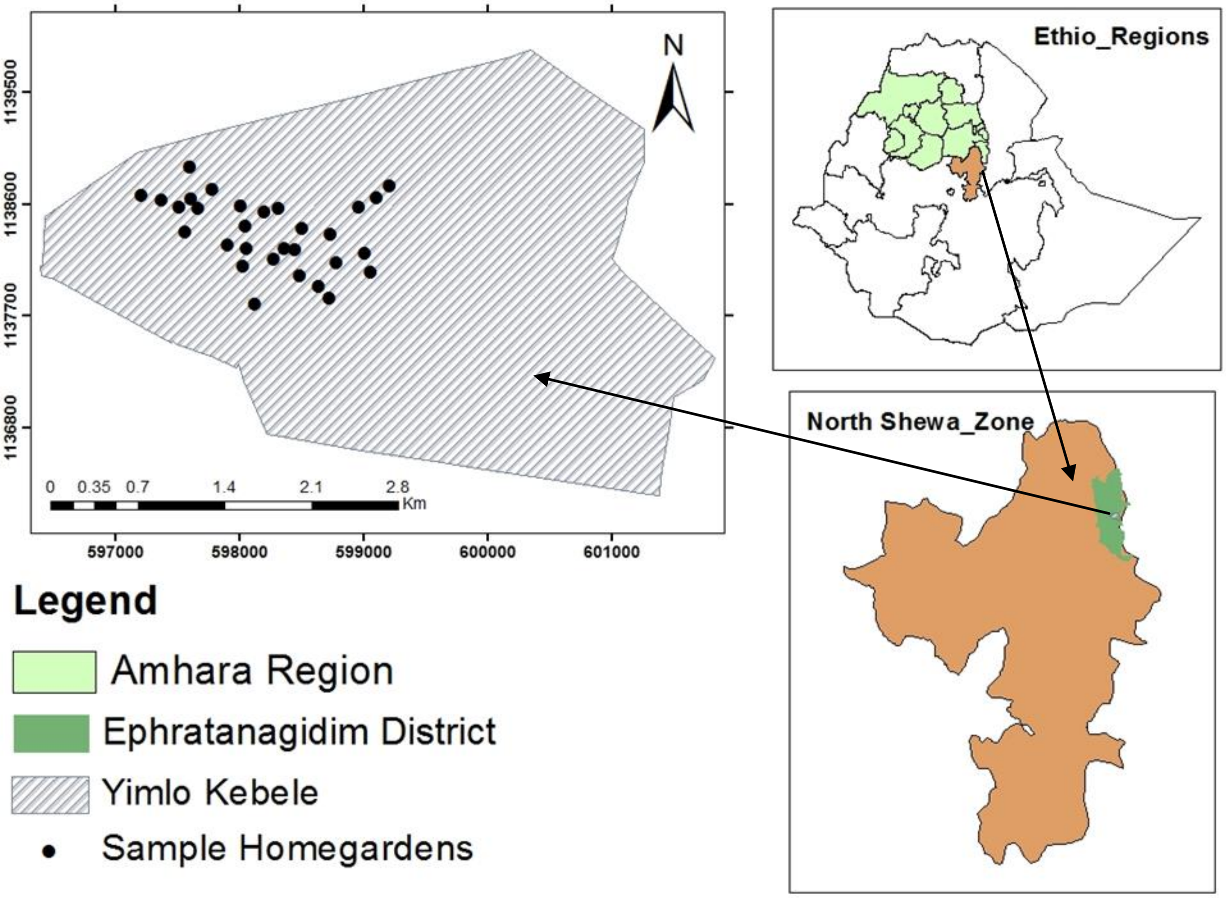

Figure 3.1 Location of the study area.

3.1.2 Climate

The study area is categorized under moist tropical climate and receives a mean annual rainfall ranging from 900 - 1200 mm with considerable variation from year to year (*Ephratana Gidim* Wereda Agricultural Office [EGWAO], 2018). The rainfall pattern is bimodal, with short rain season, which is extended between March and June and long rain season between July and October. The mean monthly temperature is 22°C with a mean monthly minimum and maximum temperatures of 11°C and 36°C, respectively. The major agro-ecological zones proportion of the district constituted from *Weyena Dega* (72%) and *Kola* (18%) (EGWAO, 2018).

3.1.3. Soils

The area study is comprised of different soil types. The major soil types of the study district are vertisol (58%), cambisol (25%) and nitosol (17%). The most dominant soil in the district is vertisol (DBARC, 2016). Since it is dominated by vertic nature of the soil, the area is liable to soil erosion and degradation due to deforestation.

The study area is dominated by vertisols which are dark montmorillonite rich soil. It is swelling during the wet season and cracking during the dry season. The texture is more of clay. Clay soil contains a high percentage of fine particles and colloidal substance and becomes sticky (Brady and Weil, 2002). The soil has variable organic matter content (1-6 %) and is formed in warm, sub-humid or semi-arid climate (EGWAO, 2018).

3.1.4 Population

Ephratana gidm district has a total population of 199,077. Out of these 99,421 (49.94%) are males and 99,656 (50.06%) are females (Federal Democratic Republic of Ethiopia Population Census Commission [FDREPCC], 2008). The area is characterized by high population density i.e. 187 persons per km^2. From the total households 90 % are living in the rural area and the rest 10 % are living in the urban area (EGWAO, 2018).

3.2 Sampling and Data Collection Methods

Vegetation sampling

Prior to sample collection, the reconnaissance survey was carried out to identify, characterize and understand the different features of the study area. This was carried out for stratification and clustering of the sampling homegarden agroforestry systems. The sites were selected purposively based on the existence of HG agroforestry practices. The district experts were involved in selecting the hosting farmer and representative HG in the *Yilmo Kebele*. A stratified sample of 30 farm households was selected. The sample was stratified according to landholding size of the homegarden. The HGs were categorized into three classes, i.e. small (< 0.05 ha), medium (0.06 - 0.1 ha) and large (> 0.1 ha). Finally 30 homegardens were randomly selected in order to capture a representative mixture of size of homegardens. The number of samples in each land size was 10 homegarden. The households were selected based on information from district rural land administration and use office. All sampled homegardens were between 30 and 32 years old and the size of homegardens ranged from 0.01 to 0.42 ha. All HG are located close to the homestead of the farmers.

There is no sample measurement using quadrat. A complete enumeration of the woody species was carried out in each sample using the method used by Motuma Tolera *et al*. (2008). However, for coffee sampling, 10 m × 10 m plot was used by Mesele Negash (2013). The information obtained from the a survey was the composition of wood species, DBH, height; land size and management practices.

On each homegarden woody species seedlings (<2.5 cm diameter and height < 1 m), saplings and shrub (2.5 - 5 cm diameter and height 1 - 2 m) and trees and shrub (≥5 cm diameter and height ≥ 2 m) were recorded by complete counting method (Jiangshan *et al*, 2009). For the coffee shrubs, the diameter was measured at 40cm from the ground using the method used by Mesele Negash (2013).

The diameter was measured by using caliper, diameter tape and measuring tape depending on the size of woody species. The height was measured using clinometer and graduated stick. All tree and shrub species were recorded in their local names and later the scientific names were obtained from using the books of Azene Bekele (2007) and Edwards *et al*. (1995).

Soil Sampling

Soil samples were collected between November and December 2010 from 10 HGs from each of the three HG sizes. In each homegarden (plot), four sampling locations were selected following the distribution of vegetation cover and from each HG (Sidzabda *et al.*, 2016). Soils were collected from two depths 0–30 and 31–60cm. The four subsamples at each location and depth class were composited to get one composite sample for each depth class per plot. A total of 60 soil samples were taken from the two depths (0–30 cm and 31–60 cm). Mesele Negash (2013) uses this soil depth to determine the carbon stock of traditional agroforestry system in Southern Ethiopia. A one kilogram of composite soil sample was collected using an auger. The soil samples were taken for analysis to the soil laboratory of Debre birhan Agricultural Research Center (DBARC). Two soil cores were taken from each sample depth to determine bulk density using core sampler.

3.3. Methods of Data Analysis

3.3.1 Floristic Composition, Population Structure and Diversity

Woody species structure was determined through quantitative analysis using relative frequency, relative density, relative dominance, basal area, and importance value index

Basal area (BA) is the cross-sectional area of a tree estimated at breast height (1.3 m), which is expressed in m^2. Basal area was calculated using the formula of Philip (1994):

$$BA = \pi r^2 \quad \underline{\hspace{4cm}} \text{Eq. (1)}$$

Size class, species richness (Margalef Index), Shannon diversity (H'), and evenness (E) and Simpson diversity indices (D’) were calculated and analyzed to understand the wood species composition (diversity) of the HG. Diversity indices provide more information about community composition than simply species richness (i.e., the number of species present). These indices take into account for the relative abundances of different species (Krebs, 1999).

Shannon-Wiener Diversity Index

Shannon's index accounts for both abundance and evenness of the species present. The Shannon diversity index (*H'*) is high when the relative abundance of the different species in the sample is even and is low when few species are more abundant. It is based on the theory that when there is a large number of species with even proportions, the uncertainty that a randomly selected individual belongs to a certain species increases and thus diversity increases. It relates the proportional weight of the number of individuals per species to the total number of individuals for all species (Kent and Coker, 1992).

The Shannon diversity index is calculated as follows:

$$H' = - \sum_{i=1}^{n} pi \ln pi \underline{\qquad\qquad\qquad\qquad\qquad} \text{Eq. (2)}$$

Where, *H '* = Shannon-Wiener index of species diversity s = number of species in community pi = proportion of total abundance represented by $_i^{th}$ species. Value of the index (*H'*) usually lies between 1.5 and 3.5, although, in exceptional cases, the value can exceed 4.5 (Kent and Coker, 1992). The larger the *H'* value the higher the diversity. Shannon diversity index places most weight on the rare species (Krebs, 1999). It is also moderately sensitive to sample sizes (Magurran, 1988).

Evenness refers to the variability in the relative abundance of species. Evenness index describes the equality of species abundance in a community (Begon *et al.*, 2006). Evenness (E') was calculated as:

$$E = \frac{H'}{Hmax} = \frac{H'}{lnS} \text{ With Hmax = lnS} \underline{\qquad\qquad\qquad\qquad\qquad\qquad} \text{Eq. (3)}$$

Where, *H'* = *is* the Shannon diversity index, *S* = is the number of species, *Pi* = is the proportion of total individuals in the i^{th} species and H max = ln(s) (species diversity under max equitability conditions).

Simpson's Index Diversity (1-D)

The Simpson's diversity index was derived from probability theory and it is the probability of picking two organisms at random which are of different species (Magurran, 1988). We get Simpson's diversity (D):

$D = 1 - \sum P_i^2$ ____________________ Eq. (4)

Where D = Simpson's diversity index

P_i = as described above

Simpson's diversity index gives relatively little weight to the rare species and more weight to the most abundant species. It ranges in value from 0 (low diversity) to a maximum of (1-1/S), Where S= number of species (Krebs, 1999).

Species richness (Margalef Index) is calculated as the ratio of the number of species in an area divided by the log of the total number of individuals in the samples. The higher the Margalef Index, the higher the species richness of the population (Margalef 1958).

$\text{Margalef Index} = \frac{N-1}{\ln(n)}$ ______________________________Eq. (5)

Where, N = the number of species, n= is the total number of individuals in the sample.

Importance Value Index

The importance value index (IVI) indicates the importance of species in the ecosystem and it is the sum of relative density, relative dominance and relative frequency (Kent and Coker, 1992);

Importance Value Index (IVI) for each species = RD + RBa + RF --------------------- Eq. (6)

1. Relative density (RD) = $\frac{\text{Number of individuals of species}}{\text{Total number of individuals}} * 100$

2. Relative Basal Area (RBa) = $\frac{\text{Dominance of a species}}{\text{Total dominance of all species}} * 100$

3. Relative frequency (RF) = $\frac{\text{Frequency of a species}}{\text{frequency of all species}} * 100$

IVI = RD + RBa + RF., this index helps to the importance of woody species in the HG agroforestry system of *Ephratana Gidm.*

3.3.2 Carbon Estimation

Aboveground biomass

The above- and belowground biomass (ton ha^{-1}) of trees, shrubs and coffee was estimated using allometric equations developed in the tropics. There is a large degree of uncertainty exists in estimations of C stocks and fluxes at the local, regional, and global scale. Some of the uncertainties in biomass quantification are model errors or inconsistencies in methods, lack of species-specific allometric equations and the complexities of the systems and landscapes (IPCC, 2003; Chave *et al.* 2004 and Sileshi, 2014). Species-specific allometric equations, though ideal for biomass estimations, were not available for all tree species in the study region. In addition due to complex nature of TOF i.e. tree stands in agroforestry typically show irregular shapes, plastic and sensitive to local environmental conditions, human management and tree managements (Frank and Eduardo 2003; Dossa *et al*,. 2007; Harja *et al*., 2012; and Kuyah *et al.*, 2012a). Therefore, to reduce the uncertainty of biomass quantification; estimate the aboveground biomass of the trees and shrubs, four allometric equations were evaluated; that of Brown (1997), Chave *et al*. (2005), FAO (1997) and Kuyah *et al*. (2012a). The C stocks were estimated from the biomass of tree and shrubs and the soil up to the depth of 60 cm. All trees and shrubs >2.5 cm dbh were considered for determining above- and belowground biomass. The information on wood specific gravity (density) was obtained from the global wood density database (Zanne *et al.,* 2009). Average wood density value of the known species was used for species which wood density was not found.

The following allometric equations were evaluated and compared statistically to choose the best allometric equation to estimate the carbon stock:

Brown (1997) which is developed for wet tropics:

$AGB = 42.69-12.800(D) +1.242(D^2)$ -- Eq. (7)

Where, AGB = aboveground biomass of tree^{-1} (kg) and D = dbh (cm)

Chave *et al*. (2005) developed for wet tropical woody biomass and calculated as:

$AGB = WD*\exp(-1.239+1.980*\ln((D) +0.207*(\ln(D))^2_0.0281*(\ln(D))^3)$______Eq. (8)

Where, AGB = aboveground biomass of tree^{-1} (kg), D = dbh (cm) and WD = species-specific wood gravity (density) in g cm-3

FAO (1997) recommended for parkland trees by the UNFCCC (2006):

$AGB (kg) = \exp(-2.134+2.530*\ln(dbh))$________________Eq. (9)

Kuyah *et al*. (2012a) for wet tropical agroforestry tree and shrub species:

$AGB = 0.091 \times D^{2.472}$ ___________________Eq. (10)

Where, AGB = aboveground biomass of tree^{-1} (kg) and D = dbh (cm)

The total aboveground biomass for coffee shrub was estimated using equation developed by Mesele Negash *et al.*, 2013 for south-east traditional agroforestry system coffee shrub in Ethiopia:

$AGB= 0.147 \times d_{40}{}^2$_______________Eq. (11)

Where, AGB= aboveground biomass of tree^{-1} (kg) and D = dbh (cm)

Quantifying belowground biomass can be expensive and no practical standard techniques yet exist (Brown, 2002). Belowground biomass (>2 cm diameter) of the tree and coffee plants using the generic equation (Kuyah *et al.,* 2012b):

$BGB = 0.490AGB^{0.923}; R^2=0.95$__________________Eq. (12)

Where BGB is the belowground biomass (kg dry matter per plant) and AGB is aboveground biomass (kg dry matter/plant). The biomass was estimated in a hectare basis.

Then tree biomass was converted into C by multiplying the total biomass by 0.47 (IPCC, 2006).

Carbon stock = Y * 0.47_______________Eq. (13)

Where, Y= AGB + BGB tree^{-1} (kg) and the total woody biomass and carbon stock was set in a hectare basis.

Soil Carbon Stock Estimation

Soil samples were collected for determining soil carbon. The soil samples were collected and air-dried at room temperature, homogenized and sieved using a 2 mm sieve for chemical analysis. The soil analysis was conducted at the Debrebirhan Agricultural Research Center (DBARC) following the standard laboratory procedures. Soil carbon content was analyzed using the method of Walkey and Black.

In addition, soil samples were collected using a 98.12 cm^3 steel cylinder for bulk density analysis auger (Figure 3.2 a and b). The cylinder was inserted into the soil and carefully lifted up. The excess soil of the ring was cut using a trowel. The soil was placed in a plastic bag. The dry weight was determined in the laboratory for oven drying. The temperature for oven drying was 105^{0}C for 48 hours. Then, soil C stock (ton C ha^{-1}) for each sampled depth was calculated using the following equation (Pearson *et al.*, 2007):

$$BD = \frac{Wav.\ dry}{V} \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(Eq.14)}$$

Where: BD = bulk density of the soil sample per the HG in g/cm^3, Wav.dry = average dry weight of soil sample per the HG in gram V = volume of the soil sample in the core sampler auger in cm^3

$$\text{SOC (ton C ha}^{-1}\text{) = WBC (\%) * d* Bd (g/cm}^{-3}\text{) *100-------- Eq. (15)}$$

Where, WBC = Walkley-Black Carbon, d = soil depth (cm) and Bd = bulk density

(a) (b)

Figure 2.2 sampling using (a) core sampler (b) auger soil sampling in the homegarden.

Total Carbon Stock

Since the area is not a forest and the carbon pool in the litter and dead wood is insignificant. There is hardly any appreciable amount of litter and dead wood present in the study area. Therefore, the total carbon stocks (carbon density) were calculated by summing up all the carbon stocks of each carbon pool of the vegetation (Pearson *et al.,* 2007). Total Carbon stock density of the study area could be calculated as:

$$\text{Total carbon} = AGC + BGC + SOC \qquad \text{Eq. (16)}$$

Where: AGC = aboveground carbon; BGC = belowground carbon and SOC = Soil organic carbon.

3.3.3 Statistical Analysis

The comparison between allometric equations was carried out to choose the suitable equation fitting to homegarden using R^2, mean square error and standard error. Both vegetation and soil carbon data were treated using univariate analysis. Variables were compared using one-way analysis of variance (ANOVA) using General Linear Model (GLM). MS Excel spreadsheet and Statistical Package for Social Sciences (SPSS) for Window versions 16 (SPSS Inc., Chicago, USA, 2007) software were used to process the data. If statistical significance difference was observed ($P<0.05$), mean separation analysis was carried out using Duncan test.

Chapter Four. RESULTS AND DISCUSSIONS

4.1 Woody Species Composition and Diversity four

A total of 39 woody species, representing 24 families were identified and recorded in the homegarden agroforestry practices of the study area (see Appendix1). The result from this study showed that HG agroforestry comprised of high number of woody species compared to other land uses found in and around the country (Antaryami *et al*, 2016; Dawit Kebede, 2012). Homegarden agroforestry has been known for its diversity, ecosystem balance, sustainability, household food security and rural development (Tesfaye Abebe, 2005; Tadesse Kippie, 2002).The woody species richness of the HG agroforestry was comparable with other homegarden agroforestry found in different part of Ethiopia like, (Motuma Tolera *et al*., 2008; Fikrey Tesfaye 2015; Aklilu Bajigo and Mikrewongel Tadesse, 2015a and Yirefu Tefera *et al*., 2016**)**. However, the woody species richness is by far lower than some sites both in Ethiopia and Africa countries. For example, 120 trees and shrubs are found from Sidama zone in Southern Ethiopia (Tesfaye Abebe, 2005), 459 tree and shrub species around Kenya in central and eastern Kenya (Oginosako *et al*., 2006), 289 woody plants from suburban areas of Sri Lanka (Sandya, 2009), and 122 trees and shrubs from Northeast India (Das, 2005).The planting of various exotic and native woody species in the HGs lead to higher species richness and diversification of products (Figure 4.1).

Figure 3.1 HG agroforestry with different strata.

Among the woody species, trees constituted 87% (34species) and shrubs 13% (5 species) (Table 4.1). Native tree and shrub species accounted for 54% (21 out of 39 woody species recorded). Homegarden agroforestry practices are among the agroforestry systems with the potential to maintain diverse plant species. It has commonly been characterized as diverse and sustainable land use systems (Kumar and Nair, 2004; Kabir, 2008). A total of 1282 individuals of woody plants were encountered in 30 Homegardens. The highest proportion of individuals of woody species were recorded in Large HG (56.6%), followed by Medium HG (23.2%) and Small HG (20.2%) (Table 4.1).

Table4.1. Composition of woody species with homegarden size class.

	Homegarden Size			
	Small	**Medium**	**Large**	**Total**
Total abundance	259	297	726	1282
Trees > 5cm dbh (%)	87	78	74	
Seedlings and saplings < 5 cm dbh (%)	8	7	9	
Matured Coffee shrub (%)	5	15	17	

The frequency of woody species was variable and tree species were the most frequent woody species compared to shrub species. This is due to greater accessibility, adaptability, economic or ecological value of the species so that farmers select these species to plant for a better product.

The dominantly observed species were *Melia azedarach* (93.3%) followed by *Coffea arabica* (90%), *Croton macrostchyu*s (80%) *Cordia africana* (76.6%) and *Ehretia cymosa* (56.6%) while, 10 species had the lowest frequency less than 6.08% (Figure 4.2). Tree species with a better adaptability and greater economic or ecological value or both were found to be frequently distributed across the homegardens (Abiot Molla and Gonfa Kewessa, 2015). Dominance of exotic species like *Melia azedarach* could be also due to better adaptability to different sites as well as its vigorous growth (Zebene Asfaw and Agreen, 2007). In addition, *Coffea arabica* is dominantly found in the study area because farmers plant this species as a cash crop. It is observed that this species is compatible with HG practices, for example, in the southern Ethiopia, mainly in *Gedeo* zone (Tesfaye Abebe, 2005). *Croton macrostchyu*s, *Cordia* *africana* and *Ehretia cymosa* are dominantly found in the study area because these species are used as a shade for coffee. Farmers' preferred to plant these species to enhance the growth of coffee, the shade loving species. Therefore, *Croton macrostchyu*s, *Cordia africana* and *Ehretia cymosa* are planted as a shade and source of organic matter for coffee seedlings (SLUF, 2006; Zebene Asfaw, 2008; Yitebitu Moges, 2009).

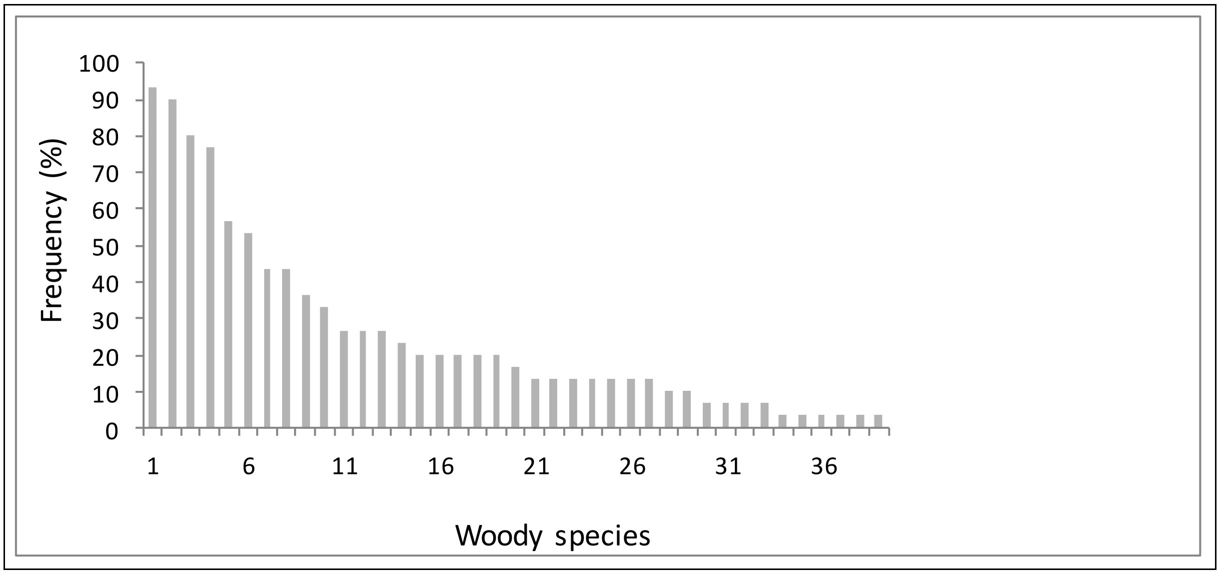

Figure 4.2 Frequency occurrences of woody species across the all homegarden agroforestry in *Ephratana gidm* district, (for more details see Appendix 2).

Diversity Indices

Shannon diversity, Evenness and Simpson diversity index did not significantly differ among the homegarden size class, but Margalef's diversity index of species richness was highly significant ($P < 0.001$). The mean number of woody species per hectare (ha) was 147. The maximum diversity of an individual garden was recorded in a large size garden and the minimum diversity was found in a medium homegarden (Table 4.2). However, large farm size planting perennial crop and tree components and livestock (Mersha Gebrehiwot, 2013) which maximize the diversity of woody species. In regarding to on species richness HGs are the highest human-made agro ecosystem next to natural forest (Kang and Akinnifesib, 2000; Kumar and Nair, 2004). This is due to selective and repeated planting and management of useful woody species from a natural regeneration (Gotz *et al*., 2004 and Kumar and Nair, 2004).

The value of described by the Shannon diversity index (H') for woody species was from 1.6–1.9 with the mean value 1.7 (Table 4.2). HG agroforestry consists of a good collection of tree shrub and annual species in the *Ephratana Gidm*. The mean Shannon diversity index (1.7) is higher than as reported by Tesfaye Abebe (2005) in Sidama village (H' = 1.41) and Bikila Mengstu and Zebene Asfaw (2016) in the Dallomena district (H'= 0.47). However, lower than other countries, Keeriyagaswewa village (H'= 2.13) as reported by APN (2012). It is also comparative with Siwalakulama village (H'= 1.77) found by (Senanayake *et al*., 2009). In addition, the measure of evenness (*E*) was 0.8. This means the relative homogeneity of the species in the samples is 80%. Some species are thus more abundant than others. Species evenness varied between 0.43 and 0.96 (Table 4.2).

As the size of homegardens increased, woody species richness within homegarden size basis showed increase. However, species richness ha^{-1} was the highest in small sized homegardens followed by, medium sized (Table 4.2). In other words, there is an inverse relationship between land size and tree species richness. The same result reported by higher the species richness the smaller the land size as shown by Kumar (2011). The land owners of the homegardens often adopt more intensive management and denser planting in multiple layers, thus, higher tree species richness (Eskil *et al*., 2014). However, Tesfaye Abebe (2005) and Kabir and Webb (2008) found that there is a positive relationship between land size and species richness. The number of tree species per hectare increased with increasing farm size.

Table 4.2 Mean woody species Shannon index, Shannon evenness, Simpson's index of diversity , Margalef's index and number of species.

Homegarden Class	H'	E	1-D	MI	No. of species ha^{-1}
Small	1.8 (0.08)	0.85 (0.02)	0.78 (0.02)	8.3 (0.7)^{b}	261(37) ^{a}
Medium	1.6 (0.1)	0.79 (0.05)	0.75 (0.03)	7.3 (0.5)^{b}	102 (8) ^{b}
Large	1.9 (0.2)	0.76 (0.04)	0.75 (0.05)	12.4 (1.0)^{a}	80 (11) ^{b}
Overall mean	1.7 (0.07)	0.8 (0.03)	0.76 (0.02)	9.1 (0.6)	147 (20)
P_ value	Ns	Ns	Ns	< 0.001	< 0.001

SE is shown in parenthesis. Letter with the same are not significant at 0.05; Ns= not significant p >0.05; SE standard error

4.2 Woody Species Structure

The Important Value Index (IVI) of all woody species in the study area is listed descending order in (Table 4.3). The species with the highest IVI were *Coffea arabica, Cordia africana, Melia azedarach* and *Croton macrostachyus structuraly very important woody species in the study area.* On the other hand, 6 tree/shrub species (*Persea americana Acacia polycantha, Casuarina equisetifolia, Arundo donax, Ceiba pentandra and Commiphora africana*) were found to be very rare each occurred only in one of the farm plot (appendix 1).

The IVI is an aggregate index that summarizes the density abundance, and distribution of a species. It measures the overall importance of a species and gives an indication of the ecological success of a species in a particular area (Kent and Coker 1992). The IVI values can also be used to prioritize species for conservation, and species with high IVI value need less conservation efforts, whereas those having low IVI value need high conservation effort (Neill *et al*., 2001). Native tree species ranked high in terms of frequency, abundance and dominance had an importance value index in the homegarden, this support homegarden agroforestry practices are among the agroforestry systems with the potential to harbor native woody species (Kumar and Nair, 2004; Kabir, 2008) (Table 4.4). The three commonly planted native tree species, namely *Coffea arabica, C. africana and C. macrostchyus* account for about 73.31% of the relative abundance of all recorded tree species in the homegarden of the study area investigated. The dominance of native species may be due to their ecological and economic importance for use as timber, the source of organic matter and income generation. This finding is in line with the reports by Ewuketu Linger (2014) which show that species with multiple uses showed higher IVI value. Similar results were reported by Yitebitu Moges (2009) from a comparison of woody species diversity along an elevation gradient in southern Ethiopia.

This could be associated with their importance in improving soil fertility and high economic importance; hence the farmers prefer this tree and maintain it in their homegarden. The existence of these species in the homegarden agroforestry, that it has the advantage of conserving native species. The studied homegardens are dominated by *Coffea arabica* species hence can be classified as Coffee -based homegarden agroforestry practice.

Table 4.3 Tree density ha^{-1}, Relative frequency, Relative abundance, Relative dominance and Importance Value Index of woody species.

Scientific Name	RF (%)	RA (%)	RD (%)	IVI	Tree density/ha
Coffea Arabica	9.12	67.42	21.00	97.54	685
Cordia Africana	7.77	4.45	20.46	32.68	45
Melia azedarach	9.46	3.49	9.37	22.32	35
Croton macrostchyus	8.11	1.44	5.20	14.75	15
Eucalyptus camaldulensis	4.39	3.94	6.25	14.59	40
Ficus sur	2.70	0.48	7.44	10.62	5
Ehretia cymosa	5.74	1.74	3.07	10.56	18
Acacia nilotica	2.03	2.38	4.30	8.70	24
Ficus sycomorus	2.70	0.30	4.92	7.92	3
Prunus africana	5.41	1.41	0.47	7.29	14
Combretum molle	0.68	0.15	6.31	7.13	2
Calpurina aurea	4.39	2.20	0.32	6.91	22
Mangifera indica	2.70	1.59	1.79	6.08	16
Grewia bicolor	3.72	0.51	1.73	5.95	5
Citrus aurantifolia	3.38	0.57	0.22	4.17	6
Jatropha carcus	2.03	1.50	0.22	3.75	15
Carica papaya	2.36	0.72	0.56	3.65	7
Rhamnus prinoides	1.35	1.74	0.00	3.10	18
Olea europaea	2.03	0.33	0.72	3.07	3
Ziziphus spina-christi	1.35	0.15	1.20	2.71	2
Citrus sinensis	2.03	0.24	0.23	2.50	2
Ziziphus mucronata	2.03	0.21	0.13	2.37	2
Leucaena leucocephala	1.69	0.27	0.38	2.34	3
Psidium guajava	1.35	0.39	0.41	2.16	4
Ricinus communis	1.35	0.36	0.30	2.01	4
Jacaranda mimosifolia	1.35	0.12	0.38	1.85	1
Celtis africana	1.35	0.12	0.36	1.83	1
Citus limonia	1.35	0.21	0.18	1.74	2
Faidherbia albida	0.68	0.15	0.87	1.70	2
Schinus molle	1.01	0.15	0.05	1.22	2
Piliostigma thonningii	1.01	0.09	0.07	1.18	1
Delonix regia	0.68	0.12	0.20	1.00	1
Cupressus lusitanica	0.68	0.06	0.24	0.97	1
Arundo donax	0.34	0.48	0.05	0.87	5
Persea americana	0.34	0.27	0.26	0.87	3
Casuarina equisetifolia	0.34	0.03	0.19	0.56	1
Ceiba pentandra	0.34	0.06	0.11	0.51	1
Acacia polycantha	0.34	0.09	0.01	0.44	1
Commiphora africana	0.34	0.03	0.02	0.39	1
	100.00	100.00	100.00	300.00	

The structural parameters of woody species for each size class are shown in (Table 4.4). The three HG size class showed variations in their structural characteristics except for the dbh. The basal area and stem density were significantly affected by the size of the homegarden ($P < 0.05$). However; dbh showed that there was no any significant different among homegarden size class. The mean number of stem decreased in the order Small> Large > Medium. The mean density of all the woody species recorded was 424 individuals per hectare (Table 4.4). This result showed that the density is higher than the result reported by Bikila and Zebene Asfaw (2016) in Dallomena district, South-East Ethiopia. Indigenous woody species accounted for 73% (24m^2 ha^{-1}) of total basal area on average across all homegarden (n=30). Among all homegarden, the dominant indigenous tree /shrub species were *Cordia africana* (mean basal area 6.71m^2 ha^{-1}) and *Coffea arebica* (mean basal area 6.89 m^2 ha^{-1}). Similar result was reported by Mesele Negash (2013) in traditional agroforestry system of south-eastern rift valley of Ethiopia.

According to Motuma Tolera *et al.* (2008) and Getahun Haile *et al*. (2016) the determinant factor for variation in the structure of elements within HG agroforestry are due to the wealth status of the household, by the area of the homegarden and the age of the homegarden. The land size strongly influenced the composition and structure of woody species. The traditional management practices of the farmers affected both the structure and composition of the forest (Feyera and Denich, 2006). The tree density higher in small size class was may be excluding of annual crop and growing of woody species. For example, in larger HG the spatial arrangements between trees and crops were distinct. Most of the trees are planted around and close to the homestead. Low tree density is found away from the homestead. It is because cash crops such as bananas or annual crops are grown for immediate needs and local markets. These have to be close to homestead for controlling and management. (Mahmuda Islam *et al*., 2014. Jaman *et al*., 2016)

Table 4.4 Mean diameter abreast height, basal area and stem density for each hoegarden agroforestry size class.

Homegarden size	DBH(cm)	Basal area (m^2 ha^{-1})	Stem density ha^{-1}
Small	15.9(1.3)	17.3 (5.5) ^{a}	625.8 (125.5)^{a}
Medium	17.0(1.6)	9.1 (1.4)^{b}	309.5 (59.4)^{a}
Large	15.3(1.1)	6.9 (0.9)$_{b}$	337.6 (50)$^{\mathbf{b}}$
Mean	16.1(0.8)	11.1(2.0)	424.3 (54.4)
P- Value	Ns	<0.038	<0.025

Ns - Not significant at 0.05; Standard error of the mean (SE) in parenthesis.

The mean basal area of woody species was higher than that reported for *Enset*-coffee systems of southern Ethiopia (Zebene Asfaw, 2003); (Mesele Negash, 2013) and that of some agroforestry systems in the tropics (Asase and Tetteh 2010). However, it is lower than that of coffee-based agro forests in Guinea (Correia *et al*., 2010) and cocoa-based agroforestry in southern Cameroon (Herve and Vidal, 2008). These difference could be the dominance of large tree species in the homegarden like; *Ficus* species (Chave *et al*, 2003).

4.3 Structure of Selected Tree Species

Trees in the HG are also managed for coffee shade. The shade trees are scattered and have lower density compared to other trees/shrub. Coffee production is maximized using shade trees (Aerts *et al.,* 2011). The shade trees have desirable characteristics and it is important to select the right species for shade with the management techniques (Zebene Asfaw, 2003). Shade tree species need to have economic or ecologic importance in coffee-based agroforestry system. The population structures the six dominant tree species is shown in (Figure 4.3).

The distribution of population structure for the three tree species *M. azedaracha* and *E. camaldunesis* have an inverted U-shape, which shows a high number of intermediate classes, but a very low number in the small and large diameter classes (Figure 4.3). This indicates that low number of seedling. The distribution of population structure of *Ficus sur* and Cordia *africana* look like an inverted J-shape. There are low numbers of individuals in the lower diameter classes but increases towards the higher classes. Nevertheless, *Eucalyptus camaldulensis* and *Ehretia cymosa* have low seedling populations. However, increases at the middle diameter class and then low toward the larger diameter class. And so, the highest densities of tree species were found at the intermediate diameter class. Generally, the result settles that tropical agroforestry is rich in structure and composition reported by many authors (Kumar and Nair, 2004 and Motuma Tolera *et al*., 2008).

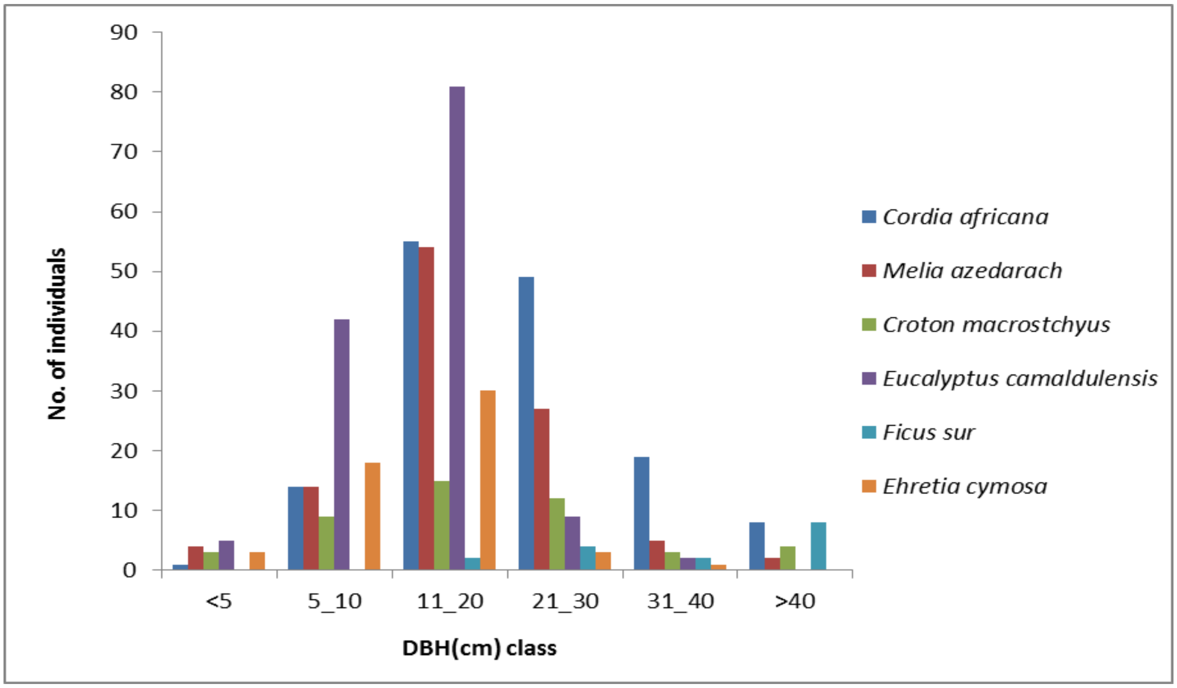

Figure 4.3 Diameter class distributions of six Important Value Index dominant tree species.

4.4 Biomass and Carbon Stock in Homegarden agroforestry System

We assess the fit of model in term of error and coefficient of determination (R^2). The equation of Brown (1997) and FAO (1997) overestimated AGB by 280.53 kg/tree and 249.01 Kg/tree respectively. The equation of Cahve *et al.* (2005) underestimated AGB by 52.16 kg/tree. However, the AGB determination using Kuyah *et al.* (2012a) was optimal compare with the rest (Table 4.5).

The calculated aboveground woody species biomass using the Brown (1997), Kuyah *et al*., (2012a) and FAO (1997) had high mean standard error, low R^2 value and high root mean square error . However, aboveground woody species biomass using (Chave *et al*., 2005) calculation had the lowest mean standard error, root mean square error and relatively high R^2 value (R^2= 0.87) which used diameter at breast height and wood density (Table 4.5).

Table 4.5 Aboveground biomass of four different equations with coefficient of determination and root mean square error.

Equation	Model	Estimate biomass (kg/tree)	R^2	rMSE%
Kuyah *et al*. 2012a	$Y= 42.69-12.800(D) +1.242(D^2)$	156.71±11.8	0.73	18.5
Brown 1997	$Y= 42.69-12.800(D) +1.242(D^2)$	280.53±19.65	0.78	27.5
FAO 1997	$Y = \exp(-2.134+2.530*\ln(dbh))$	249.01±19.51	0.72	31.4
Chave *et al*. 2005	$WD*\exp(-1.239+1.980*\ln((D) +0.207*(\ln(D))^2\_0.0281*(\ln(D))^3)$	52.16±2.7	0.87	2.9

± = Mean standard error

The underestimate of Chave *et al*. (2005) from 20 cm dbh while the equations of Brown (1997) and FAO (1997) overestimates biomass from 20 cm dbh (Figure 4.7). Brown (1997) and FAO (1997) underestimate biomass for smaller trees (< 20 cm) with (R^2 = 0.78; rMSE = 27.5% and R^2 =0.72; MSE = 31.4% respectively). Chave *et al*. (2005) underestimate for big tree (> 20 cm) but it was consistent biomass estimation across dbh class with (R^2 = 0.87; MSE =2.9%). High value of mean square error showed that the trend in the estimation of trees varied across dbh size class for different equations. This was also as a result of large number of smaller tree in samples. The highest error of Brown (1997) equation may be due to the fact that the equation was developed for non-agroforestry system and a large number of a smaller tree. In addition, the highest error of FAO and Kuyah equation may be developed for areas not a similar condition to this study area. This difference may be the result of differences in species composition, temperature, rainfall, soil conditions and tree management.

As a result, Chave *et al.* (2005) allometric equation developed for wet tropical woody species was adopted for estimating the aboveground biomass. The difference is observed in the (Figure 4.4) below.

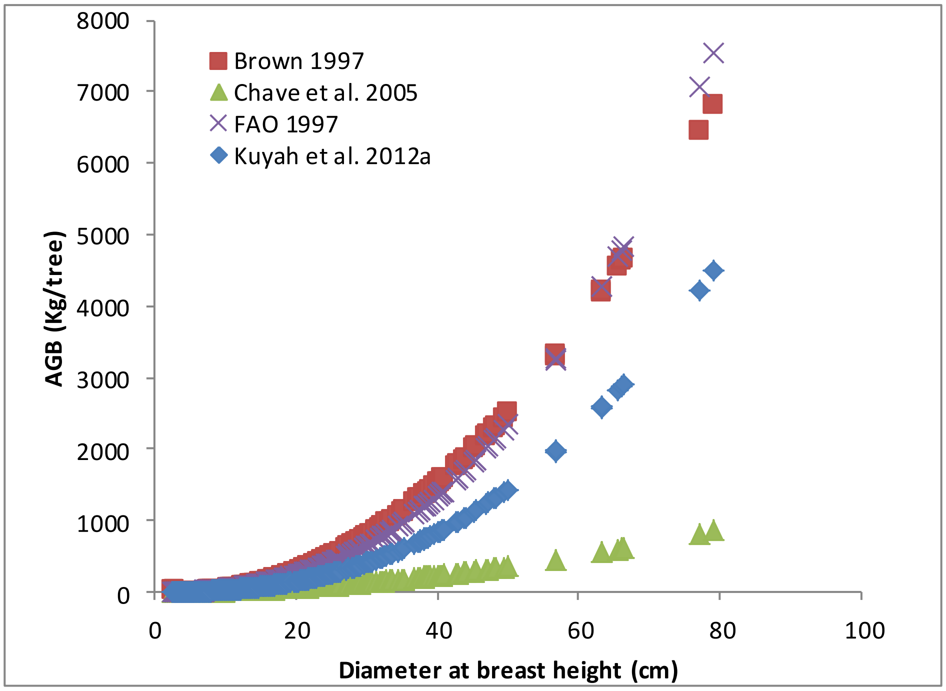

Figure 4.4 A scatter plot of aboveground biomass estimated by different equation against diameter at breast height.

The result shows that there were no statistically significant differences (P = 0.228) between homegarden size class in the mean total (Above plus below ground) biomass (Table 4.6). Mean total aboveground woody biomass, including coffee ranged from 51.2 ton ha^{-1} in large homegarden to 72.9 ton ha^{-1} in Small homegarden and for below ground biomass from 19.1 ton ha^{-1} in large homegarden to 25.6 ton ha^{-1} in small homegarden.

Table 4.6 Mean aboveground, belowground and total biomass (ton ha^{-1}) of woody species components grown in homegarden agroforestry systems.

Biomass	Homegarden size class	Trees/Shrub	Coffee	Total
AG biomass	Small	71.9±39.0	1.0±1.1^{b}	72.9±38.6
	Medium	53.9±29.5	2.7±1.6^{b}	56.6±30.1
	Large	42.4±15.7	8.8±4.6^{a}	51.2±15.9
	P-value	ns	0.001	ns
BG biomass	Small	25.1±12.7	0.5±0.5^{b}	25.6±12.6
	Medium	19.2±9.8	1.2±0.7^{b}	20.4±10.2
	Large	15.5±5.3	3.6±1.8^{a}	19.1±5.4
	P-value	ns	0.001	ns
Total biomass	Small	97.1±51.7	1.5±1.6^{b}	98.6±51.6
	Medium	73.1±39.4	3.9±2.3^{b}	77.0±40.8
	Large	57.9±21.0	12.4±6.4^{a}	70.2±21.3
	P-value	ns	0.001	ns

Homegarden area having the same letter are not significantly ($p > 0.05$) different from each other; ns -not significant and ± Standard deviation.

However, for coffee shrub aboveground biomass there is significant difference between homegarden size classes (Table 4.6). Coffee biomass was statistically significant among HG size ($P<0.001$). Large HG has more coffee density than small HG and Medium.

Regarding the carbon stock, the mean C stock of total biomass (above plus below ground biomass) for the 30 sampled homegarden was 40.9±3.7 ton C ha^{-1}, mean ±SE. The mean AGB was 30.03 ton C ha^{-1} (73.5%) and the BGB was 10.82 ton C ha^{-1} (26.5%). Statistically there were no any significance difference among homegarden size ($p=0.262$), but mean carbon stocks per unit area was slightly higher in the small HG (49.3±8.1 ton C ha^{-1}). The mean carbon stock for medium and large size HG was 38.4±6.4 ton C ha^{-1} and 35±3.3 ton C ha^{-1}, respectively (Figure 4.5). The small homegarden relatively higher may be as result of large basal area and tree density (Russell, 2002; Albrecht and Kandji, 2003 and Kumar, 2006). This result is in contrary to the study of Kumar (2011). The smaller size HG had higher biomass and carbon stock than medium and large. This may be due to the intensive management of farm plots by the farmers of *Yilmo Kebele*.

The total biomass C stocks of the HG agroforestry in *Ephratana gidm* ranges 35– 49.3 ton C ha^{-1} (Figure 4.5). And the average aboveground C storage potential of agroforestry systems in semiarid, sub-humid, humid and temperate regions has been estimated to be 9, 21, 50 and 63 ton C ha^{-1}, respectively (Montagnini and Nair, 2004). The mean carbon stock substantially lower than the range reported from the Bangladesh and Indonesia, which ranges from 6.25- 193.83 ton C ha^{-1} (Jaman *et al.*, 2016) and 30- 123 ton C ha^{-1} (Roshetko *et al*., 2002a). However, the carbon stock of HG of *Ephratana gidm* is higher than the HG of Woleyata 15 ton C ha^{-1} as reported by Aklilu Bajigo *et al.* (2015b) and 29.13 ton ha^{-1} of carbon stock in *Yirga cheffe* coffee based agroforestry system (Fikrey Tesfaye, 2015). The HG from Sri Lanka which is the tropical region is 13 ton C ha^{-1} (Mattsson *et al.* 2014). This difference is due to the difference in the amount of trees in the agroforestry systems. And it could be variability of model use for biomass estimation (IPCC, 2003; Chave *et al.*, 2004, Jose, 2009, Mahmuda Islam *et al*., 2014 and Sileshi, 2014).

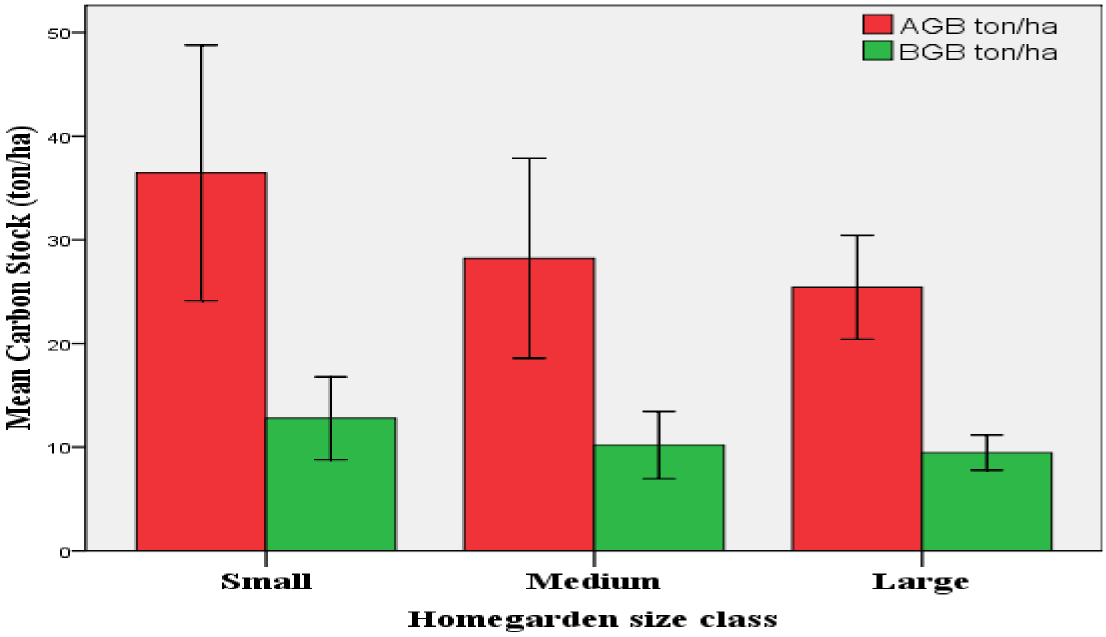

Figure 4.5 Above and below ground carbon stock in the three homegarden sizes. Error bar show the standard error.

4.5 Soil Carbon

The results of the soil bulk density, organic matter, carbon concentration and carbon content in the homegarden agroforestry of *Ephratana gidm* are given in (Table 4.7). The average bulk densities were 1.06 $g \cdot cm^{-3}$, 1.12 $g \cdot cm^{-3}$, and 1.09 $g \cdot cm^{-3}$, in 0–30, 31–60, and 0–60 cm intervals of depth, respectively, and did not differ significantly ($p = 0.60$) across depths. Organic matter and the carbon concentration decreased with the depth as shown in (Table 4.7), although these values did show statistical differences between soil depth intervals ($p < 0.001$). This is common in almost all cultivated mineral soils and is a reflection of the accumulation of higher quantities of litter and other organic materials on the surface and their rapid decomposition (Nair, 1993). The relative mean soil C stock to 60cm depth was 123.19 ton C ha^{-1} in the study area (Table 4.7). The SOC stocks in HG agroforestry are noticeably high compared to the SOC stocks of other ecosystems and soils. Mulugeta Lemenh and Fisseha (2004) reported SOC stocks for semi-arid *Acacia etabica* woodland in southern Ethiopia to be 43 ton C ha^{-1} and Dossa *et al.* (2007) reported SOC stocks for shaded-grown coffee systems to be 97.27 ton C ha^{-1} in both studies for the 0-60 cm soil layer. The overall mean values of SOC, although measured to a depth of 60 cm were larger than to the average SOC density measured to a depth of 1 m for West Africa (42–45 ton C ha^{-1}), for the whole Africa (64–67 ton C ha^{-1}) (Batjes, 2001). This SOC was smaller than what has been reported by Mesele Negash (2013) in south-eastern Rift Valley escarpment of indigenous agroforestry systems (178-186 ton C ha^{-1}). These differences may be associated to differences of tree species composition and forest structure, density of trees, basal area, forest conservation status soil depth and soil water content in each region and may be homegarden age difference (Russell 2002; Jose, 2009). Agroforestry system on soil C sequestration depends largely on the amount and quality of input provided by tree and non-tree components of the system and on properties of the soils themselves, such as soil structure and their aggregations (Nair *et al*., 2009a). Soil organic matter (SOM) content may increase with time, homegarden agroforestry systems (Beer *et al.*, 1998). Because in a highly productive system, regular addition of pruning and root turnover over the years results in the accumulation of soil organic matter (SOM) and nutrient stocks in the soil (Lehmann *et al*., 1998; Kumar *et al*., 2001).

Table 4.7 Soil Bulk density, Organic matter, Carbon concentration and Total carbon stocks.

Sample Depth (cm)	Bulk Density (g·cm^{-3})	Mean Soil Carbon%	Mean of % Organic Matter	Total soil Carbon (ton/ha^{-1})
0__30	1.06±0.03	2.24±0.14^{b}	3.85±0.23^{b}	70.96±3.88^{b}
31_60	1.12±0.03	1.59±0.12^{c}	2.73±0.21^{c}	52.23±3.94^{c}
Total (0__60)	1.09±0.04	3.82±0.22^{a}	6.57±0.37^{a}	123.19±5.79^{a}
P_ value	ns	0.001	0.001	0.001

Homegardens with high species richness (Margalef Index >9.7) had higher SOC storage (137.9 ton ha^{-1}) and those with low species richness (Margalef Index < 7.6) had lower SOC (110.2 ton ha^{-1}) within 60 cm depth (Figure 4.6). There were a statically significances difference ($p = 0.026$) in SOC content in relation to species richness. High species richness of HG is likely to access species with strong resources-utilization characteristics compared with less species-intensive systems (Tilman *et al*., 1997) and may promote a greater NPP (Vandermeer, 1989), which in turn could contribute to higher C sequestration. Increase numbers of species promote higher SOC accumulation in the upper soil (Saha *et al.*, 2009). In general, the SOC stock decreased with soil depth across all treatments.

The surface layer (0–30cm) contributed 58% to the total (0– 60 cm) SOC stock for the homegarden agroforestry system in the study area. The findings of Mulugeta Lemenih and Itanna (2004) showed that in the Rift valley of Southertn Ethiopia, 50 % of soil C was retained in the upper 20 cm of the soil.

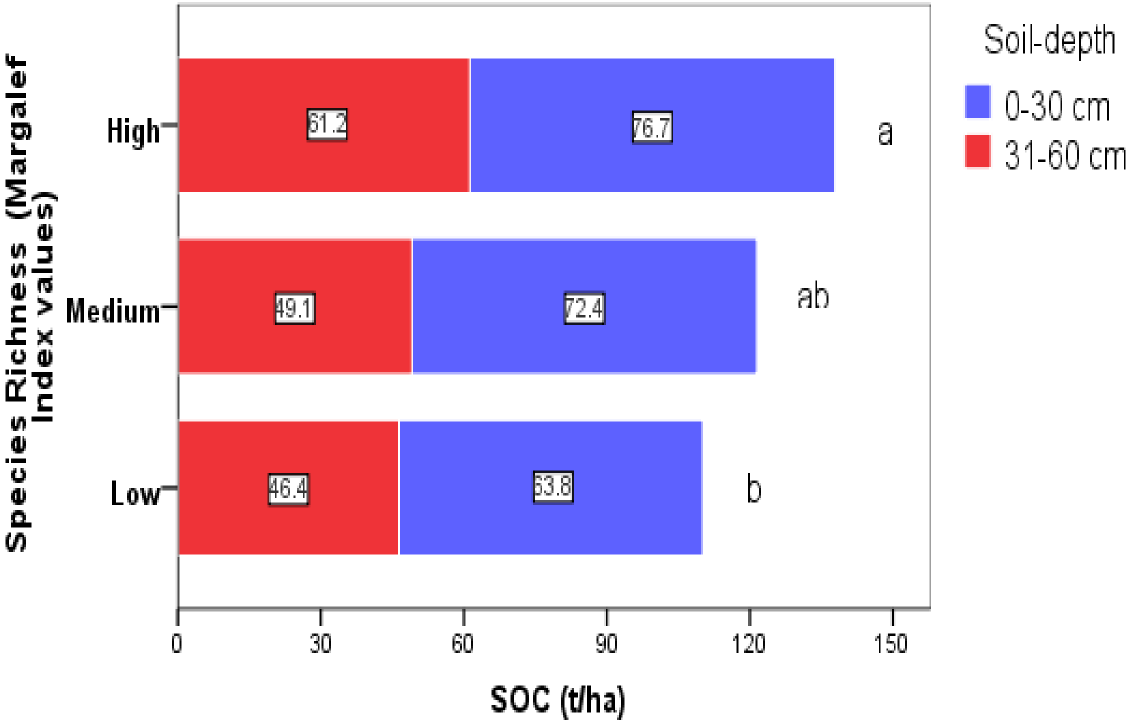

Figure 4.6 Soil organic carbon content across soil depths in homegarden with different species richness's. Plant Species Richness classes based on Margalef Index values: Low (<7.6), Medium (7.6–9.7) and High (>9.7).

4.6 Total Carbon Stocks

Mean total (biomass plus soil) carbon stock of the homegarden agroforestry system is 164.04 ton/ha (Table 4.8), SOC stock accounted around 75% of the total ecosystem C stock. This result showed that the role of soil in is an important carbon pool. This finding is consistent with the report of Habtamu Assaye and Zerihun Asrat (2016) that states soil is the largest pool of organic carbon in the terrestrial biosphere, and hence, minor changes in SOC storage can impact atmospheric carbon dioxide concentrations. The total carbon stock both from the soil and biomass was 164.04 ton C ha^{-1}. This is higher than the carbon stock (mean 156.28 ton C ha^{-1}) of humid tropical climate of Kerala agroforestry systems (Kunhamu, 2016), 95.78 ton C ha^{-1} (Fikrey Tesfaye, 2015) coffee- based agroforestry in *Yirgacheffee* Southern Ethiopia and 86.4 ton C ha^{-1} *Welayita* zone HG agroforestry (Aklilu Bajigu *et al*., 2015b). However, it is lower than compared to other studies (293.4 ton C ha^{-1}) Southern HG (Mesele Negash, 2013).

The C-stock potential of tropical agroforestry was estimated between 12 and 228 ton C ha^{-1} with a medium value of 95 ton C ha^{-1} (Albrecht and Kandji, 2003). The result was greater than the average C stock potential of tropical agroforestry. This suggests that homegarden agroforestry practices of the study area sequester considerably more C than do tropical forest ecosystems. There are, however, considerable variations in species composition and site characteristics for biomass and C accumulation among the different homegarden regions due to their high biomass, these systems contain large C stocks (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004 and Mahmuda Islam *et al*., 2014). While the agroforestry systems of individual farmers are of limited size, on a per area basis smallholder systems accumulate significant amounts of C, equaling the amount of C stored in some secondary forests over similar time periods (Roshetko *et al*., 2002b).

Table 4.8 Total means carbon stocks in the homegarden agroforestry system of the study area.

Component	Carbon (ton ha^{-1})	% of Total
Above-ground biomass carbon	30.03	18.3
Below- ground biomass carbon	10.82	6.6
Soil organic carbon (0-60)	123.19	75.1
Total Ecosystem carbon	164.04	100

4.7 Relationship between diversity and carbon stocks

A correlation analysis was conducted by using aboveground biomass carbon with selected diversity parameters and homegarden size measures from 30 of homegardens (Table 4.9). There were significant correlation between the AGB carbon and the stand characters (i.e., Basal area ha^{-1}, Trees density ha^{-1}, Shannon index H’ and DBH). This result showed that these parameters directly influenced the AGB. Even though statistically not significant, the HG size has a negative correlation in carbon stock. The larger the homegarden size the lesser the carbon stock per unit area due to small basal area and low stem density (Table 4.9).

Table 4.9 Non-parametric correlation (Spearman's Rho)

Spearman's Rho	Basal area	Size	No. of species	Shannon	Trees density	DBH
Basal area (ha^{-1})	1					
Size (ha^{-1})	-0.46**	1				
No. of species (ha^{-1})	0.11	0.39*	1			
Shannon (H')	0.29	0.10	0.68**	1		
Tree Density (ha^{-1})	0.52**	-0.47**	0.26	0.09	1	
DBH (cm)	0.62**	-0.03	-0.04	0.24	-0.04	1
AGB_C Stock (t/ha)	0.89**	-0.31	0.20	0.40*	0.39*	0.66**

** Correlation is significant at the 0.01 level (2-tailed);
* Correlation is significant at the 0.05 level (2-tailed)

Basal area is significantly correlated to aboveground carbon stock ($r= 0.89$; $P<0.001$) than number of species and Shannon (H') indices with ($r=0.11$; $P>0.05$ and $r= 0.29$; $P>0.05$) respectively. Similar result is reported by Jaman *et al*. (2016) from quantification of carbon stock and tree diversity of homegardens in *Rangpur* district, Bangladesh where basal area is strongly affect carbon stock potential of homegarden agroforestry. Tree density of the study area varied from 115.7 to 1301.6 per hectare (9-95 trees per homegarden). Correlation analysis showed a positive and significant relationship between tree density and carbon stock where ($r=0.39$; $p<0.01$) (Table 4.9). Tree density is an important factor to store carbon as it directly relates to the carbon stock (Roshetko et al., 2002a). Considering the relationship between tree density and biomass carbon stock it is indicated that tree density is a strong determinant factor of aboveground carbon stock. Diameter at breast height is also a strong determinant factor which is significantly affecting carbon stock potential of homegarden agroforestry($r=0.66$, $p< 0.001$); similar result reported by (Mattsson *et al.*, 2014).

Chapter Five. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The experiences of establishing HG by the farmers' of *Ephratana gidm* are not only to optimize food production and sustainable land management, but are also important for conserving indigenous species, optimizing biomass and improving carbon stock, this in turn contributes to climate change adaptation and mitigation. The dominant system in the study area can be called "c*offee-based"* due to dominance and presence of coffee in each practice of the HG. The HG also conserves indigenous species such as, *Commiphora Africana, Cordia africana, C. macrostachyus, Ehretia cymosa* and *Prunus africana*. *Cordia africana* is intensively exploited for income generation mainly for timber production. This species is at risk. The local community has a great role to account for these indigenous species. The woody plant species evenness and diversity index's were not affected by homegarden size. There were differences between smaller and larger homegardens in terms of their most structural parameters such as tree density, basal area and species density. Homegarden size increase basal area, tree density and number of species decrease.

The results suggested that homegarden size was not the factor for AGB carbon stock however, the investigated homegardens in the study area hold a wide range of carbon between 9 to 89.3 ton ha^{-1} and a mean above-below ground biomass C stock of 41.4 ton C ha^{-1}, which is higher than other reported carbon estimates for homegardens in different ecological zones and equaling the amount of C stored in other tree-based systems. The carbon estimates found here are reflecting the differences in tree density, tree diversity and management practices between individual homegardens. In addition, there were strong and positive interaction between AGB carbon and HG basal area of trees/shrubs. Homegarden with large basal area retained more carbon in their biomass compared to those with small basal area.

The finding of the present study revealed that homegardens should be established by maintaining proper species composition model focusing on the diversity of tree species so that it sequester a substantial amount of carbon and contribute to the global climate change mitigation.

The soil C is a substantial component of the total C stock (biomass + soil). Higher species richness (woody perennials) ensures greater stability of the soil organic matters.

5.2 Recommendations

I suggest that considering soil C in C sequestration calculations, which at present is not recognized by Kyoto Protocol. Based on the result here the expansion potential of HG agroforestry into degraded lands or larger units is not straight forward if carbon stock and tree diversity should be kept. The results of this study show that the investigated homegardens have a good capacity for carbon storage capacity which provides useful information for the national process of whether homegardens should be considered to be included as an activity within Ethiopia commenced National Programme on REDD$^+$. This implies that developed countries provide incentives and financial compensation to developing countries for climate change mitigation benefits from maintaining and enhancing forest biomass.

There should be a strategy to expand homegarden agroforestry in the rural farming community to optimize both biomass and food production. In addition, the study suggested timely and appropriate mechanism to explore the CDM/ REDD investment on smallholder farmers can access international C investment funds to convert low-biomass lands, such as sole agricultural lands, to productive tree-based systems which contain much higher C stocks. Governments are generally supportive of tree-planting efforts, as a means of achieving conservation, reforestation and watershed protection objectives, as well as improving the livelihoods of homegarden farm families.

Chapter Six. REFERENCES

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Appendix 1. List of measured tree and plant species in homegardens and their frequency of occurrence

Botanical Name	local name	Family	Origin	Frequency of occurrence		
				Small	Medium	Large
Acacia nilotica	Kesel girar	Fabaceae	I	1	2	3
Acacia polycantha	Gimarda	Fabaceae	I	-	-	1
Arundo donax	Meka	Poaceae	I	-	-	1
Calpurina aurea	Digita	Fabaceae	I	2	4	7
Carica papaya	Papaya	Caricaceae	E	5	1	1
Casuarina equisetifolia	Shewushewe	Casuarinaceae	E	-	-	1
Ceiba pentandra	Yeferngi tit	Bombacaceae	E	-	1	-
Celtis Africana	Qewet	Ulmaceae	I	-	1	3
Citrus aurantifolia	Lomi	Rutaceae	E	2	6	2
Citrus sinensis	Birtukan	Rutaceae	E	1	-	5
Citus limonia	Bahro	Rutaceae	E	1	-	3
Coffea Arabica	Buna	Rubiaceae	I	8	9	10
Combretum molle	Weyiba	Combretaceae	I	-	-	2
Commiphora africana	Anqa	Burseraceae	I	1	-	-
Cordia africana	Wanza	Boraginaceae	I	7	8	8
Croton macrostchyus	Bisana	Euphorbiaceae	I	7	9	8
Cupressus lusitanica	Yeferngi tside	Cupressaceae	E	1	-	1
Delonix regia	Yedredawa zaf	Fabaceae	E	1	-	1
Ehretia cymosa	Game	Boraginaceae	I	5	4	8
Eucalyptus camaldulensis	Bahir zaf	Myrtaceae	E	5	3	5
Faidherbia albida	Girar	Fabaceae	I	-	1	1
Ficus sur	Shola	Moraceae	I	1	3	4
Ficus sycomorus	Bamba	Moraceae	I	3	2	3
Grewia bicolor	Teye	Tiliaceae	I	5	5	1
Jacaranda mimosifolia	Jacaranda	Bignoniaceae	E	1	2	1
Jatropha carcus	Ayiderqe	Euphorbiaceae	E	1	-	5
Leucaena leucocephala	Lucina	Fabaceae	E	1	1	3
Mangifera indica	Mango	Anacardiaceae	E	4	2	2
Melia azedarach	Mime	Meliaceae	E	9	10	9
Olea europaea	Weyira	Oleaceae	I	2	2	2
Persea americana	Avocado	Lauraceae	E	1	-	-
Piliostigma thonningii	Chewu wanza	Fabaceae	I	1	-	2
Prunus africana	Tikur enchet	Rosaceae	I	7	2	7
Psidium guajava	Zeituna	Myrtaceae	E	3	-	1
Rhamnus prinoides	Gesho	Rhamnaceae	I	1	1	2
Ricinus communis	Gullo	Euphorbiaceae	E	2	-	2
Schinus molle	Kundoberebere	Anacardiaceae	E	2	1	-
Ziziphus mucronata	Foch	Rhamnaceae	I	3	1	2
Ziziphus spina-christi	Kurkura	Rhamnaceae	I	1	1	2

I= Indigenous; E= Exotic

Appendix 2 Legend.

Number	Botanical Name	
1	*Melia azedarach*	
2	*Coffea arabica*	
3	*Croton macrostchyus*	
4	*Cordia africana*	
5	*Ehretia cymosa*	
6	*Prunus africana*	
7	*Eucalyptus camaldulensis*	
8	*Calpurina aurea*	
9	*Grewia bicolor*	
10	*Citrus aurantifolia*	
11	*Mangifera indica*	
12	*Ficus sur*	
13	*Ficus sycomorus*	
14	*Carica papaya*	
15	*Citrus sinensis*	
16	*Ziziphus mucronata*	
17	*Olea europaea*	
18	*Acacia nilotica*	
19	*Jatropha carcus*	
20	*Leucaena leucocephala*	
21	*Citus limonia*	
22	*Celtis africana*	
23	*Ziziphus spina -christi*	
24	*Jacaranda mimosifolia*	
25	*Psidium guajava*	
26	*Ricinus communis*	
27	*Rhamnus prinoides*	
28	*Piliostigma thonningii*	
29	*Schinus molle*	
30	*Cupressus lusitanica*	
31	*Delonix regia*	
32	*Faidherbia albida*	
33	*Combretum molle*	
34	*Persea americana*	
35	*Acacia polycantha*	
36	*Casuarina equisetifolia*	
37	*Arundo donax*	
38	*Ceiba pentandra*	
39	*Commiphora africana*	

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Mesafint Minale was born in Bahir Dar, Ethiopia in 1989 G.C. He was completed his elementary and secondary education at Bahir Dar in July 2004 and 2008 respectively. He attended a B.Sc. degree in Agro Forestry at Hawassa University, Wondo Genet College of Forestry and Natural Resources from October, 2008 - July, 2011. After graduation, he was employed as a Junior Researcher at the Amhara Regional Agricultural Research Institutes. In 2016, he joined Bahir Dar University College of Agriculture and Environmental Science for his study of M.Sc. degree in Environment and Climate Change.