Woody Plant Species Diversity and Carbon Stocks Potential of Homegarden Agroforestry in Ephratana Gidimdistrict, Central Ethiopia.

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Research

Keywords: Agroforestry, biomass, carbon stock, climate change, species diversity

Posted Date: December 21st, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1169232/v1

WOODY PLANT SPECIES DIVERSITY AND CARBON STOCKS POTENTIAL OF HOMEGARDEN AGROFORESTRY IN EPHRATANAGIDIM DISTRICT, CENTRAL ETHIOPIA.

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ABSTRACT

Background: Tropical agroforestry systems can contribute incredible benefit for carbon sequestration and plant diversity. This system is one of the common practices in the Central part of Ethiopia. This is because of source of the multifunctional ecosystem services, such as food, feed, biodiversity conservation and carbon storage potential.

Methodology: This study was carried out to assess the influence of land size on floristic diversity, richness and biomass carbon stock. The homegardens were classified into small (<0.06 ha), medium (0.06–0.1 ha) and large (>0.1 ha). Biomass of the homegarden was computed using allometric equations.

Results: A total of 39 woody species, belonging to 24 families were recorded in all the study homegardens. Tree density 625.8 tree ha^{-1} and basal area 17.3 m^2ha^{-1} were highest for small-size HGs. However, large homegarden had more species richness (Margalef Index) per garden (12.4) compared to medium and small size homegarden. Mean biomass carbon ranged from 9 to 89.3 ton ha^{-1}. Mean biomass carbon stock per unit area was higher in small homegarden (49.3 ton ha^{-1}) compared to medium (38.4 ton ha^{-1}) and large (35 ton ha^{-1}).

Conclusions: 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 homegarden management in carbon storage thereby for climate change adaptation and mitigation purpose.

Keywords: Agroforestry; biomass; carbon stock; climate change; species diversity

Background

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). The increased atmospheric CO_2 concentration distorts the living standard of the people and makes earth unsuitable for life (Kumar and Nair, 2011). Generally, there are signs of climate change in the world, particularly in East African countries including Ethiopia. This is revealed by the recurrent drought, floods and famine that have threatened millions of people and livestock

(Mesele Negash., 2013). Removing atmospheric carbon (C) and storing it within vegetation pool in terrestrial ecosystems is one of the means to mitigate GHG emissions (IPCC, 2013).

The world needs carbon sequestration techniques that provide social, environmental, and economic benefits while reducing atmospheric CO_2 concentration (Kumar and Nair, 2011). Thus, tree-based farming (agroforestry system) is believed to be a major potential for carbon sink and could absorb large quantities of C (Kumar and Nair, 2011). Agroforestry as a land use system is getting wider recognition not only in terms of agricultural sustainability but also in issues related to CC (Mesele Negash, 2013). Agroforestry systems maximize carbon stocks in the terrestrial biosphere 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 could offer the highest C sequestration (IPCC, 2007).

The precise relation between diversity and sustainability is still heavily debated. However, home-garden agroforestry is ecologically and socio-economically sustainable due to their species diversity. 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 ((Tesfaye Abebe *et al*., 2005). In addition, it has a potential for 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). HG agroforestry could also play a significant role in adaptation and mitigation 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).

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. 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. Few studies are conducted in relation to HG and carbon stock (Mesele Negash, 20013).

Most of the reports which are studied in Amhara region focus on the plant species diversity of the natural/church forests. 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 traditional homegarden agroforestry of *Ephratanagidim* district for woody species diversity conservation and the potential role 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. The objectives of this study were to assess the current structure and composition of woody plant species and to estimate the biomass carbon stock in homegarden agroforestry.

MATERIAL AND METHOD

Study Site Description

The study was carried out in *Ephratanagidim* district, located in the central part of Ethiopia. It is geographically located between $9^{\circ}\ 45^{'}$ N to $10^{\circ}\ 11^{'}$ N latitude and $39^{\circ}\ 43^{'}$ E to $40^{\circ}\ 06^{'}$ E longitude.

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 (*Ephratanagidim* 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 altitude of the district ranges from 1200 to 2500 m.a.s.l. The major soil types of the study district are vertisol (58%), cambisol (25%) and nitosol (17%) (DBARC, 2016).The study area is specifically located in *Yilmo Kebele* (Figure 1)

Sampling and Data Collection Methods

Vegetation sampling

The sample was stratified according to landholding size of the HG. The HGs were categorized into three classes, i.e. small (< 0.05 ha), medium (0.06 - 0.1 ha) and large (> 0.1 ha) based on the existing HG size. The number of samples in each land size was 10 HG. All sampled HG 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 survey was the composition of wood species, DBH, height; land size and management practices. On each HG 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). 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).

Methods of Data Analysis

Diversity Analysis

To compare woody species composition among homegarden size class, species richness (Margalef Index), Shannon diversity (H'), and evenness (E) and Simpson diversity indices (D') were calculated and analyzed:

$$H' = - \sum^{n}_{i=1} pi \ln pi \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \text{Equation (1)}$$

Where, H' = Shannon-Wiener index of species diversity s = number of species in community pi = proportion of total abundance represented by $_{i}^{th}$ species.

Evenness index describes the equality of species abundance in a community. Evenness (E') was calculated as:

$$E = \frac{H'}{Hmax} = \frac{H'}{lnS} \text{ with } H_{max}=\ln S \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \text{Equation (2)}$$

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 maximum equitability conditions).

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

$$D = 1 - \sum p_i^2 \text{ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Equation (3)}$$

Where D = Simpson's diversity, P_i = as described above

Species richness (Margalef Index): The higher the Margalef Index, the higher the species richness of the population:

$$\text{Margalef Index} = \frac{N-1}{\ln(n)} \text{ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Equation (4)}$$

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

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 will be calculated using the formula of :

$$BA = \pi r^2 \text{ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Equation (5)}$$

Importance Value Index

The importance value index (IVI) indicates the importance of species in the system and it is calculated with three components as follow:

Importance Value Index (IVI) for each species = RD + Rd + RF---- Equation (6)

Where Relative density (RD), Relative dominance (Rd) and Relative frequency (RF)

Carbon Estimation

Aboveground tree biomass carbon

The above- and belowground biomass (Mg ha^{-1}) of woody plants for 30 homegarden was estimated using allometric equations developed by Chave *et al.* (2005) for wet tropical woody species and Mesele Negash *et al*., (2013) for south-east traditional agroforestry system coffee shrub in Ethiopia and Kuyah *et al.,* 2012b. The C stocks of the tree, shrub and coffee were determined. All trees and shrubs >2.5 cm dbh were considered for determining above and belowground biomass, which were used in estimating carbon stocks in woody species in the 30 homegarden agroforestry system. Values for wood specific density were taken from the global wood density database (Zanne *et al.,* 2009).

The equation developed by Chave *et al*. (2005):

AGB = WD*exp(-1.239+1.980*ln((D)+0.207*(ln(D))2_0.0281*(ln(D))3)-- Equation(7)

Where; AGB = above ground biomass of tree-1 (kg), D = dbh (cm) and WD = species-specific wood density in g cm-3

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:

$AGB= 0.147 \times d_{40}{}^{2}$ ________________Equation (8)

Where; AGB= above ground biomass of $tree^{-1}$ (kg) and D = dbh (cm)

Belowground biomass (>2 cm diameter) of the tree and coffee plants were calculated using the generic equation developed by (Kuyah *et al.,* 2012b):

$BGB = 0.490AGB^{0.923}$; R^2=0.95______________________Equation (9)

Where BGB is the belowground biomass (kg dry matter/ plant) and AGB is aboveground biomass (kg dry matter/plant). For comparisons on unit area basis for each homegarden the values was extrapolated to hectare size.

Then tree biomass was converted into C by multiplying the total tree/shrub biomass by 0.49 (IPCC, 2006).

Carbon stock = Y * 0.49_______Equation (10)

Where; Y= AGB + BGB tree^{-1} (kg).

Eventually, total woody biomass carbon stock calculated on a hectare basis.

Statistical Analysis

Prior to statistical analyses, all data were checked for meeting the assumptions of normality using Kolmogorov–Smirnov's test (and by inspecting the histogram of distribution) and homogeneity of variance using Levene's test. In cases where some assumptions (normality and/or homogeneity) were violated, log transformed data were used for the analyses. Variables were compared using one-way analysis of variance (ANOVA) following linear model (GLM) procedure at $P < 0.05$ with the help of Statistical Package for Social Sciences (SPSS) for Window versions 16 (SPSS Inc., Chicago, USA, 2007) . If statistical significance difference were observed $P<0.05$, Duncan test was used to separate means.

RESULTS AND DISCUSSIONS

Woody Species Composition and Diversity four

A total of 39 woody species, representing 24 families were identified and recorded in the HG agroforestry practices of the study area. 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. HG agroforestry has been known for its diversity, ecosystem balance, sustainability, household food security and rural development (Tesfaye Abebe *et al.,* 2005).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; Aklilu Bajigo *et al*., 2015 and Yirefu Tefera *et al*., 2016). However, the woody species richness is by far lower than some sites in Ethiopia. For example, 120 trees and shrubs are found from Sidama zone in Southern Ethiopia (Tesfaye Abebe *et al.,* 2005). Plantings of various exotic and native woody species in the HGs lead to higher species richness and diversification of products (Figure 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 was recorded in a large size HG and the minimum diversity was found in a medium homegarden (Table 1). However, large HG 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 (Kumar and Nair, 2004). This is due to selective and repeated planting and management of useful woody species from a natural regeneration (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 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 *et al*., (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). 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 1). 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 1). 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 and Nair (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 *et al.,* (2005) 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.

Woody Species Structure

The Important Value Index (IVI) of all woody species in the study area is listed descending order in (Table 2). 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.

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) (Table 2). 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 structural parameters of woody species for each size class are shown in (Table 3). 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 3). This result showed that the density is higher than the result reported by Bikila Mengistu and Zebene Asfaw (2016) in 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 $6.71m^2ha^{-1}$) and *Coffea arebica* (mean basal area 6.89 $m^2\ ha^{-1}$). Similar result was reported by Mesele Negash (2013).

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 the area of the homegarden. The land size strongly influenced the composition and structure of woody species. 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. These have to be close to homestead for controlling and management (Jaman *et al*., 2016). The mean basal area of woody species was higher than that reported for *Enset*-coffee systems of southern Ethiopia ((Mesele Negash, 2013). However, it is lower than that of coffee-based agro forests in Guinea (Correia *et al*., 2010). These difference could be the dominance of large tree species in the homegarden like; *Ficus* species (Chave *et al*, 2003).

Carbon Stock

The mean C stock of total biomass (above plus below ground biomass) for the 30 sampled HG was 40.9 ± 3.7 ton C ha^{-1}, mean $\pm$SE. The mean AGB carbon was 30.03 ton C ha^{-1} (73.5%) and the BGB cabon 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 6). The small homegarden relatively higher may be as result of large basal area and tree density (Kumar and Nair, 2004). This result is in contrary to the study of Kumar and Nair (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 *Ephratanagidim* ranges 35– 49.3 ton C ha^{-1} (Figure 3). 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 *Ephratanagidim* is higher than the HG of Woleyata 15 ton C ha^{-1} as reported by (Aklilu Bajigo *et al.* 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 (Sileshi, 2014).

Relationship between diversity and carbon stocks

A correlation analysis was conducted by using AGB carbon with selected diversity parameters and HG size measures from 30 of HG (Table 4). 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). Even though statistically not significant, the HG size has a negative correlation in carbon stock. The larger the HG size the lesser the carbon stock per unit area due to small basal area and low stem density (Table 4).

Basal area is significantly correlated to AGB 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 HG 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 7). 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).

CONCLUSIONS AND RECOMMENDATIONS

The experiences of establishing HG by the farmers' of *Ephratanagidim* 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 HG also conserves indigenous species such as*, Commiphora Africana, Cordia africana, C. macrostachyus, Ehretia cymosa* and *Prunus africana*. The woody plant species evenness and diversity index's were not affected by homegarden size.

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 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 $REDD^{+}$. 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.

List of abbreviations: AGB: above ground biomass; BGB: belowground biomass; C: carbon; CDM: Clean Development Mechanism; DBARC: Debre Birhan Agricultural Research Center; CO2e: Carbon dioxide equivalent; DBH: Diameter at Breast Height; EGWAO: *Ephratana Gidm Wereda* Agriculture Office; HG: homegarden; IPCC: Intergovernmental Panel on Climate Change; IVI: Important Value Index; REDD+: Reducing Emissions from Deforestation and Forest Degradation.

Funding: The study was funded by Amhara Region Agricultural Research Institute (ARARI), Ethiopia

Conflict interests: The authors declare that they have no conflict of interests.

Acknowledgements: I would like to express my deepest gratitude and sincere thanks to my advisor Dr.Menale Wondie whose guidance, constructive comments and suggestions have been highly invaluable for the completion of the study. I am particularly grateful for their cooperation *Ephratana gidm* district, Agriculture and Rural Development Bureau. Special thanks go to farmers who allowed me to collect samples from their farmlands. I offer my regards to all institutions and individuals who supported me in any way during the entire period of my study.

Authors' contribution: Mesafint Minale, designed and conducted the experiments at field, data collection, analysis, interpret the results and finally prepared the draft manuscript. Menale Wondie, designed the experiments, interpret the results, review the full manuscript and improve the contents of these manuscripts. All authors read and approved the final manuscript.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

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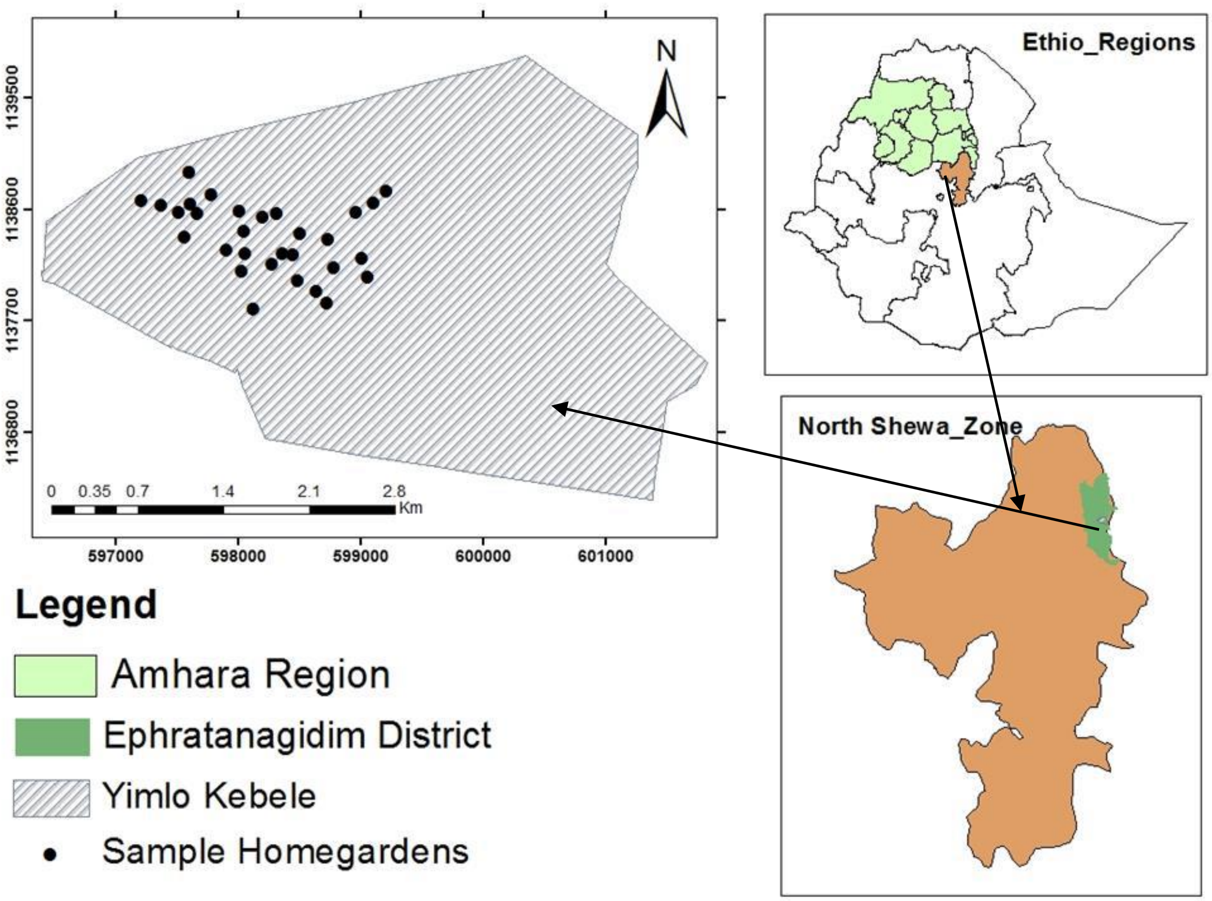

Fig 1 location of the study area

Fig 2 Homegarden agroforestry with different strata's.

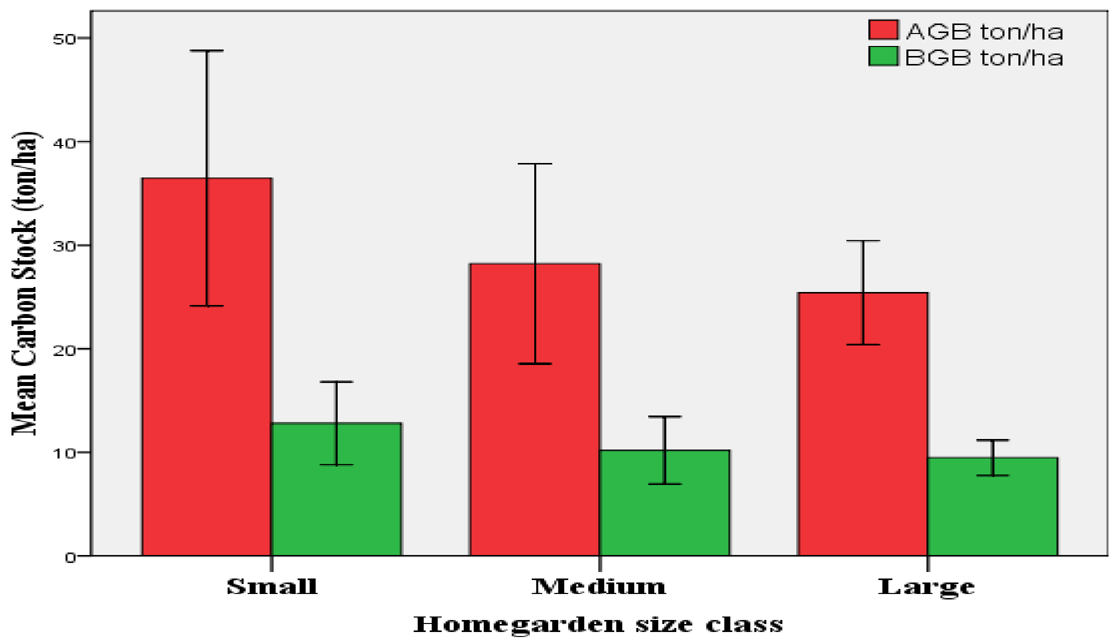

Figure 3 Above and below ground carbon stock in the three homegarden sizes. Error bar show the standard error.

Table 1 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

Table 2 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	

Table 3 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)**[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.

Table 4 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)