

Full Length Research Paper

# Diversity and standing carbon stocks of Agroforestry trees in Wenago District, Ethiopia

<sup>1</sup>Talemos Seta\* and Sebsebe Demissew<sup>2</sup>

<sup>\*1</sup>Addis Ababa University, Department of Plant Biology & Biodiversity Management, P.O. Box 32935, Addis Ababa, Ethiopia.

<sup>2</sup>Addis Ababa University, Professor, Department of Plant Biology and Biodiversity management Keeper, National Herbarium, Addis Ababa, Ethiopia.

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Tree species composition, similarity index and aboveground carbon (AGC) stocks of agroforestry system were assessed in Wenago district, Ethiopia. A total of 20 agroforests were surveyed through a stratified random sampling within four PAs (Peasant Associations). A sampling plot of 900 m<sup>2</sup> was used in each agroforest for plant data (trees with DBH ≥ 15 cm) collection. Shannon-Wiener diversity (H') and Sorensen's similarity indices were used to compute species diversity and species composition respectively. Aboveground carbon stocks of trees were computed using allometric relationships, assuming C as 50% of biomass. A total of 24 tree species under 24 genera and 19 families were identified. The highest stem density (564.4 individuals ha<sup>-1</sup>) was recorded in the 40-60 cm DBH class. The total value of the AGB is 37.31 t ha<sup>-1</sup>. The density of trees and DBH classes have weak correlation with standing AGB (R<sup>2</sup> = 25%, P < 0.001) and strong correlations (R<sup>2</sup> = 64%, P < 0.001) between species richness and aboveground biomass. The highest AGB (15.8 t ha<sup>-1</sup>) was recorded in the DBH range of 80-100 cm. Thus, it gives a highlight for responsible bodies to consider the role of agroforestry system particularly for climate change mitigation strategies.

**Key words:** Aboveground biomass, agroforestry system, wenago district, species diversity, carbon stock.

## INTRODUCTION

Land use changes of the world have contributed substantially to the rising concentration of CO<sub>2</sub> in the earth's atmosphere (IPCC 2007; Nair et al. 2010). Increasing the size of the global terrestrial sink is one strategy for mitigation of CO<sub>2</sub> build-up in the atmosphere. Under the Kyoto Protocol's Article 3.3, A & R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases (Nair et al., 2009; 2010). Agroforestry is a collective name for land use systems where woody perennials (trees, shrubs, palms, bamboos etc.) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Bishaw and Abdelkadir 2003; Nair et al., 2009; Schoeneberger, 2008).

There are both ecological and economic interactions between the different components of AFS. Based on assessments of global terrestrial carbon sinks, two primary beneficial attributes of agroforestry have been identified. The first is direct near-term carbon storage in trees and soils through accumulation of carbon stocks in the form of live tree biomass, wood products, soil organic matter and protection of existing products. The second involves potential to offset greenhouse gas emissions through energy substitution (e.g. fuel wood from woodlots) and fertilizer substitution (through biological nitrogen fixation and biomass production) (Nair et al. 2009; Albrecht and Kandji 2003) as it responds to climatic change through sequestration of carbon in above-ground plant biomass and the soil. The analysis of C stocks from various parts of the world shows that 1.1–2.2 x 10<sup>15</sup> g C could be removed from the atmosphere over the next 50 years if AFS are implemented on a global scale (Albrecht and Kandji, 2003). Similarly, studies have confirmed that the agroforestry practices have a potential to sequester

\*Corresponding author. Email: [talemos.seta@yahoo.com](mailto:talemos.seta@yahoo.com)

greater amount of C replacing carbon emissions caused by deforestation from natural forests (Gupta et al., 2009 and Takimoto et al., 2009). Average carbon storage by agroforestry practices, of which fertilizer trees is an integral part has been estimated as 9, 21, 50, and 63 t C ha<sup>-1</sup> in semiarid, sub humid, humid, and temperate regions respectively (Montagnini and Nair, 2004; Verchot et al., 2007).

Gedeo agroforests in southern Ethiopia is a well known land-use system which is considered as self-sustaining and self-regulating as compared to other land-use system in the area (Tadesse Kippe, 2002). Different scholars Tadesse Kippie (2002), Negash et al. (2005), Negash (2007) have conducted studies on the area of indigenous management practices, socio-economic role, livelihoods and other environmental services of agroforestry systems. Despite the studies related with the aforementioned topics Tadesse Kippie (2002), Negash (2007), literatures on carbon stocks and sequestration potential to its role in climate change mitigation have been very limited in AFS of Gedeo Zone in particular and Ethiopia in general. Estimation of AGB is the most important aspect of studies of carbon sequestration (Ketterings et al., 2001) and a useful measure for comparing structural and functional attributes of forest as well as agroforestry ecosystems across a wide range of environmental conditions (Brown and Schroeder, 1999). The extent of tree species diversity and carbon stock in standing tree biomass of the AFS remains largely unexplored. Therefore, the major objective of the present study is to determine the species diversity of trees in AFS and carbon stocks of tree biomass through estimation of standing aboveground biomass. This study offers an opportunity to assess carbon stock of tree species in AFS, an important process to reduce atmospheric carbon and mitigate climate change and gives information as to which tree species store more carbon during its growth and development in the AFS.

## MATERIALS AND METHODS

### Study Area

This research was conducted in Wenago district, Gedeo zone (Figure 1), SNNPRS; southern Ethiopia. The study area is located at about 390 km south of Addis Ababa, capital city of Ethiopia. The altitude of the study area ranges from 1200 to 2100 m asl, with different agroforestry practices; rainfall of 800 to 1500mm per annum and annual temperatures of 11°C-29°C. Although studies indicated that annual rainfall in Ethiopia would increase with climate change, rainfall has been decreasing by 6 mm annually since the turn of 19th century in Wenago district. The standardized rainfall anomaly analysis showed that the Belg (February to May rainy season) rainfall is susceptible to drought

occurrences in the study area in 6 of 21 years. The population density of Wenago district is about 956.2 persons km<sup>-2</sup>; far greater than the SNNPR average of 122/km<sup>2</sup> (Bishaw et al., 2013). According to SLUF (2006), the Wereda's soil comprises largely (90%) brown soil, 5% red soil and another 5% black soil. Among the indigenous AFS in the study area; enset-coffee-tree agroforests found in elevations between 1600 and 2000 m asl where the enset and coffee are shaded by an upper storey of trees such as *Erythrina brucei*, *Millettia ferruginea*, *Cordia africana*, *Croton macrostachyus*, *Polyscias fulva*, and *Albizia gummifera* which were considered under the subject of this study. The understory is dominated by root and herbaceous plants like *Dioscoria alata*, *Colocasia esculenta*, *Musa* spp. and *Capsicum* species (Mebrate, 2007).

## Methods of data Collection

### Sampling Technique

A total of 4 Peasant Associations (PAs) were selected by stratified random sampling technique from Wenago district. Of the four peasant association, a total of 20 agroforests (five from each PA) were selected by purposive sampling to determine the composition and carbon stocks of canopy tree species. In each agroforest, one 30 X 30 m (900 m<sup>2</sup>) sample plot was purposefully laid for data collection. Individuals per plant species with a DBH ≥15 cm in each sample sites were counted and tree parameters measured regardless of shrubs and herbs encountered. Only the measured data (trees with DBH ≥15 cm) were used in the analysis. Plant identification was attempted in the field and voucher specimens were brought to the National Herbarium (ETH), Addis Ababa University, Science Faculty, for final confirmation.

### Aboveground Tree Biomass (AGB)

There is no allometric equations developed for trees in agroforestry to estimate AGB and carbon stock in Ethiopia except a few developed for coffee (Negash et al., 2013a) and enset (Negash et al., 2013b) in enset-coffee-tree system very recently. Researchers in the world have a tradition of applying allometric equations developed for tree species of the natural forest to estimate AGB of trees in agroforestry though not accurate. This is due to the fact that destructive harvesting of trees in the system is costly, labor intensive, and time taking for both AGB and belowground biomass determination. Biomass studies have largely focused on the aboveground portion relative to the belowground portion of vegetation biomass, owing partly to the difficulty in accessing plant roots (Chave et al., 2005; Brown et al., 1989). For estimating carbon stock, tree in-

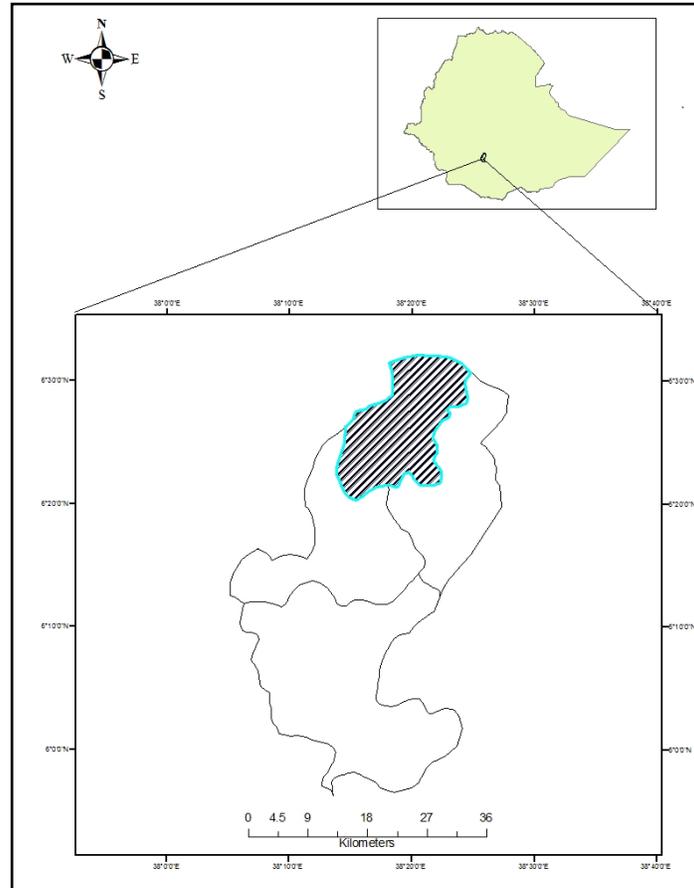


Figure 1. Location map of Wenago District

inventories followed by using allometric relationships between the aboveground biomass (AGB) of a tree and its trunk diameter (Brown 1997; Brown et al., 1989) have been used. For the present study, three allometric equations developed by Brown (1997), Chave et al. (2005) and Kuyah et al. (2012) were evaluated to estimate the aboveground biomass of the agroforestry trees and no significant difference have been found among the equations. However, the allometric equation of Kuyah et al. (2012) shown below, typically relating tree diameter to biomass was used for the present study.

$$AGB = 0.091 \times DBH^{2.472}; R^2 = 0.98, n = 72$$

where AGB (kg dry matter plant<sup>-1</sup>) = aboveground biomass, DBH(cm) = diameter at breast height. This equation was selected because it had the highest R<sup>2</sup> and lowest error of prediction values, used only breast height diameter, and developed for trees grown in agroforestry systems in western Kenya. Moreover, the study site is having similar environmental conditions (climate and soils) to our current study sites.

### Data Analysis

Shannon-Wiener diversity index (Shannon and Weaver 1949), Shannon's evenness and Sorensen's similarity

index (Kent and Coker 1992) were calculated to analyze species diversity and species composition of tree species in agroforests of the study area.  $H' = -\sum p_i \ln p_i$ ,

Where,

$H'$  = Shannon Diversity Index

$P_i$  = the abundance of  $i^{\text{th}}$  species expressed as a proportion of total cover.

Evenness (Equitability)  $J = H'/H'_{\text{max}}$ , where:

$J$  = Evenness,

$H'$  = Shannon-Wiener diversity index and

$H'_{\text{max}} = \ln S$ , where  $S$  is the number of species.

Species compositions were contrasted among PAs using a Sorensen's similarity index. It has been used to determine the pattern of species turnover among successive communities and to compare the agroforests among Peasant Association. Sorensen's similarity index uses species presence/absence data for sample sets and is calculated as  $S = 2a/2a+b+c$  Where:  $S$  = Sorensen's similarity coefficient

$a$  = Number of species common to both samples

$b$  = Number of species in sample 1 but not in 2

$c$  = Number of species in sample 2 but not in 1

**Table 1.** Species diversity and evenness of trees.

PA's	R	H'	J'
Sugale	15	2.21	0.78
Mokonissa	16	2.37	0.85
Dedero	19	2.60	0.86
Jemjemo	18	2.52	0.87

**Table 2.** Sorensen's similarity Index among PAs

PA	Sugale	Mokonisa	Dedero	Jemjemo
Sugale	1.00	0.93	0.79	0.88
Mokonissa		1.00	0.82	0.81
Dedero			1.00	0.84
Jemjemo				1.00

To investigate the structural role of tree in the sampling plots, the importance value index (IVI) of each species was calculated using the percentage of relative abundance (R.A.), relative dominance (R.D.) and relative frequency (RF) (Whittaker 1970).

$$I.V.I = R.A + R.D + R.F,$$

Where;

R.A=Total no. of each species/Total no. of all species\*100

R.D=BA of each species/BA of all species\*100

R.F= Chance to find each species/Chance to find all species\*100

Here, BA (basal area) was calculated, for all trees with a diameter at breast height  $\geq 15$  cm, by using the formula:  $BA = 0.785 \text{ DBH}^2$  Where, BA is basal area and DBH is the diameter of the trees at breast height. The canopy trees with high IVI values were compared among the four Peasant associations. To test the significance of the difference between categories, correlation coefficient was carried out using R14.0 software. The biomass density of overall trees were summed up to get total biomass density in each plot and then extrapolated to hectare using conversion factor. The biomass stock density of a sampling plots were converted to carbon stock densities after multiplication with default carbon fraction of 0.50, as the dry biomass contains 50 % organic carbon (Penman et al., 2003; Cannel et al., 1995; Dixon et al., 1994; MacDicken, 1997; Ravindranath et al., 1997; Richter et al., 1995; Schroeder, 1992). The aboveground biomass carbon stocks were correlated against species richness and stand density using Pearson's coefficient of correlation at  $P \leq 0.05$ . Similarly, the aboveground biomass carbon stocks distributions against different DBH class were also correlated at the same confidence level to test the significant difference.

## RESULTS

### Species diversity and composition of Agroforestry system

The canopy tree species recorded in the coffee-enset-tree agroforests were 24 distributed in 24 genera and 19 families excluding the most dominant coffee and enset plants (Appendix I), other trees less than 15 cm and herbs in the agroforests. Fabaceae and Myrtaceae contain 3 species each which accounts 25% (12.5% each) of the total whereas the remaining 13 families comprised of only one species each. Species richness calculated among four study sites are 15, 16, 19, 18 canopy tree species from Sugale, Mokonissa, Dedero and Jemjemo respectively. When extrapolated to hectare basis an average of 33.3, 35.6, 42.3 and 40 tree species  $\text{ha}^{-1}$  in Sugale, Mokonissa, Dedero, and Jemjemo PA respectively. Moreover, the pooled Shannon Diversity Index of the agroforests was 2.43 with the evenness of 0.84 which shows that all the study sites have relatively good diversity and evenness (Table 1).

The tree species in agroforests are evenly distributed among the study sites due to the presence of indigenous enset-coffee shade trees dominating the system with large number of stands.

Sorensen's similarity index calculated among Peasant associations showed that all the study sites have the highest similarity with each other (Table 2).

From the total of 24 tree species identified in agroforests of the study area, 53.52% (13 plant species) are found in common for all the four PAs. However, among the four PAs, Sugale and Mokonissa are more similar (93%) in species composition than others as observed from the table 2 above.

### The Important Value Index (IVI) of tree species in Agroforestry system

The IVI calculated from the vegetation data showed the six dominant, abundant and frequently occurred tree species of the AFS (Table 3a and 3b).

Tree species such as *Cordia africana*, *Millettia ferruginea*, *Albizia gummifera*, *Croton macrostachyus* and *Erythrina brucei* are commonly found in every visited enset-coffee-tree based agroforests of the study area. Similarly, of the 24 tree species, six with the highest IVI accounted for 58.44% for Sugale followed by 57.08%, 49%, and 47.7% for Mokonissa, Dedero, and Jemjemo respectively. This might be because of the fact that these trees have a multipurpose role both in terms of ecological and economic values for the local communities.

### The DBH Vs density of trees in agroforestry system

The DBH of trees from the agroforests was classified into five DBH classes. Accordingly, the pooled result showed that the highest total stand density (551.4 individuals  $\text{ha}^{-1}$ ) was recorded in the 40-60 cm range where as the lowest

**Table 3a.** Scientific names of the agroforestry trees with the highest IVI values in Sugale and Mokonissa.

Trees in Sugale	(IVI)	Tree in Mokonissa	(IVI)
<i>Cordia africana</i> Lam.	49.32	<i>Millettia ferruginea</i> (Hochst.) Baker	41.22
<i>Millettia ferruginea</i> (Hochst.) Baker	35.44	<i>Cordia africana</i> Lam.	39.20
<i>Albizia gummifera</i> (Gmel.) C.A.Sm	33.38	<i>Podocarpus falcatus</i> Thunb.	24.98
<i>Syzygium guineese</i> (Willd.) DC.	22.34	<i>Erythrina brucei</i> Schweinf.	23.59
<i>Croton macrostachyus</i> Del.	20.13	<i>Croton macrostachyus</i> Del.	22.71
<i>Erythrina brucei</i> Schweinf.	18.45	<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	19.55
<b>Percent</b>	<b>58.44%</b>		<b>57.08%</b>

**Table 3b.** The agroforestry trees with the highest IVI values in Dederero and Jemjemo.

Trees in Dederero	(IVI)	Trees in Jemjemo	(IVI)
<i>Cordia africana</i> Lam.	38.66	<i>Cordia africana</i> Lam.	41.16
<i>Millettia ferruginea</i> (Hochst.) Baker	35.74	<i>Millettia ferruginea</i> (Hochst.) Baker	35.18
<i>Croton macrostachyus</i> Del.	19.73	<i>Erythrina brucei</i> Schweinf.	17.58
<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	18.51	<i>Podocarpus falcatus</i> Thunb	17.21
<i>Erythrina brucei</i> Schweinf.	18.34	<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	16.01
<i>Podocarpus falcatus</i> Thunb	15.91	<i>Croton macrostachyus</i> Del.	15.88
<b>Percent</b>	<b>49%</b>		<b>47.7%</b>

(15.6 individuals ha<sup>-1</sup>) was in the DBH range of greater than 100 cm. However, Sugale, one of the study PA, has the highest stand density (222.3 individuals ha<sup>-1</sup>) in the <20-40 cm DBH class and even zero in >60-80 cm. This occurrence of high stand density in smaller diameter class might be due to the fact that the Peasant association of Sugale is the immediate surroundings of the highway crossing to Moyale from Dilla town whereby it gives more access to timber trees for sale than other study areas. In contrast, Jemjemo (284.4 individuals ha<sup>-1</sup>) and Dederero (237.8 individuals ha<sup>-1</sup>) PAs have the highest stand density in the DBH range of 60-80 and 80-100 cm respectively. This truth might also be as a result of their occurrence a bit far from the main road whereby it restricts the access of timber trees in their agroforestry system. Generally speaking, the DBH-stand density distribution does not follow the L shaped pattern where the smaller diameter class have higher stand density in Mokonissa, Dederero and Jemjemo PAs (Figure 2). Thus, the agroforestry system requires further management

and follow-up for the sustainable use by the local people in the future.

### Aboveground Biomass and Carbon stock Distribution

The aboveground biomass estimate of Sugale, Mokonissa, Dederero and Jemjemo PAs are 4.6, 10.38, 11.34 and 10.99 ton ha<sup>-1</sup> respectively (Table 4 and Appendix II). The four peasant associations have the total AGB of 37.31 t ha<sup>-1</sup>

Since the major parameter used in the model is mainly the DBH, larger diameter class stored a large stock of AGB whereas small amounts of AGB have been stocked by small diameter class. Accordingly, the AGB showed that the highest value (15.8 t ha<sup>-1</sup>) was recorded in the DBH range of 80-100 cm where small number of trees representing largest diameter followed by 40-60 cm where large number of trees representing this diameter class with AGB of 7.37 t ha<sup>-1</sup>. The carbon stock was deri-

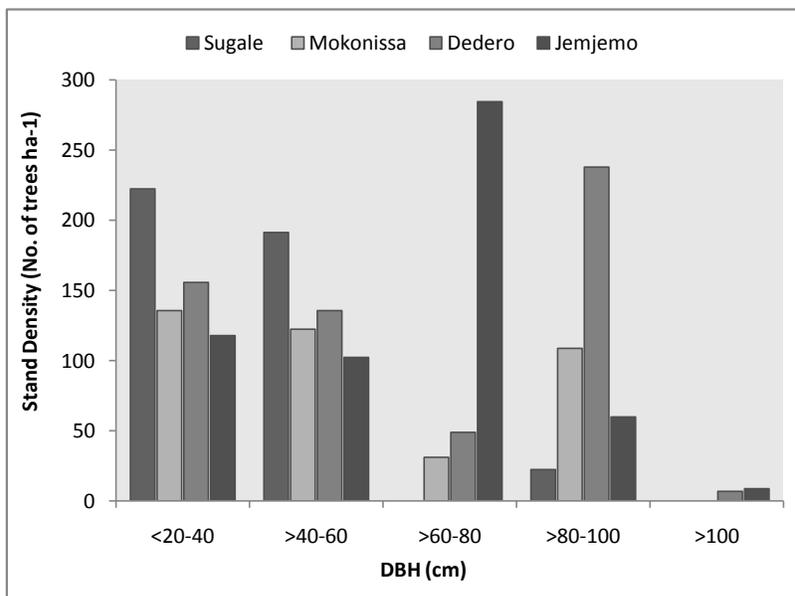


Figure 2. Tree density (No ha<sup>-1</sup>) in different diameter classes for the study sites.

Table 4. The Aboveground Biomass (Ton ha<sup>-1</sup>) in different Diameter class.

DBH	<20-40	>40-60	>60-80	>80-100	>100
Sugale	0.6	1.74	0	2.26	0
Mokonissa	0.35	1.94	1.44	6.65	0
Dedero	0.61	1.81	2.31	4.74	1.87
Jemjemo	0.34	1.88	3.39	2.15	3.23
Total	1.90	7.37	7.14	15.8	5.1

ved directly from the aboveground biomass of trees and the total result of four study sites have shown the carbon stock of 18.66 t C ha<sup>-1</sup>. Similarly, the highest AGC stock (7.9 t C ha<sup>-1</sup>) was recorded in the DBH range of 80-100 cm followed by 3.69 t C ha<sup>-1</sup> in the DBH of 40-60 cm (Figure 3). The AGB estimated for all sites have shown the trend that the density of trees in the system and the respective DBH have weak correlation with standing AGB (R<sup>2</sup> = 25%, P <0.001, n = 68). In contrast, it has been observed that there is strong correlations (R<sup>2</sup> =64%, P < 0.001, n=68) between species richness and aboveground biomass. Accordingly, the AGB estimated for DBH classes showed the decreasing order from Dedero>Jemjemo> Mokonissa> Sugale PAs.

**Species' relative contribution to C storage in Agroforestry sytem**

The tree species identified from 20 agroforests have a DBH range between 15 and 123 cm. The role of large trees in determining C stocks in AFS of the present study shows its paramount importance towards providing

environmental services. Accordingly, from all tree species encountered in the present study, nine species (DBH> 60 cm) contributed 69.53 % of the pooled AGC storage of the the agroforestry system. The nine species are *Albizia gummifera*, *Cordia africana*, *Ekebergia capensis*, *Polyscias fulva*, *Erythrina brucei*, *Millettia ferruginea*, *Podocarpus falcatus*, *Prunus africana* and *Syzygium guineense*. Because of the frequent occurrence of these native canopy trees, this agroforests are quite similar in their structure with moist afro-montane forests of the country. Consequently, these species constitute the backbone of the Gedeo AFS as they function as both coffee and enset shade trees in addition with socio-economic and environmental provisions like carbon sequestration. Those trees mentioned above are with the highest IVI values contributing the largest AGB carbon in the system. To further explore the evenness of the species' contributions, the average contribution of each species to carbon stocks per hectare was calculated and explained it in terms of percentage (Table 4). The two species with the relative AGC stock contribution of 49.13% in Sugale PA are *Albizia gummifera* and *Syzygium guineense*. The seven species that contribute

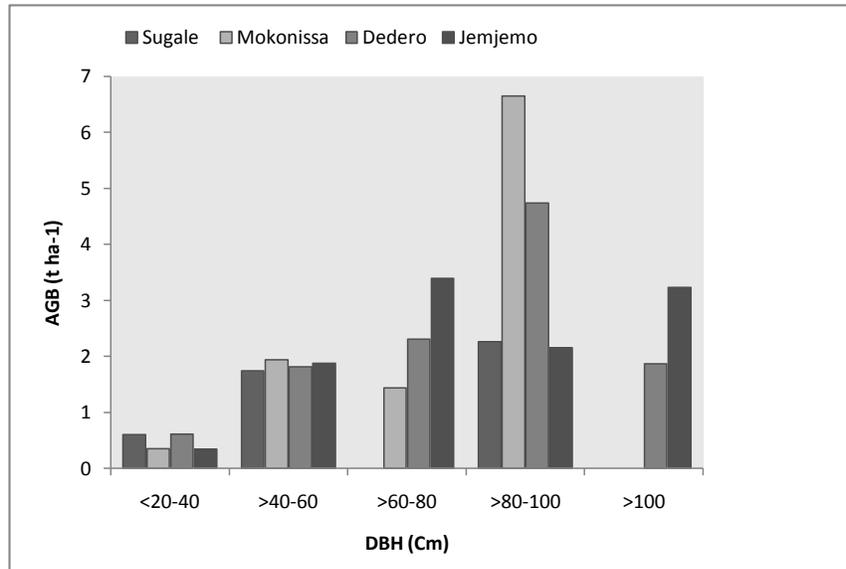


Figure 3. Aboveground Biomass against DBH classes of the study sites.

Table 4. Species relative contribution to C storage in the study sites (DBH > 60 cm).

PAs	Species relative contribution to C stock (%)	No. species
Sugale	49.13	2
Mokonissa	78.03	7
Dederro	78.80	8
Jemjemo	81.83	8

78.03% of the total standing AGC stock in the Mokonissa PA are *Cordia africana*, *Dracena steudneri*, *Erythrina brucei*, *Eucalyptus*, *Podocarpus falcatus*, *Prunus africana* and *Syzygium guineense*. Moreover, in Dederro PA the eight species contribute to a carbon stock of 78.80%. The species are *Cordia africana*, *Croton macrostachyus*, *Ekebergia capensis*, *Eucalyptus sp*, *Milletia ferruginea*, *Podocarpus falcatus*, *Prunus africana* and *Syzygium guineense*. In Jemjemo PA, eight canopy trees contribute the highest species relative carbon stock (81.83%). The tree species are *Albizia gummifera*, *Cordia africana*, *Erythrina brucei*, *Eucalyptus*, *Milletia ferruginea*, *Podocarpus falcatus*, *Prunus africana*, *Syzygium guineense* which have highest relative carbon stock contribution.

## DISCUSSION

### Species Diversity and composition

The Gedeo agroforests in general and Wenago in particular are small in size but possessing diverse tree

species integrated and often managed around home-steads (Tadesse Kippie 2002). It forms a structural continuity over a wide range of the agricultural matrix. In a study conducted by Negash (2007), a total of 50 plant species within 35 plant families have been recorded in Wenago considering all plant species into account during sampling in contrast to the present study (24 tree species) which only considered tree species with a DBH  $\geq 15$  cm (GBH of 47 cm). Moreover, Tesfaye Abebe (2005) identified an average of 21 species in each farm of Sidama which is found closer to the present study sites. Mohammed (2008) from his study also recorded a total of 29 tree species in the coffee AFS of Haro; Manna Wereda of Jimma Zone. He found that only one species existing in all the agroforests i.e. *Croton macrostachyus* while five species were found in nine agroforests out of 19 samples. With regard to the number of species per plot, De Foresta and Yao (2007) have found an average of 6.5 species in a study on characterization of agroforests near Jimma but 8.8 species per plot was recorded in the present study.

Moreover, similar studies done across the tropics shows variation in tree species richness between AFS even within

the same geographic region. Accordingly, the AFS can have as few as one canopy tree species/ha and up to 64 species/ha in Cocoa AFS of Southern Bahia, Brazil (Carlo et al. 2004). Species richness in coffee agroforestry system of Mexico ranged from 2 to 7 tree species/ha (Mas and Dietsch 2003), Cocoa agroforestry system in Cameroon had 15 to 26 tree species/ha (Sonwa et al., 2007) in which case the tree species richness of the present study outweighs.

Tadesse Kippe (2002) equates the Gedeo farming system where wenago district included to natural forests in terms of their architectural complexity, composition, and arrangement, and because of the interactions among system components. These floristically and structurally diverse agroforests provide a habitat and microclimate suitable to a variety of plant and animal species (Harvey et al. 2010) though it has been decreasing since then due to population pressure. Of 24 tree species identified in agroforests, 53.52% (13 plant species) are found in common for all the four PAs. This might be due to the closeness of the study sites with each other and the local people preferences to some selected tree species to integrate in their enset-coffee and enset-coffee-fruit based agriculture. However, among the four PAs, Sugale and Mokonissa are more similar (93%) in species composition than others. This similarity might also be due to the fact that both are found closer to each other and closer to the highway crossing Wenago district to Moyale. In this type of agroforests there is a lot of selection of species for betterment of coffee production and dynamics of agroforests which is going to be more homogenous as productivity increases in one species shade agroforest while quickly decrease as tree species are increased. This difference in species found in agroforests clearly depicts the difference of management and species selection trends of local people for productivity of agroforests (Declerck et al. 2006). A study done by Albuquerque et al. (2005) showed that although, the proportions of species used for different purposes vary, in general, traditional agroforests with highest IVI values contribute substantially towards meeting the basic subsistence needs of their owners for products and services such as food including vegetables and fruits, medicines, forage, shade and ornamentals.

### The DBH distribution Vs density of trees in agroforestry system

The pattern of diameter class distribution has often been used to represent the population structure of a forest as well as complex agroforestry system (Khan et al. 1987). The overall distribution pattern of diameter classes in the canopy agroforests here suggests that the stands consist of species with relatively wider age classes. Tesfaye Abebe (2005) recorded a total population of trees per farm averaged 855 (475 per ha) in Sidama agroforestry

system which is closer to the density value of the present study with a total population of trees per farm averaged 492.22 ha<sup>-1</sup>. In the study of Tesfaye Abebe (2005) the high tree density is due to presence of closely-spaced eucalyptus trees which, because of their highly competitive effects, are planted on farm boundaries and in separate woodlots. However, a bit higher tree density for the present study is due to the frequent occurrence of native species such as *Albizia gummifera*, *Cordia africana*, *Croton macrostachyus*, *Ekebergia capensis*, *Polyscias fulva*, *Erythrina bruce* and *Millettia ferruginea* which farmers regard to be complimentary to crop production and shade trees. PAs with more coffee plants have the highest number of associated tree species followed by PAs with enset plants followed by woodlots as observed by the researcher. Farm size, woodlot area and road access affected both diversity and density of trees and tree species richness of farms increased with size and remoteness of farms as confirmed by vegetation data of the present study (Tesfaye et al. 2010).

### Aboveground Biomass and Carbon stock Distribution

A study from Central America where *Coffea arabica* has been commonly studied in association with *Erythrina* and *Cordia* shade species indicate standing AGB production of 20 t ha<sup>-1</sup> and 29 t ha<sup>-1</sup> respectively (Fassbender et al., 1985) where the DBH classes of the study was not specified. The canopy trees with wider diameter classes have a higher AGB as compared to the smaller diameter class for the present study and the overall distribution pattern of diameter classes in the canopy agroforests suggests that the stands consist of species with relatively wider age classes though the age class was not considered in the study. Studies in Cameroon showed that total biomass in cacao agroforests (304 t ha<sup>-1</sup>) (Duguma et al. 2001) are much higher than the total biomass of present study (37.31 t ha<sup>-1</sup>) as the present study only considered the standing AGB of coffee-enset-tree agroforests.

However, studies on biomass in the highly heterogeneous agroforestry-dominated landscapes of the East African highlands are scarce and data available have been very limited. Glenday (2008) computed a carbon stock of 19 t C ha<sup>-1</sup> in AGB for AFS around the *Arabuke Soko* forest on the Kenyan coast. Kumar (2011) made an attempt to compute the AGC stocks of homegarden trees (>20cm GBH) in Central Kerela, India and average AG standing stocks of C ranged from 16 to 36 ton ha<sup>-1</sup> with standard error values in the range of 0.74–2.18 whereby the standing carbon stock of the present study is in between this value. According to Henry et al. (2009) conversion from food crops to homegardens agroforestry would result in an AGB increase of 0.5–0.6 ton C ha<sup>-1</sup> year<sup>-1</sup> so that enhancing

agroforestry practice has vital role for carbon accumulation and may thus reduce pressure on adjacent natural forest and woodlands. This opens potential opportunities for payments for avoided deforestation and forest degradation which in turn could be used as a strategy for climate change mitigation.

### Species' relative contribution to C storage in Agroforestry

Study done by Dossa et al. (2008) in South western Togo describes total plant C stock in the shaded coffee system as 82 ton C ha<sup>-1</sup>, of which 67 ton (82%) is found in AGC fractions. AGC stock in the shaded coffee system of the same study is dominated by the *Albizia* trees, which contributed 82% of the total AGC. However, from the present study, *Albizia* trees contributed 33% of AGC stock only but *Cordia africana* contributed about 37% of the standing AGC stock. This is due to the fact that the system is a mix of different canopy trees other than only one dominating the AFS. Total vegetation C in the open-grown coffee system was only 23 ton ha<sup>-1</sup>, 60% of that amount was allocated to AGB. The major contributor to AGC in the open-grown coffee system was coffee stem, which made up 53% of total AGC in that system (Dossa et al. 2008). From the present study, those trees mentioned above are with the highest IVI values contributing the largest ABG in the system. Therefore, from this result one can conclude that the canopy trees of the enset-coffee agroforests in the study area can hold more than half of the total standing AGB carbon which would help as a strategy in reducing carbon emission to atmosphere as climate change mitigation. Furthermore, the households plant the canopy trees for production of fuel wood, construction materials, maintenance of soil fertility and as a source of fodder for livestock which would comparatively help in storing large amount of carbon (Tesfaye Abebe et al. 2010; Negash, 2007; Mebrate 2007).

### CONCLUSIONS

The canopy tree species with wider diameter class distribution contributes high AGB and in turn carbon stock in the existing AFS. The total carbon density of 18.66 t ha<sup>-1</sup> in the study areas was only determined from AGB of standing trees using (Kuyah et al., 2012) allometric equation. This shows that the AFS and sustainable management have a great potential to be a significant carbon sink. Accordingly, there are great opportunities for increasing the contribution such as a decrease of negative effect of climate change and increase of household income. However, in recent time, an understanding of the potential of agroforestry to contribute for climate change mitigation is rudimentary. Therefore, better information is required on the role of

agroforestry from environmental, ecological and economic point of view.

The use of generalized biomass equations to predict AGB stocks of trees in agroforests is a limitation for this study as there have been no species-specific biomass equations for trees encountered in the area. Thus, the complete carbon accounting of this AFS should be conducted in order to be recognized in national as well as international level as a strategy for climate change mitigation. With regard to policy issues, an understanding of the capacity of enset-coffee agroforests to store carbon relative to natural forests must be developed. Though it is not timely, it is appropriate to explore the CDM and other mechanisms by which communities of smallholder farmers of the Wenago agroforests in particular and Gedeo in general can access international carbon investment funds as they have productive tree-based systems which contain much higher C stocks from small landholding size.

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**Appendix I.** List of plant species collected from the study area. Plant species in **Bold** (DBH >15 cm) are only used for the data analysis of this study. Otherwise the remaining plant species are frequently occurred trees with DBH < 15 cm.

	<b>Scientific Name</b>	<b>Local Name</b>	<b>Family Name</b>
1	<i>Acacia abyssinica</i> Hochst.ex Benth.		Fabaceae
2	<b><i>Albizia gummifera</i> (Gmel.) C.A.Smith</b>	<b>Gorbee(G)</b>	<b>Fabaceae</b>
3	<i>Allophylus abyssinicus</i> (Hochst.) Radlkofer		Sapindaceae
4	<i>Casuarina equisetifolia</i> L.		Casuarinaceae
5	<i>Catha edulis</i> (Vahl) Forssk. ex Endl.	Chat(Am)	Rutaceae
6	<i>Coffea arabica</i> L.		Rubiaceae
7	<b><i>Cordia africana</i> Lam.</b>	<b>Wodessa(G)</b>	<b>Boraginaceae</b>
8	<b><i>Croton macrostachyus</i> Del.</b>	<b>Mekenisa(G)</b>	<b>Euphorbiaceae</b>
9	<i>Delonix regia</i> (Boj.ex Hook.) RaJ.		Fabaceae
10	<i>Dovyalis caffra</i> (Hook f. & Harv.) Hook f.	Koshim(Am)	Flacourtiaceae
11	<b><i>Dracaena steudneri</i> Engler</b>		<b>Dracaenaceae</b>
12	<b><i>Ekebergia capensis</i> Sparrn</b>	<b>Lol (Am)</b>	<b>Meliaceae</b>
13	<i>Ensete ventricosum</i> (Welw.) Cheesman	Enset(G,Am)	Musaceae
14	<b><i>Erythrina brucei</i> Schweinf</b>	<b>Woleyna</b>	<b>Fabaceae</b>
15	<b><i>Eucalyptus globulus</i> Labill</b>	<b>Honcho</b>	<b>Myrtaceae</b>
16	<b><i>Fagaropsis angolensis</i> (Engl.) Dale</b>	<b>Sissa</b>	<b>Rutaceae</b>
17	<b><i>Ficus sur</i> Forssk</b>	<b>Ode'ee</b>	<b>Moraceae</b>
18	<b><i>Grevillea robusta</i> R. Br.</b>		<b>Proteaceae</b>
19	<b><i>Jacaranda mimosifolia</i> D. Don.</b>		<b>Bignoniaceae</b>
20	<b><i>Mangifera indica</i> L.</b>	<b>Mango</b>	<b>Anacardiaceae</b>
21	<i>Melia azadirachta</i> L		Meliaceae
22	<b><i>Millettia ferruginea</i> (Hochst.) Baker</b>	<b>Dhaxatto</b>	<b>Fabaceae</b>
23	<b><i>Moringa stenopetala</i> (Bak.) Cuf.</b>	<b>Shiferaw</b>	<b>Moringaceae</b>
24	<i>Musa Paradisiaca</i> L.	Muz(Am)	Musaceae
25	<b><i>Olea capensis</i> L. subsp. <i>macrocarpa</i> (C. H. Wright) Verdc.</b>		<b>Oleaceae</b>
26	<b><i>Persea americana</i> Mill.</b>	<b>Avocado(Am)</b>	<b>Lauraceae</b>
27	<b><i>Podocarpus falcatus</i> Thunb</b>	<b>Birbissa(Or)</b>	<b>Podocarpaceae</b>
28	<b><i>Polyscias fulva</i> (Hiern) Harm.</b>	<b>Talaha(G)</b>	<b>Araliaceae</b>
29	<b><i>Pouteria adolfi-friedericii</i> (Engl.) Baehni</b>	<b>Gudubo(G)</b>	<b>Sapotaceae</b>
30	<b><i>Prunus africana</i> (Hook.f.) Kalkam</b>	<b>Gerbicho(G)</b>	<b>Rosaceae</b>
31	<b><i>Psidium guava</i> L.</b>	<b>Zeytun(Am)</b>	<b>Myrtaceae</b>
32	<i>Rhamnus prinoides</i> L'Herit.	Gesho(Am)	Rhamnaceae
33	<b><i>Spathodea campanulata</i> Beauv.</b>		<b>Bignoniaceae</b>
34	<b><i>Syzygium guineese</i> (Willd.) DC.</b>	<b>Baddeessa(G)</b>	<b>Myrtaceae</b>
35	<b><i>Vernonia amygdalina</i> Del.</b>	<b>Gerawa(Am)</b>	<b>Asteraceae</b>

Note: Am= Amharic language, G= Gedeoffa language, Or= Ormomiiffa language

**Appendix II.** Mean Height (m), DBH (cm), Tree density (No plot<sup>-1</sup>), AGB (t ha<sup>-1</sup>) and Carbon stock (t C ha<sup>-1</sup>) of tree species in the study areas.

Pas	Scientific name	DBH	H	Density	AGB (kg tree <sup>-1</sup> )	T ha <sup>-1</sup>	T C ha <sup>-1</sup>
Sugale	<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	85.35	36	8	0.54	1.20	0.60
	<i>Cordia africana</i> Lam.	45	26	65	0.11	0.25	0.12
	<i>Croton macrostachyus</i> Del.	36	18	12	0.06	0.14	0.07
	<i>Erythrina brucei</i> Schweinf.	42	20	10	0.09	0.21	0.10
	<i>Eucalyptus globulus</i> Labill	15	8	14	0.01	0.02	0.01
	<i>Fagaropsis angolensis</i> (Engl.) Dale	22.3	12	3	0.02	0.04	0.02
	<i>Ficus sur</i> Frossk.	19.1	11	8	0.01	0.03	0.01
	<i>Pouteria adolfi-friedericii</i> (Engl.) Baehni	40.12	21	2	0.08	0.19	0.09
	<i>Millettia ferruginea</i> (Hochst.) Baker	36	18	42	0.06	0.14	0.07
	<i>Persea americana</i> Mill.	34	15	15	0.06	0.12	0.06
	<i>Podocarpus falcatus</i> Thunb.	32	19	6	0.05	0.11	0.05
	<i>Polyscias fulva</i> (Hiern) Harm.	52.5	16	2	0.16	0.36	0.18
	<i>Prunus africana</i> (Hook.f.) Kalkam.	53.5	26	5	0.17	0.38	0.19
	<i>Spathodea campanulata</i> Beauv.	52.5	15	2	0.16	0.36	0.18
	<i>Syzygium guineense</i> (Willd.) DC.	81	42	2	0.48	1.06	0.53
Total				196	2.07	<b>4.60</b>	<b>2.30</b>
<b>Scientific name</b>							
Mokonissa	<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	56.7	32	12	0.20	0.44	0.22
	<i>Cordia africana</i> Lam.	87	45	25	0.57	1.26	0.63
	<i>Croton macrostachyus</i> Del.	47.8	25	16	0.13	0.29	0.14
	<i>Dracaena steudneri</i> Engler.	87.3	20	3	0.57	1.27	0.64
	<i>Erythrina brucei</i> Schweinf.	67.5	24	11	0.30	0.67	0.34
	<i>Eucalyptus globulus</i> Labill.	87.3	22	8	0.57	1.27	0.64
	<i>Ficus sur</i> Frossk.	55.7	28	4	0.19	0.42	0.21
	<i>Pouteria adolfi-friedericii</i> (Engl.) Baehni.	42	30	4	0.09	0.21	0.10
	<i>Mangifera indica</i> L.	41	13	14	0.09	0.20	0.10
	<i>Millettia ferruginea</i> (Hochst.) Baker.	38	19	46	0.07	0.16	0.08
	<i>Persea americana</i> Mill.	28	15	12	0.03	0.08	0.04
	<i>Podocarpus falcatus</i> Thunb.	100	54	10	0.80	1.78	0.89
	<i>Polyscias fulva</i> (Hiern) Harm.	32	20	3	0.05	0.11	0.05
	<i>Prunus africana</i> (Hook.f.) Kalkam.	71.3	35	3	0.35	0.77	0.39
	<i>Spathodea campanulata</i> Beauv.	54.1	14	5	0.18	0.39	0.19
<i>Syzygium guineense</i> (Willd.) DC.	81.5	44	3	0.48	1.07	0.54	
Total				179		10.37	5.19

	Scientific name	DBH	H	Density	AGB (kg/tree <sup>-1</sup> )	T ha <sup>-1</sup>	TC ha <sup>-1</sup>
Dedero	<i>Albizia gummifera</i> (Gmel.) C.A.Sm.	56.7	32	27	0.20	0.44	0.22
	<i>Cordia africana</i> Lam.	87	28	49	0.57	1.26	0.63
	<i>Croton macrostachys</i> Del.	67	20	9	0.30	0.66	0.33
	<i>Dracaena steudneri</i> Engler.	42	15	10	0.09	0.21	0.10
	<i>Ekebergia capensis</i> Sparrm.	68	34	6	0.31	0.69	0.34
	<i>Erythrina brucei</i> Schweinf.	54	18	10	0.17	0.39	0.19
	<i>Eucalyptus globulus</i> Labill.	87.3	32	12	0.57	1.27	0.64
	<i>Ficus sur</i> Frossk.	55.7	28	5	0.19	0.42	0.21
	<i>Grevillea robusta</i> R. Br.	19.1	25	17	0.01	0.03	0.01
	<i>Mangifera indica</i> L.	38	12	14	0.07	0.16	0.08
	<i>Millettia ferruginea</i> (Hochst.) Baker.	82	34	44	0.49	1.09	0.54
	<i>Moringa stenopetala</i> (Bak.) Cuf.	27.4	8	16	0.03	0.07	0.04
	<i>Persea americana</i> Mill.	34	14	10	0.06	0.12	0.06
	<i>Podocarpus falcatus</i> Thunb.	102	54	3	0.84	1.87	0.93
	<i>Polyscias fulva</i> (Hiern) Harm.	36	18	6	0.06	0.14	0.07
	<i>Prunus africana</i> (Hook.f.) Kalkam.	78	36	7	0.43	0.96	0.48
	<i>Spathodea campanulata</i> Beauv.	52.2	16	9	0.16	0.36	0.18
	<i>Syzygium guineese</i> (Willd.) DC.	83	45	2	0.50	1.12	0.56
	<i>Vernonia amygdalina</i> Del.	27.7	8	7	0.03	0.07	0.04
		<b>Total</b>			<b>263</b>		<b>11.33</b>
PA	Scientific name	DBH	H	Density	AGB (kg/tree <sup>-1</sup> )	T ha <sup>-1</sup>	TC ha <sup>-1</sup>
Jemjemo	<i>Albizia gummifera</i> (Gmel.) C.A.Sm	82.16	45	2	0.49	1.09	0.55
	<i>Cordia africana</i> Lam.	73.9	24	68	0.38	0.84	0.42
	<i>Croton macrostachys</i> Del.	53.5	20	9	0.17	0.38	0.19
	<i>Ekebergia capensis</i> Sparrm.	59.2	25	11	0.22	0.49	0.24
	<i>Erythrina brucei</i> Schweinf.	67.5	25	13	0.30	0.67	0.34
	<i>Eucalyptus globulus</i> Labill.	81	45	17	0.48	1.06	0.53
	<i>Ficus sur</i> Frossk.	53.7	22	6	0.17	0.38	0.19
	<i>Mangifera indica</i> L.	27.5	13	17	0.03	0.07	0.04
	<i>Millettia ferruginea</i> (Hochst.) Baker.	76.3	32	42	0.41	0.91	0.46
	<i>Olea capensis</i> L. subsp. <i>macrocarpa</i> (C. H. Wright) Verdc.	34.5	16	6	0.06	0.13	0.06
	<i>Persea americana</i> Mill.	27.7	10	15	0.03	0.07	0.04
	<i>Podocarpus falcatus</i> Thunb.	86.3	50	8	0.56	1.23	0.62
	<i>Polyscias fulva</i> (Hiern) Harm.	51	16	15	0.15	0.34	0.17
	<i>Prunus africana</i> (Hook.f.) Kalkam.	78	36	5	0.43	0.96	0.48
	<i>Psidium guava</i> L.	15.2	7	7	0.00	0.01	0.00
	<i>Spathodea campanulata</i> Beauv.	48.4	28	5	0.13	0.30	0.15
	<i>Syzygium guineese</i> (Willd.) DC.	127.4	40	4	1.46	3.23	1.62
	<i>Vernonia amygdalina</i> Del.	24.84	8	8	0.03	0.06	0.03
	<b>Total</b>			<b>258</b>		<b>12.22</b>	<b>6.11</b>