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Woody Biomass and Soil Carbon Stocks under Patch Natural Forests and Adjacent Enset-Coffee Based Agroforestry in the Midland of Sidama Zone, Ethiopia

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Abstract: Trees in agroforestry systems are potential sinks of atmospheric C due to their fast growth and productivity, high and long-term biomass carbon stock. Soil under forest and agroforestry also plays a major role in global C sequestration. The potential of woody species and selected perennial plants in carbon sequestration in the patch natural forests and enset-coffee based agroforestry land uses in the midland of Sidama zone, Ethiopia was examined. The assessment on biomass carbon stocks was based on a total inventory for woody stems at ≥5 cm diameter at breast height (DBH), except coffee and enset. The diameter of coffee and Enset shrub was measured at 15 cm and 10cm aboveground, respectively. Aboveground biomass was estimated using appropriate allometric equation. The aboveground carbon stock was calculated by multiplying the 0.5 conversion factor to the biomass. Soil organic carbon was sampled by using "X" design at depths of 0-30cm for each patch natural forest, enset-coffee based agroforestry and annual crop agricultural land uses. The results indicted the total biomass carbon stock in the patch natural forests was significant ($p < 0.05$) higher (258.67±41.1 Mg ha^{-1}) than values for enset-coffee based agroforestry (175.3±9.77 Mg ha^{-1}). In terms of SOC, the differences were in the order of: patch natural forests (76.18±3.58 Mg ha^{-1}) > ECAF (66.79±2.73Mg ha^{-1} > annual crop agricultural land (38.93 ± 2.75 Mg ha^{-1}). In CO_2 sequestration, highest estimate values were from patch natural forests which sequestered (58.04%) of CO_2 over its lifetime followed by enset-coffee based agroforestry (41.96%). The results of the present study confirm that the patch natural forests and enset-coffee based agroforestry play a major role in climate change mitigation.
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Kew words: biomass; carbon stock; CO_2 ; SOC

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1. Introduction

The increasing concentration of CO_2 and other greenhouse gases in the atmosphere is now widely recognized as the current issue in the globe, because of a principal cause of global warming. The largest proportion of CO_2 resulting from the burning of fossil fuels and the conversion of tropical forests to agricultural production (Paustian *et al*., 2000). Emissions from deforestation and degradation are a significant (18-20%) source of annual greenhouse gas emissions into the atmosphere (IPCC, 2007). Forests and agroforests offer two main options in reducing the concentration of atmospheric CO_2 and other GHGs; (i) increasing forest biomass and (ii) utilize forest directly as a source of raw materials for energy production (VanKooten, 2000).

Forest ecosystems store more than 80% of all terrestrial aboveground C and more than 70% of all SOC (Six *et al*., 2002). As a leading tree based system especially in the tropics, afforestation and reforestation has been suggested as one of the most appropriate land management systems for mitigating atmospheric CO_2 (Dixon, 1995; Albrecht and Kandji, 2003; Montagnini and Nair, 2004). The report of Flint & Richards (1996), indicated that the tropical natural forest carbon sequestration range from 17-350 Mg C ha^{-1} in aboveground biomass. Therefore, providing incentives for conserving, restoring, reducing deforestation, reforestation and better managing forests provide an effective way to mitigate climate change (Stern, 2006).

The tree components in agroforestry systems are also potential to sinks of atmospheric C. This is due to their fast growth, productivity, high and long-term biomass carbon stock, and extensive root system in agroforestry systems (Montagnini and Nair, 2004). Most of the available reports on C sequestration in AFS are accumulated in above and belowground compartments under different conditions of ecology and management (Nair *et al*., 2011). The estimates range from 0.29 to 15.21 Mg ha^{-1} $year^{-1}$ aboveground and 30–300 Mg C ha^{-1} up to 1m depth in the soil (Nair *et al.,* 2010). The potential to sequester carbon varies the type of the system, species composition, and age of component species, geographic location, environmental factors, and management practices (Jose, 2009).

Soil under forests and agroforestry play a major role in global C sequestration (Lal, 2002). 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 such as soil structure and their aggregations (Nair *et al.,* 2009a). The soil organic carbon concentration and pools were higher in under agroforestry than monocropping and increased with tree age (Jose, 2009). Carbon sequestration in soil is affected by two major activities, which is aboveground litter decomposition and belowground root activity (Lemma *et al*., 2007). Litter decomposition rate, amount of litter and the quality of litter are the major sources of SOC (Mafongoya *et al*., 1998; Issac and Nair, 2006; Lemma *et al*., 2007).

In the study area Sidama Zone, South Ethiopia, there are different traditional agroforetry practices.; (i) tree– enset–coffee, (ii) tree–enset (iii) Eucalyptus woodlot, (iv) scattered /parkland trees on maize fields, (v) boundary planting, and (vi) scattered trees on grazing fields (Asfaw and Agren, 2007).These traditional agroforestry practices are perennial plant dominated and they may promote biodiversity and socioeconomic alternatives to local communities. In addition, in the study area, there are different natural patch forests, which are culturally protected from humans and animals disturbance and separated by agroforestry land uses that have been practiced for long period. However, the contribution of agroforestry land use and protected patch forests on biomass and soil carbon stocks has not been study so far. An overall objective of this study was to investigate status of woody species and selected perennial plants biomass carbon stock in patch natural forests and adjacent Enset-Coffee based agroforestry (ECAF) with particular emphasis on their contribution to climate change mitigation. Specific objectives were to: (i) estimate the amount of woody species and selected perennial plant biomass carbon stock in ECAF and patch natural forests; (ii) estimate soil carbon stock under ECAF, patch natural forests, and annual crop agricultural land uses; (iii) estimate the carbon stock pools in carbon dioxide equivalent under patch natural forests, ECAF and annual crop agricultural land uses.

2. MATERIALS AND METHODS

2.1 Study area description

Two study sites, Wonsho and Shebedino district (here after woreda) were selected in Sidama Zone of Ethiopia ($7^0$00'–$7^0$06' N and 38^0–34' E 38^0–37' E) of southern Nations, Nationalities and regional state (Figure 1). The elevation of the study area ranges from 1500 m to 3027 m.a.s.l. and terrain relatively hilly (60%), flat (15%) and undulate (25%) (Negassa, 2005). The soils at the study sites mainly classified as Nitosols (Asfaw, 2007). The average annual rainfall of Shebedino woreda is 1300-1500 mm and temperature is between 18-25^{0}c (Negassa, 2005). Thirty three percent of the Woreda is classified as Dega[3] and the remaining 67 % is Weina-dega[4].

[3] (> 2300 m.a.s.l.)

[4] (1500 – 2300 m.a.s.l)

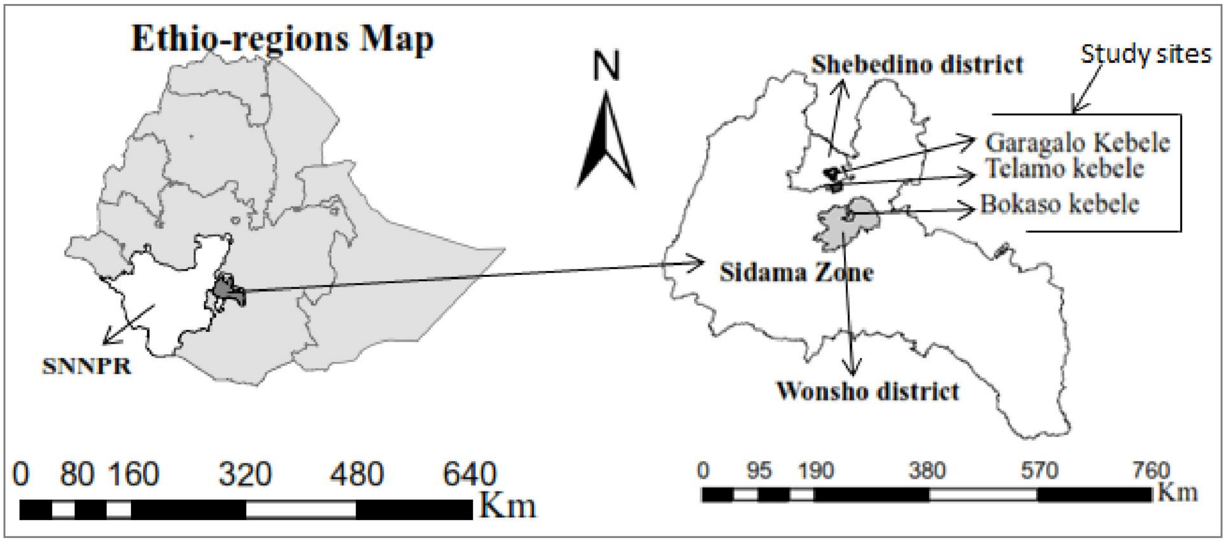

Figure1. Map of study of areas in midland of Sidama, Southern Nations, Nationalities, and People Regional state (SNNPRs), Ethiopia

The mean annual temperature and rainfall of Wonsho woreda range from 20-25 ^{0}c and 1200 mm-1600 mm, respectively (Negassa, 2005). The area is largely found in the agro climatic zone of Weina-Dega (59%) and Dega (41 %,).

Two of the natural patch forests namely “Arossa", "Akako" are found Garagalo Kebele[5] and Telamo Kebele in Shebedino woreda, respectively. "Abo" patch forest is found at Bokaso Kebele in Wonsho woreda. The native forest patches are separated by agroforestry land uses that have been practiced for long period of time, and settlements. This study was including the three patch forests that are protected by cultural system and separated by an agroforestry land use in between.

2.2 Method of data collection

2.2.1 Sampling techniques

Systematic sampling method was employed for this study. The sampling procedures focused on identification of area having patch forest in the midland of Sidama (Akaka, Arossa and Abo patch natural forests were identified). Other sampling procedure was identifying of the orientation of each patch forest and defining the adjacent ECAF from the patch forests. Each forest was divided into four parts where one line run through the center from east to west and the other running from south to north. In order to located quadrat for adjacent enset-coffee based agroforestry, the four transect lines was extended up to 2 km. On each line E-W and S-N a serious of quadrats were laid. Hence, 12 quadrats in each transect were established with 48 quadrats used for biomass assessment in adjacent ECAF. Similarly, in each patch natural forests the total of 48 quadrats (16 quadrats for each) was used both vegetation and carbon stock assessment.

2.2.2 Sampling design and tree sampling

For this study a quadrat size of 20 x20 m was employed for both ECAF and patch natural forests and other selected perennial plants assessment used **(**Mac Dicken, 1997). All tree diameters ≥ 5cm in the larger plot were measured at breast height (DBH, 1.3m) (Mac Dicken, 1997). In the plot, local names of trees were recorded and later scientific names were identified from “Useful Trees and Shrubs for Ethiopia” (Bekele, 2007), and Flora of Ethiopia and Eritrea (Edwards *et al*., 1995; Hedberg *et al*., 2004 and Hedberg *et al*., 2006). Within main plot, sub-plots of 5 x 5 m were laid for coffee and enset shrubs measurement. The diameter of coffee shrub was measured at 15cm aboveground (Segura *et al.,* 2006) and Enset was measured at 10 cm aboveground (Negash *et al*., 2012a).

2.2.3 Model selection for estimating aboveground biomass (AGB)

Because of high species richness in tropical forests, it is difficult to use species-specific regression models (Brown and Schroeder, 1999). Therefore, mixed and nondestructive species tree biomass regression models were used for AGB estimation of natural forest and agroforestry. The best estimator of this study was selected based on rainfall distribution, diameter range, prediction errors, R^2, simplicity of the models and sample size. Since study areas were close to semi humid type of agro-ecology, the following

[5] the lowest administration unit

regression models applicable in semi humid ecology were selected (Table 1). Brown (1997) regression equation to estimate tree biomass; Segura *et al*., (2006) regression equation for coffee shrub aboveground biomass estimation and Negash *et al.,* (2012a) regression equation for enset aboveground biomass estimation were used (Table 1).

Table 1. Regression models to fit for estimation of aboveground biomass

Regression models for ABG of trees species estimation	Authors name	R^2 PNF	R^2 ECAF
Y= exp {-2.134+2.530*ln(D)	Brown *et al*.,(1997)	0.91	0.89
Regression models for AGB *of Coffea arabica* estimation	Authors name		R^2
L+og$_{10}$(y)= -1.181+1.991*log$_{10}$(D$_{15}$)	Segura *et al.,* (2006)		0.96
Regression models for AGB *of Enset ventricosium* estimation	Authors name		R^2
Ln(Y) = ln(d$_{10}$)	Negash *et al*., (2012a)		0.95

PNF= patch natural forest, d= diameter, d_{10}= diameter at 10cm aboveground, D_{15}= diameter at 15 cm aboveground

2.2.4. Soil sampling design

The strongest response of soil carbon stock to land cover change occurs in the top 20-30 cm (IPCC, 1997). Soil for organic carbon was sampled by using "X" design with a depth of 0-30 cm at each patch natural forests, ECAF and annual crop agricultural land (considering as base line). Within 1m x 1 m area, soil samples from four corners and at the center were taken by pressing an auger to a depth of 30 cm, and the five soil samples were composited (Roshetko *et a*l., 2002; Takimoto *et al*., 2008). Therefore, 90 composite soil samples (30 in each land use types) were used for organic carbon determination. Soil bulk density, near to the center of the design was selected and soil sample from (0-10 cm, 10-20 cm and 20-30 cm) using 10 cm length and 7.15 cm diameter core sampler was taken (Roshetko *et a*l., 2002). The average value of soil bulk density was used in each corresponding composite soil sample for the determination of soil organic carbon.

2.3 Data analysis

2.3.1 Biomass Carbon Stock Estimation

The methods for determining of the aboveground biomass (AGB) of forests are the combination of forest inventories with allometric tree biomass regression models (Houghton *et al*., 2001; Brown, 2002; Houghton, 2005). This estimation of AGB in the forests and agroforestry is based on plot inventories that involve in the following three steps (Brown *et al.,* 1989; Houghton *et al*., 2001; Chave *et al*., 2005) :(i) The selection and application of an allometric biomass function for the estimation of individual tree biomass, (ii) Summation of individual tree AGB per plot, (iii) The calculation of an across-plot average to hectare based. In this study, the selected allometric equations given in the above table 1 were used.

Root biomasses of woody species were often estimated from root-shoot ratios (R/S) by taking 25% of aboveground biomass (Cairns *et al*., 1997; Roshetko *et al.,* 2002). The belowground biomass of enset was 35% of aboveground biomass (Blomme *et al.,* 2008).

Biomass measurements of C stock by implication C sequestration are direct derivatives of estimates, assuming that 50% of the biomass is made up by C (Mac Dicken, 1997; Nair *et al.,* 2011).

2.3.2 Soil organic carbon determination

SOC was determined according to Walkley-Black method (Walkley and Black, 1934) in Hawassa University Wondo Genet College of forestry and natural resources soil laboratory. The soil samples for soil carbon analysis were air-dried and passed through a 2 mm sieve (Lemma, 2006). Soil bulk density was also determined in the soil laboratory by oven dry method by dividing oven dried weight of the soil samples at 105^0C for 24 hours to the volume of the core. The weight of the gravel and the root > 2mm were subtracted for determining soil bulk density. The soil carbon stock in hectare based was calculated according to Lemma, (2006).

SOC (Mg ha^{-1}) = SOC (g kg^{-1}) x d x BD (Mg m^{-3}) x 10,
Where d= sampled soil depth in meter (m), and BD = bulk density (Mg m^{-3}).

The total carbon stock density (TCSD) of the patch natural forests and enset-coffee based agroforestry land uses was the summation of AGB, root biomass and soil carbon stocks.

2.3.3 Carbon stock in carbon dioxide equivalent

Different carbon pools were calculated in carbon dioxide equivalent based on using Practitioners Field Guide/Manual of Yayu Forest Coffee Biosphere

Reserve in Ethiopia (Getu *et al*., 2011) and American carbon registration tool for Carbon Pools and Emission Sources (ACR,2010).

CS CO_2 equivalent (ton CO_2 equivalent ha^{-1}) = CS (t) * 44/12, Where CS= the mean Carbon stock in ton ha^{-1} at time of (t), here t refers to the time of the study was started (2012/2013). 44/12 = Ratio of molecular weight of CO_2 to carbon (44= the molecular weight of CO_2 and 12= the molecular weight of carbon).

2.4. Statistical analysis

The effect of land use variation on carbon stocks were tested using one way ANOVA. Means exhibited significance difference between each land uses was tested by Least Significance Difference (LSD) at $p < 0.05$. All statistical computations were made using SAS statistical Software version 9.0.

4. RESULTS

4.1 Vegetation characteristics

A total of 75 different woody species were recorded and categorized under 31 families, of which 43 species under 30 families were from the patch natural forests and the remaining 32 species under 21 families from adjacent land use (here after Enset-Coffee based Agroforestry, ECAF). Twenty two woody species belonging to 15 families were common to both the patch natural forests and ECAF. A total of 3734 woody species individuals (abundance) were recorded from all sample plot (n=48) of the patch natural forests and 2379 woody species and 3773 enset individuals were recorded in ECAF. The average DBH, basal area and height of woody species in the study patch natural forests were (38.24 cm, 32.92 m^2 ha^{-1} and 11.17 m, respectively. In adjacent ECAF, the average DBH, basal area and height of woody species were 19.69 cm, 12.51 m^2 ha^{-1} and 9.59 m, respectively .In the study area, the proportion of indigenous woody species was higher (86.67%) than exotic (13.33%) woody species.

4.2 Aboveground biomass (AGB) distribution

The distributions of mean aboveground biomass in diameter classes were presented in figure 2. The mean aboveground biomass showed an increasing trend from DBH ≥ 5 cm to 45 cm. The contribution of trees having ≥ 45 cm diameter to AGB was greater in the patch natural forests (59.8%) than the ECAF (20.2%). In contrast, the contribution of trees having < 45 cm diameter to AGB was greater in ECAF (79.8%) than the patch natural forests (40.2%).

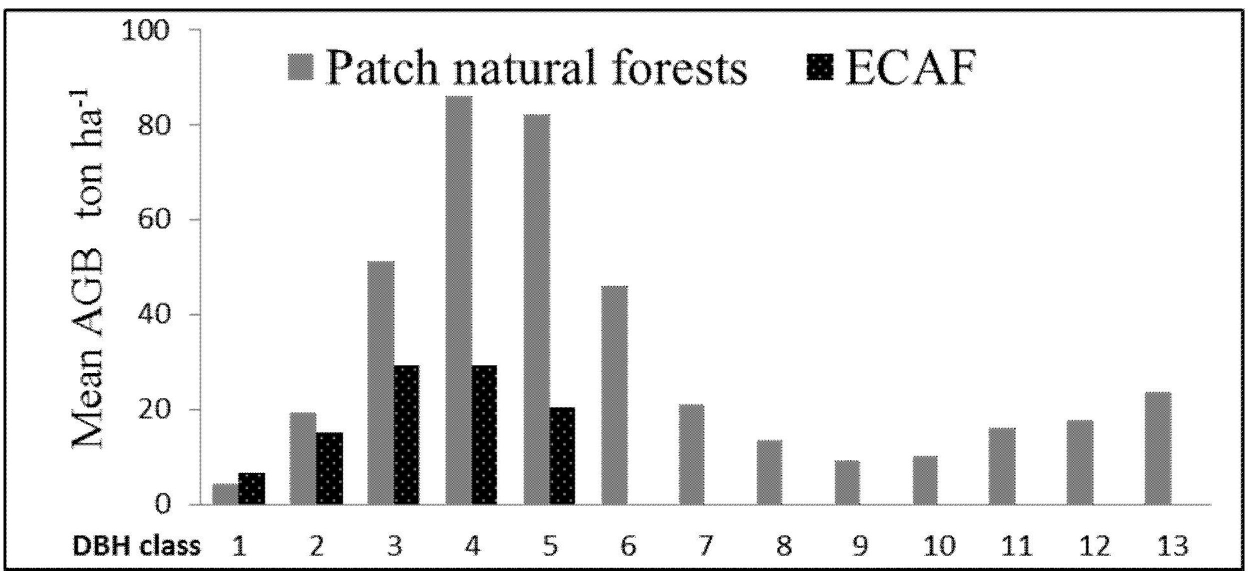

Figure 2.The mean AGB distribution of woody species in diameter class for the patch natural forests and ECAF in the midland of Sidama zone, Ethiopia

Diameter class in cm **1**= 5-15, **2**= >15-25, **3**= >25-35, **4**= >35-45, 5= >45-55, **6**= >55-65, **7**= >65-75, **8**= >75-85, **9**= >85-95, **10**= >95-105, **11**= >105-115, **12**= >115-125, **13**= >125

4.2.1 Biomass carbon stocks

The mean value of different carbon pools of the three patch natural forests and ECAF of the study area is presented in table 2.

The Abo-Bokaso patch natural forest has the highest total mean value of AGBC and BGRBC which contributed 38.72% of the overall mean biomass carbon stock. While the contribution of Akako-Telamo and Arossa-Garagalo patch natural forest was 32.38%

and 28.89% of the overall mean biomass carbon stock, respectively. Moreover, there was significant difference of the different carbon pools at $p < 0.05$ between each site except, BGRBC between Akako-Telamo and Arossa-Garagalo patch forest. In the case of ECAF, woody species including coffee and *Enset ventricosium* contributed 44.14% and 55.86% carbon of the overall mean value biomass carbon stock in ECAF, respectively (Table 2).

Table 2. The mean (±std) carbon stocks of different carbon pools for woody species in each patch natural forest and ECAF in the midland of Sidama zone, Ethiopia

	Patch natural forest/site name			Enset-Coffee based agroforestry	
Carbon pools (Mg ha^{-1})	Akako-Telamo	Arossa-Garagalo	Abo-Bokaso	woody species +coffee	*Enset-ventricosium*
AGBC	201.1^{a}±12.5	179.3^{b} ±8.7	240.4^{c}±18.1	61.87	72.5
BGRBC	50.3^{a} ±7.8	44.8^{ab} ±6.5	60.1^{c} ±9.2	15.48	25.38
TBC	251.3^{a}±25.7	224.2^{b}±21.1	300.5^{c}±39.3	77.35	97.88

Mean with the same letter are not significant at $P < 0.05$. AGBC = aboveground biomass carbon, BGRBC = belowground root biomass carbon and TBC= total biomass carbon

4.3 Soil organic carbon (SOC) stock and total carbon stock density (TCSD)

• Soil organic carbon at 0-30 cm depth in three-land use types and TCSD are indicated in table 3. The mean SOC content was significantly lower under annual crop agriculture than patch natural forests and ECAF. There were also significance differences at ($p < 0.05$) of SOC between the three land use types. The total mean carbon stock density, which includes the AGBC, BGRBC and SOC, indicated higher significant differences at ($p < 0.05$) between the adjacent ECAF and patch natural forests. There were also significance differences of AGBC and BGRBC stock at ($p < 0.05$) of the two lands use.

Table 3. Mean (±std) carbon stocks of different carbon pools for different land use types in the midland of Sidama zone, Ethiopia

Different carbon pools	Patch natural forests	ECAF	Annual agriculture
AGBC stock Mg ha^{-1}	206.93^{a} ±32.88	134.36^{b} ±7.68	--**-----
BGRBC Stock Mg ha^{-1}	51.73^{a}±8.28	40.85^{b} ±2.11	---**-----
SOC Stock Mg ha^{-1}	76.18^{a}±6.58	66.79^{b}±3.73	38.93^{c}±1.75
TCSD Mg ha^{-1}	334.86^{a} ±41.1	242.02^{b} ±39.77	----**----

Mean with the same letter between raw are not significant different at $P < 0.05$.
**= no any kind of biomass measurement taken, since absence of tree species in the farm.

4.4 Carbon dioxide equivalent (CO_2-e) distribution

Aboveground biomass carbon stock of woody species in carbon dioxide equivalent along the diameter classes is shown in the figure 3. The maximum CO_2-e was stored in the patch natural forests (21.45%) and ECAF (29.23%) at 35-45 cm DBH class. The lower (5-15 cm DBH class) in the patch natural forests and ECAF stored only 1.08% and 6.4 % CO_2-e respectively. Similarly, contribution of trees having ≥ 45 cm diameter to CO_2-e was greater in the patch natural forests (59.76%) than the adjacent ECAF (20.18%). However, the contribution of trees having < 45 cm diameter to CO_2-e was greater in adjacent ECAF (79.82%) than the patch natural forests (40.24%).

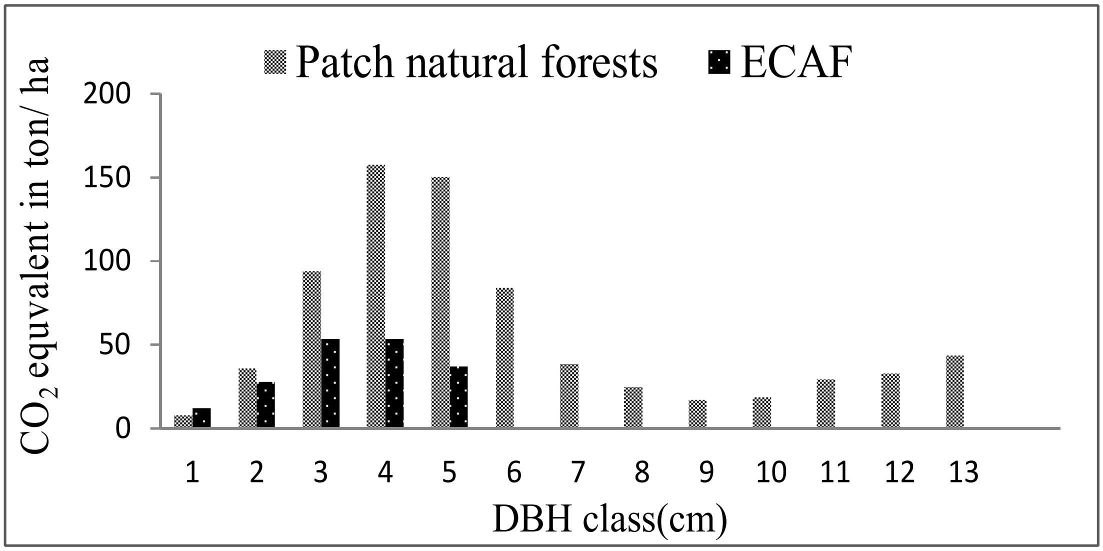

Figure 3.The average AGBC stocks in CO_2 equivalent of woody species in diameter class for patch natural forests and ECAF in the midland of Sidama, Ethiopia

Diameter class in cm: **1**= 5-15, **2**= >15-25, **3**= >25-35, **4**= >35-45, **5**= >45-55, 6= >55-65, **7**= >65-75, **8**= >75-85, **9**= >85-95, **10**= >95-105, **11**= >105-115, **12**= >115-125, **13**= >125

4.4.1 Carbon stock pools in carbon dioxide equivalent (CO_2-e)

The different carbon pools (AGBC, BGRC and SOC) and TCSD in carbon dioxide equivalent in each land use type were indicated in figure 4. The contribution of AGBC stock in carbon dioxide sink was higher in the study patch natural forests (60.6%) than ECAF (39.4%). Similarly, the sink of CO_2 in BGRBC stock and total carbon stock density (TCSD) was greater in the patch natural forests than ECAF. CO_2-e in the soil organic carbon stock of the patch natural forests (41.88%) and ECAF (36.72%) were significantly ($p < 0.05$) higher than in annual agricultural land uses (21.4%).

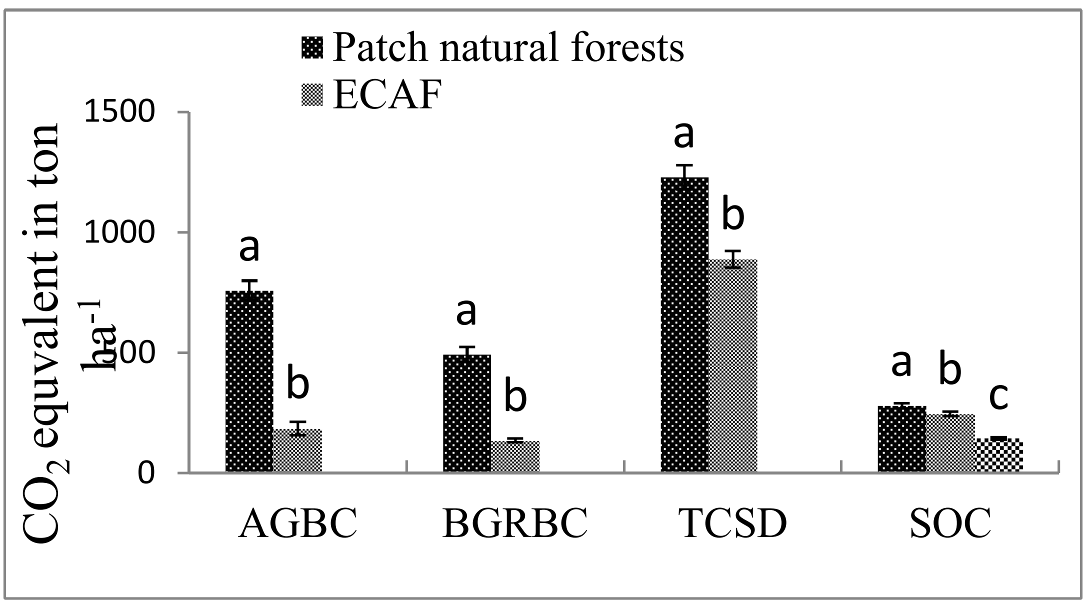

Figure 4.Carbon stock pools in carbon dioxide equivalent across different types of land use in the midland of Sidama, Ethiopia

Mean with same letter are not significant difference at P < 0.05. AGBC= Aboveground biomass carbon; BGRBC= Belowground root biomass carbon; TCSD= total carbon stock density and SOC= soil organic carbon.

5. DISCUSSION

5.1 Carbon stock pools and implication to climate change mitigation

AGB accumulation revealed that tree species with lower range of diameter possess more density but accumulated less biomass and sequestration. The greater contribution of large trees to AGB in patch natural forests was in conformity with the findings of earlier workers (Brown and Lugo, 1992; Brown *et al*., 1995; Brown, 1996; Clark and Clark, 1996). However, beyond the maturity, the trees generally have marginal carbon sequestration capability (Lal and Singh, 2000). Because the matured forests do not add up any further biomass and most part of the gross primary productivity is either used up in respiration or returned to soil as litter.

The amount of AGB carbon stored in the patch natural forests of the present study was comparable with the report of Flint & Richards (1996) in Southeast Asia (17-350 Mg C ha^{-1}) tropical natural forest and high forests in Bale Mountains (200 Mg ha^{-1}) Tadesse (2010). The amount of AGB carbon stored in the ECAF was also comparable with the report of Kirby and Potvin (2007), reported as 145 Mg C ha^{-1}, in traditional agroforestry systems but less than that of dammar agroforestry in Indonesian (177.8 Mg ha^{-1}) (Retnowati, 2003). Similarly, the estimated BGRBC stock in the patch natural forests was comparable with the report of Ngo *et al.*(2013) study in primary forests (42.8 Mg ha^{-1}) but higher than secondary forest (22.3 Mg ha^{-1}) in Singapore. The BGRB carbon stock in ECAF was comparable with the report of Retnowati (2003) study in dammar agroforestry in Indonesian (44.2 Mg ha^{-1}).

SOC in patch natural forests was also in line with the report of Rey-Benayas *et al*. (2011) study on native forest in the humid tropical lands, where SOC stock ranges 62.2 - 78.5 Mg ha^{-1} up to 30 cm depth. The SOC stock in ECAF (66.79 Mg ha^{-1}) agrees with the report of Retnowati (2003) study in dammar agroforestry in Indonesian, where the SOC stock was 63.4 Mg ha^{-1} and study by Tesfay (2011) on Yirgacheffe coffee-based agroforestry, where SOC stock was 66.65 Mg ha^{-1} using similar soil sampling design and depth.

The total carbon stock density in the study patch natural forests was relatively comparable to that of found in primary forest (Jiranan *et al.,* 2011), reported as 342 Mg ha^{-1}. It also in line with other studies of Ngo *et al.(*2013) study in primary and secondary forest in Singapore, where the total carbon stock density of primary forest was 336.7 Mg ha^{-1}, but higher than study in secondary forest (274.2 Mg ha^{-1}). Similarly, the total carbon stock density in ECAF lines with the study in India, where the total carbon stock in agroforestry system was 246.5 Mg ha^{-1} (Murthy *et al*., 2013) and higher than other homegarden systems and humid tropical agroforestry systems. The variation of carbon stock within and between land uses could be the different methods, tools applied, regional variability in soil, topography, climate and forest type, tree density, tree age, and the uncertainties associated with the methods used.

The variation of the different carbon pools in the patch natural forests and enset-coffee based agroforestry could be the density, species variability's, age of trees and accumulation of biomass (Brown and Lugo, 1982; Sanford and Cuevas, 1996; Terakunpisut *et al*., 2007). In other words, higher biomass in patch natural forests is also associated with higher diversity, and higher species diversity leads to greater carbon sequestration.

The higher SOC stocks under ECAF and patch natural forests than annual crop agricultural lands uses could be the presence of more trees in the systems and aboveground biomass increases (Solomon *et al*., 2002; Lemenih and Itanna, 2004; Lemenih *et al*., 2005).

The forest-based systems are known to have the largest potential to mitigate climate change through conservation of existing carbon pools, expansion of carbon sinks (e.g., agroforestry) and substitution of fossil fuels for wood products (Schlamadinger *et al*., 2007). Agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation (Murthy *et al*., 2013). It has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change. Carbon sequestration potential that can realistically sequester over its lifetime in the study patch natural forests and ECAF systems has a role for mitigating carbon dioxide emissions into the atmosphere. The present study indicated that the patch natural forests and ECAF reduce 58.04% and 41.96% of CO_2 emissions into the atmosphere.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Trees are one of most powerful tools to pull carbon from the atmosphere and sequester it in the soil for long-term storage. Tree based land use and protecting intact forests are such important components to address climate change. Carbon stock in different carbon pools (aboveground and belowground) has a potential to decrease the rate of enrichment of atmospheric concentration of CO2. Patch natural forests and adjacent Enset-Coffee based Agroforestry in Sidama zone in Shebedino and Wonsho districts of southern part of Ethiopia produce considerable amount of biomass for mitigating climate change. However, agroforestry and natural forests alone cannot solve the current climatic problems, but can only be one among a range of strategies.

6.2 Recommendations

- Species specific model is required in order to get the reliable information about the biomass carbon stocks;
- Woody species <5cm DBH as well as dead wood, dead standing trees, logs of carbon sequestration be needed further study;
- Government, researchers and NGOs and any concerned body should be facilitated the values of carbon trades.

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