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Carbon Stock of Indigenous Agroforestry Practices in Dellomenna District Southeast Ethiopia: Implication for Climate Change Mitigation

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Abstract
Trees in agroforestry systems are potential sinks of atmospheric carbon (C) due to their fast growth, productivity, high and long-term biomass C stock. Soil under forest and agroforestry also plays a major role in global C sequestration. This study was initiated to assess woody species and soil C sequestration of traditional agroforestry practices. Three study sites (namely: Buriketu, Chire and Erba) were systematically selected based on the presence of traditional agroforestry practices. Forty eight sample quadrats (16 quadrats in each site) having an area of 20m x 20m (400 m^2) were used for vegetation biomass estimation. Soil organic carbon (SOC) was sampled by using "X" design at depths of 0-30cm within each quadrats. Woody species biomass carbon stocks were estimated using an allometry equation of Y (Kg) = 34.4703 - 8.0671 DBH + 0.6589 DBH^2. The types of agroforestry practices found in the study area are scattered trees in farm lands (parkland agroforestry), homegarden and live fence system. The mean AGBC stock showed an increasing trend from DBH ≥ 5 cm to 71 cm while a decreasing trend was noticed greater than 71 cm diameter classes. The mean carbon stocks (Means±Std) of different carbon pools in the indigenous agroforestry practice were 47.82±10.09, 11.96±2.52, 59.77±12.61, 150.61±6.9, 210.39±14.1 for AGBC stock, BGBC stock, TBC stock, SOC and TCSD, respectively. CO_2 assimilation by total biomass of woody species ≥ 5cm DBH in traditional agroforestry practices was estimated to be 219.15ton/ha. Estimation of CO_2 sequestration indicated that indigenous agroforestry practices of the area have been sequestered (772.02 ton/ha). The results of the present study confirmed that indigenous agroforestry practice play a major role in climate change mitigation. This study was focused on the biomass carbon stock of woody species ≥5 cm DBH, however, woody species <5cm DBH, dead wood, dead standing trees, fallen branches and litter-fine woody debris were also have a potential for C stock, thus further study on these components is recommended to provide reliable information.
Keywords Biomass carbon, Ecosystem services, Global warming, Soil organic carbon.
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1. Introduction

Agroforestry land use system provides various ecosystem services. Some of the benefits are diversification of household income, fiber, food and energy to local communities and also provides cultural services such as agro-tourism, aesthetic values and education (Negash 2013). Agroforestry also provides regulating services such as soil conservation, watershed protection, pest control and sinks for carbon and thereby contributing to the mitigation of global climate change (IPCC 2000; Albrecht and Kandji 2003). However, long history of sedentary agriculture leads to climate change through the increasing of CO_2 and other greenhouse gases and biodiversity losses (Bishaw and Asfaw 2010). According to Montagnini and Nair (2004), tree components of agroforestry systems are one of the options to sink atmospheric C due to their fast growth and productivity, high and long-term biomass carbon stock, and extensive root system. The C storage potential of agroforestry systems in semiarid, sub-humid, humid and temperate regions has been estimated to be 9, 21, 50 and 63 Mg C ha^{-1}, respectively (Montagnini and Nair 2004). The potential of above ground C stock of agroforestry systems in humid tropics extend up to 70 Mg C ha^{-1} (Mutuo *et al*. 2005).

Soil ecosystem of agroforestry land use system also plays a major role in global C sequestration (Lal 2002). The term ''soil C sequestration'' implies removal of atmospheric CO_2 by plants and storage of fixed C as soil organic matter. SOC is recognized as a strategy for C sequestration under the Clean Development Mechanisms of the Kyoto Protocol (Nair *et al.* 2009b). For instance, the soil under cocoa agroforestry store 37 Mg C ha^{-1} in the Southern Cameroon (Sonwa *et al*. 2009).

Despite of various benefits of agroforestry, little scientific studies has been paid to the role of agroforestry systems in climate change mitigation (Kumar and Nair 2004; McNeely and Schroth 2006). Most studies on agroforestry systems in the tropics including Ethiopia have been focused on socio-economic and soil fertility management. The areas of agroforestry systems in Ethiopia is not well documented, but some 2.32 Mg ha^{-1} are considered as agroforestry land use according to some estimates based on satellite image (Brown *et al*. 2012). Some of the traditional agroforestry practices in the country include coffee shade tree systems, scattered trees on the farm land, homegardens, woodlots, farm boundary practices and trees on grazing lands (Asfaw 2003; Abebe 2005).

In Dellomenna District (the study area), farmers have been practicing integration of trees, crops and livestock components in their lands. These indigenous agroforestry practices constitute perennial and herbaceous plants that can promote biodiversity conservation, climate change mitigation, and socioeconomic alternatives to the local communities. Indeed, the contribution of this indigenous agroforestry practice on C stock has not been studied. Therefore, this study was initiated to investigate extent of woody species and soil carbon stocks in indigenous agroforestry practices with particular emphasis on their contribution to climate change mitigation.

2. Materials and Methods

2.1. The study area

Dellomenna District is situated between 6^0 40\` to $7^0$10\`N latitude and $39^0$30\` to 40^0 E longitude. The altitude of the district ranges between 1000 - 2500 meter above sea level. Mean annual rainfall in the area varies from around 700 mm to 1200 mm and temperature is 18°C (Feyera 2006). The total area of the district is 461,665 hectares (Feyera 2006). The major land use categories of the district are forest land, agriculture, grazing land, and settlement (Feyera 2006). Natural forest and wood lands still accounts the largest share of the land use types in the district. Worku (2011) also indicated that homegarden, multipurpose trees on the farm land and farm boundary, agrosilvopastural, apiculture with trees and silvopasture are some of the example of agroforestry practices in the area.

2.2. Data Collection Methods

2.2.1. Sampling techniques

Systematic sampling techniques were employed on the basis of potential indigenous agroforestry practices of the area. Accordingly three kebeles (namely: Buriketu, Chire and Erba) were selected. Based on the topography, four transect lines were aliened at interval of 500 m between transect lines in each Kebele. On each transect, four quadrats was laid at an interval of 200 m. The first transect line and quadrant was selected by systematic random sampling. A total of 48 quadrats (16 quadrats in each Kebele) were used for carbon stock assessments.

2.2.2. Sampling design

A quadrat size of 20m x 20 m (400 m^2) was used for all woody plants assessment for diameter ≥ 5cm as described in Hernandez *et al.* (2004). Within 20m x 20m, four sub-quadrants of 5m x 5m at the corners and one in the center were laid for coffee biomass assessment. The diameter of woody species at breast height (DBH1.3m) was measured using a caliper or diameter tape (MacDiken 1997).

Soil organic carbon was sampled by using "X" design with a depth of 0-30 cm (Figure 1). That is, soils from four corners and at the center were mixed to make representative composite soil sample in each quadrat. Forty eight (48) composite soil samples were used for organic carbon determination. For bulk density, soil sample near to the center of the quadrant was taken using 4.3 cm length and 3 cm diameter core sampler.

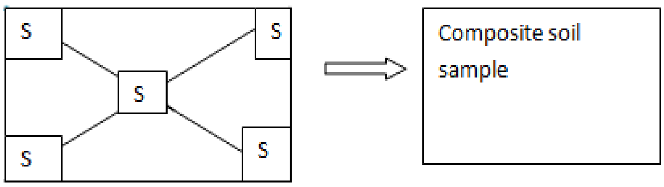

Figure **1**. Diagrammatic representation of soil sampling design, S - stands for soil
Source: Adapted from (IPCC 1997)

2.2.3. Estimation of Above ground biomass (AGB) carbon stock

According to Brown and Schroeder (1999), the use of species-specific regression models is difficult; hence, mixed and non-destructive species tree biomass regression models were used for estimation of AGB. 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. The present study area is close to moist kola type of agro-ecology. Thus, the following regression models that can be applicable in moist kola were selected (Table 1).

Table 1. The allometeric model for estimating of AGB C stock in the study area

Models/ regression equation	Reference
For woody species /trees:	
$Y(Kg) = 34.4703 - 8.0671\ DBH + 0.6589\ DBH^2$ (R^2=0.95)	Brown *et al*. (1989)
For Coffea arabica:	
$L+og_{10}(y) = -1.181+1.991*log_{10}(d15)$ (R^2=0.96)	Segura *et al*. (2006)

2.3. Data analysis

Carbon stock (CS) were converted in the form of CO_2 equivalent (ton CO_2 equivalent ha^{-1}) = CS (t) * 44/12 as described in Getu *et al*. (2011). Where CS= the mean Carbon stock in ton ha^{-1} at time of (t), 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). Cairns *et al*. (1997) and Roshetko *et al.* (2002) indicated that below ground biomass (BGB) of woody species were estimated from root-shoot ratios (R/S) by taking 25% of AGB. The C content of AGB and BGB was assumed as 50% of the estimated whole-tree biomass (Mac Dicken 1997; Nair *et al*. 2011).

SOC was determined using Walkley-Black method (Walkley and Black 1934). The soil samples for soil carbon analysis were air-dried and passed through a 2 mm sieve. Soil bulk density was also determined by dividing oven dried weight of the soil samples at 105^0C for 24 hours to the volume of the core sampler. The soil carbon stock in hectare based was calculated as described in Lemma (2006); i.e., 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) was the summation of AGB, root biomass and soil carbon stocks. Finally, the variation in carbon stocks was tested using one way ANOVA. Means exhibited significance difference was tested by Least Significance Difference (LSD) at $p < 0.05$ using SAS version 9.0.

3. Results and Discussions

3.1. Indigenous agroforestry practice

The types of agroforestry practices found in the study area are scattered trees in farm lands (parkland agroforestry), homegardens and live fence system. Trees dominated in the indigenous agroforestry practice are fruit trees and trees for live fence.

3.2. Carbon stock pools

3.2.1. Aboveground biomass (AGB)

The mean aboveground biomass C stock showed an increasing trend from DBH ≥ 5 cm to 71 cm while a decreasing trend was noticed greater than 71 cm diameter classes (Figure 2).

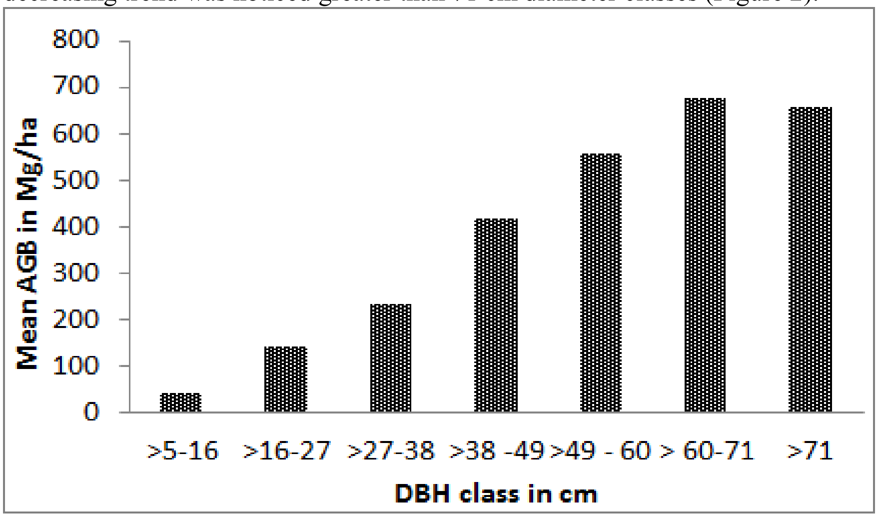

Figure 2. The average AGB distribution of different woody species in diameter classes

The greater contribution of large trees to AGB in study sites were in conformity with the findings of other scholars (Brown *et al*. 1995; Brown 1996; Clark and Clark 1996) who reported up to 50% contribution to AGB by the large trees. However, the trees have marginal carbon sequestration capability (Lal and Singh 2000). This could be due to 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.

3.2.2. Total carbon stock density

The total means carbon stock density (TCSD) which includes the AGBC stock, BGBC stock and SOC stock, was presented in Table 2.

Table 2. Mean carbon stocks of different carbon pools in the traditional agroforestry practice of the study area

	Different carbon pools Mg ha^{-1}				
Kebeles/ sites	AGBC stock	BGRBC stock	TBC stock	SOC	TCSD
	Means(±Std)	Means(±Std)	Means(±Std)	Means(±Std)	Means(±Std)
Buriketu	86.99±26.04	21.75± 6.51	108.73±32.4	162.66±15	271.39±38
Erba	25.55±8.37	6.39±2.09	31.94±10.46	136.67±9.4	168.61±18
Chire	30.93±7.44	7.73±1.86	38.66±9.31	152.49±14	191.16±19
Overall mean	**47.82±10.09**	**11.96±2.52**	**59.77±12.61**	**150.61**±6.9	**210.39**±14.1

In the study area, the total biomass (above and below ground) values for various indigenous agroforestry practice range from 31.94-108.73 Mg ha^{-1}. This result agrees with the study of indigenous agroforestry systems which ranges from 105-173 Mg ha^{-1} in Gedeo Zone, Southern Ethiopia (Negash 2013). It is in line with the findings of others scholars elsewhere (Dixon 1995; Albrecht and Kandji 2003) that ranges from 12-228 Mg C ha^{-1}, but higher than the range reported for agroforestry systems in sub-Saharan Africa (4.5–19 Mg C ha^{-1}) (Unruh *et al.* 1993).

The mean SOC stock of indigenous agroforestry systems in the study area was found to be 150.61 Mg ha^{-1}. In line with the present study, SOC stocks of 115-122 Mg ha^{-1} was reported by Negash (2013). Batjes (1996) also indicated SOC stocks of 41 Mg ha^{-1} for 0-30 cm soil depth.

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

The different carbon pools (AGBC, BGRC, TBC and SOC) and TCSD in carbon dioxide equivalent in the study area was presented in Figure 3.

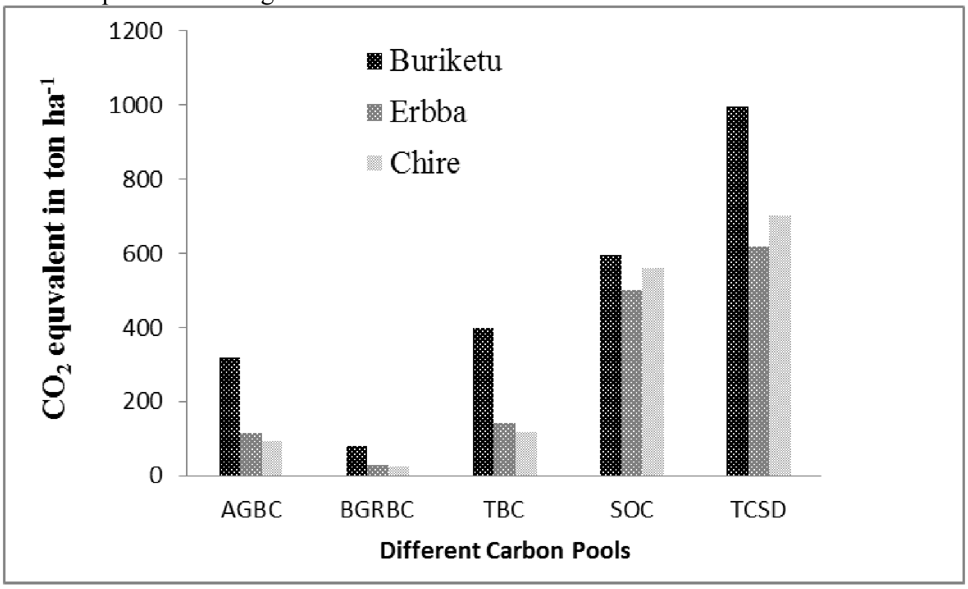

Figure 3. Carbon stock pools in carbon dioxide equivalent across study Kebele

CO_2 assimilation by aboveground and belowground biomass of woody species ≥ 5cm DBH in indigenous agroforestry practices was estimated to be 175.34 and 43.85 ton/ha, respectively. Similarly, CO_2 assimilation by total biomass of woody species ≥ 5cm DBH in traditional agroforestry practices was estimated to be 219.15 ton ha^{-1}. Murthy *et al*. (2013) indicated that agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. It has the ability to enhance the resilience of the system for coping with the adverse impacts of climate change.

4. Conclusion and Recommendations

The types of agroforestry practices found in the study area are scattered trees in farm lands (parkland agroforestry), homegarden and live fence system. Trees dominated in the indigenous agroforestry practice are fruit trees like *Mangefira indica* and trees for live fence. The mean AGBC stock showed an increasing trend from DBH ≥ 5 cm to 71 cm while a decreasing trend was noticed greater than 71 cm diameter classes. The mean carbon stocks (Means±Std) of different carbon pools in the indigenous agroforestry practice were 47.82±10.09, 11.96±2.52, 59.77±12.61, 150.61±6.9, 210.39±14.1 for AGBC stock, BGBC stock, TBC stock, SOC and TCSD, respectively. CO_2 assimilation by total biomass of woody species ≥ 5cm DBH in traditional agroforestry practices was estimated to be 219.15ton/ha. Estimation of CO_2 sequestration indicated that indigenous agroforestry practices of the area have been sequestered (772.02 ton/ha). This study was focused on the biomass carbon stock of woody species ≥5 cm DBH, however, woody species <5cm DBH, dead wood, dead standing trees, fallen branches and litter-fine woody debris were also have a potential for C stock, thus further study on these components is recommended to provide reliable information.

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Conflict of interest
The authors declare that they have no conflict of interest.

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