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COMPARATIVE ASSESSMENT OF SOIL ORGANIC CARBON STOCK POTENTIAL UNDER AGROFORESTRY PRACTICES AND OTHER LAND USES IN LOWLANDS OF BALE

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Abstract

Soil organic carbon is the carbon associated with soil organic matter that is made up of decomposed plant and animal materials. This study was conducted in Dallo Mena district to estimate the amount of soil carbon stock stored in shade grown coffee (SC) and homegarden agroforestry practices (HG), and adjacent natural forest (NF) and annual crop field (CF) and to show the potential of agroforestry practices in soil organic carbon storage capacity. The study site was selected based on spatial analogue approach. From each land uses nine plots were selected by using systematic sampling method following the transect line. Soil organic carbon stock (100cm depth) were the highest for the NF(170.11 ± 14.59 Mg ha^{-1}), followed by SC(127.96 ± 9.43 Mg ha^{-1}), HG(107.62 ± 12.55 Mg ha^{-1}) and CF(97.56 ± 6.85 Mg ha^{-1}). Agroforestry and other land uses of Dallo Mena districts are providing various ecological as well as economical benefits for the community. It is used as income source, conserving different plant species diversity and at the same time storing large amounts of soil organic carbon. Therefore, there is significant difference among natural forest, shade grown coffee agroforestry practice, homegarden agroforestry practice and annual crop field in soil organic carbon storage capacity.

Key words: Adjacent, Benefit, Capacity, Land use, Storage

Introduction

Soil is the major pool of terrestrial organic carbon in the biosphere and storing more carbon than that of in plants and atmosphere combined. Carbon is the organic content of the soil, in the partly decomposed vegetation, in the organisms that decompose vegetation and in the fine roots. Soil organic carbon is the carbon associated with soil organic matter. It is the organic fraction of the soil that is made up of decomposed plant and animal materials as well as microorganisms. Soil organic carbon (SOC) is minerals which are important for all soil biological, physical and chemical fertility the soil (FAO, 2001).

According to ICRAF, 2002 agroforestry is defined as a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefit for land users at all levels. It is one of the land use systems that have a capacity of high carbon storage potential and sequesters large amount of carbon both on biomass and in the soil. In agroforestry landscapes, land use, and the associated management practices exert strong impacts upon soil organic carbon stocks. Agroforestry practices is deliberately storing and improving the SOC pool. Sequestering C in soils is a 'win-win' principle by removing excess CO2 from the atmosphere and improves soils by enhancing organic matter (Janzen, 2006). The carbon storage potential of agroforestry system is undetermined but it may sequester up to 300 Mg C ha−1 in 1 m depth (Lorenz and Lal, 2014). Texture, climate, vegetation, and land use pattern is one of major limiting factors which determine the amount of soil organic Carbon. The amount of carbon stored in the soil is three times more than that stored in the world vegetation and double than in the atmosphere (Lal, 2005).

The carbon storage potential of undisturbed soil is from 10tones up to 160 t C/ha in the 30 cm soil depth (Wynn et al., 2006) and up to 250 t C/ha in some favorable undisturbed areas (Webb, 2002). In case of Ethiopia the average organic carbon stored in the Kafa forest soil was 639.64±286.10 t ha^{-1}(Aticho, 2013). The potential of agroforestry systems to sequester C in the humid tropics vegetation is more than 70 Mg C ha^{-1} and in the top 20cm of soil is up to 25 Mg C ha^{-1}. In case of land use and vegetation type the difference is comes due the management practice and plant species diversity difference between different land uses. Therefore, the objective of this study is to estimate the amount of soil organic carbon stored in agroforestry practices, adjacent natural forest and annual crop field and to show the potential of agroforestry practices in soil organic carbon storage capacity.

Materials and methods

Study Area

Dallo Mena is located in Oromia regional state in the south west parts of the Bale zone and surrounded by Meda Walabu woreda in south, Goba woreda in North, Berbere woreda in north east, Guradhamole woreda in the east and Harena Buluk woreda in west and south west direction (Lulekal *et al.*, 2008). The altitude ranges from 1314 to 1508 m.a.s.l.

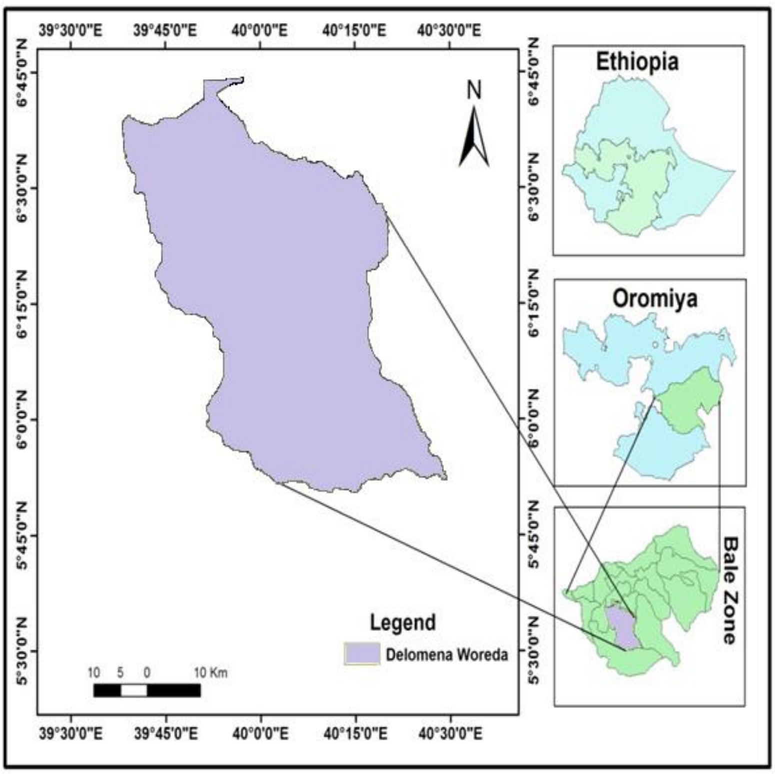

Figure 1: Map of study areas

Geology and Soil

The area is geologically including Dallo Mena basalt constitutes which is the main rock types of the district that are chemically and mineralogical uniform in composition. The dominant soil of the district is Nitosol with reddish brown to red-orange color.

Topography and Climate

Dallo Mena district is dominantly characterized by flat lands and moderately steep rolling hills with valley bottoms. The rainfall pattern of the area is bimodal rainfall with mean annual rainfall is 986.2mm and the mean annual temperature is 22.5 °C (Gamachu, 1977). The rainfall pattern of the area is with the major rainy season from March to June and with short rainy season from September to November.

Farming Activities

Mixing farming system is the major farming system practiced in the district. This farming system is the major livelihoods of the rural community (Senbeta, 2006). Coffee is the major cash crop with Teff, sorghum, maize, haricot bean and sesame are the main crops cultivated by farmers. Fruits like mango, banana, papaya and avocado, and vegetables like cabbage, carrot, pepper, onion, Irish potato and sweet potato are also grown in the area. The common livestock in the area are cattle, sheep, goat, hen and apiculture.

Methods

Sampling Techniques

Sample plot was located by using systematic sampling method (Kent and Coker, 1992). The soil sample was collected following the transect line. In each land uses three parallel transect line was drown. From each transect line three points were selected for sampling. For this study a plot size of 10m x10m was used.

Sampling Design

Soil Sampling Design and Sample Collection

Soil samples at four land uses were collected from the 10m X 10m plots. The plot was divided into four corners and one central sub-plot. Then out of five sub-plots one was randomly selected and pits of 1m x

2m with 1m depth was dug. The pit was used to collect soil samples to assess organic carbon and bulk density. From each pit, soil samples were taken at four depths: 0 - 10cm, 10 - 30cm, 30 - 60cm and 60 - 100cm. For the purpose bulk density another soil core sample were taken from each 10cm of 100cm vertical soil depth with a sharp-edged steel cylinder of height 10 cm and diameter 7.2 cm core sampler. Regardless of the difference in soil layers taken for soil physical and chemical analysis, similar replication and sampling design were followed across all land uses.

Data Analysis

Soil Organic Carbon Stock Estimation

The soil sampled were air dried, crushed and mixed with mortar and sieved through 2mm mesh size sieve. The soil sample was analyzed for organic carbon determination by following Walkley and Black (1934) procedure through titration method. Bulk density was determined after drying of core sample soil at 105ºC for 48 hours up to constant weight of the soil occurred. Finally the soil carbon stock of each land use was calculated by multiplying the laboratory analytical data, that is in mass per unit mass of soil (g C 100 g soil^{-1}) with the soil's bulk density (BD), and is expressed in mass per volume of soil (g cm^{-3}), and with soil depth, (Getu *et al.*, 2011). Finally based on the Mekuria *et al.* (2009) the SOC was calculated as follows;

$$SOC = C\% \times D \times BD \times 2 \quad (1)$$

Where, SOC = Soil Organic Carbon (Mg ha^{-1})

C = Carbon Concentration in percent (%)

D = the total depth at which the sample was taken (cm)

BD = Bulk density (g/ cm^{3})

2 = Constant Factor

Calculation for equivalent soil masses, soil layer thickness correction were carried out by following the procedure of Ellert *et al. (*2001) and Dawit *et al*. (2002) according to the following equation;

$$Z_{corr=}\frac{p_{forest}}{p_{LU}}Z \quad (2)$$

Where, Zcorr = adjusted thickness of sample soil layers under plantations or on farm fields

p_{forest} = bulk density of the sampled soil layers under the natural forest

p_{Lu} = bulk density of the sampled soil layers under plantations or on farm fields

z = thickness of soil layers used during field sampling

According to Pearson *et al*., (2005), after calculating the plot based soil carbon stock, extrapolating the result into hectare basis was carried out by using expansion factor indicated below.

$$\textit{Expansion factor} = 10000m^2/\textit{Area of plot } (m^2) \ldots\ldots (3)$$

Statistical Analysis

Carbon stock of all land uses was tested by using one way ANOVA. Mean comparison of the four systems in terms of soil organic carbon stock were tested by least significant difference (LSD) test at P < 0.05 by using SAS statistical software version 9.1.3.

Results

Vertical Distribution of Percent Carbon, Bulk Density and Soil Organic Carbon in Each Land Uses

The overall mean percent carbon value of NF and CF were significantly different. Whereas for SC and HG is highly significant. Generally, for all land uses the overall mean Percent carbon value were significantly different at ($p < 0.05$). In all land uses the higher carbon percent were recorded in the first depth (0-10cm). But when we compare the overall mean carbon percent the higher carbon percent was recorded in the natural forest (5.23±0.51) and the lower in the agricultural land (2.93 ± 0.20). The overall depth wise compassion within land uses showed that the amount of carbon percent is significantly vary from each other (Table 1).

Except for CF the overall mean BD value of each land uses were significantly different from each other. The overall BD status for all system as the depth increase, the value of BD is also increases (Table 1 (A, B, C and D)). Comparing the overall BD of the whole system, the highest BD was recorded in CF (1.03 ± 0.01) and the lowest in the NF (0.77±0.02) (Table 1).

The overall mean of SOC values of NF and CF were highly significant different with the p-value of at ($p < 0.05$). But for SC and HG is not significantly different. Depth is one of the major factors in soil organic carbon (SOC) accumulation. Throughout the whole system the SOC value of the second (10-30cm) and third depth (30-60cm) is not significantly different from each other. Generally, from all land uses the highest and the lowest SOC value were stored in the NF (170.11±14.59) and CF (97.56±6.85) respectively (Table 1).

Table 1. Mean (±SE) depth wise comparison of %C, BD (g/cm3) and SOC (Mg ha-1) stock of each land uses in Dallo Mena Woredas of Bale

A) Natural Forest

Depth	Mean (± SE)		
	% C	BD(g/cm^3)	SOC(Mg ha^{-1})
0-10	7.92 (±1.47)^a	0.59 (±0.03)^c	90.37(±16.20)^c
10-30	5.15 (±0.67)^b	0.79 (±0.027)^b	157.73(±18.04)^b
30-60	3.97 (±0.27)^b	0.84 (±0.01)^{ab}	172.33(±26.25)^b
60-100	3.90 (±0.70)^b	0.86 (± 0.02)^a	260.01(±20.17)^a
Overall	5.23 (±0.51)	0.77 (±0.02)	170.11(±14.59)
P-value	0.0102	< 0.0001	<0.0001

Means with the same letters across column are not significantly ($P > 0.05$) different

SE = Standard error, %C= Percent carbon, BD= Bulk density and SOC = Soil organic carbon

B) Shade Grown Coffee Agroforestry Practices

Depth	Mean (± SE)		
	% C	BD (g/cm^3)	SOC (Mg ha^{-1})
0-10	8.99(± 1.88)^a	0.77 (±0.05)^b	120.19(±25.49)^a
10-30	3.30 (± 0.30)^b	0.88 (±0.03)^a	99.05(±10.15)^a
30-60	3.28 (± 0.47)^b	0.95 (±0.03)^a	136.39(±17.79)^a
60-100	2.46 (± 0.24)^b	0.98 (±0.02)^a	156.20(±15.97)^a
Overall	4.51(± 0.65)	0.89 (± 0.02)	127.96(±9.43)
P-value	0.0001	0.0013	0.1745

Means with the same letters across column are not significantly ($P > 0.05$) different

SE = Standard error, %C= Percent carbon, BD= Bulk density and SOC = Soil organic carbon

C) Homegarden Agroforestry Practices

Depth	Mean (± SE)		
	% C	BD(g/cm^3)	SOC(Mg ha^{-1})
0-10	5.30±0.71^a	0.89±0.02^b	84.82±11.78^a
10-30	3.05±0.26^b	0.90±0.04^b	91.39±8.65^a
30-60	2.47±0.60^b	0.98±0.02^a	96.61±20.46^a
60-100	2.11±0.39^b	1.01±0.02^a	157.66±40.89^a
Overall	3.23±0.33	0.94±0.01	107.62±12.55
P-value	0.0006	0.0034	0.1410

Means with the same letters across column are not significantly (P > 0.05) different

SE = Standard error, %C= Percent carbon, BD= Bulk density and SOC = Soil organic carbon

D) Annual Crop Field

Depth	Mean (± SE)		
	% C	BD(g/cm^3)	SOC(Mg ha^{-1})
0-10	3.74±0.39^a	1.02 ± 0.01^a	55.09±6.05^c
10-30	3.31±0.50^{ab}	1.03 ± 0.02^a	87.03±4.49^b
30-60	2.40±0.27^b	1.03 ± 0.03^a	111.03±14.13^b
60-100	2.26±0.11^b	1.04 ± 0.02^a	137.10±7.24^a
Overall	2.93±0.20	1.03 ± 0.01	97.56±6.85
P-value	0.0126	0.8844	< 0.0001

Means with the same letters across column are not significantly (P > 0.05) different

SE = Standard error, %C= Percent carbon, BD= Bulk density and SOC = Soil organic carbon

Soil Organic Carbon Stock Among the land uses

The overall depth wise mean SOC values among the land uses were significantly ($p < 0.05$) different (Table 2). Except in first layer (0-10cm) of SC were the highest SOC values were recorded, in the reaming depth the highest values were recorded in the NF.

Table 2. Mean (±SE) SOC (Mg ha^{-1}) among different land uses in Dallo Mena Woreda of Bale

Land Use	Mean (± SE) of SOC (Mg ha^{-1})			
	0-10	10-30	30-60	60-100
CF	55.09 (± 6.05)^{b}	87.03 (± 4.49)^{b}	111.03 (± 14.13)^{b}	137.10 (±7.24)^{b}
HG	84.82 (±11.78)^{ab}	91.39 (± 8.65)^{b}	96.61 (±20.46^{b}	157.66 (± 40.89)^{b}
NF	90.37 (±16.20)^{ab}	157.73 (±18.04)^{a}	172.33 (±26.25)^{a}	260.01 (± 20.17)^{a}
SC	120.19 (± 25.49)^{a}	99.05 (±10.15)^{b}	136.39 (±17.79)^{ab}	156.20 (±15.97)^{b}
P-value	0.0207	0.0004	0.0138	0.0056

Means with the same letters across column are not significantly (P > 0.05) different

SE = Standard error, CF= Annual crop field , HG= Homegarden, NF= Natural Forest, SC= Shade grown coffee

Total Soil Organic Carbon Stocks among the Land Uses

The carbon content, BD and SOC stock values among the four land uses were significantly ($p < 0.05$) different (Table 3). The soil carbon content for NF and SC were significantly differed from HG and CF. For BD the highest BD (1.03±0.01) results were recorded to CF while the lowest was recorded for NF (0.77±0.02). The natural forest recorded high SOC (170.11±14.59) in 0-100cm soil depth than the remaining land uses. From the two agroforestry practices SC store more carbon (127.96 ±9.43) than HG (107.62±12.55).

Table 3. Mean (±SE) carbon content, BD (g/cm^{3}) and soil organic carbon stocks (Mg ha^{-1}) of the four land use system (NF, SC, HG and CF) in Dallo Mena Woredas of Bale

Land Use	Mean (± SE)		
	% C	BD (g/cm^{3})	SOC (Mg ha^{-1})
CF	2.93 (± 0.20)^{b}	1.03 (± 0.01)^{a}	97.56(±6.85)^{c}
HG	3.23 (± 0.33)^{b}	0.94 (± 0.01)^{b}	107.62(±12.55)^{c}
SC	4.51 (± 0.65)^{a}	0.89 (± 0.02)^{b}	127.96(±9.43)^{b}
NF	5.23 (± 0.51)^{a}	0.77 (± 0.02)^{c}	170.11(±14.59)^{a}
P-value	0.0010	< 0.0001	< 0.0001

Means with the same letters across column are not significantly (P > 0.05) different

SE = Standard error, % C = Percent carbon, BD = Bulk density and SOC = Soil organic carbon

Discussion

Soil Organic Carbon Stocks

Land use and depth are major factors which determine the storage potential of carbon in the soil. The amount soil organic carbon (SOC) stored among all land uses and in each depth is vary from each other. With increasing soil depth the amount of percent carbon and SOC was decreased. Due to the deciduous characteristics of different plant species, higher accumulation of litter was observed in the top layer. The decomposed litter and plant residues was recycled and contributed to high SOC stock in the top layer of all land uses. In addition to this, the fine roots of different shrubs (eg. coffee) and other plant species is concentrated in the upper layer of the soil. Due to this factor there is high recycling of dead root in to the soil which contributed a lot for the SOC in the top layer. In reverse to this the value of bulk density were increased with depth. In addition to the above ground vegetation and soil management practice, the amount SOC stored in the soil was affected by the soil depth. This is due to the presence of tree roots and microbial action which correlated to root exudates. Jobb´agy and Jackson (2000) described that the vertical distribution of SOC were determined by the vegetation type through its root-shoot allocation and root distributions along the vertical direction of soil profile.

The overall mean SOC value of the whole system is vary from each other. Due to the conversion of native forest into other land uses will change the total soil organic carbon, the soil organic carbon of other land uses (SC, HG and CF) was lower than that of the original NF. The mean soil organic carbon stock stored in 100cm soil depth of all land uses are; for NF (170.11±14.59), SC (127.96±9.43), HG (107.62±12.55) and CF (97.56±6.85). This higher mean SOC stock can be due to the accumulation of higher organic matter in soil surface and fast decomposition of litter which results in maximum storage of carbon (Sheikh *et al.*,2009). In the forest ecosystem due to the high plant coverage it contains higher litter accumulation in the soil surface. Since litter is one the organic matter source, it contributes a lot for the increment of SOC level in the forest ecosystem. In the case of shade grown coffee agroforestry practice, the amount SOC is less than NF and greater than the homegarden and annual crop field. This is also due to higher litter accumulation and relatively less soil disturbance in the system. In the coffee production process shade tree is one of the major component in order to increase the quality of coffee yield. Due to this reason the amount of litter decomposed and recycled in to the soil is relatively higher.

In the homegarden agroforestry practice, having encompassed different types of plants, there is significant amount of litter to be recycled. But most of the leaves are used by farmers as a fodder for their domestic animal. Also in this system there is different plant component (annual crops) which needs intensive soil management. Intensive soil management is one the major factor which affects the amount of SOC stored in the soil. Due to all this factors the amount of SOC is decreased in this system. The same is true for crop field. Due to higher soil disturbance, the amount of SOC has decreased to a great extent. It is only pure annual crop cultivation system and the crop residue of cultivated crop is harvested and transported in to their home for animal feed. Due to this external factor only very less amount of crop residue were recycled in to the soil. According to Ladegaard *et al.* (2005) the amount of SOC is determined by the extent and type of vegetation cover. These all factors might affect the amount SOC in the system.

Conclusion

Agroforestry and other land uses providing various ecological as well as economical benefits for the community. It is used as income source, conserving different plant species diversity and at the same time storing large amounts of organic carbon in the soil. The overall mean SOC value of the whole system is vary from each other. Due to land use change will affect the soil organic carbon, the soil organic carbon of other land uses (SC, HG and CF) was lower than that of the original NF. In the forest ecosystem due to the high plant coverage it contains higher litter accumulation in the soil surface which is high contribution for soil organic carbon. In the case of shade grown coffee agroforestry practice, the amount SOC is less than NF and greater than the homegarden and annual crop field. This is also due to higher litter accumulation and relatively less soil disturbance in the system. In the homegarden agroforestry practice, having encompassed different types of plants, there is significant amount of litter to be recycled. Also in this system there is different plant component (annual crops) which needs intensive soil management. Intensive soil management is one the major factor which affects the amount of SOC stored in the soil. Due to all this factors the amount of SOC is decreased in this system. The same is true for crop field. Due to higher soil disturbance and complete removal of crop residue, the amount of SOC has decreased to a great extent. According to Ladegaard *et al.* (2005) the amount of SOC is determined by the extent and type of vegetation cover. These all factors might affect the amount SOC in the system. Therefore, there is significant difference among natural forest, shade grown coffee agroforestry practice, homegarden agroforestry practice and annual crop field in soil organic carbon storage capacity.

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