Evaluating Organic Carbon Storage Capacity of Forest Soil: Case Study in Kafa Zone Bita District, Southwestern Ethiopia

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Abstract: Soil, forest and atmosphere are potential carbon sinker in the terrestrial ecosystem, of which the share of soil is more than that of forest and atmosphere. In Ethiopia very few studies have been conducted on forest soil organic carbon storage capacity. The purposes of this study was to determine organic carbon storage capacity of Kafa forest soil and to generate relevant information for stakeholders on forest soil organic carbon storing capacity that helps them for land management decisions and carbon trading. To achieve these goals, a representative forest land was selected in Bita district and five successive soil profiles were excavated at different slope positions of the toposequence. Soil samples were collected from each horizon of the soil profiles to determine soil carbon concentration and bulk density. Organic carbon storage (t ha$^{-1}$) capacity of each horizon was obtained by multiplying the bulk density, organic carbon concentration and horizon thickness of the soil. The amount of organic carbon stored (t ha$^{-1}$) in each profile was obtained by summing up organic carbon stored in the successive horizons of the respective profiles. Multiple linear regression model was employed to describe the effects of independent variables on dependent variables and Pearson’s correlations analysis was used to determine the relationship between dependent and independent variables. Regression analysis revealed a unit rise in soil organic carbon concentration, bulk density and sampling depth rises soil organic carbon stock by 5.47, 1.53 and 25.64 t ha$^{-1}$, respectively. Soil organic carbon storage capacity was significantly (P < 0.0001) affected by organic carbon concentration and sampling depth. Besides, correlation analysis indicated, the amount of organic carbon stored in the soil has a positive relationship with organic carbon concentration and bulk density. Thus, soil organic carbon concentration and bulk density improvement are the most important management interventions to increase soil organic carbon storage capacity. Therefore, stakeholders should focus on management activities that improve soil organic carbon concentration and bulk density to boost carbon stock capacity of the soil.

Keywords: Soil organic carbon storage • Bulk density • Soil organic carbon concentration

INTRODUCTION

Proper soil and forest management is low technology demanding practice to increase carbon storage in the terrestrial ecosystem [1-3]. For several years many research has been conducted on aboveground biomass production and its ability to sequester atmospheric carbon [3]. But, little recent studies show the capacity of soil to store organic carbon. The amount of carbon stored in soil is 3-2.5 times greater than the amount sequestered in vegetation and two times the amount existed in atmosphere [4]. Globally, about 1.5 x 10$^{12}$ ton of carbon (organic or inorganic) is stored in soil (soil of grass, crop, forest, bush and shrub and other lands) [1] of which the share of forest soil is around 1.1 x 10$^{12}$ ton [5]. Due to relatively large size and long residence time of organic carbon in soil, soils are potentially important natural sink for carbon. However, the amount of organic carbon stored in soil is varying among soil groups, agro-ecological zones and human interference such as disturbing natural vegetation, soil ecosystems and poor soil management interventions [2].
Under ideally equivalent environmental conditions and management practices the distribution and volume of organic carbon concentration in soil varies with soil depth [5]. In addition carbon concentration in soil varies with the magnitude of precipitation, it increases with precipitation (optimum in humid and cold climates) [6].

Litteratures are showing enormous amount of carbon is lost from soil due to inappropriate land management including land use change, drainage of peat lands and deforestation. Land use change for agriculture causes loss of 7.8 x 10^6 ton carbon from global soil pool [7]. Conversion of native forest to cropland reduces soil organic carbon storage by 42% (8). Study conducted in the southwestern Ethiopia indicated, conversion of forest land to continuous cultivation causes loss of 32.98-36.63% organic carbon [3]. This shows conversion of forest land to crop land affects carbon stored both in the forest biomass (above ground) and soil (below ground). Though the adverse effects of deforestation is clearly observed at global and local level more than ever, peoples in the developing countries are continued clearing forests for various purposes. So, more works has been expected from scientists to find out appropriate solutions for policy issues and convince stakeholders (policy makers, land use planners and others) to protect forest land and execute afforestation program. To convince the stakeholders showing the social, economic and ecological benefit obtained from aboveground forest resource alone is not adequate evidence but, benefits obtained from below ground (soils) should be includes in the context of carbon storage. Therefore, this study was conducted to determine the organic carbon storage capacity of Kafa forest soils and to generate relevant information on forest soil carbon storage for policy makers and other stakeholder.

**MATERIALS AND METHODS**

**Study Area Description:** Kafa Zone is located in the Southern Nation, Nationalities and People’s Regional State (SNNPRS), the most ethnically and linguistically diverse region of Ethiopia. Bonga is the administrative town of Kafa Zone which is located at 450km away from Addis Ababa. The Zone is mostly covered with evergreen montane cloud forest and is part of the Eastern Afromontane Biodiversity Hotspot.

The Zone has a total land area of 10602.7 square kilometer of which 23.1% is cultivated, 31.54% is forestland, 6.03% grazing land, 24.9% cultivable land and the remaining 14.43% is uncultivable (swampy and wetlands). According to 2007 census, the total population of the Zone is 858,600 with population density of 90 persons per kilometer square.

Its altitude is range from 500 to 3500 m.a.s.l (meters above sea level) with the mean annual rain fall and temperature of 1001 - 2200mm and 10.1 to 27.5°C, respectively.

**Soil Sample Collection and Laboratory Analysis**

**Forest Soil Sampling:** The land features of the study area particularly the highlands are mountainous and rugged with good natural vegetation coverage. Based on the topographic features and vegetation conditions Bita district was believed to represent the highland forest areas of the Zone. Therefore, a representative toposequence was selected in the district and five soil profiles were excavated at different land positions (upper, middle, lower and toe slope). In each soil profiles, master soil horizons were identified by following FAO (2006) guideline for soil description and soil samples (both core sample for bulk density and disturbed sample for organic carbon analysis) were collected separately from each horizon of the respective profile.

**Soil Sample Preparation and Laboratory Analysis:**

Soil samples were air-dried at room temperature, milled and passed through a 2mm sieve for soil organic carbon determination. The analysis was carried out at JIJE Analytical Service Laboratory, at Addis Ababa Ethiopia in 2011. Wet oxidation method was employed to determine the total organic carbon content of the soil [7]. Bulk density was determined by dividing the oven dry (110°C for 24hrs) weight (g) of soil to volume of the core (cm³).

**Soil Organic Carbon Storage Capacity Determination:**

Soil organic carbon storage (t ha⁻¹) capacity was obtained by summing up the organic carbon stored in the successive horizons of the respective profile [8]. The organic carbon (OC) stored in a soil horizon was determined as a product of bulk density, carbon concentration and horizon thickness [3, 9].

**Statistical Analysis:** Statistical Package for theSocial Sciences(SPSS) version 16 was used to analyze soil data. Multiple linear regression model was used to describe the effects of independent variables on dependent variables as described follow;
\[ Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + e \]

where:
- \( Y \) is the dependent variable (C-storage t ha\(^{-1}\))
- \( x_1, x_2 \) and \( x_3 \) are the independent variables such as sampling depth, bulk density and organic carbon content
- \( b_1, b_2 \) and \( b_3 \) are the coefficients that describe the effect of the independent variables on dependent variable
- \( b \) is the value \( Y \) is predicted to have when all the independent variables are equal to zero
- \( e \) is the noise or error that influence C-storage

Student's test distribution was used to determine the significant levels of the regression (\( P \leq 0.5 \)).

**RESULT AND DISCUSSION**

**Soil Horizon Designation:** During soil profile description O, A, E, B and C master horizons were identified with varying thickness of each profile. O, A, E, B and C horizons were identified at top, middle and lower land positions while O, E and B horizons at the toe. The difference in the master horizons types and its thickness may be explained by differences in slope position (topography) as factors influencing soil formation. This is agreed with the insight of other author who stated slope position (topography) affects soil physical properties such as soil depth, bulk density, texture, structure and chemical properties like C, N, P, K, CEC, EC and others [10].

**Statistical Model Validity for Data Analysis:** Selection of an appropriate statistical model for data analysis is principal and the most important tasks in research. The type of model used to analyze data, determines the outputs results and conclusions. Proofing the suitability of selected model for specific data is basic step in research. Accordingly, multiple linear regression model was selected to determine the effects of soil bulk density, organic carbon and sampling depth on soil carbon storage capacity. The reliability of this model was checked as shown in Table 1 Reference source not found. The regression coefficient of determination \( R^2 \) is 0.862 (Error! Reference source not found.). This implies about 86.20% of variation in the soil carbon storage data is explained by soil sample depth, bulk density and organic carbon concentration.

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df is degree of freedom for SS (sum of squares)

**Table 1:** Model Summary

**Table 2:** ANOVA of C-storage (t ha\(^{-1}\))

In addition, as indicated in Table 2 below P-value was < 0.001 while F-calculated value was very high. This suggests soil sample depth, bulk density and organic carbon concentration are important indicators of soil organic carbon storage capacity. Therefore, based on these realities the selected model is highly significantly fitted with the existing data.

As shown in Fig. 1. This also indicates the appropriateness of the model for this particular data.

**Effects of Soil Carbon and Horizon Thickness on Soil Organic Carbon Storage Capacity:** Organic carbon storage (t ha\(^{-1}\)) capacity of the study soil was increases by 1.53t ha\(^{-1}\) with a unit increase in soil sampling depth where holding the other independent variables constant. With 95% confidence soil sample depth goes up by one cent meter, the average soil organic carbon storage capacity increased from 0.29 t ha\(^{-1}\) to 2.78 t ha\(^{-1}\) (Table 3).
Soil sampling depth was significantly (P<0.05) affect soil organic carbon storage capacity. As the sampling depth of soil increases, organic carbon storage also increases. This implies deep soil profile allows more organic carbon accumulation than the shallow depths.

Soil organic carbon storage capacity was expected to increase by 5.47 t ha⁻¹ for each unit increase in organic carbon concentration while holding the other independent variables constant. Similarly, due to unit increment in soil profile (sampling) depth organic carbon storage capacity of the soil was increased by 25.64 t ha⁻¹. The concentration of organic carbon and profile (sampling) depth were highly significantly affects (P < 0.0001) carbon storage capacity of that soil. This indicates land management practices that build up soil organic carbon content and protecting soil depth from detachment and transportation by water erosion is very important to improve or maintain the organic carbon storage capacity soils.

Soil bulk density of the study site was positively related with sample depth and organic carbon storage but, negatively associated with soil organic carbon concentration (Table 2 Table 4). However, the association of soil bulk density with sample depth, organic carbon concentration and organic carbon storage was non-significant (P>0.05).

Soil sampling depth was positively correlated with soil bulk density and negatively correlated with soil organic carbon concentration and carbon storage capacity (Table 2 Table 4). The association of sampling depth with soil carbon concentration and carbon storage was significant (P = 0.01) but non-significant with bulk density (P > 0.05).

Soil organic carbon concentration was negatively correlated with soil bulk density and sampling depth but, positively with soil organic carbon storage (Table 2 Table 4). The degree of association of soil organic carbon concentration with sampling depth and organic carbon storage capacity was highly significant (P = 0.001). Soil organic carbon concentration was negatively correlated with sampling depth and bulk density and positively with soil carbon storage capacity.
But, the correlation was negative with sampling depth and positively with bulk density and organic carbon concentration (Table 2 Table 4). The association of carbon storage capacity with soil organic carbon concentration and sampling depth was highly significant ($P = 0.001$) but non-significant ($P > 0.05$) with soil bulk density.

On average the amount of organic carbon stored in the study soils was about 639.64±286.10 t ha$^{-1}$ (Table 5). The upper and lower limit confidence intervals of organic carbon stored in this soil is 995.10 and 352.60 t ha$^{-1}$, respectively. This implies protecting forest land has contribution to climate change mitigation by storing such huge amount of carbon in soil profile. Therefore, in carbon treading policy the concerned bodies should consider the amount of carbon stored in soil in addition to above ground biomasses to encourage forest land protection and researchers should generate information in the area.

**CONCLUSION**

Regression analysis revealed a unit rise in soil organic carbon concentration, bulk density and sampling depth rises soil organic carbon stock by 5.47, 1.53 and 25.64 t ha$^{-1}$, respectively. Soil organic carbon storage capacity was significantly ($P < 0.0001$) affected by organic carbon concentration and sampling depth. Moreover, correlation analysis indicated, the amount of organic carbon stored in the soil has a positive relationship with organic carbon concentration and bulk density. The average quantity of organic carbon stored in the soil was 639.64±286.10 t ha$^{-1}$. This implies quantity of organic carbon stored in the soil has been governed by soil organic carbon concentration and bulk density. Thus, soil organic carbon concentration and bulk density improvement are the most important management interventions to increase soil organic carbon storage capacity. Therefore, stakeholders including the community, government, non-government and international organizations should focus on management activities that improve soil organic carbon concentration and bulk density to boost carbon stock capacity of the soil. Further researches are demanded to generate adequate information from other similar land use types to convince policy makers and other stakeholders on protecting forest lands to get benefits from carbon treading. Also, in carbon trading policy carbon stored in forest soils should be equally valued with carbon stored in forest biomass.

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**REFERENCES**