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Land Use Changes on Soil Carbon Dynamics, Stocks in Eastern Himalayas, India

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Abstract

We evaluated four different land use systems for their potential of soil organic matter (SOM) dynamics in an acid soil of the eastern part of the Indian sub-Himalayas. Mean (of 0-30 cm soil layer at 10 cm interval) bulk density value was highest in the plots under Guava (*Psidium guajava*) based agro-forestry system (AFS; 1.03 Mg m^{-3}) and was lowest in Alder (*Alnus nepalensis*) based AFS (0.95 Mg m^{-3}). Plots under hedge and Alder based AFS had about 62 and 59% higher SOC concentrations compared with the control plots (mean of three soil layers = 16.0 g kg^{-1}) in the 0-30 cm soil layer. Again, plots under guava based AFS had similar SOC concentration to the control plots in that soil layer. For all land use systems (except for the control plots), SOC contents in the 10-20 cm depth was significantly higher than in the 0-10 and 20-30 cm soil layers, indicating the importance of the middle layer for SOC sequestration. The particulate organic matter–C (POM-C) content closely followed similar trend to SOC content in different soil depths and land use systems. This conclusively proved that different AFS systems had significant roles in SOC retention. As hedge and Alder based AFS had significantly higher SOC stock and POM-C than the Guava based AFS and the control plots, the former management practices are recommended for better soil carbon retention (and thus for mitigation of global warming) in the Indian sub-Himalayas.

Keywords: **SOC, particulate organic C, C sequestration, Agro-forestry system**.

Introduction, scope and main objectives

The extent and degree to which Soil Organic Matter is bound to inorganic mineral particles regulate its dynamics (Barrios et al., 1996). Carbon present in particulate organic matter (POM) can build up fast under management practices that reduce soil disturbances. This fraction (POM) can also present an initial indicator of changes in C dynamics and total SOC under different land management practices (Bhattacharyya et al., 2009). A loss of soil organic carbon (SOC) due to unsuitable land use and management practices can deteriorate soil quality (Lal, 2004). On the other hand, proper land use and management practices can lead to increased SOC and improved soil quality that can mitigate atmospheric CO_2 rise (Lal, 2004). The present study was carried out to ascertain the effects of growing different hedgerow species on SOC contents and to estimate the relative advantage of growing these plants over a control plot in terms of total SOC stocks in the 0 to 30 cm soil depth in the eastern part of the Indian Himalayas. The specific objective was to study the impacts of different AFS on the selected SOM fractions (POM-C and SOC) in the surface soil layer after five years of land management practices in an acidic soil of the Eastern sub-Himalayas. The main hypothesis was that the plots under AFS would have significantly higher SOC content and its labile pools in the 0-30 cm soil layer compared with the control plots, as the added biomass by the trees would have notable impacts in the plots under AFS.

Methodology

Site

The experimental site is located between 25º39" 25º41"N latitude to 91º54"-91º63"E longitude. Triplicate soil samples from all plots from 0-10, 10-20 and 20-30 cm depths were collected from one location each under all hedge species using a core sampler. Representative sub-samples were taken to determine various physico-chemical properties using normal protocols (Page et al., 1982).

Soil organic matter fractionation study

Particulate organic matter was measured following the method depicted by Cambardella and Elliott (1992), with a little modification.

Statistical analysis

We analysed soil properties using ANOVA for a randomized block design (with four treatments and three replications). Tukey's honestly significant difference test was used as a *post hoc* mean separation test ($P < 0.05$) using SAS 9.1 Statistical analysis were carried out at all depths within a land use and the differences were considered significant when $P < 0.05$. Linear regression was used to find relationships between SOC and POM-C. Correlation coefficient was also observed for the relationships between SOC fractions and different soil parameters.

Results

Soil bulk density

Mean bulk density in the plots under Guava based AFS (1.03 Mg m^{-3}) was significantly higher than the Alder based AFS (0.95 Mg m^{-3}) (Table 1). Irrespective of the land use systems, soil bulk density augmented with soil depth. Soil bulk density values for different depths between and among the AFS systems were non-significant. However, down the profile bulk density values increased due to more compaction in the soil strata.

Carbon fractions and stock of the agro-forestry systems

Plots under hedge based AFS had about 63 and 62% higher mean (of three soil layers) SOC content (25.9 g kg^{-1}) compared with the Guava based AFS and control plots, respectively (Table 1). Plots under Alder and hedge based AFS had similar mean SOC values and had higher SOC contents in the sub-surface soil layer than the surface layer (0-10 cm). Similar trend was observed for the mean SOC stock/content values. Mean SOC stock was highest in the plots under hedge based AFS. Plots under Hedgerow based system had about 21% higher SOC content in the 10-20 cm soil layer than the 0-10 cm soil layer (24.3 Mg ha^{-1}). Similarly, for the Alder based system, the sub-surface (20-30 cm) layer had about 22% higher SOC than the 0-10 cm soil layer (Table 1).

Plots under the hedge and Alder based AFS had significantly higher POM-C values than the control plots (Table 2). Like total SOC, plots under Guava based AFS and control treatments had similar POM-C concentrations, and the plots under the hedgerow and Alder based AFS had similar POM-C contents (Table 2). The middle layer of all land use systems contained significantly higher POM-C stock than the surface layer (Table 2).

Discussion

Alterations in SOC fractions

Particulate organic matter-C can serve as a functional part of soil quality index and is a insightful indicator of land management outcomes on SOC (Bhattacharyya et al., 2009). In this experiment, a greater amount of POM-C was observed in hedge and Alder based AFS soils than in soils of Guava based AFS, and there was a greater variations in POM-C under the hedge/Alder based system relative to the mean (of other AFS systems) POM-C (Table 2). These results suggest that the accrued organic C occurred also in POM fraction in these acid soils. Therefore, perennial vegetation should be maintained for a long time period to increase the slow and passive pools of SOM, apart from the known benefit that the atmospheric CO_2 is also fixed in the aboveground biomass.

We also observed that POM-C was higher in the plots under hedge-based AFS compared with the Alder-based AFS, especially in the surface soil layer (Table 2). The C sequestration potential of any soil is reliant upon its C saturation level, which is the highest amount of C associated with silt and clay particles (Bhattacharyya et al., 2009). The results showed that the amounts of POM-C was on average 9.7 Mg ha^{-1} soil in the 0-30 cm soil depth layer plots under hedge based AFS.

Thus, in these highly erodible and acidic soils, the conversion of lands (with a double cropping) to a hedge based AFS should be widely used to improve soil health and sequester SOC.

Relationships among soil organic matter parameters

Relationship between POM-C (g kg^{-1}) and SOC (g kg^{-1}) in AFS was

POM-C = 0.415 x SOC - 0.147

This conclusively proved that different AFS affected SOC pools significantly.

Conclusions

Conversion of fallow to hedge based AFS resulted in greater SOC build up in the 0-30 cm layer in these acid soils of the Indian Himalayas. The soils have enormous potential for SOC sequestration and conversion of crops to hedge-based AFS could be one of the efficient approaches to improve C retention in this region. For all land use systems (except for the control plots), SOC contents in the 10-20 cm depth was significantly higher than in the 0-10 and 20-30 cm soil layers, indicating the importance of the adopted land use systems on SOC sequestration (as SOC in the middle layer is less liable to be lost by erosion and biochemical processes). This is one of the rare studies that evaluated rate of soil carbon retention by different agro-forestry systems in the Indian Himalayas.

Table 1. Effects of various agro-forestry systems on mean (± SD) soil organic carbon concentration and content in the Indian sub-Himalayas

Farming system/soil depth	Total SOC (g kg^{-1})	Soil bulk density (Mg m^{-3})	Total SOC content (Mg ha^{-1})
1. Hedge based AFS			
0-10 cm	24.8 ± 3.6B	0.98 ± 0.03B	24.30B
10-20 cm	28.9 ± 3.9A	1.02 ± 0.03AB	29.48A
20-30 cm	24.1 ± 3.2B	1.05 ± 0.03A	25.31B
Mean	25.9 ± 3.6 a	1.00 ± 0.03 a	25.9 a
2. Alder based AFS			
0-10 cm	24.1 ± 3.2B	0.93 ± 0.02B	22.41B
10-20 cm	24.4 ± 3.5B	0.95 ± 0.02AB	23.18B
20-30 cm	27.9 ± 3.6A	0.98 ± 0.02A	27.34A
Mean	25.4 ± 3.4[a]	0.95 ± 0.02b	24.13 a
3. Guava based AFS			

0-10 cm	18.4 ± 2.3[a]	1.01 ± 0.01B	18.54[a]
10-20 cm	15.7 ± 2.0B	1.02 ± 0.01B	16.01B
20-30 cm	13.3 ± 2.1C	1.06 ± 0.01A	14.10C
Mean	15.8 ± 2.2b	1.03 ± 0.01a	16.24 b
4. Control (without a tree)			
0-10 cm	16.3 ± 1.9A	0.99±0.02B	16.14B
10-20 cm	14.7 ± 1.9B	1.01±0.02B	14.85B
20-30 cm	16.8 ± 2.0A	1.07±0.02A	17.98A
Mean	16.0 ± 1.9c	1.02±0.02a	16.32 b

Values followed by similar uppercase letters within a column for a particular land use system are not significant at P <0.05. Means of different land use systems within a column followed by similar lowercase letters are not significant at P <0.05.

Table 2. Effect of various agroforesty systems on mean (± SD) total N and particulate organic matter-carbon contents in the Indian sub-Himalayas

AFS system/ Soil depth (cm)	**POM-C ($g\ kg^{-1}$)**	**Total N ($g\ kg^{-1}$)**	**C/N Ratio**	**POM-C/SOC**	POM-C Stock (Mg/ha)
1. Hedge based AFS					
0-10	8.5 ± 1.2B	2.0 ± 0.1A	12.4 ± 1.2B	0.34 ± 0.02A	8.33C
10-20	11.3 ± 1.4A	1.9 ± 0.1A	15.2 ± 1.5A	0.39 ± 0.02A	11.3[a]
20-30	8.9 ± 1.0B	1.8 ±0.1A	13.4 ± 1.2B	0.37 ± 0.02A	9.35B
Mean	9.2 ± 1.2 [a]	1.9 ± 0.1 [a]	13.7 ± 1.3 [b]	0.36 [a]	9.66 [a]
2. Alder based AFS					
0-10	9.2 ± 0.8B	1.7 ± 0.1B	14.2 ± 0.4A	0.38 ± 0.01A	8.56B
10-20	10.4 ± 0.9[a]	1.8 ± 0.2B	13.5 ± 0.4A	0.43 ± 0.01A	9.88A
20-30	8.8 ± 0.8B	2.1 ± 0.2A	13.3 ± 0.4A	0.31 ± 0.01B	8.62B
Mean	8.6 ± 0.8[a]	1.9 ± 0.2[a]	13.6 ± 0.4[b]	0.34[a]	9.02 [a]
3. Guava based AFS					
0-10	4.2 ± 0.6B	1.1 ± 0.1 A	16.7 ± 0.6A	0.23 ± 0.04B	4.24B
10-20	4.8 ± 0.5A	0.9 ± 0.1B	17.5 ± 0.5A	0.30 ± 0.04A	4.90A
20-30	3.9 ± 0.4B	0.8 ± 0.1B	16.6 ± 0.6A	0.30 ± 0.04A	4.13B
Mean	4.6 ± 0.5 [b]	0.9 ± 0.1 [b]	17.0 ± 0.5 [a]	0.29 [b]	4.42 [c]

4. Control (without a tree)					
0-10	4.0 ± 0.5B	1.9 ± 0.1A	8.5 ± 0.8B	0.25 ± 0.01B	3.96C
10-20	5.6 ± 0.6AB	1.5 ± 0.1B	9.8 ± 0.9A	0.38 ± 0.01A	5.66B
20-30	6.1 ± 0.7A	1.6 ± 0.1B	10.4 ± 0.9A	0.37 ± 0.01A	6.53A
Mean	4.9 ± 0.6[b]	0.17±0.0[a]	9.5 ± 0.9[c]	0.31 ± 0.0[b]	5.38 [b]

Values followed by similar uppercase letters within a column for a particular land use system are not significant at $P < 0.05$ according to Tukey's HSD test. Means of different land use systems within a column followed by similar lowercase letters are not significant at $P < 0.05$ according to Tukey's HSD test.

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