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Status of Soil Organic Carbon Stocks Under Different Land Use Systems in Wet Temperate North Western Himalaya.

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ABSTRACT

The present investigation was carried out in wet temperate region. The seven land uses selected were: agri-horticulture (AH), silvi-pasture (SP), agri-silviculture (AS), horticulture (H), forest (F), agriculture (A) and grassland (G), three altitude gradients viz., 1500-1800 m, 1800-2100 m , 2100-2400 m asl were selected. Soil physico-chemical property reveals that maximum bulk density (1.207 g cm^{-3}) was recorded in the horticulture land use system and least in forest and silvi-pasture (0.983 g cm^{-3}), respectively. The bulk density recorded at the upper soil layer (0-20 cm) was found to be significantly lower than the deeper soil layer (20-40 cm). Maximum soil organic carbon (2.45%) was found in the forest and least in agriculture (0.58%), respectively. The soil organic carbon percent also enhanced significantly with the ascending altitudinal ranges. Forest land use system displayed the maximum value of soil organic carbon stock (52.01 t ha^{-1}) in 0-40 cm layer and least in silvi-pasture systems (17.01 t ha^{-1}), respectively. In the altitudinal range, the total soil organic carbon stock declined with increasing altitudinal range. In the soil layer effect, SOC stock in 0-20 cm in layer was found to be significantly higher than that of L_2 layer.Maximum soil organic carbon stock (0-40 cm layer) was recorded in forest land use system (108.9 t ha^{-1}), which was followed by agri-horticulture (51.0 t ha^{-1}), horticulture (46.3 t ha^{-1}), respectively.

Keywords:

Bulk density, **c**arbon stocks, Himalaya, landuse systems, soil

INTRODUCTION

Agricultural activities greatly contribute to global net flux of CH_4, N_2O and CO_2 from the terrestrial biosphere into the atmosphere. The increased flux from the change and intensification of land use in order to feed needs of the rapidly growing human population, increased biomass burning and soil cultivation, increased number of livestock, increased acreage of paddy fields and increased use of nitrogen fertilizer have been considered as most important factor for the increased flux. Following the agreement of Kyoto-protocol in 1977 policy makers or the Ministers of Agriculture of many countries have involved in discussion about policy measures to decrease greenhouse gases emission from agriculture. Various possible measures have been identified to decrease emission of CO_2, CH_4, and N_2O from agricultural sources. However, few of these measures have been tested at field scale, Forests have been identified as net sink of atmospheric CO_2 (Valentine et al. 2000). On the other hand changes in the land use and agricultural activities release annually 1.8 Pg carbons (Oliver et al. 1999). This indicates that agriculture is a net source of CO_2.

Concentration of atmospheric CO_2 can be lowered either by reducing emissions or by taking CO_2out from the atmosphere and stored in the terrestrial, oceanic or aquatic ecosystems. Several studies have established the fact that carbon sequestration by trees could provide relatively low cost net emission reductions (Parks and Hardie 1995; Plantinga and Birdsey 1995; Callaway and Card 1996; Stavin 1999; Kanime et al. 2013). Most of the carbon enters the ecosystem through the process of photosynthesis in the leaves. After the litter fall, the detritus is decomposed and forms soil organic carbon by microbial process. Inter-governmental Panel on Climate Change has recognized soil organic carbon pool as one of the five major carbon pools for the Land Use Land Use Change in Forestry sector. It is mandatory for all nations to provide soil organic carbon pool and changes from LULUCF sector under National Communications to the United Nation's Framework Convention on Climate Change. Soil especially, the forest soil is one of the main sinks of carbon on earth because these soils normally contain higher soil organic matter however, the soil organic carbon (SOC) has been ignored since long because it was treated as a dead biomass. Soil contains an important pool of active carbon that plays a major role in the global carbon cycle (Melilo et al. 1995; Prentice et al. 2003). Soil organic matter is a key component of terrestrial ecosystem. Enhanced sequestration of atmospheric CO_2 in the soil, ultimately as stable soil organic matter, provides a more lasting solution than sequestering CO_2 in standing biomass. Soils store 2.5 to 3.0 times as much that stored in plants (Post et al. 1990) and two to three times more than the atmospheric as CO_2 (Davidson 2000). The conversion of natural vegetation to various lands uses results in rapid decline in soil organic matter (Post et al. 2000). Up to 87% decrease in soil organic carbon due to deforestation has been reported by researchers (Totey et al. 1986; Singh, 1995). Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux from the soil (Post et al. 2000; Tian et al.2002).

No systematic project / study has been undertaken to estimate the soil organic carbon pool in forests, as well as in other land uses in the north western Himalayas, India. Although some investigations have been carried out and data generated on the soil organic carbon pool in the forests, but it was on the basis of desk review by using some indirect methods or using some assumptions. Soil organic carbon in India basedon different forest types were estimated (Chhabra et al. 2002 but the bulk density, which is the key factor for soil organic carbon estimation has been calculated indirectly in their method. Therefore, a study was conducted to estimate SOC pool under different land uses. The results of this study have provided the authentic and comprehensive estimates of the SOC pool under different land use systems. Information generated from this study can be used as a benchmark for future work to estimate the changes in SOC pool in these land uses.

MATERIALS AND METHODS

Site description

The study was carried out in Rohru Forest Division of Shimla district of Himachal Pradesh, which is located between 31°13'5" to 31°13'55"N latitude and 77°39'30" to 77°41'15"E longitude, (Survey of India, Top sheet No. 53 of E/11). It falls in the wet temperate zone of north-western Himalaya.The climate of the study areas varies a lot depending upon the altitude and the aspect. Precipitation is in the form of rains mainly during rainy season but snowfall occurs during winter months. Seasons are very distinct *viz.*,Summer (April to June), Monsoon (July to September) and winter (October to March). The forests of study area were having vegetation of temperate nature mainly the following forest types (Champion and Seth, 1968).12/C_1- Low Himalayan temperate forest, 12/C_{16}- Mohru Oak forest, 12/C_2- Upper west Himalayan temperate forest, 12/2S_1- Low-level blue-pine forest and 13/C_4- West Himalayan high level dry blue pine forest. The details of the different land use systems used for the current investigation are listed below:

Table 1. Land use systems

Land use systems	System units/altitudinal gradients		
	1500-1800 m	**1800-2100 m**	**2100-2400 m**
Agri -horticulture (AH)	Apple + Maize Apple + Jower	Apple + Potato Apple + Maize	Apple + Maize Apple + Amaranthus
Silvi -pasture(SP)	Robinia + Grasses Kail + Grass Deodar +Grasses	Robinia + Grasses Deodar + Grass	Kail + Grasses
Agri -silviculture (AS)	Maize + Robinia Jower + Robinia Maize + Morus		Quercus + Amaranthus Quercus + Fagopyrum
Horticulture (H)	Apple	Apple	Apple
Forest (F)	Kail, Deodar	Deodar	Fir, Spruce, Kail
Agriculture (A)	Maize, Jower	Maize, Potato	Maize, Amaranthus Fagopyrum
Grassland (G)	Pure natural grasses	Pure natural grasses	Pure natural grasses

Soil samples were collected by dividing each main plot area into five areas each 10 x 10 m. Soil samples for each sub area were obtained by digging five profiles of 20 x 50 cm (Sub-surface area) by 50 cm deep. Composite samples from all sub area were obtained for each depth. Samples were air dried in shade, ground with wooden pestle, passed through 2 mm sieve and stored in cloth bags for further laboratory analysis.

Soil analysis and carbon stock

The physical and chemical analysis of the air-dried soil is briefly described as follows. Soil organic carbon was determined by wet digestion method (Walkley and Black 1934). Bulk density of soil was estimated through specific gravity method (Singh 1980). Soil organic carbon stock was calculated using equation 1 given below:

Soil Organic Carbon stock = ([Soil bulk density (g cm^{-3}) x Soil depth (cm) x Carbon (%)] x100..... (Equation 1), (Nelson and Sommers 1996).

Statistical analysis

The data obtained were subjected to statistical analysis using Randomised Block Design of experimentation as per the procedure suggested by Gomez and Gomez (1984). Wherever, the effects exhibited significance at 5 per cent level of probability, the critical difference (CD) was calculated. Analysis was carried out on computer using the package “STATISTCS”.

RESULTS AND DISCUSSION

Soil physico-chemical properties

Bulk density

It is crystal clear from the data presented in the Table 2 that bulk density (g cm^{-3}) varied significantly under different land use system, altitudinal ranges and soil layer layers. Bulk density under different land use system followed the trend horticulture >agri-horticulture> agriculture> grassland >agri-silviculture> forest = silvi-pasture. In our finding it was observed the land use system which is intensively managed have higher bulk density and it declined as the intensity of land management system declined. The high value of bulk density in the soils can also be ascribed to lower soil organic carbon content. These findings are in the line with that of Karan et

Table 2: Average soil organic carbon, bulk density and soil organic carbon SOC) as influenced by average effect of land use system, altitudinal gradient and soil

A) Land use system (T)	**Soil organic Carbon (%)**	**Bulk density (g cm $^{-3}$)**	**Soil organic carbon (t ha $^{-1}$ SOC)**
T_1- Agri -horticulture	0.96 ^{b}	1.19 ^{b}	24.36 ^{b}
T_2– Silvi -pasture	0.76 ^{f}	0.98 ^{e}	16.01 ^{e}
T_3– Agri -silviculture	0.88 ^{c}	1.03 ^{d}	19.28 ^{d}
T_4- Horticulture	0.85 ^{d}	1.21 ^{a}	22.09 c
T_5- Forest	2.45 ^{d}	0.98 ^{e}	52.01 ^{a}
T_6- Agriculture	0.58 ^{g}	1.18 ^{c}	16.84 ^{d}
T_7- Grassland	0.80 ^{a}	1.03 ^{d}	17.47 ^{d}
SE±	0.02	0.01	1.27
CD $^{0.05}$	0.03	0.01	2.53
B) Altitudinal gradient (A)			
A_1– 1500-1800 m	1.01 ^{c}	1.13 ^{a}	24.91 ^{a}
A_2– 1800-2100 m	1.03 ^{b}	1.08 ^{b}	23.92 ^{ab}
A_3– 2100-2400 m	1.09 ^{a}	1.05 ^{c}	23.20 ^{b}
SE±	0.01	0.01	0.83
CD $_{0.05}$	0.01	0.01	1.66
C) Soil layer (L)			
L_1– 0-20 cm	1.25 ^{a}	1.03 ^{b}	27.62 ^{a}
L_2 20-40 cm	0.83 ^{b}	1. 14 ^{a}	20.41 ^{b}
SE±	0.01	0.01	1.26
CD $_{0.05}$	0.01	0.02	2.52

al. (1991) and Cihacek and Ulmer (1998), who reported higher values of bulk density in cultivated soil in comparison to grasslands. Higher bulk density in horticulture based system as reported in our case have also been reported by Kumar (2003). The current studies further revealed that agroforestry system types integrating fruit trees as woody perennial in place of forest/ fodder tree had higher bulk density value. The above findings indicated that fruit tree based agroforestry system or orchard land use system have less potential to improve upon the physico-chemical properties of the soil e.g. bulk density in the current studies.

Bulk density showed a decreasing trend

Table 3: Soil carbon inventory (t ha^{-1}) under different land use systems along an altitudinal gradient in north western wet temperate Himalaya

Land use systems (T)	Altitudinal range (A)									Mean
	1500-1800			1800-2100			2100-2400			
	L_1 (0-20 cm)	L_2 (20-40 cm)	0-40 cm	L_1 (0-20 cm)	L_2 (20-40 cm)	0-40 cm	L_1 (0-20 cm)	L_2 (20-40 cm)	0-40 cm	
T_1-Agri - horticulture	28.99	19.50	48.49	28.34	23.35	51.69	29.31	23.65	52.96	51.05
T_2-Silvi - pasture	21.16	16.58	37.74	20.41	13.54	33.95	17.17	11.17	28.94	33.54
T_3-Agri - silviculture	24.12	15.17	39.24	24.32	16.71	41.03	21.46	19.49	40.95	40.41
T_4-Horticulture	27.26	17.30	44.56	26.29	10.90	37.19	30.89	26.28	57.17	46.31
T_5- Forest	64.25	52.06	116.3	61.33	48.00	109.3	61.03	40.31	101.3	108.99
T_6-Agriculture	18.73	20.13	38.86	20.66	11.28	31.94	20.19	14.91	35.10	35.3
T_7-Grassland	21.67	17.81	39.48	20.18	15.00	35.18	19.10	15.32	34.42	36.36
Mean	29.45	22.65	52.10	28.79	19.83	48.62	28.45	21.66	50.11	

with increasing altitudinal ranges (Table 2). This can again be owed to increasing trend of soil organic matter with increasing altitudinal range. As we know, soil organic matter increases with the increasing altitude because of slower decomposition rate with increasing altitude. Table 2 also revealed that bulk density increased with the increasing depth of soil layer. The lower bulk density values in upper layer of soil profile may have resulted from the dilution of soil matrix (mineral matter) with lesser denser material (organic matter) and improvement in soil aggregation. Improvement in aggregation encouraged fluffy and porous conditions in soil which resulted in low bulk density value. The reduction of bulk density of soil due to increase in soil organic carbon has been amply reported in literature (Coote and Ramsay 1983, Sharma et al. 1995).

Soil organic carbon (%)

It is evidently clear from the data presented in the Table 2 that soil organic carbon was significantly influenced due to land use system. Maximum soil organic carbon (2.45%) was found in the forest land use system, which was followed by agri-horticulture (0.96%), agri-silviculture (0.88), horticulture (0.85%), grassland (0.796%) and silvi-pasture (0.76%) and agriculture (0.58%), respectively in the descending order. The increased organic carbon content in soils under tree based system may be ascribed to more leaf litter deposition and root turnover from trees

(Zegeye 1991). Lower organic carbon in agriculture land use system than grassland as recorded in our studies has also been reported by Cihacek and Ulmer (1998) and Pal et al. 2013.

In our study, we found that the organic carbon increased with increasing altitudinal range (Table 2) which can be owed to continuous accumulation of leaf litter and slower decomposition rate at the higher altitude than at lower ones. Slower decomposition means less mineralization and hence losses of organic carbon through erosion will be lower at higher altitude and hence more carbon content conservation.

The carbon fixed by the plant is the primary source of organic matter input into the soil, which provides substrate for microbial process and accumulation of soil organic matter. The belowground allocation of photosynthates is also an important factor for improving soil organic carbon content. The result from the present studies also revealed a maximum accumulation of soil organic carbon in surface layer (1.25 %) which decreased with increasing soil depth (Table 2). The greater accumulation of soil organic carbon on the surface is due to the incorporation of leaf litter. Similar findings i.e. decrease in organic carbon content with increase in soil depth have also been reported by Minhas et al. (1997). Organic carbon content is affected by leaf litter, higher rate of turnover of minute rootlets death and decomposition of roots and exudation of organic chemicals and hence organic carbon of soil will also increase (Huck, 1983 and Waisel et al. 1991).

The high soil organic carbon under tree based system can be attributed to increased accumulation followed by decomposition under tree based land use system. These results are also in line with the findings of Kater et al. (1992), Koul and Panwar 2012; Rhodes (1995) and Arora et al. (2013).

Soil organic carbon stocks

It is evident from the data presented in Table 2 that soil organic carbon was significantly influenced by land use system, altitudinal range and soil layer effect.Maximum soil organic carbon stock (SOC stock) was recorded in forest land use system (52.01 t ha^{-1}), which was followed by agri-horticulture (24.36 t ha^{-1}), horticulture (22.09 t ha^{-1}), agri-silviculture (19.28 t ha^{-1}), grassland (17.47 t ha^{-1}) and agriculture (16.84 t ha^{-1}), respectively in the descending order. This may have happened because of enhanced accumulation of leaf litter in the tree and fruit based land use systems. The abundant litter and/or pruned biomass returns to soil, combined with the decay of roots contribute to the improvement of organic matter under complex land use systems (Beer et al. 1990; Rao et al. 1998; Kumar et al. 2001). Low amounts of soil organic carbons stocks under the agriculture land use system can be ascribed to intensive cropping as also reported by Lal et al. (1998).

In the altitudinal range, a slight but significant difference was observed between 1500-1800 m and 2100-2400 m asl elevation ranges. However, altitudinal range of 1800-2100 m asl remained statistically at par with A_1 and A_3. It may be due to sharp decline in the bulk density of the A_1 and A_3 soil layers. It was also evident from the Table 2 that soil organic carbon stock declines appreciably from L_1 (0-20 cm) to L_2 layer (20-40 cm). The increase or decrease in the soil organic carbon pool was associated with the bulk density and organic carbon content of the soil of a particular depth. The higher amount of soil organic carbon stock on the surface layer i.e. 0-20 cm may be explained in the sense that there is continuous accumulation of leaf litter on the surface which keeps on decomposing and thus enriches the upper layer (0-20 cm) continuously. These results are in line with the findings of Minhas et al. (1997), Nairand Chamuah (1988), Joao Carlos (2001) and Arora et al. (2013).

Carbon inventory

Soil organic carbon pool inventory

It is evidently clear from the data presented in the Table 3 that maximum soil organic pool in 0-40 cm layer was found in forest land use system (108.99 t ha^{-1}) followed by agri-horticulture (51.06 t ha^{-1}), horticulture (46.31 t ha^{-1}), etc. in descending order, respectively. The total soil organic carbon stock as observed in the forest land use system was found to be 3-4 times higher over other land use systems as explained earlier also. Higher soil organic carbon pool in the forest land use system can be ascribed to greater incorporation of leaf litter and addition of decayed roots to the upper soil layers than in the other land use systems. In addition to it, the intensity of cropping in other land use is higher than forest land use. The soil carbon stock i.e. 108.99 t ha^{-1} in our system is slightly lower than the world average for temperature evergreen forest i.e. 134.9 t C ha^{-1} (Houghton 1995). This may be due to the nature of the forest. Our forests are categorized as warm temperate Himalayan forest hence the average temperature of our forest is higher than the average temperature of cool temperate forest of the world. Higher temperature may have helped in greater decomposition and loss of the soil organic carbon from our forest land use system. Moreover, the soil of our study site is sandy loam, which is known for lower soil organic carbon content.

CONCLUSIONS

Soil physico-chemical property reveals that maximum bulk density (1.21 g cm^{-3}) was recorded in the horticulture land use system, which was followed by agri-horticulture (1.19 g cm^{-3}), agriculture (1.18 g cm^{-3}), grassland (1.03 g cm^{-3}), agri-silviculture (1.03 g cm^{-3}), forest and silvi-pasture (0.98 g cm^{-3}), respectively. Maximum soil organic carbon (2.45%) was found in the forest which was followed by the land use system of agri-horticulture (0.96%), agri-silviculture (0.88%), horticulture (0.85%), grassland (0.80%), silvi-pasture (0.76%) and agriculture (0.58%), in descending order respectively. The soil organic carbon percent also declined significantly with the ascending altitudinal ranges. The soil organic carbon percent declined from L_1 (1.25%) to L_2 (0.88%) layer.Forest land use system displayed the maximum value of soil organic carbon stock (52.01 t ha^{-1}), which was followed by agri-horticulture (24.36 t ha^{-1}), horticulture (22.09 t ha^{-1}), agri-silviculture (19.28 t ha^{-1}), grassland (17.47 t ha^{-1}) and silvi-pasture (17.01 t ha^{-1}), respectively in the descending order. In the altitudinal range effect, the total soil organic carbon stock declined with increasing altitudinal range. Maximum soil organic carbon stock (0-40 cm layer) was recorded in forest land use system (108.99 t ha^{-1}), which was followed by agri-horticulture (51.05 t ha^{-1}), horticulture (46.31 t ha^{-1}), etc. in descending order respectively. The total soil organic carbon stock observed in the forest land use system (108.99 t ha^{-1}) was found to be 3-4 times higher over other land use systems. These finding further evinced that forest conserve the major pool of the carbon stocks in the wet temperate areas of the north western Himalaya, which need to be conserved, but conversion of agriculture field into apple based agroforestry systems is recommended for sequestration of the atmospheric CO_2in the soil pool.

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