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Assessing soil organic carbon in agroforestry systems in different altitudes of Tehri District, Uttarakhand, India

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Abstract

An agroforestry system that combines trees and shrubs with crops, increases organic carbon accumulation in soil by providing continuous supply of organic matter over time. Soil organic carbon is a key component of terrestrial ecosystem that helps in enhanced sequestration of atmospheric CO_2 in the soil. This study was carried out during the year 2017 in Tehri Garhwal of Uttarakhand. Three agroforestry systems selected were Agrihorticulture (AH), Agrisilviculture (AS) and Agrihortisilviculture (AHS) in three altitude *viz.*, Lower altitude (286-1200 m), Middle altitude (1200-2000 m), and Upper altitude (2000-2800 m). Ten sample plots (100m^2) were randomly laid out in each agroforestry system on each altitude of each block. Soil organic carbon was determined using the Walkley and Black method. Soil physico-chemical properties revealed that maximum bulk density (1.38 g cm$^{-3)}$ was recorded in the agrisilviculture system and minimum in agrihorticulture system (1.29 g cm$^{-3)}$. Maximum soil organic carbon (2.74%) was found in the agrihorticulture system and minimum in agrisilviculture system (2.48%). The soil organic carbon percent also increased significantly with the ascending altitudes. It was concluded that upper altitude (2000-2800m) and agrihorticulture system had accumulated greater soil organic carbon pool and suggested that, if need be, conversion of agriculture field should be into agrihorticulture system in Northwestern Himalayas for better soil carbon sequestration.

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Introduction

Forest soil is one of largest sinks of carbon on earth while soil organic matter is the key component of terrestrial ecosystem. It is also globally important as forests and terrestrial ecosystem play a pivotal role in mitigation of climate change to reduce the emission of CO_2. The main issue of soil carbon management in India revolves around the fact that a few parts of the country has soils containing high amount of soil organic carbon (SOC) whereas other parts show a reverse trend (Dadhwal et al., 1993; Gupta et al.,1994). Sequestration of atmospheric CO_2 into 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 CO (Davidson, 2000). Land use system can significantly influence soil organic carbon (Post et al., 2000; Tian et al., 2002). Many studies have been carried out on SOC assessment in Forest of Garhwal Himalaya and a few studies (Bhardwaj et al., 2013; Kumar et al., 2012; Goswami et al., 2014; Verma et al., 2016) had been focused on agroforestry systems in North Western Himalaya. But, no ideal investigation has been conducted to estimate SOC in traditional agroforestry in Garhwal Himalayas, India. Therefore, this investigation was carried out to determine soil organic carbon in traditional agroforestry systems at different altitudes.

Materials and Methods

The present investigation was carried out (2017) in the Tehri Garhwal district of the Uttarakhand state of India. The Tehri district lies between the parallels of 30° 03' and 30° 53' N and 77° 56' and 79° 04' E having geographical area of 3,642 km2 (FSI, 2015). The location map showing the details of the study area has been presented in Fig.1.

Depending on the topography, for the detailed study the district was divided into three zones viz. i.e. foot hill/sub tropical zone is lower altitude (286-1200 m), middle altitude (1200-2000 m) and upper altitude (2000-2800 m) (Singh and Singh, 1992). Six blocks representing three altitudinal zones were selected for present study in Tehri district. Site characteristics of study sites is given in (Table 1).

Species combination in each system

Based on the soil sampling, the common existing agroforestry systems in Tehri district was appeared agrisilviculture system (trees and agriculture crops), agrihorticulture system (edible fruit trees and agriculture crops), and agrihortisilviculture system (trees including edible fruit trees, forest trees and agriculture crops). Species combination in each system has been shown in Table 2 from where soil sample has been collected.

Soil sampling method

10 sample plots of (100 m^2) were randomly laid out in each agroforestry system on each altitude of each block. But at Upper altitudes, Sample plots were laid out in each agroforestry system in only three blocks. On other three blocks, there were no settlement zone and agriculture land at Upper altitude. Thus 540 sample plot were laidout in lower altitude and middle altitude. At Upper altitudes, 270 sample plots were laid out. Total 1350 (one thousands three hundred fifty) soil samples were collected from 32 (thirty two) different villages covering three agroforestry systems (Agrisilviculture, Agrihortisilviculture, Agrihorticulture). The soil sample was taken from the centre of each plot by driving a core sampler up to 30 cm depth (Mac Dicken, 1997). Soil core were sectioned into 0-10, 10-20 and 20-30 cm increments for 30 cm samples, then soil was categorized as top soil (up to 10cm) and sub soil (up to 30cm).

Soil processing and laboratory procedures

The collected soil samples were oven dried at 60^0C for 48 hours and till constant weight homogenized using sieved with 2 mm mesh. Composite samples were prepared by mixing the sieved soil and preserved in zip lock poly bag. Bulk density of the soil samples was calculated as per standard methods given by Mc Dicken (1997). Soil organic carbon was determined using the (Walkley and Black, 1934) method. Soil organic carbon stock was calculated by using the equation given by Pearson et al., (2007). Soil Organic Carbon stock (t / ha) = Soil bulk density (g cm^{-3}) x Soil depth (cm) x Carbon (%)].

Results and discussion

Soil organic carbon (SOC) is the basis of soil fertility. It releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against harmful substances. In the present case, soil organic carbon was estimated in three agroforestry systems (Agrisilviculture, Agrihorticulture and Agrihortisilviculture system) at three altitudes (lower, middle and upper) in Tehri district. Results showed that considering the altitudes, bulk density did not show significant differences with altitudes (Table 3). The value of SOC% was found minimum (2.41%) at the lower altitude and maximum (3.02 %) at upper altitude which can be owed to continuous accumulation of leaf litter and lower decomposition rate at the higher altitude than at lower altitude.

Consider to systems, the bulk density was significantly ($P \leq 0.01$) different with agroforestry systems. Highest bulk density was recorded in agrisilviculture system as compared to other systems, due to continuously accumulation of leaf litter. Similar findings have been reported by workers in the past *viz*. (Rajput, 2010; Chisanga, 2012). SOC% was significantly ($P \leq 0.01$) different with agroforestry systems and it was comparatively higher (2.74%) in agrihorticulture system than other systems (Table 4) as SOC (%) was significantly influenced by different agroforestry systems and Soil organic stock was found maximum (32.26 Mg ha^{-1}) in agrihorticulture system and followed by (24.32 Mg ha^{-1}) in agrihortisilviculture system, which is 45 % increase from agrisilviculture system and 33% from agrihortisilviculture. It was proved from the value soil organic carbon was influenced by agroforestry system as the abundant tree litter come back to soil, and thereby improve organic matter under tree and fruit based system (Beer et al., 1990; Rao et al., 1998; Kumar et al., 2001).

The data on bulk density varied under different agroforestry system along altitudes. Interaction between bulk density with altitudes and agroforestry systems (Table 5) showed a statistical significance among treatments ($P \leq 0.01$). The value indicated that agrisilviculture had higher soil bulk density at lower altitude but it was lower in agrihorticulture and agrihortisilviculture system at middle and upper altitudes. Bulk density followed a trend of Agrisilviculture>Agrihortisilviculture>Agrihorticulture along altitudes. The plausible reason for higher bulk density in agrisilviculture system may be due to more tillage operations for cultivating agricultural crops and low input of litter fall.

Consider to SOC % with altitudes and agroforestry systems, the interactions effect differ significantly ($P \leq 0.01$) to each other (Table 6). It was found that agrihorticulture gave higher (3.45 %) SOC at the upper altitude and lower (2.09 %) at lower altitude in agrisilviculture system indicates that SOC% is generally lowest in agrisilviculture system at all the altitudes. This might be due to more accumulation of leaf litter from trees and fruit, fruit based system contained maximum soil organic carbon (Zegeye, 1999). The interaction between systems and altitudes for soil organic carbon stock followed the same trend as that of SOC%. Generally it was observed that SOC was lowest in agrisilviculture system at all altitudes and maximum value of soil organic carbon stock was obtained in agrihorticulture system followed by agrihortisilviculture system due to enhanced accumulation of leaf litter in the tree and fruit based land use systems (Beer et al., 1990; Rao et al., 1998; Kumar et al., 2001).

Table 1. Site characteristics of study sites.

Attributes	Lower altitudes/Subtropical zone (286-1200m)	Middle altitude/Sub temperate zone (1200-2000m)	Upper altitudes/ temperate zone (2000-2800m)
Location	$30^0$15’ to $30^0$26’N and $78^0$60’ to $78^0$43’S	$30^0$26’ to $30^0$35’N and $78^0$43’ to $78^0$40’S	$30^0$38’ to $30^0$40’N and $78^0$36’ to $78^0$35’S
Rainfall	Moderate (Approx 1000m)	Moderate to heavy (1000-2000mm)	Heavy rainfall (< 2000m)
Climate	Humid	Humid & Cold	Heavy cold
Soil type	Sandy loamy, Fertile	Sandy loamy, Less fertile	Mostly loamy, Rich in organic matter
Dominant Agroforestry system	Agrisilviculture system, Agrihortisilviculture system, Agrihorticulture system	Agrisilviculture system, Agrihortisilviculture system, Agrihorticulture system	Agrisilviculture system, Agrihortisilviculture system, Agrihorticulture system
Tree Density (No. of individual/100m^2	AHS= 2.36 AS=2.30 AH= 1.93	AHS=2.08 AS=1.93 AH=1.83	AHS=1.90 AS=1.73 AH=1.68
Crop Density (No. of individual/100m^2)	AHS=249 AS= 221.76 AH=270.5	AHS=261.5AS=290.12 AH=201.58	AHS=199.5 AS=319.25 AH=213

Table 2. Species combination in each agroforestry systems in different altitudes.

Altitudes (m)	System	Trees	Crops
286-1200	AS	*Adina cordifolia* (Roxb.) Hook.f*Grewia oppositifolia, Anogeissus latifolia* (Roxb.ex DC) Wall.ex Bedd. *Melia azedarach, Celtis australis, Ficus roxburghii, Rhus Parviflora* Roxb., *Toona ciliata, Prunus cerasoides, Bauhinia variegata, Celtis australis,, Pinus roxburghii, Pyrus communis* L., *Woodfordia fruticosa* (L.) Kurz, *Ficus auriculata, Pyrus pashia*	*Echinochloa frumentacea, Oryza sativa* L., *Cajanus spp.* (L.) Millsp. *Glycine max, Hordeum Vulgare, Cajanus cajan, Curcuma longa, Vigna mungo (L.) Gatern, Glycine max, Zea mays, Hardeum vulgare L , Lens esculenta L., Pisum sativum L., Macrotyloma uniflorum* (Lam.) Verdc. *Vigna* mungo (L.) Hepper *Sorghum vulgare* L., *Triticum aestivum L.*
	AHS	*Adina cordifolia* (Roxb.) Hook.f, *Mangifera* indica L. *Citrus limon*Brum.,*Grewia oppositifolia, Anogeissus latifolia* (Roxb.ex DC) Wall.ex Bedd. *Melia azedarach,Psidium guajava* L., *Toona ciliata, Celtis australis, Melia azedarach, Citrus limon* Brum. *Bauhinia variegata* (L.)Benth., *Ficus palmate, Ficus roxburghii, Prunus cerasoides, Bauhinia variegata, Celtis australis, Mangifera indica Citrus limon, Psidium guajava, Celtis australis, Musa Paradisica* L. *Prunus cerasoides, Quercus leucotrichophora, Malus domestica,* Borkh**.** *Citrus sinensis* Osbeck. *Pyrus communis* L. *Juglans regia, Prunus armeniaca* L., *Prunus persica* Batsch. *Ficus palmata*	*Echinochloa frumentacea, Oryza sativa* L., *Glycine max, Cicer arientinum L, Cajanus spp*
	AH	*Mangifera* indica L. *Citrus limon*Brum, *Carica papaya* L, *Citrus aurentium, Embilica officinalis* Gaertn, *Prunus persica* Batsch, *Psidium guajava* L., *Punica granatum*	*Glycine max* (L.) Merr, *Pisum sativum* L *Ehinochloa frumentacea* Link.
1200-2000	AS	*Celtis australis* L., *Ficus roxburghii* Wall., *Grewia oppositifolia* Roxb., *Melia azedirach* L., *Morus alba* L., *Pinus roxburghii* Sargent., *Quercus leucotrichophora* A.Camus, *Rhus parviflora* Roxb., *Toona ciliata* M.Roem., *Woodfordia fruticosa* (L.) Kurz	*Amarnathus blitum* L., *Ehinochloa frumentacea* Link., *Setaria italic (L.)P.Beauv, Oryza sativa L., Glycine max, Cicer arientinum L, Cajanus spp, Sorghum vulgare L., Triticum aestivum L.*
	AHS	*Celtis australis* L., *Ficus roxburghii* Wall., *Grewia oppositifolia* Roxb., *Melia azedirach* L., *Morus alba* L., *Pinus roxburghii* Sargent., *Quercus leucotrichophora* A.Camus, *Citrus aurentium, Psidium guajava* L. *Pyrus communis* L. *Embilica officinalis* Gaertn, *Mangifera indica* L, *Musa paradisiacia* L., *Prunus armenica* L. *Prunus persica* Batsch., *Punica granatum* L. *Pyrus communis* L., *Malus domestica* Borkh	*Fagopyrum esculentum* Mill., *Oryza sativa* L.,
	AH	*Citrus aurentium, Psidium guajava* L. *Pyrus communis* L. *Embilica officinalis* Gaertn, *Mangifera indica* L, *Musa paradisiacia* L., *Prunus armenica* L. *Prunus persica Batsch., Punica granatum* L. *Pyrus communis* L., *Malus domestica* Borkh	*Glycine max* (L.) Merr., *Pisum sativum L. Ehinochloa frumentacea Link*
2000-2800	AS	*Quercus leucotrichophora* A.Camus, *Rhododendron arboreum* Sm, *Myrica esculenta* Buch.-Ham, *Grewia oppositifolia* Roxb.	*Eleusine coracana* (L.) Gatern, *Fagopyrum esculentum* Mill., *Amarnathus blitum* L *Ehinochloa frumentacea* Link.
	AHS	*Pyrus communis* L., *Prunus persica* Batsch, *Prunus persica* Batsch, *Prunus armenica* L. *Juglanse regia* L. *Pyrus communis* L.	*Amarnathus blitum* L. *Fagopyrum esculentum* Mill, *Ehinochloa frumentacea* Link
	AH	*Pyrus communis* L., *Prunus persica* Batsch, *Prunus persica* Batsch, *Prunus armenica* L. *Juglanse regia* L. *Pyrus communis* L.	*Amarnathus blitum* L., *Ehinochloa frumentacea* Link

*****AS = Agrisilviculture system, AHS = Agrihortisilvicultre system, AH = Agrihorticulture system.

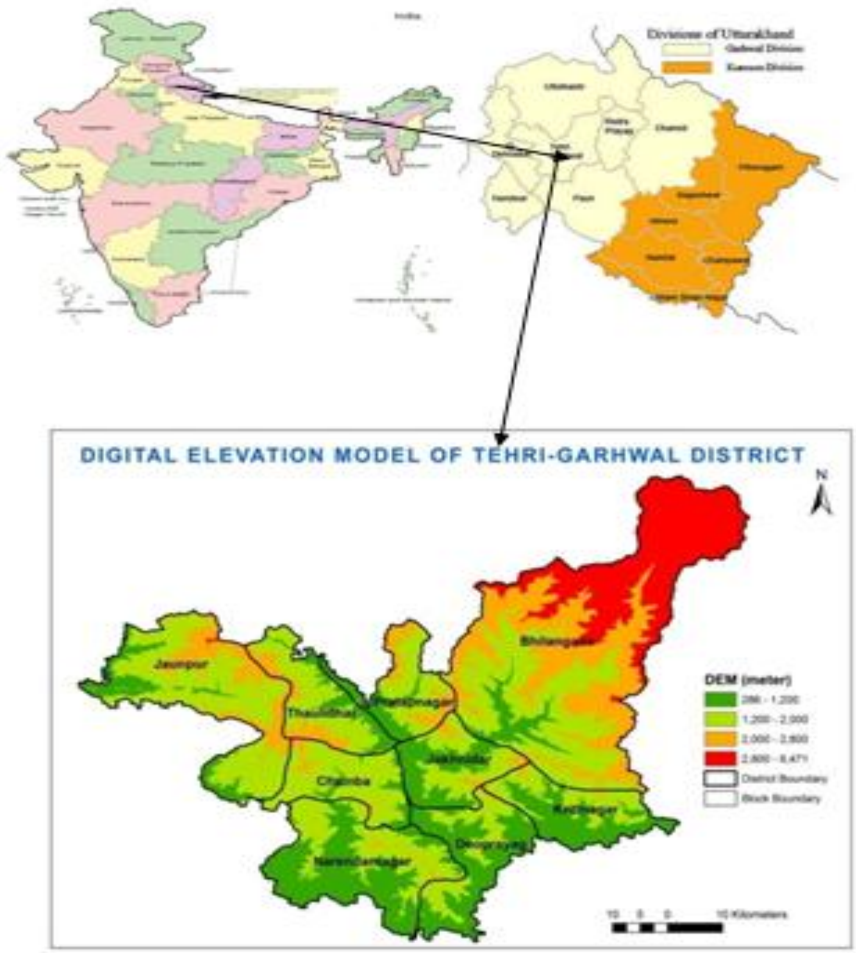

Fig. 1: Geographical location of study area.

Table 3. Influence of altitudes on soil bulk density (g cm^{-3}), SOC (%) and SOC (Mg ha^{-1}).

Parameters	Altitudes(m)				
	286-1200	**1200-2000**	**2000-2800**	**Significance**	**CD**
Bulk density	1.33 ± 0.012	1.32 ±0.003	1.32 ±0.013	NS	-----
SOC %	2.41± 0.07	2.42 ±0.07	3.02 ±0.14	($P \leq 0.01$)	0.183
SOC	23.54±0.51	23.75± 0.47	31.50± 1.15	($P \leq 0.01$)	2.056

NS=Non significance, SOC= Soil organic carbon

Table 4. Effect of agroforestry systems on soil bulk density (g cm^{-3}), SOC (%) and SOC (Mg ha^{-1}).

Parameters	Agroforestry system			
	AH	**AHS**	**AS**	**CD**
Bulk density	1.29± 0.026	1.30 ±0.017	1.38 ± 0.015	0.017
SOC %	2.74 ±0.09	2.64 ±0.06	2.48 ±0.09	0.183
SC SOC Mg/ha	32.36± 0.09	24.32± 0.06	22.20± 1.03	0.017

Significance at the level of probability of 1% ($P \leq 0.01$); SOC= Soil organic carbon; AH=Agrihorticulture; AHS=Agrihortisilviculture; AS=Agrisilviculture.

Table 5. Interaction effect of systems and altitudes on bulk density, SOC (%) and SOC (Mg ha^{-1}).

Parameter	Altitudes (m)	Agroforestry systems			
		AH	AHS	AS	CD
Bulk density	286-1200	1.26± 0.02	1.28±0.006	**1.45**±0.01	0.09
	1200-2000	1.30± 0.003	1.32 ±0.004	1.35± 0.002	
	2000-2800	1.31 ±0.003	1.32 ± 0.007	1.34± 0.003	
SOC %	286-1200	2.52 ±0.07	2.62± 0.07	2.09± 0.09	0.31
	1200-2000	2.26±0.08	2.41± 0.07	2.59± 0.06	
	2000-2800	**3.45± 0.12**	2.88 ±0.14	2.74 ±0.16	
SOC Mg/ha	286-1200	25.97± 1.07	24.86± 0.73	19.78 ±0.73	3.56
	1200-2000	25.03± 0.90	23.11 ±0.78	23.04 ±0.73	
	2000-2800	**45.72± 1.98**	24.99 ±1.41	23.79± 1.65	

Significance at the level of probability of 1% ($P \leq 0.01$) ; AH=Agrihorticulture AHS=Agrihortisilviculture AS=Agrisilviculture SOC= Soil organic carbon.

Table 6. Pearson correlation coefficient between bulk density, SOC (%) and SOC (Mg ha^{-1})

Correlation matrix			
Parameter	**SOC%**	**Bulk density (g cm^{-3})**	**SOC (t/ha.)**
SOC%	1		
Bulk density	0.085	1	
SOC (t ha^{-1})	0.783*	0.460	1

*Significance at 1% level ($P \leq 0.01$)

Pearson correlation coefficient was analyzed between bulk density, SOC (%) and SOC (Mg ha^{-1}) revealed that there was positive but non-significant correlation between bulk density with SOC% and bulk density with SOC Mg ha^{-1} (Table 5).

Conclusions

Finally, it was inferred agrihorticulture (AH) system had higher soil carbon stock (Mg ha^{-1}) among three systems at three altitudes. Among altitudes, upper altitude (2000-2800 m) at temperate zone contained maximum soil organic carbon (Mg ha^{-1}). Considering altitudes, soil organic carbon showed increasing trend with increasing altitudes. This study showed that structures, management of agroforestry system and altitudes have direct influence on rate of soil organic carbon accumulation. It was concluded that upper altitude (2000-2800 m) and agrihorticulture system had accumulated greater soil organic carbon pool and suggested that, if need be, conversion of agriculture field should be into agrihorticulture system in North-western Himalayas for better soil carbon sequestration.

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