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Soil Organic Carbon in Three Selected Agroforestry System at Temperate Zone (2000-2800m) of North Western Himalaya, Uttarakhand, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change is largely driven by the increased concentration of greenhouse gases like carbon dioxide (CO_2) in the atmosphere. While halting climate change entirely may not be feasible at this point, mitigating its effects is crucial, and agroforestry is one of the key strategies that can help in

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this regard and to mitigate some of its consequences by reducing CO_2 in the atmosphere and promoting sustainable land management. Therefore, the objective of this study was to collate and synthesize the existing information on the soil organic carbon with three agroforestry system (viz.Agrihortisystem, Agrihortisilviculture system and Agrisilviculture system) at temperate region in North Western Himalaya , Uttarakhand, India.The present study was carried out durung the year 2016-2018.Stratified random sampling techniques were used for this study. Ten sample plots (100m^2) were randomly laid out in each agroforestry system in temperate zone (2000-2800m) of each developmental block. Soil organic carbon was determined at three different depth 0-10, 10-20 and 20-30 cm. Soil organic carbon was determined using the Walkley and Black method. Weighing bottle method were used for determining bulk density. The results revealed considerable that SOC of agroforestry systems goes along with the following order: Agrihortisystem (45.72 MgCha-1) >Agrihortisilviculture system (24.99 MgC ha-1) >Agrisilvi culture system (23.79 MgC ha-1) The study concluded that the agrihorticulture system at higher altitudes (2000-2800 m) had a significantly greater soil organic carbon pool. It was suggested that, if necessary, converting agricultural fields to agrihorticulture systems in the Northwestern Himalayas could enhance soil carbon sequestration.

Keywords: Soil carbon sequestration; agroforestry system; temperate zone; bulk density.

1. INTRODUCTION

“Agroforestry has a highly significant and positive effect on SOC sequestration in the temperate zone. SOC stocks in temperate AFS are generally higher than in treeless agricultural sites” (Mayer et al, 2022). “Soil organic carbon is a key component of terrestrial ecosystem that helps in enhanced sequestration of atmospheric CO_2 in the soil. The hill and mountain environment covers 54 Mha of the total geographical area of 329 Mha of India” (Kumar, 2018). “The Indian Himalayas are a mountain range characterized by varying altitudes, slopes, aspects, and climate resulting in wide ecological diversity. The northwest Himalayas (NWH) spread over Jammu & Kashmir, Himachal Pradesh, and Uttarakhand and cover 17.7 Mha of the land of India” (Arora and Bhatt, 2016). “The valleys of NWH receive 1,600–2000 mm of precipitation and have fertile soil” (Bhardwaj et al, 2021). While soil properties, including SOC, is decreased over the years due to improper land use practices (Singh et al, 2019), the adoption of improved land use practices (cropping systems, conservation tillage, nutrient management, etc.) has been reported to enhance the SOC, microbial carbon, and available N, P and K contents of Himalayan soils (Gogoi et al, 2021). “The C status of the Himalayan soil varies according to the land use pattern followed, i.e., forests, plantation crops, and grasses are major C sinks because of their high storage potential and low decomposition processes compared to other agricultural crops” (Babu et al, 2021; Yadav et al, 2021; Wani et al, 2022).

Various studies regarding different SOC pools have been conducted in different parts of the hilly ecosystems like the eastern Himalayas (Yadav et al, 2019; Babu et al, 2020) and western Himalayas (Yadav et al, 2019). “However, very few studies on changes in SOC due to land use practices i.e., forest, plantation, agricultural cropland, etc., in the Kashmir Himalayas have so far been conducted. Hence, a comprehensive study on the effects of land use management on soil C stocks is needed to identify viable land-use systems for C buildup in Kashmir Himalaya in face of changing climatic parameters. Furthermore, C stock measurement is also required by an international agreement between 192 countries in the world that have joined to form a treaty” (Mathew et al, 2020). North-Western Himalaya is very rich in natural vegetation and plantation crops and has fertile land to cultivate various crops. This study is conducted to determine and compare the carbon stock capacity of three different agroforestry systems in temperate region of North-Western Himalaya, Uttarakhand, India. Certainly, the findings of this study can help in choosing appropriate agroforestry system by the farmers of the region to achieve sustainable crop productivity and income.

2. MATERIALS AND METHODS

2.1 Study Area

The Present investigation was carried out in the year 2014 to 2018 in the tehri Garhwal district of Uttarakhand, state of India. (Fig. 1) which is the part of North Western Himalayan region. The district lies between latitude of 30^{0}03’ and 30^{0} 53’ North l and longitudes 77^{0} 56’ and 79^{0} 04’ East and has an area of 3,642 km^2 (ISFR, 2019). The Tehri district has been divided into three agro-climatic zones viz: sub-tropical zone (300-1200m), sub-temperate zone (1200-2000m) and temperate zone (2000-2800 m) on the basis of topography, elevation and temperature condition (Singh and Singh, 1992). The site characteristics of study sites are given in Table 1.

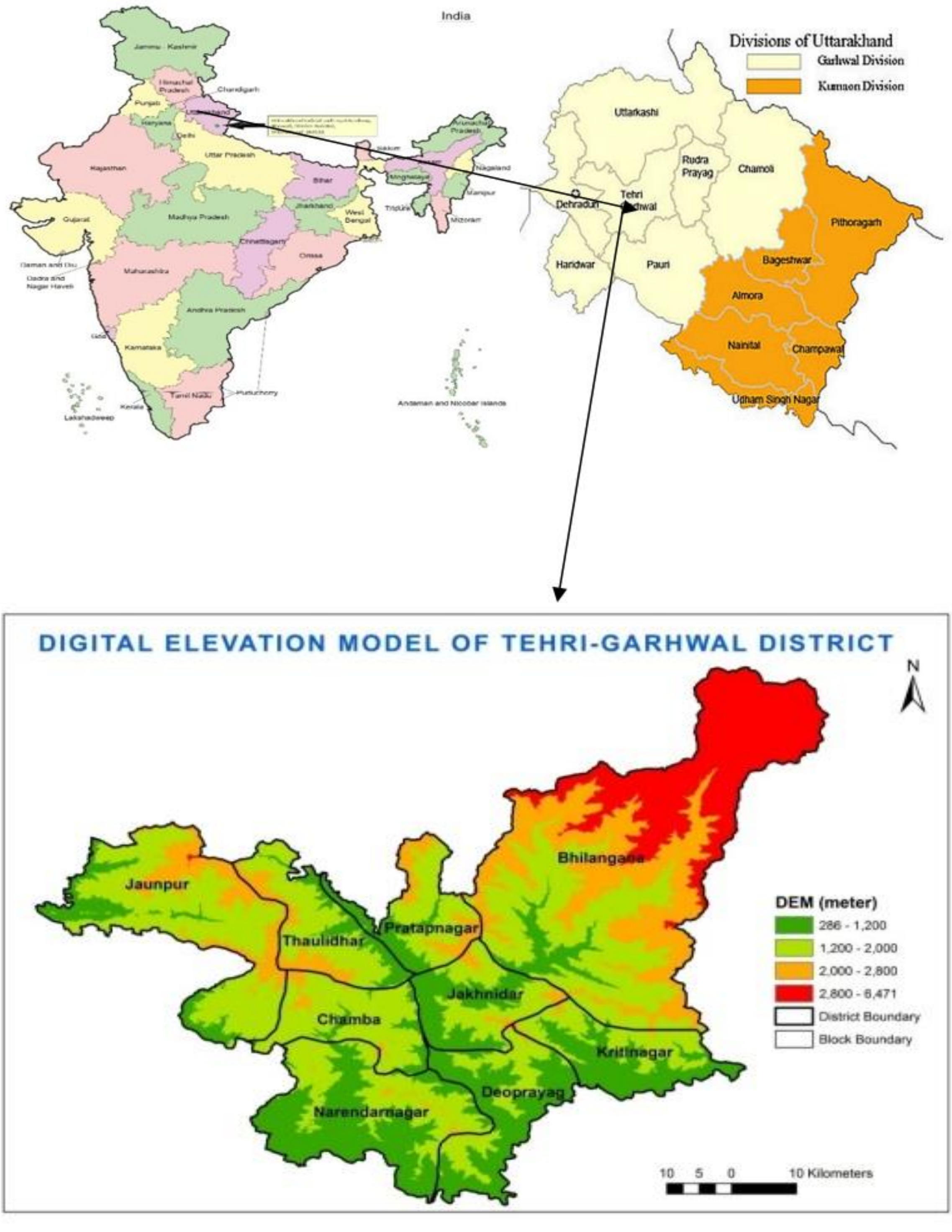

Fig. 1. Geographical location of study area

Table 1. Site characteristic of study sites

S. No.	Attributes	Temperate Zone (2000-2800m)
1	Location	$30^{o}38'$ to $30^{0}40'$N and $78^{0}36'$to $78^{0}35'$S
2	Rainfall	Heavy rainfall (< 2000m)
3	Climate	Heavy cold
4	Soil type	Most loamy, rich in organic matter
5	Dominant agroforestry system	Agrisilviculture system, Agrihortisilviculture system, Agrihorticulture system
6	Tree density (No. of trees/100m^2)	AHS=1.90, AS=1.73, AH=1.68
7	Crop density (No. of crops/100m^2)	AHS=199.5, AS=319.25, AH=213

2.2 Species Combination in Each Agroforestry System

Based on field survey, 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.

2.2.1 Agrisilviculture System (AS)

It is quite common throughout the district. This system is managed for the production of fuel, fodder, fibre and small timber trees with the agricultural corps. Agriculture crops such as *Triticum aestivum, Eleusine coracana*, *Fagopyrum esculentum, Amarnathus blitum, Ehinochloa frumentacea* are grown in monoculture or mixed cropping on the permanent terraces prepared across the hill slopes, while fodder, fuel and timber trees such as *Quercus leucotrichophora*, *Rhododendron arboretum, Myrica esculenta*, *Grewia oppositifolia* etc are deliberately left or grown on the bunds of terraces.

2.2.2 Agrihorticulture system (AH)

This system is commonly practices in those areas where fuel and fodder is easily available from other sources, and or size of the land holding is large compared to other systems. Agriculture crops mainly *Triticum aestivum, Amarnathusblitum*, *Ehinochloa frumentacea*, *Eleusine coracana, Solanum tuberosum*etcwith space of horticulture trees such as *Pyrus communis*, *Prunus persica*, *Prunus armenica, Juglanse regia, Pyrus communi, Citrus limon, C. sinensis, Malus domestica* etc.

2.2.3 Agrihortisilviculture (AHS)

This system is managed for production of fruits, grains, fodder and fuelwood. Fruit trees are planted at regular space with in the fields, and fodder or small timber trees are left on the field bunds while the annuals are grown as intercrop of the tree. Species are grown same as that in the other two systems.

2.3 Methodology

2.3.1 Soil sampling methods

Stratified random sampling techniques were used for this study. Out of nine blocks, six blocks on mid elevation were selected in the district for first stage sampling. Five villages were selected randomly from three blocks, one village from Devparayag block, two villages from Chamba block and Pratapnagar block. There were no settlement area in temperate zone (2000-2800m) at Thauldhar, Jakhnidhar and Kritinagarblock. Three agroforestry systems; Agrihorticulture (AH), Agrisilviculture (AS) and Agrihortisilviculture (AHS) have been selected in temperate zone (2000-2800m) of each developmental block. Ten sample plots (100m^2) were randomly laid out in each agroforestry system in temperate zone (2000-2800m) of each developmental block. Composite samples were obtained for three soil layers, 0-10, 10-20 and 20-30 cm.

2.3.2 Laboratory procedure

Weighing bottle method were used for determining bulk density (Singh,1980). 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).

Table 2. Species combination in each agroforestry system at temperate zone (2000-2800m)

Component					
Dominant Forest trees			DominantAnnualcrops+grass+weeds		
Agrisilviculture system	Agrihorti silviculture system	Agrihorticulture system	Agrisilviculture system	Agrihorti silviculture system	Agrihorticulture system
Quercus leucotrichophora, *Rhododendron arboretum, Myrica esculenta*, *Grewia oppositifolia*	*Grewia oppositifolia, Quercusleucotrichophora, Rhododendron arboreum*, *Myrica esculenta*, *Citrus limon, C. sinensis, Juglans regia, Malus domestica*.	*Pyrus communis*, *Prunus persica*, *Prunus armenica Juglanse regia, Pyrus communi, Citrus limon, C. sinensis, Malus domestica*	*Triticum aestivum, Eleusine coracana*, *Fagopyrum esculentum, Amarnathusblitum, Ehinochloa frumentacea*, *Lantana camara*	*Triticum aestivum, Amarnathusblitum, Fagopyrum esculentum*, *Ehinochloa frumentacea*, *Eleusine coracana, Solanum tuberosum, Amranthusvirdius*	*Triticum aestivum, Amarnathusblitum*, *Ehinochloa frumentacea*, *Eleusine coracana, Solanum tuberosum, Cynodondactylon*

2.4 Statistical Analysis

Data was analyzed applying analysis of variance (ANOVA), Wherever the effects exhibited significance at P ≤0.01 probabilities, the critical difference (CD) was calculated. All analysis was performed using IBM-SPSS 16.0 version (SPSS 2007).

3. RESULTS AND DISCUSSION

The value indicated that the bulk density was significantly (P≤ 0.01) different with three selected agroforestry systems. The highest bulk density was recorded (1.33g cm^{-3}) in Agrisilviculture system (AS) followed by Agrihortisilviculture system (AHS) and found least in Agrihorticulture system (1.30 g cm^{-3}) (Table 3). The plausible reason for higher density in agrisilviculture system (AS) may be due to the more tillage operations for cultivating agricultural crops and low input of litter fall as well minimum accumulation of leaf litter. Similar work reported by (Bhalawe, et al. 2024, Henneron, et al. 2022 and Bhalawe, et al. 2019). Maximum bulk density (1.33g cm^{-3}) was recorded in the agrisilviculture system and minimum in agrihorticulture system (1.30 g cm^{-3}). Soil organic carbon is a function of vegetation, rainfall and temperature and a determining factor of soil quality, productivity and carbon sequestration potential. Soil organic carbon (SOC) and Soil organic carbon percentage (SOC%) was significantly (P≤ 0.01) of three selected agroforestry systems are vary greatly. It was comparatively highest (45.72 Mg ha^{-1}) in Agrihorticulture systems (AH) Which was followed by Agrihortisilviculture system (AHS) and found minimum (23.79 Mg ha^{-1}) in Agrisilviculture system (Table 3) due to the abundant litter or pruned biomass returns to soil, combined with the decay of roots contribute to the improvement of organic matter and addition of FYM under fruit tree based systems (Parmar et al., 2022; Bhalawe et al., 2024, Bhalawe et al. 2013).

Table 3. Influence of agroforestry systems on bulk density, SOC (%) and SOC (Mg ha^{-1}) in temperate region

AFS	Bulk density	SOC%	SOC
AS	1.33	2.73	23.79
AHS	1.31	2.88	24.99
AH	1.30	3.44	45.72
CD	0.02	0.31	3.56

Significance at the level of probability of 1% (P ≤ 0.01)

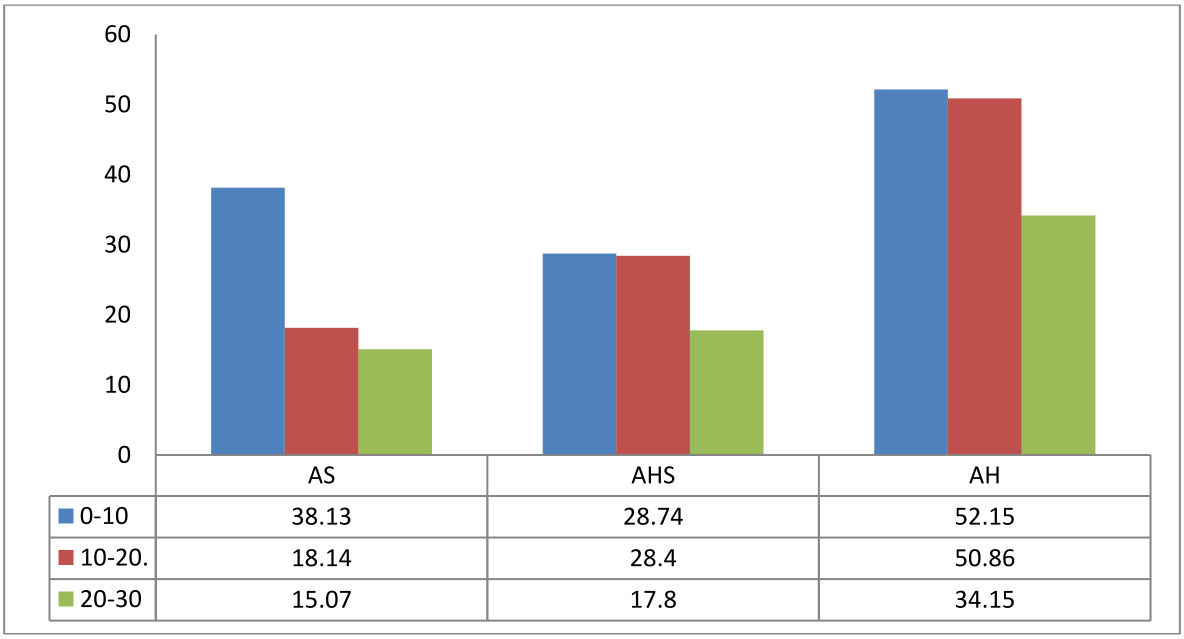

Fig. 2. Soil organic carbon (Mg ha^{-1}) on soil depth in agroforestry systems in temperate region

Soil organic carbon content of different soil samples (depth) collected from three selected agroforestry systems was compared and obtained highest soil organic carbon (52.15 Mg ha^{-1}) in 0-10 cm depth, which was followed by (50.86 Mg ha^{-1}) at 10-20 cm depth in Agrihorticulture system (AH) and lowest in 20-30 cm depth due to the percentage of organic carbon decreases with increasing soil depth as a higher amount of plant biomass was confined within the surface and subsurface layer of soil. Similar results were reported by Bhardwaj et al., 2013; Bhalawe et al., 2013; Bhalawe et al., 2019) (Fig. 2).

4. CONCLUSION

It was concluded agrihorticulture system had accumulated greater soil organic carbon in temperate region of North Western Himalaya. It is suggested that, if need be, conversion of agriculture field should be into crops and Fruit based system. Farmers should be adopted agrihoticulture system for better soil carbon sequestration. Three selected agroforestry systems have been studied for this. In which it was seen that Agrihorticulture system (AH), which is a very good source of business along with food and still has a capability of storing sufficient carbon. Agroforestry systems can store 23.79 Mg C ha^{-1} to 45.72 Mg C ha^{-1}. Therefore, policy programs promoting the establishment of agroforestry systems in ideal lands in Tehri district should be considered.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript**.**

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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