Eco. Env. & Cons. 29 (November Suppl. Issue) : 2023; pp. (S326-S331)

ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i06s.049

Soil Organic Carbon Stock in the Tea Gardens of North –East India as Affected by the Organic and Conventional Management Practices

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(Received 1 June, 2023; Accepted 28 July, 2023)

ABSTRACT

This study focuses on the tea (*Camellia sinensis*), which plays a vital role in India's economic development. The objective is to evaluate the soil organic carbon (SOC) stocks in tea soil in Assam and emphasize the importance of restoring SOC content through the adoption of various management practices. The study was conducted in two tea estates, one organic and one conventional, in Golaghat district, Assam. Composite soil samples were collected from different depths (0-20 cm, 20-40 cm, and 40-60 cm) in each estate. Physical and chemical properties of the soil, such as bulk density, particle density, porosity, pH, electrical conductivity (EC), organic carbon content, and cation exchange capacity (CEC), were analyzed. The SOC stocks were higher in the topsoil (0-20cm) for both management systems, with higher values observed in the organic system. The decline in SOC stocks in the conventional system may be attributed to intensive tillage, organic matter uptake by tea bushes, and lack of organic inputs. In contrast, the organic system, with balanced organic fertilization and litter accumulation, promoted higher SOC content.

Key words: *Sustainable practices, Soil organic carbon, Tea cultivation, Organic management, Conventional management*

Introduction

The understanding and implementation of sustainable practices are crucial in meeting the demands of today's world. However, the sustainability of crop production systems, particularly those reliant on soil quality, can be adversely affected by certain farming methods. Prolonged cultivation of agricultural lands, including tillage and inversion, coupled with the removal of crop residues, accelerates the decomposition of soil organic matter. As a result, this leads to a significant loss of soil carbon (20–67%) and ultimately results in soil degradation. Consequently, the physical, chemical, and biological properties of the soil diminish (Lal *et al.*, 2020). In India, soil quality restoration through soil organic carbon (SOC) management has become a major requirement. To successfully address this need, comprehensive knowledge regarding SOC stocks is essential. SOC plays a crucial role in sustaining agricultural productivity by influencing the physical, chemical, and biological properties of soils. However, the SOC content in Indian agricultural soils often falls below the critical limit of 2% in the root zone due to extractive farming practices, low input of organic fertilizers, and the prevalence of soil degradation caused by erosion, salinization, and other processes. Therefore, sequestering atmospheric carbon dioxide in the soil as stable soil organic matter offers a long-term solution to improve soil quality. To evaluate carbon sequestration processes in soils, it is necessary to compare the carbon stock under different management practices in tea soil of Assam.

Tea (*Camellia sinensis*) is a significant cash crop that plays a vital role in India's and the state's economic development. According to recent statistics, Assam alone accounts for 52.9% of the country's tea production, while Bengal contributes 24.8%, Tamil Nadu 14.6%, Kerala 5.7%, Karnataka 0.5%, and other states 1.5%. Out of the total 1,421 major tea gardens in the country, 767 are located in Assam. Additionally, there are approximately 200,000 small tea growers in India, with 100,000 in Assam alone. Despite the overall increase in tea plantation productivity worldwide, concerns arise regarding stagnant or declining yields in older plantations (40 years old and above) over the last two decades. Even though these plantations were established with sufficient gaps (over 25%), they no longer respond positively to known agronomic practices (Dutta *et al.,* 2008), possibly due to a decline in soil carbon stock. The intensive use of chemical fertilizers can jeopardize soil conservation efforts and create potential health hazards (Pradhan, 1992). Therefore, measuring SOC adequately is necessary to establish benchmark information for the present and determine future changes in tea plantation systems. This study aims to evaluate SOC stocks in different soil layers up to a depth of 60 cm.

Consequently, the objective of this article is to emphasize the importance of restoring SOC content in the root zone through the adoption of various management practices. The article also provides recommendations for tea growers to embrace recommended management practices (RMPs) that facilitate SOC sequestration and the restoration of soil health.

Materials and Methods

The study was conducted in two tea estates, Hatikhuli and Diffloo, located in Golaghat district, Assam. Hatikhuli tea estate is an organic tea estate with coordinates latitude 26°35'0.50"N and longitude 93°21'12.40"E. It spans a geographical area of 4.80 sq.km and was established in 1907. The conversion from an inorganic to an organic tea estate began in 2007, and it received certification in 2011. On the other hand, Diffloo tea estate is a conventional tea estate situated at latitude 26°36'33"N and longitude 93°35'14"E. It covers an area of 486.69 hectares and was established in 1890. For the study, composite soil samples were collected from both tea estates. The samples were obtained from three depths (0-20cm, 20-40 cm, and 40-60 cm) in each tea garden, resulting in a total of sixty samples per estate. Each depth sample was air-dried, ground, sieved through a 2-mm sieve, and packed in labeled poly pouches. The soil texture was determined using the International Pipette Method (Piper, 1966)). Undisturbed soil samples were also collected using a tube core sampler from the field, and the bulk density was determined by Core method (Bodman, 1942). Water holding capacity (WHC) was measured using Keen's box method (Piper (1966). Soil pH was determined in a 1:2.5 soil-water suspension (Jackson, 1973). Cation exchange capacity (CEC) was analyzed using the neutral normal ammonium acetate (NH4OAc) leaching method (Jackson, 1973). The organic carbon content was estimated using Walkley and Black's rapid titration method (Walkley and Black 1934).

To calculate the soil carbon stock, the following formula was utilized: C stock (Mg ha-1) = C content (g C kg-1) × Bulk density (Mg m-3) × Depth (m) × 10, as described by Bhardwaj *et al.* 2019. The mean, range, and standard variation, were analyzed using standard statistical procedures.

Results

Physical characteristics

The texture of the soil was silty clay in both the management systems under study. Sand, silt and clay fractions of the soils varied from 55.5 to 78.5, 2.4 to 14.8 and 11.3 to 31.9 per cent under organic management whereas in conventional management it varies from 64.00 to 77.4, 2.4 to 14.3 and 17.9 to 29.8 per cent, respectively. The Bulk density of the soil ranged from 1.05 to 1.45 g/cm^3 with a mean value of 1.41 g/cm^3 under organic and 1.06 to 1.62 g/cm^3

with a mean value of 1.52 g/cm^3 under conventional system. Soil bulk density was found to increase with depth under both the management systems. Bulk density in D_1 (0-20 cm depth) under organic system was 1.40 g/cm^3, D_2 (20-40 cm depth) was 1.44 g/cm^3 and D_3 (40-60 cm depth) was 1.48 g/cm^3. Under conventional system D_1 (0-20 cm depth) was 1.53 g/cm^3, D_2 (20-40 cm depth) was 1.55 g/cm^3 and D_3 (40-60 cm depth) was 1.57 g/cm^3 (Fig. 1). Particle density ranged from 2.1 to 2.71 g/cm^3 with a mean value of 2.43 g/cm^3 under organic system and from 2.12 to 2.73 g/cm^3 with a mean value of 2.51 g/cm^3 under conventional system. Total porosity of the soil ranged from 27.6 to 48.2 per cent with a mean value of 41.98 per cent and water holding capacity from 30.00 to 34.1 per cent with a mean value of 31.5 per cent under organic management, whereas in conventional management the total porosity of the soil

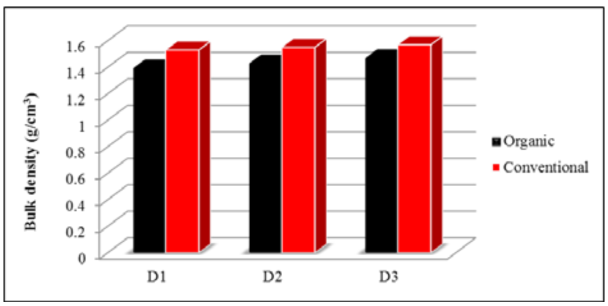

Fig. 1. Variation of bulk density with depth under organic and conventional management

ranged from 27 to 42.91 per cent with a mean value of 39.07 per cent and water holding capacity from 27 to 31.4 per cent with a mean value of 28.93 per cent (Table 1).

Chemical characteristics

The pH of the soils varied from highly acidic to acidic in reaction ranging from 4.1 to 5.4 with a mean value of 5.2 under organic management whereas under conventional management pH values ranged from 3.6 to 5.1 with a mean value of 4.7. The EC ranged from 0.01 to 0.04 (dS $^{m-1}$), with mean value of 0.015 (dS $^{m-1}$) under organic management whereas under conventional management it ranged from 0.01 to 0.04 (dS $^{m-1}$) with mean value of 0.021 (dS $^{m-1}$). The organic carbon content of the soils ranged from 0.46 to 1.81 per cent with mean value of 0.76 per cent under organic management, whereas under conventional management it ranged from 0.27 to 0.85 per cent with an average value of 0.57 per cent. The soil varied in CEC ranging from 4.1 to 14.7 cmol(p$^+$) kg^{-1} with mean value of 7.9 cmol(p$^+$) kg^{-1} under organic management, whereas under conventional management it ranged from 4.6 to 10.9 cmol(p$^+$) kg^{-1} with mean value of 7.7 cmol(p$^+$) kg^{-1} (Table 2).

pH under both the systems were found to increase with depth. pH under organic in D_1, D_2 and D_3 were found to be 5.13, 5.14 and 5.24, respec-

Table 1. Soil physical properties under organic and conventional management system

Parameters	Organic					Conventional		
	Mean	Range	Standard dev	Variance	Mean	Range	Standard dev	Variance
BD (gm/cm^3)	1.41	1.05-1.45	0.207	0.043	1.52	1.06-1.62	0.215	0.046
PD (gm/cm^3)	2.43	2.1-.2.71	0.326	0.106	2.51	2.12-2.73	0.346	0.12
Porosity (%)	41.98	27.6-48.2	4.51	20.38	39.07	27-42.91	3.34	11.17
WHC (%)	31.5	30.00-34.12	1.17	1.39	28.93	27.0-31.4	1.24	1.55
Sand (%)	70.3	55.5-78.5	4.94	6.02	71.2	64.0-77.4	2.29	10.6
Silt (%)	6.8	2.4-14.8	2.45	24.44	5.5	2.4-14.3	1.9	3.68
Clay (%)	22.9	11.3-31.9	4.29	18.44	23.4	17.9-29.8	3	9.97
Textural class	Silty clay				Silty clay			

Table 2. Soil chemical properties under organic and conventional management system

Parameters	Organic					Conventional		
	Mean	Range	Standard dev	Variance	Mean	Range	Standard dev	Variance
pH (1:2.5)	5.2	4.1-5. 4	0.34	0.11	4.7	3.6-5.1	0.489	0.24
EC (dS $^{m-1}$)	0.015	0.01-0.04	0.007	4.91	0.021	0.01-0.04	0.0065	4.37
Organic carbon (%)	0.76	0.46-1.81	0.28	0.083	0.57	0.27-0.85	0.137	0.018
Cation exch. Capacity [cmol (p$^+$) kg^{-1}]	7.9	4.1-14.7	2.38	0.728	7.7	4.6-10.9	1.54	2.40

tively. Under conventional management pH in D_1, D_2 and D_3 were found to be 4.68, 4.72 and 4.78, respectively (Fig. 2a). With respect to depth organic carbon was found to be higher at the surface 0-20 cm depth and gradually decreased with the increase in soil depth in both the management system (Fig.2b). CEC showed an irregular trend with respect to depth in both the management systems. A higher value was observed at the surface (D_1), which decreased in D_2 and again showed an increasing trend in D_3 (Fig.2c).

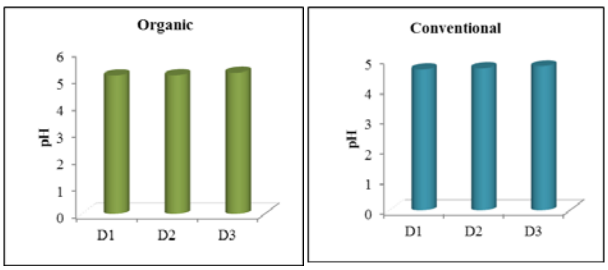

Fig. 2(a). pH under organic and conventional management wih depth

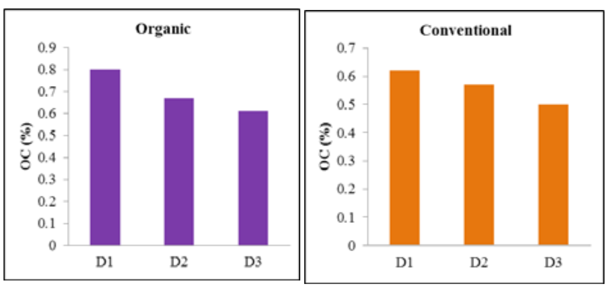

Fig. 2(b). Organic carbon under organic and conventional management with depth

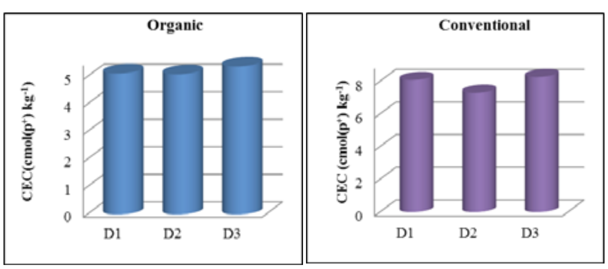

Fig. 2(c). CEC under organic and conventional management with depth

Soil organic carbon proportion and stock distribution

SOC exhibited range of 0.5–1.32 percent on top soil (20cm), 0.46–1.24 per cent in middle layer (40cm) and 0.46–.081 per cent in the bottom layer (60cm) across different plantations carrying median values 0.76 per cent, 0.66 per cent and 0.58 per cent in respective depths in organic tea garden. With respect to depth organic carbon was found to be higher at the surface 0-20 cm depth and gradually decreased with the increase in soil depth in both the management system (Fig. 2b). Mean SOC stock in the organic tea plantation was estimated at 2156.79 mg/ ha up to 20 cm depth, 1794.16 mg/ ha up to 40 cm depth and 1622.31 mg/ ha up to 60 cm depth (Fig 3). The values ranged from 1450 mg/ ha to 3564 mg/ha across 20 cm soil depths, 1058 mg/ ha to 1942 mg/ha across 40 cm soil depths and 1009.2 mg / ha to 1252 mg/ ha across 60 cm soil depths in the organic plantations.

In conventional management, SOC per cent exhibited range of 0.46–0.85 per cent on top soil (20cm), 0.27–0.81 per cent in middle layer (40cm) and 0.7–.031per cent in the bottom layer (60cm) across different plantations carrying median values 0.60 per cent, 0.63 per cent and 0.49 per cent in respective depths. Mean SOC stock in the organic tea plantation was estimated at 1968.14 Mg/ C ha up to 20 cm depth , 1666.65 mg/ ha up to 40 cm depth and 1555.83mg/ ha up to 60 cm depth (Fig.3). The values ranged from 1214.4 mg /ha to 2992 mg/ha across 20 cm soil depths, 831.6 mg/ha to 2543.4mg/ ha across 40 cm soil depths and 1026 mg/ha to 2217.6 mg/ha across 60 cm soil depths in the organic plantations.

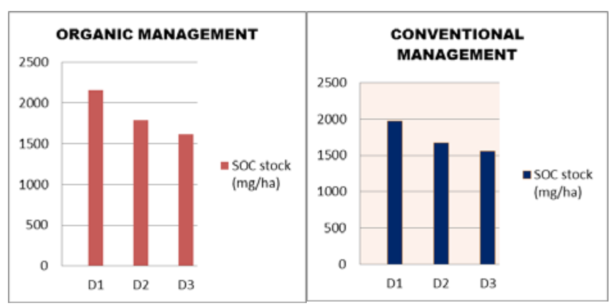

Fig. 3. Organic carbon stock under organic and conventional management with depth

Discussion

Physical characteristics

Regardless of the depth, the soil texture in both the organic and conventional management systems was determined to be silty clay. In the organic system, the soil's bulk density was lower, which could be attributed to the addition of organic compost. This organic matter input contributed to a decrease in soil bulk density, as observed in previous studies by Valpassos (2001). The findings regarding soil bulk density and total porosity indicated that organic management led to an increase in soil porosity, achieved by a decrease in soil bulk density, as reported by Werner (1997) in organic systems. Similar results comparing organic and conventional management were mentioned by Swezey *et al.* (1998) and Glover *et al.* (2000). Regarding depth, the soil bulk density in both management systems was observed to increase with greater depth. This may be due to subsurface layers being more compacted, containing less organic matter, less aggregation, and experiencing reduced root penetration compared to surface layers. As a result, subsurface layers have less pore space, leading to higher bulk density, as noted by Phukan and Baruah (2012).

Chemical characteristics

Regardless of depth, the soil pH was measured to be 5.17 in organic tea cultivation and 4.73 in conventional tea cultivation. The conventional system exhibited higher acidity compared to the organic system. Previous studies have indicated that the use of nitrogenous fertilizers in conventional tea cultivation, such as NH_4SO_4 and urea, contributes to soil acidity (Tee *et al.,* 1987; Ma *et al.,* 1990). Continuous application of these acidifying fertilizers without incorporating lime can lower the soil pH to levels below 4, which are unfavorable for crop production (Tisdale and Nelson, 1975). Baruah *et al.,* (2012) also reported an increase in soil pH under organic tea cultivation, although it remained within the desired range.The organic carbon content in organic tea cultivation was measured at 0.76%, while the conventional system exhibited a lower content of 0.57%. The increase in organic carbon in the organic management system can be attributed to the presence of microbial biomass resulting from organic amendments. These findings align with Glover *et al.* (2000), who observed that organic systems tend to maintain higher levels of soil organic matter compared to conventional systems. The cation exchange capacity (CEC) in organic tea cultivation was determined to be 7.89 cmol (p+) kg^{-1}, while the conventional system had a value of 7.79 cmol (p+) kg^{-1}. The higher CEC in the organic management system can be attributed to the higher presence of organic matter. Previous studies, conducted by Hallsworth (1958) and Chan (1992), have demonstrated the relationship between soil organic matter and CEC in well-defined soil sets.

Regarding depth, both the organic and conventional management systems exhibited an increase in soil pH with greater depth, likely due to lower acidity as reported by Pati *et al.* (2010). The organic carbon content was generally higher in the surface layer (0-20 cm) and gradually decreased with increasing soil depth. The higher organic carbon content at the surface may be attributed to greater biomass addition through leaf litter in conventional tea cultivation and the combined addition of biomass and organic manure in organic tea cultivation (Gangopadhyay *et al.,* 2016). The CEC showed an irregular trend in both tea cultivation systems, which may be influenced by differences in clay content, pH, and the percentage of organic matter in the soil (Krull, 2004).

Soil organic carbon proportion and stock distribution

The soil organic carbon (SOC) stocks were observed to be higher in the 0-20 cm depth for both the organic and conventional management systems. Similar findings were reported by Ray and Mukhopadhyay (2012) in different tea-growing regions of West Bengal, India, where higher values of SOC stocks were found in the 0-20 cm depth. In the organic management system, the SOC stocks were higher compared to the conventional management system.The decline in SOC stocks in the conventional management system may be attributed to the adoption of conventional management practices, which involve intensive tillage and significant uptake of organic matter by the tea bushes and shade trees. These practices could contribute to a decrease in SOC stocks over time. On the other hand, the organic management system, characterized by balanced organic fertilization, subsequent pruning, and increased litter accumulation on the floor, may enhance microbial activity in the soil, leading to higher SOC content in organic tea plantations.Overall, the results suggest that organic management practices, including the application of organic fertilizers, pruning, and litter accumulation, contribute to increased soil organic carbon stocks compared to conventional management practices.

Conclusion

The management practices employed in tea gardens of North-East India, specifically organic and conventional approaches , have differing effects on soil carbon stock. Organic management practices, which emphasize the use of organic amendments, reduced chemical inputs, and potentially agroforestry systems, promote the accumulation of soil carbon. These practices enhance soil health, fertility, and sustainability while providing a continuous supply of carbon to the soil through organic inputs. On the other hand, conventional management practices, characterized by the use of synthetic fertilizers, pesticides, and mechanized farming techniques, may have negative impacts on soil carbon stocks. Further long-term studies comparing organic and conventional approaches in tea gardens of North-East India would provide more detailed insights into their respective impacts on soil carbon sequestration.

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