



Variability in soil organic carbon pools in different land use systems in the north-eastern region of India

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ABSTRACT

The current study was carried out during 2020 to 2022, at Horticulture Research Centre (HRC), Nagicherra, Agartala, Tripura to assess and compare the effects of various land use systems, including bamboo, tea, mango, lemon, rice-rice, wheat-millet, okra-onion and uncultivated soils, on soil organic carbon (SOC) dynamics. SOC is a critical component of terrestrial ecosystems, influencing soil health, fertility and carbon sequestration potential. The NEH region of India, Tripura characterized by its diverse agro-ecological zones and land use systems (LUS), presents a unique opportunity to investigate the various land use regimes' effects on SOC pools. Walkley and Black carbon (WBC) significantly vary among the selected LUS, ranging from 7.14–12.48 g/kg, with the maximum values in tea LUS. In 0–30 cm depth, very labile C (C_{VL}) pools are very variable among the selected LUS (2.04–5.35 g/kg), which is the highest in tea and mango compared to the uncultivated system. The C pools in selected LUS indicated the deviation depth and land use pattern. Lability index (LI) varies from 1.50–1.63 and 1.40–1.74 in 0–30 cm and 30–60 cm depth, respectively. Carbon pool index (CPI) assessed highest in tea LUS, 1.78 and 2.1 from 0–30 and 30–60 cm, respectively. Carbon management index (CMI) was higher in selected LUS compared to uncultivated system.

Keywords: Active and passive carbon, Carbon management index, Carbon pools, Lability index, Land use systems

The resilience and fertility of soil are significantly impacted by soil organic carbon, which is determined by a variety of management approaches (Kooch *et al.* 2020). According to numerous studies (Morris *et al.* 2018, Mahala *et al.* 2023), SOC is a key indication of soil quality since it is essential for maintaining soil health and providing the essential nutrients to plants. SOC serves as the primary source of plant nutrients as well as significant carbon storage, contributing to the maintenance of the overall environmental quality through carbon sequestration and greenhouse gas emission reduction (Manjaiah *et al.* 2017). Land-use systems play a crucial role as long-term carbon sinks, particularly in tree-based systems, where carbon is sequestered in both the soil and above/below-ground biomass components. The impact of land-use change on SOC, especially in the topsoil layers, has been well-documented by Gualberto *et al.* (2023).

To check the quality of carbon in soil under various land-use systems, Blair *et al.* (1995) introduced the Lability Index (LI), Carbon Management Index (CMI), and Carbon Pool Index (CPI). These indices serve as valuable tools for evaluating soil carbon alterations and sequestration resulting from management strategies that account for both labile carbon and total SOC, as emphasized by Roy *et al.* (2023). Mir *et al.* (2023) further emphasized that soil depth and land-use change significantly affects SOC pools and CMI, making the latter a crucial long-term sustainability indicator and soil carbon restoration parameter. Despite the existing knowledge, there is a need for additional research in the north-eastern Indian region, like in Tripura, to comprehensively investigate the impact of LUS and their management strategies on soil carbon reservoirs. The present study utilizes the LI, CMI, and CPI to evaluate soil quality, exploring the fractions of SOC, as well as the active and passive pools of SOC within four distinct LUS.

MATERIALS AND METHODS

Study area and sampling locations: The current study was carried out during 2020 to 2022, at the Horticulture Research Centre (HRC), Nagicherra, Agartala (latitudes 23.81°N and longitudes 91.32°E, respectively; 49 m amsl),

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Tripura. Land area of 10491 km², Tripura is primarily hilly (60%) and encircled by Bangladesh on three sides. Samples were collected from different depths (0–15; 15–30, and 30–60 cm) under various land use systems at the Horticulture Research Centre (HRC), Nagicherra, Agartala, Tripura.

Demography and weather condition: It is an area with relatively warm, humid temperatures that is made up of high hills and plains areas scattered with valleys and rivers. The region receives 2146 mm of rain on average every year (May–November). Mid-November to early March sees a brief, moderate winter with mainly dry weather and average highs of 28°C. The lengthy, sweltering summers have plenty of sunshine and pleasant days. This time of year (April–July) sees a lot of rain, which frequently causes flooding in the city.

Selected land use systems: In present study, seven land use systems were selected as plantation crop (bamboo, tea), horticultural crops (mango, lemon) and agricultural crops (rice-rice, wheat-millet and okra-onion) and also selected the uncultivated field as a reference. All the land use systems were maintained by Horticulture Research Centre (HRC), Nagicherra, Agartala, Tripura.

Soil Sampling and carbon stock quantification: Representative soil samples were collected from a chosen LUS at depths of 0–15, 15–30, and 30–60 cm. Data between 0–15 and 15–30 cm were averaged and published as 0–30 cm for simplicity's sake. After being gathered, the soil samples were stored in airtight polythene bags and delivered to a lab for additional processing. The samples were air dried, crushed and kept in plastic bags pending additional examination of their carbon stock and various physicochemical characteristics. The one-way ANOVA statistical method is used for the data analysis. Using a combined electrode and conductivity bridge, a digital pH meter was used to determine the pH and EC (µS/cm) of soil samples in a 1:2 soil: water suspension (Jackson 1973). By removing intact cores with a known volume, bulk density was ascertained (Vehmeyer and Hendrickson 1948). Oxidizable OC was determined by Walkley and Black's (1934) rapid titration method. The technique developed by Walkley and Black and adapted by Chan *et al.* (2001) was used to identify the pools of SOC that were highly labile, labile, less labile, and recalcitrant. The oxidizable organic carbon that can be extracted with 12N H₂SO₄ is known as the Very Labile Carbon (C_{VL}). Labile carbon (C_L) fraction is the difference in oxidizable organic carbon recovered with 18N against 12N H₂SO₄ (18N-12N H₂SO₄). The difference between oxidizable organic carbon extracted using 24 N versus 18N H₂SO₄ (24N-18N H₂SO₄) is known as Less Labile Carbon (C_{LL}).

Using the data from the pools, active and passive carbon stocks were computed. The very labile (C_{VL}) and Labile pools (C_L) were added to identify the active carbon stock, while the non-labile or recalcitrant pools (C_{NL}) and less labile (C_{LL}) were added to determine the passive carbon stock. The eq. (4) formula (Blair *et al.* 1995) is used to generate the Carbon Management Index (CMI), which is

a multiplicative function of the Carbon Pool Index (CPI) and Liability Index (LI):

$$\text{Liability of C} = \frac{\text{C in fraction oxidized by KMnO}_4 \text{ (mg labile C/g soil)}}{\text{C remaining unoxidized by KMnO}_4 \text{ (mg labile C/g soil)}} \quad (1)$$

$$\text{CPI} = \frac{\text{Total carbon of sample (mg/g)}}{\text{Total carbon in reference sample (mg/g)}} \quad (2)$$

$$\text{Liability Index (LI)} = \frac{\text{Liability of C in sample soil}}{\text{Liability of C in reference soil}} \quad (3)$$

$$\text{CMI} = \text{CPI} \times \text{LI} \times 100 \quad (4)$$

RESULTS AND DISCUSSION

The pH of selected LUS has been found 4.66–5.60 under the strongly acidic range. The uncultivated system showing significantly higher EC compared to tea, mango, lemon, rice-rice and wheat-millet systems (Table 1). Bulk density varies from 1.21–1.38 g/cm³, with significantly low BD in tea LUS compared to uncultivated system. Walkley and Black carbon (WBC) is significantly variable among the selected LUS, ranging from 7.14–12.5 g/kg, with the maximum values in tea LUS (Table 1).

Temperate forests have substantially larger estimations of SOC stock (0–30 cm) (132.7 Mg C/ha). On the other hand, the SOC stock decreased by roughly 29% and 68%, respectively, when native forests were rehabilitated into

Table 1 Soil physicochemical properties of different land use system (LUS)

LUS	pH (1:2)	EC (µS/cm)	BD (g/cm ³)	WBC (g/kg)
Bamboo	5.02 ± 0.41 ab	437 ± 6.03 ab	1.26 ± 0.04 bcde	10.2 ± 0.52 cd
Tea	4.66 ± 0.2 b	374 ± 8.54 d	1.21 ± 0.07 e	12.5 ± 1.08 a
Mango	4.71 ± 0.06 b	364 ± 9.5 d	1.24 ± 0.03 cde	11.4 ± 0.31 ab
Lemon	5.01 ± 0.74 ab	369 ± 5.03 d	1.23 ± 0.08 de	10.7 ± 0.53 bc
Rice-Rice	5.60 ± 0.29 a	392 ± 19.4 c	1.35 ± 0.02 ab	9.83 ± 0.25 cde
Wheat-Millet	5.02 ± 0.35 ab	426 ± 0.58 b	1.33 ± 0.08 abcd	9.37 ± 1.06 de
Okra-Onion	4.97 ± 0.30 ab	441 ± 15.7 ab	1.34 ± 0.04 abc	8.79 ± 0.42 e
Uncultivated land	5.64 ± 0.69 a	446 ± 5.86 a	1.38 ± 0.08 a	7.14 ± 0.38 f
LSD (P<0.05)	0.75	16	0.11	1.11

EC, Electrical conductivity; BD, Bulk density; WBC, Walkley and Black carbon.

bamboo plantation and jhum land (Ahirwal *et al.* 2022). Despite adding various organic matter (OM) inputs to cropped soils, it takes time for OM to build up in the soil. Babu *et al.* (2020) revealed that undisturbed forest soil exhibited the highest concentrations of organic carbon (145.8 Mg/ha), active carbon (73.7 Mg/ha), and passive carbon (72.1 Mg/ha). Following closely, the alder + large cardamom system displayed noteworthy levels, recording 140.7 Mg/ha of organic carbon, 70.9 Mg/ha of active carbon, and 69.8 Mg/ha of passive carbon. The primary source of OM addition in native forests soils is leaf litter fall, which remains in the soil until it decomposes (Cardinael *et al.* 2012). In 0–30cm depth, C_{VL} pools very significantly variable among the selected LUS (2.04–5.35 g/kg), observed highest in tea and mango compared to uncultivated system. According to the findings presented by Babu *et al.* (2020), undisturbed forest soils and those associated with the alder + large cardamom cultivation exhibited a greater proportion of highly labile carbon fractions across all depths compared to other land uses. C_{VL} is a readily decomposable fraction of carbon that delivers essential nutrients to plants and helps as an early indicator for comparing soil management (Hazra *et al.* 2018). Differences in the C_{VL} pool are associated with organic residue supply in the soil. C_L pools varies from 2.09–2.98 g/kg, with highest in okra-onion LUS compared to uncultivated LUS. C_{LL} observed significantly higher in wheat-millet LUS (2.97 g/kg) compared to other LUS and uncultivated system.

The recalcitrant or C_{NL} showed significantly higher quantity in tea, mango and lemon LUS compared to uncultivated (Table 2). In 30–60 cm depth, SOC pools showed lower value than 0–30 cm soil depth. In 30–60 cm depth, C_{VL} pools very significantly variable among the selected LUS (1.26–2.86 g/kg), with highest in tea and mango compared to uncultivated system. C_L pools varies from 0.52–1.94 g/kg, with highest in rice-rice LUS compared to uncultivated LUS. C_{LL} observed significantly higher in wheat-millet LUS (1.92 g/kg) compared to other LUS and

uncultivated system. As reported by Ahirwal *et al.* (2022), the allocation of SOC fractions in major forests reveals distinct patterns in their contributions to total organic carbon (TOC). Specifically, their study indicates that there is a greater percentage of active carbon in the 0–15 cm soil depth, contrasting with the situation in the 15–30 cm depth where such prominence is not observed. The recalcitrant C was significantly higher in tea, mango, bamboo and lemon LUS compared to uncultivated land (Table 2).

Examining seven different land use regimes in Mizoram, Sahoo *et al.* (2019) conducted measurements of both active pools (AP) and passive pools (PP) derived from TOC. Their investigation revealed a consistent decline in TOC across different lability pools with increasing soil depth. Notably, natural forests exhibited the highest TOC content at 2.75%, while grasslands displayed the lowest at 1.31%. The study also demonstrated variations in the Very Labile Carbon (C_{VL}) component, ranging from 36.11–42.74% of the total TOC across various land use systems. Wet rice cultivation had the largest active carbon (AC) pool (61.64%), whereas natural forests had the lowest (58.71%) except for natural forests. Most land use systems in the area have higher AC pools (C_{VL} and less labile), suggesting that they are liable to changes in land use and that appropriate management techniques are needed to maximize carbon sequestration.

The active and passive carbon pools significantly varied within depth as well as different land use systems. Plant litter, underground decomposition and microbial biomass all contribute significantly to AC pools, they significantly supply nutrients because of their higher lability in topsoil (Tian *et al.* 2016). It was observed that tea system having highest active and passive carbon pools compared to other LUS. There was significant variation in active and passive pools within different depths among LUS (Fig. 1). In tea and mango LUS, active and passive carbon pools are significantly higher in 0–30 cm soil layer compared to 30–60 cm. Ahirwal *et al.* (2022) noted variations in the per cent share of active carbon (AC) to total organic carbon (TOC) in the topsoil

Table 2 Soil organic carbon pools in different land use system (LUS) in 0–30 and 30–60 cm depth

LUS	0–30 cm				30–60 cm			
	Very labile (C_{VL})	Labile (C_L)	Less labile (C_{LL})	Non labile (C_{NL})	Very labile (C_{VL})	Labile (C_L)	Less labile (C_{LL})	Non labile (C_{NL})
Bamboo	3.52 ± 0.12 d	2.56 ± 0.13cd	2.72 ± 0.05 b	3.54 ± 0.21 c	2.12 ± 0.09 d	1.36 ± 0.11 b	1.6 ± 0.05 b	2.56 ± 0.02 c
Tea	5.35 ± 0.29 a	2.6 ± 0.04c	2.63 ± 0.05 b	4.93 ± 0.18 a	2.86 ± 0.18 a	1.2 ± 0.05 c	1.28 ± 0.04 c	2.95 ± 0.06 a
Mango	4.75 ± 0.18 b	2.66 ± 0.06bc	1.41 ± 0.02 g	4.87 ± 0.23 a	2.56 ± 0.14 b	1.01 ± 0.03 d	1.57 ± 0.04 b	2.82 ± 0.06 b
Lemon	4.46 ± 0.27 c	2.33 ± 0.18de	1.75 ± 0.08 f	4.48 ± 0.31 b	2.29 ± 0.08 c	1.28 ± 0.05bc	1.57 ± 0.09 b	2.01 ± 0.04 d
Rice-Rice	3.42 ± 0.07de	3.00 ± 0.29a	2.00 ± 0.14 e	3.5 ± 0.14 c	1.85 ± 0.01 e	1.94 ± 0.09 a	0.77 ± 0.04 e	1.33 ± 0.13 f
Wheat-Millet	3.34 ± 0.02de	2.88 ± 0.14ab	2.97 ± 0.06 a	2.68 ± 0.1 d	1.47 ± 0.03 f	1.24 ± 0.02 c	1.92 ± 0.07 a	1.09 ± 0.02 g
Okra-Onion	3.21 ± 0.03 e	2.98 ± 0.09 a	2.16 ± 0.06 d	2.11 ± 0.04 e	1.33 ± 0.04fg	0.93 ± 0.03 d	0.94 ± 0.05 d	1.31 ± 0.06 f
Uncultivated land	2.04 ± 0.03 f	2.09 ± 0.08 e	2.41 ± 0.11 c	2.21 ± 0.06 e	1.26 ± 0.05 g	0.52 ± 0.05 e	0.48 ± 0.01 f	1.7 ± 0.08 e
LSD ($P < 0.05$)	0.28	0.26	0.14	0.31	0.16	0.10	0.09	0.12

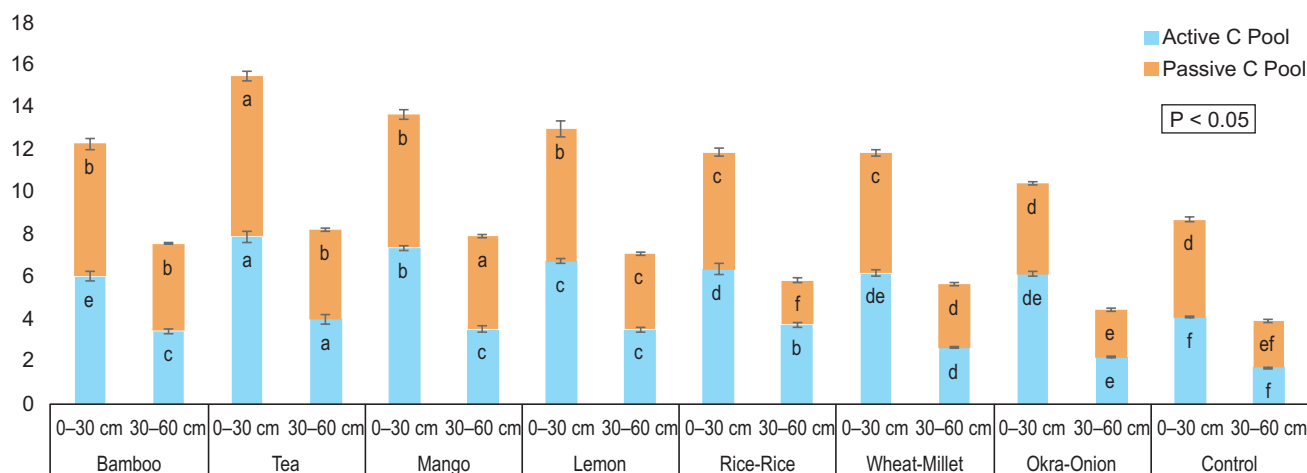


Fig. 1 Active and passive pools of selected land use system.

Table 3 Lability Index (LI), Carbon Pool Index (CPI) and Carbon Management Index (CMI) of selected land use system (LUS)

LUS	LI		CPI		CMI	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Bamboo	1.5 ± 0.13 c	1.4 ± 0.1 cd	1.41 ± 0.14 cd	1.93 ± 0.05 ab	211 ± 2.83 cd	270 ± 12.9 bc
Tea	1.54 ± 0.02 bc	1.48 ± 0.06 bc	1.78 ± 0.1 a	2.1 ± 0.25 a	275 ± 19.07 a	310 ± 26.8 a
Mango	1.52 ± 0.02 bc	1.42 ± 0.06 bcd	1.57 ± 0.06 b	2.01 ± 0.14 a	239 ± 12.6 b	285 ± 15.03 b
Lemon	1.52 ± 0.06 c	1.54 ± 0.04 b	1.49 ± 0.04 bc	1.81 ± 0.06 b	226 ± 2.12 bc	278 ± 16.22 bc
Rice-Rice	1.55 ± 0.08 bc	1.74 ± 0.12 a	1.36 ± 0.06 cd	1.49 ± 0.08 c	210 ± 3.8 cd	258 ± 5.47 c
Wheat-Millet	1.63 ± 0.02 ab	1.54 ± 0.05 b	1.34 ± 0.08 d	1.44 ± 0.1 c	216 ± 8.18 cd	223 ± 8.59 d
Okra-Onion	1.71 ± 0.06 a	1.5 ± 0.09 bc	1.19 ± 0.06 e	1.14 ± 0.03 d	203 ± 4.19 d	172 ± 5.62 e
Uncultivated land	1.44 ± 0.05 c	1.34 ± 0.04 d	1 ± 0 f	1 ± 0 d	144 ± 4.76 e	134 ± 4.31 f
LSD ($P < 0.05$)	0.11	0.13	0.13	0.20	15.6	23.9

across different forest types. Their observations revealed that a temperate forest exhibited the highest proportion, with active carbon accounting for 74.1% of the total organic carbon. In contrast, a bamboo forest displayed the lowest contribution, registering at 48.1% in terms of active carbon to total organic carbon. The passive pools also exhibiting same trend among the selected LUS. The results shown that the establishment period, tillage operations, intercultural activities, fertilization and other intervention have significant variations in active and passive carbon pools. Compared to uncultivated system, other systems i.e. bamboo, tea, mango, lemon, rice-rice, wheat-millet and okra-onion recorded higher carbon pools.

The Carbon Management Index (CMI) is a valuable metric that stems from the overall SOC pool and LI. This index provides a pragmatic comprehension of the effectiveness of managerial systems in enhancing soil quality. In the NEH region of India, Ahirwal *et al.* (2022) found that the lability index (LI) ranged from 1.50–1.63 and 1.40–1.74 in the 0–30 cm and 30–60 cm soil depth respectively, indicating higher labile carbon (C_L) in jhum land across different forest types. The Carbon Management Index (CMI) also exhibited significant variations among selected LUS compared to uncultivated systems, ranging

from 144–275 in the 0–30 cm depth and from 134–310 in the 30–60 cm depth (Table 3). Mir *et al.* (2023) reported higher CMI in forest soils and lower values in paddy-oilseed under various land use systems in the northwestern Himalayas. The study emphasizes the positive impact of long-term or perennial land use systems, consistently enriching the soil with organic matter and contributing to carbon sequestration, thereby enhancing soil quality. Forests and perennial land use systems demonstrated higher soil carbon content and pools compared to seasonally cultivated land, thereby improving soil carbon fractions and overall soil quality in the NEH Region of India.

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