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Assessment of Soil Carbon Fractions, Carbon Stock and Microbial Population under Different Tree-Based Land Use System

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Abstract

Carbon sequestration is a critical aspect of sustainable agriculture and plays a vital role in mitigating global climate change. Land use conversion can significantly influence Soil Organic Carbon (SOC) levels due to its impact on soil dynamics. This study was conducted in the Iluppur region of Pudukkottai District to investigate carbon sequestration and its distribution among different soil organic carbon pools across various land use systems. Six distinct land use systems were selected as treatment groups, including sapota, mango, guava, citrus, pomegranate, and barren land. Soil samples were collected from each system, with each treatment replicated three times, and subsequently analyzed for carbon stocks and different carbon fractions and pools. Among the various land use systems, the sapota-based system exhibited the highest content of very labile carbon (VLC) at 3.88 g kg -1 soil, followed closely by the citrus-based system. The relative distribution of organic carbon fractions in the top 15 cm of soil followed this order: very labile carbon (VLC) accounting for 30.1%, non-labile carbon (NLC) for 45.1%, labile carbon (LC) for 13.4%, and less labile carbon (LLC) for 11.4%. Introducing leaf litter into the tree-based systems led to a noteworthy increase of 19.8% in the active carbon (AC) pool compared to barren land. Moreover, the passive carbon (PC) pool was most pronounced in the soil under the pomegranate-based system, particularly at the 0–15 cm soil depth. In conclusion, these findings suggest that alternate land use systems have the capacity to sequester more carbon, which is particularly valuable in the context of changing climatic conditions.

Keywords: carbon fractions, Carbon pools, land use system

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Introduction

Human activities have significantly influenced livelihood development by rapidly modifying land-use patterns (LUC) over the past century [1]. Land use and vegetation types play a significant role in shaping soil disturbance and carbon (C) dynamics. In general, land use practices that minimize soil disturbance tend to promote the accumulation of soil organic carbon (OC), while intensive disturbance can lead to lower soil OC levels and subsequent soil degradation [2]. Transitioning from a native ecosystem (such as grassland or forest) to cultivated land can result in a substantial loss of soil C, often up to 50%. Conversely, the reestablishment of vegetation on abandoned agricultural land can enhance C sequestration [3]. Cultivated systems may reduce C content due to reduced annual C input and increased mineralization, primarily due to surface disturbance [4]. However, the impact of land use on soil C is not uniform across all soils. Among these properties, the initial native OM content in the soil is a crucial factor influencing soil OC accumulation. Native soil OM levels represent the natural balance between C inputs and losses.

Soils have the potential to sequester additional C by increasing C input and/or reducing C harvest through improved land use and crop management practices. In some cases, the levels of C in long-term grasslands, pastoral lands, and even agricultural lands can surpass their native C content with proper land use and management systems [5]. There is a rising interest in evaluating soil's capacity to act as a carbon sink across various land-use practices. This is particularly important because even a minor increase in soil organic carbon content by 0.01% has the potential to sequester carbon, which can offset the annual growth in cultivation. One potential strategy for carbon mitigation involves reducing cultivation and restoring the land to its original land cover.

The Pudukkottai region has dry climate wherein the decomposition of rate will be at faster rate. Hence making availability of abundant phyto-biomass (both above and below ground) in the form of tree-based system may bring the region to a carbon sequestering potential zone. Since vegetation is one of the most important sources to enrich soil with carbon.

Based on the background as mentioned, the experiment was undertaken to study the carbon pool variation among the different tree based systems and microbial population.

Materials and Methods

Description of study area

The Mother Teresa College of Agriculture is about located in Illuppur near Viralimalai on the national highway No.38 and bestowed with wet land, dry land, garden land and orchards in 137 acres and lies between 10.5034° North and 78.6439° east. The annual rainfall of this region is about 340 mm.

Soil sample collection

To characterize the surface soil, the surface soil samples have to be collected from the individual blocks (**Figure 1**). The soil samples will be collected from top 15 cm depth in 15 places in each field by adopting the standard procedures of soil sample collection from which, a composite soil sample of about 1 kg was collected by quartering technique. The collected soil samples were air dried, gently malleted and sieved through 2 mm sieve and preserved in polythene bags with proper labelling for further analysis. Treatment details are given in **Table 1**.

Figure 1 sample collection process

Table 1 Treatment details

Treatments	Crop	Variety
T_1	Barren land	-
T_2	Sapota	PKM 1
T_3	Mango	Bengalura
T_4	Guava	Thailand Lucknow-49
T_5	Citrus	Balaji
T_6	Pomegranate	Ragava

Analysis

The soil pH was determined in 1:2 soilwater suspensions using an Elico-glass electrode pH meter [6]. The electrical conductivity of the soil samples was determined in 1:2 soil-water suspension equilibrated after 24 hours using a conductivity bridge [7]. Soil organic carbon was determined by Walkey and Black’s [8] rapid titration method. The assessment of soil microbe populations was carried out using agar plates with suitable media, following the serial dilution technique and the pour plate method as described by Pramer and Schmidt [9]. For the enumeration of specific microorganisms, the following media were employed: Thornton's agar for total bacterial count [10], Martin's rose Bengal streptomycin agar for total fungal count, and Jensen's agar for total actinomycetes count [11].

Oxidisable organic C fractions was determined by Chan *et al.* [12] using differentratios of H_2SO_4 solution 0.5:1, 1:1 and 2:1 respectively. The amount of SOC was determined using the three acid-aqueous solution ratios allows transformation of total organic carbon C in to the following four fractions of decreasing oxidizability/lability.

Fraction1 (very labile): Organic C oxidizable under 12NH_2SO_4.

Fraction2 (labile): Difference in oxidizable Organic C extracted between 18N &12N H2SO4
Fraction3 (less labile): Difference in oxidizable Organic C extracted between 24N & 18N H2SO4.
Fraction4 (recalcitrant): Difference in oxidizable Organic C reaction with 24N when compared with the TOC

Soil organic carbon stock was calculated using the concentration of the total soil organic carbon in % (TOC), depth (cm) and bulk density (Mgm^{-3}) of each layer [13].

$$\text{C stock (tha}^{-1}\text{)} = \text{TOC x BD x D}$$

Statistical analysis

The data on various characters studied during the course of investigation were statistically analyzed as suggested by Gomez and Gomez [14]. Wherever statistical significance was observed, critical difference (CD) at 0.05 level of probability was worked out for comparison. If there are no significant differences between treatments, it was denoted as 'NS'.

Results and Discussion

Soil pH

A close scrutiny of the soil pH had indicated that the minimum value recorded was 6.3 and the maximum was 8.7 on the overall tree based cropping system (**Table 2**). The corresponding minimum and maximum values is 6.3 (Sapota and Guava) and 8.7 (Barren land). A close scrutiny of the soil pH had indicated that the minimum value recorded was 6.3 and the maximum was 8.7 on the overall tree-based cropping system. Soil pH affects the quantity, activity and types of microorganisms in soils which in turn influence decomposition of crop residues, manures, sludges and other organics. In our study mango pH is acidic due to more litter addition. The pH under Orchard was lower when compared to Agricultural Crops and silvi agri systems because of higher litter addition in these systems, which is acidic nature after its Decomposition. These results are in accordance with Maqbool et al. [15]. According to this in our study pH of barren is high due to the accumulation of $CaCO_3$ and salts [16].

Table 2 Effect of different land use systems on soil physico-chemical properties

Treatment	Soil pH	Soil EC (dS/m)	Soil Bulk density (Mg/m³)	Soil organic carbon (%)
T_1	8.7	1.02	1.27	0.45
T_2	6.3	0.22	1.00	0.75
T_3	6.7	0.32	1.08	0.58
T_4	6.3	0.26	0.87	0.67
T_5	7.4	0.28	1.14	0.58
T_6	7.4	0.28	0.15	0.76
SEd	0.56	0.06	0.13	0.03
CD (P=0.05)	1.14	0.14	0.31	0.09

Soil EC

The data on soil electrical conductivity revealed that, regardless of different land use system, T_1 barren land recorded higher EC (1.02 dS m^{-1}) and the minimum was found to be present in (0.22) in sapota (Table 2). The EC of the soil contain overall tree-based cropping system as ranging from minimum of 0.23 to maximum of 0.31 dS m^{-1}. The electrical conductivity in all land use systems of study area was within the safe limit below 1 dsm^{-1} for growing of any crop with lowest mean value in forest. It can be due to high amount of decomposing litter in forest [17]. Due to different tree cropping system it was noticed diverse EC values.

Bulk density

The data on soil bulk density revealed that, regardless of different land use system showed significant values. Irrespective of different land use system, barren land T_1 recorded highest BD (1.27 Mg m^{-3}) which was comparable with T5 (1.14 Mg m^{-3}) (Table 2). Study resulted that the bulk density content ranged from 0.15-1.27 Mg m^{-3} on the overall tree-based cropping system. The addition of organic manure resulted in lower bulk density which may be due to higher organic carbon, more pore space and good soil aggregation [18]. An increasing bulk density implies a decrease of macropores and an increase in meso- and micropores and the resultant changes impacted on hydraulic conductivity. The increasing bulk density not only induces changes in the pore-size distribution but also affects the ability of soil to shrink and to conduct water in the soil. In our research the bulk density is higher in barren land due to intensive farming practices.

Soil organic carbon

The content of Soil organic carbon in the surface soil of Orchard farm of Mother Teresa College of Agriculture is showed in (Table 2). The results obtained on soil OC showed that, regardless of different land use system, T_6 (Pomegranate) is shown to have higher organic carbon followed by sapota (0.75 %). Barren land is shown to have the lowest value for the organic carbon (0.45%). The study has resulted that the organic carbon content ranged from 2.58 - 4.41g/kg on the overall tree-based cropping system. Organic carbon is the index of organic content of the soil. The fluctuations in SOC levels can lead to alterations in soil structure, depending on the age of the trees. DeGryze et al. [19] found that after afforestation with poplar for 10 years, there was a notable enhancement in soil aggregation, reaching levels similar to those found in native forest in the mineral surface soil (0-7 cm). Additionally, SOC content in both surface and subsurface soils significantly increased over different years of plantation, with a 61% increase in surface soil and a 44% increase in subsurface soil [20].

Carbon fraction pools

The observed data organic carbon fractions showed influence due to different land use system (**Table 3**). The VLC (Very Labile Carbon) value ranges from 2.46 g/kg to 3.88 g/kg. The minimum value is 2.46 g/kg in Barren land and the maximum value is 3.88 g/kg in Sapota. The LC (Labile Carbon) value ranges from 1.02 g/kg to 1.37 g/kg. The minimum value is 1.02 g/kg in Mango and the maximum value is 1.37 g/kg in Barren land. The LL (Less Labile) value ranges from 1.2 g/kg to 1.54 g/kg. The minimum value is 1.2 g/kg in Pomegranate and the maximum value is 1.54 g/kg in Barren land. The R (Recalcitrant) value ranges from 3.73 g/kg to 5.67 g/kg. The minimum value is 3.73 g/kg in Barren land and the maximum value is 5.67 g/kg. The VLC (Very Labile Carbon) value ranges from 2.46 g/kg to 3.88 g/kg. The LC (Labile Carbon) value ranges from 1.02 g/kg to 1.37 g/kg. The LL (Less Labile) value ranges from 1.2 g/kg to 1.54 g/kg. The R (Recalcitrant) value ranges from 3.73 g/kg to 5.67 g/kg. Organic carbon Oxidizable under 12 N H_2SO_4 was designated as the very labile pool (C frac1) and the difference in organic carbon oxidized between 18 and 12 N H_2SO_4 was termed the labile pool (C frac2). These two together were designated as the active pool of organic carbon because of their easy oxidisability (by weak 12 and 18 N H_2SO_4). Land use systems have a significant effect on Total and SOC fractions in the study area. Among the different fractions, viz., CL, CLL, CVL and CR fractions, CR fraction had the smallest variation among land uses, which indicate that the non-labile fraction was less sensitive to LUS. Recalcitrant fraction of organic carbon is not easily influenced by the alterations in land use management practices [21] because these carbon fractions are strongly bound to the soil mineral matrix to form mineral-humus complexes of and thus are protected from the microbial action and least decomposed [22].

Table 3 Effect of different land use systems on soil organic carbon fractions(g/kg)

Treatment	VLC (g/kg)	LC (g/kg)	LLC (g/kg)	RC (g/kg)
T_1	2.46	1.37	1.54	3.73
T_2	3.88	1.12	1.37	5.67
T_3	2.74	1.02	1.38	4.54
T_4	3.52	1.11	1.38	5.01
T_5	3.83	1.09	1.2	4.72
T_6	2.96	1.67	1.79	5.38
SEd	0.09	0.08	0.03	0.06
CD (P=0.05)	1.12	1.09	0.08	1.09

The active pools varied from 3.83 to 5 g/kg. In tree based cropping system the minimum value was associated with barren land (3.83 g/kg) and the maximum was in (5 g/kg) sapota (**Table 4**). The passive pools varied from 5.27 g/kg to 7.17 g/kg. In tree based cropping system the minimum value is 5.27 g/kg in barren land and tha maximum value is 7.17 g/kg in Pomegranate. Active soil organic matter primarily comprises fresh plant materials and residues, undergoing rapid decomposition. As it decomposes incompletely, it transitions into slower or passive soil organic matter pools. Although the active pool constitutes a relatively small portion of total soil organic matter, it plays a crucial role in maintaining and monitoring soil quality [23]. Slow soil organic matter, primarily composed of detritus from decomposed material, exhibits partial resistance to microbial decomposition. In contrast, passive soil organic matter lacks biological activity but significantly influences soil quality.

Table 4 Effect of different land use systems on soil active pools and passive pools(g/kg) of carbon

Treatment	**Active pools (g/kg)**	**Passive pools (g/kg)**
T_1	3.83	5.27
T_2	5	7.04
T_3	3.76	5.92
T_4	4.63	6.39
T_5	4.92	5.92
T_6	4.63	7.17
SEd	0.09	1.01
CD (P=0.05)	1.28	2.32

Microbial population

The soil bacteria colony forming unit range varies between 23.2 to 46.1 CFU/g 10^{-6} (**Table 5**). In tree based cropping system the minimum and maximum values lies between 23.2 CFU/g 10^{-6} in Barren land and 46.1CFU/g 10^{-6} in Pomegranate. The soil fungi colony forming unit range varies between 9.2 to 20.2 CFU/g 10^{-6}. In tree-based cropping system the minimum and maximum values lies between 9.2 CFU/g 10^{-6} in Barren land and 20.2 CFU/g 10^{-6} in Pomegranate. Colony forming unit Fungi varies from 9.2 to 20.2 CFU/g10^{-6}. The soil actinomycetes colony forming unit range varies between 19 to 45.2 CFU/g 10^{-6}. In tree based cropping system the minimum and maximum values lies between 19 CFU/g10^{-6} in Barren land and 45.2 CFU/g 10^{-6} in Pomegranate. Colony forming units varies from 19 to 45.2 CFU/g10^{-6}. Our study confirmed that, the highest microbial count was found in tree-based soils, probably because of presence of larger carbon source in the form of organic matter present in the forest soils as compared to other land use systems [24].

Table 5 Effect of different land use systems on soil microbial colony forming units and carbon stock

Treatment	Bacteria (CFU× 10^6/gsoil)	Fungi (CFU×10^3/gsoil)	Actinomycetes (CFU×10^4/gsoil)	Carbon stock (t/ha)
T_1	23.2	9.2	19	8.57
T_2	34.3	14.6	32.1	9.40
T_3	32.6	13.1	30.2	9.39
T_4	41.5	17.7	40.0	10.05
T_5	27.8	11.2	26.1	8.66
T_6	46.1	20.2	45.2	6.38
SEd	4.8	3.6	6.2	0.9
CD (P=0.05)	9.2	7.2	13.1	2.3

Carbon stock

The carbon stock range varies between 6.38 to 10.05 (t/ha) (Table 5). The carbon stock in overall farm basis rangers from the minimum of 6.38 (Pomegranate) to the maximum of 10.05 (Guava). Soil organic carbon stock significantly increased with depths in different LUS. Similarly, soil organic carbon stock of forest under lower depths was higher as compared to agricultural land [25] which was due to higher biomass deposit under forest compared to the agricultural land. Changes in carbon stocks following land use changes can be more pronounced in light fractions compared with bulk soil [26]. Spatial distribution of different (SOC) fractions is influenced by land use and management. Chandran et al. [27] examined the impact of horticultural land use on carbon sequestration in the semi-arid tropics of Andhra Pradesh, India. The study revealed that the forest system had approximately twice the amount of SOC at all depths compared to the horticultural system, with carbon stock changes per unit area showing 169.8 Mg ha^{-1} for forests and 73.1 Mg ha^{-1} for horticultural land. In contrast, the agricultural system exhibited the lowest SOC stock, measuring 63.1 Mg ha^{-1}.

Conclusion

Based on the findings, it's evident that the pomegranate-based cropping system exhibits the highest total organic carbon content among the analyzed orchards. This suggests that it possesses significant carbon sequestration potential, resulting in improved physical and biological indicators over time, supporting sustainable plant growth. Furthermore, from a carbon sequestration perspective, the decomposition of leaf residues by microbial biomass enhances the organic acid content in the soil. This, in turn, aids in the solubilization of nutrients that would otherwise remain insoluble.

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