Plant Archives Vol. 26, No. 1, 2026 pp. 1519-1524 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.208

INFLUENCE OF LAND USE SYSTEMS ON SOIL ORGANIC CARBON FRACTIONS IN THE VITALAPURA SUB-WATERSHED OF CHIKKAMAGALURU DISTRICT, KARNATAKA, INDIA

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(Date of Receiving : 28-12-2025; Date of Revision : 02-03-2026; Date of Acceptance : 12-03-2026)

ABSTRACT

The study assessed the effect of land use systems on soil organic carbon (SOC) fractions in the Vitalapura sub-watershed of Chikkamagaluru District, Karnataka. Surface soils (0–30 cm) from agricultural land, coconut plantation, and forest land were analyzed for labile and stable carbon fractions. Agricultural land recorded higher labile carbon with PDOC (410 mg kg^{-1}), PPOC (680 mg kg^{-1}), and CWEC (95 mg kg^{-1}), indicating rapid carbon turnover. Forest land showed the highest soil microbial biomass carbon (430 mg kg^{-1}) and stable carbon pools, with non-labile carbon of 53.49 Mg ha^{-1}. Total organic carbon increased from agricultural land (7.79 g kg^{-1}; 77.88 Mg ha^{-1}) to coconut plantation (11.25 g kg^{-1}; 112.38 Mg ha^{-1}) and forest land (14.60 g kg^{-1}; 146.04 Mg ha^{-1}). The results highlight the importance of perennial land use systems in enhancing stable soil carbon sequestration.

Keywords **:** Soil organic carbon fractions; Land use systems; Labile carbon; Carbon sequestration; Soil microbial biomass

Introduction

Soil organic carbon (SOC) plays a crucial role in maintaining soil fertility, structural stability, microbial activity, and ecosystem sustainability. It is also a major terrestrial pool for carbon sequestration, thereby mitigating climate change (Rattan Lal, 2004). However, SOC is not a uniform entity and exists in multiple pools differing in turnover time and stability.

Fractionation of SOC into labile and non-labile pools provides better insight into soil carbon dynamics than total SOC alone (Blair *et al*., 1995). Labile carbon fractions such as potassium dichromate oxidizable carbon (PDOC), potassium permanganate oxidizable carbon (PPOC), cold water extractable carbon (CWEC), and soil microbial biomass carbon (SMBC) are highly sensitive to land use changes and management practices and reflect short-term nutrient availability (Chan *et al*., 2001; Vance *et al*., 1987).

Land use change, especially conversion of forest land to cultivated systems, results in depletion of SOC, particularly from stable pools (Guo and Gifford, 2002). Perennial plantations and forest ecosystems, due to continuous litter input and minimal soil disturbance, enhance SOC accumulation and stabilization (Six *et al*., 2002). In tropical Indian watersheds, land use-induced variability in SOC fractions is pronounced due to differences in vegetation cover, residue management, and soil disturbance (Bhattacharyya *et al*., 2013).

Despite their importance, detailed studies on labile and stable carbon fractions in the Vitalapura sub-watershed of Chikkamagaluru District are limited. Hence, the present study was undertaken to evaluate the effect of land use systems on SOC fractions and carbon storage.

Material and Methods

Background of the Study Area

The present study was carried out in Vitalapura sub-watershed which is situated in the Lower Tungabhadra catchment area of the Krishna Basin. The

sub-watershed is spread in one districts in the state of Karnataka, India viz., Chikkamagaluru, Geographically, the sub-watershed extends between 13°35′0″ N to 13°37′0″ N latitudes and 76°12′0″ E to 76°15′0″ E longitudes (Fig.1). The geological formation of the sub-watershed comprises a single unit the Peninsular Gneiss which is distributed throughout the study area. Stratigraphic evaluation reveals that the lithological formations belong to both the Archean and Proterozoic eras, representing different stages of geological evolution. The sub-watershed mainly consists of granite (76.36%) and migmatites with granodiorite–tonalitic gneiss (23.63%).

The terms "land use" and "land cover" (LU/LC) are often used interchangeably, but each word has its unique sense. Land cover describes the different types of features established on the earth's surface (land cover) and the anthropogenic activity that is associated with them (land use). For small study areas and easily approachable, a suitable land cover study was adopted based on survey observations. However, such methods become less viable if area is more or challenging to access. With the improvement in the geospatial techniques and a decrease in the cost of satellite data, RS and GIS technologies have emerged as useful tools for generating various spatial data on different natural resources.

In the present study, LU/LC information of each parcel was mapped using high-resolution satellite data of quick bird (0.61 m resolution) along with the data collected during ground truth verification in the Vitalapura sub - watershed.

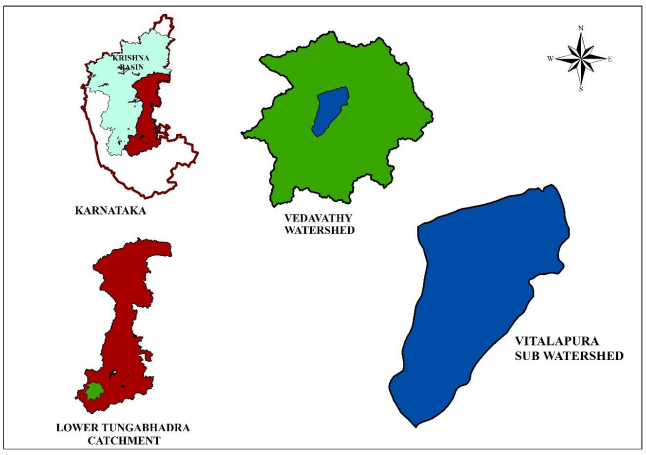

Fig. 1 : Location map of the study area

Soil Sampling

Surface soil samples (0–30 cm) were collected from agricultural land, coconut plantations, and forest land. Samples were air-dried, sieved (<2 mm), and processed for laboratory analysis.

Method of analysis of soil carbon fractions

Labile soil carbon fractions

Potassium Dichromate Oxidizable Carbon (PDOC)

Determination of potassium dichromate oxidizable carbon was carried out by wet oxidation method (Walkley and Black, 1934). Weighed 2 grams of 2 mm sieved air dry soil was powdered and passed through a 0.2 mm sieve completely.

About 0.5 g of 0.2 mm sieved soil sample was taken into a 500 ml capacity conical flask. 10 ml of 1N $K_2Cr_2O_7$ solution and 20 ml of concentrated H_2SO_4 were gently mixed and contents were kept for 30 minutes. After 30 minutes, 200 ml of distilled water, 10 ml H_3PO_4, about 0.2 g of NaF and 8 to 10 drops of diphenylamine indicator were added. Contents were titrated against standard ferrous ammonium sulphate until it becomes bright green in colour. Blank titration was run by following all the above steps without soil and calculated using the following formula;

$$\% \text{ PDOC} = \frac{10 \times 1 (\text{Blank titre value} - \text{Sample titre value} \times 0.003}{\text{Blank titre value} \times \text{weight of soil (g)}} \times 100$$

Potassium Permanganate Oxidizable Carbon (PPOC)

Potassium permanganate oxidizable carbon was determined out as per the procedure described by Blair *et al.* (1995).

Weighed 3 g of air dried (< 2 mm) soil in 50 ml centrifuge tube and 30 ml of 20 milimolar KMnO4 was added and a blank was run. Contents were shaken for 15 minutes and centrifuged for five min at 2000 rpm. 2 ml aliquot of supernatant was transferred into 50 ml volumetric flask and made up to 50 ml. The absorbance was noted at 560 to565 nm and determined the concentration of $KMnO_4$ from the standard calibration curve (plot concentration versus absorbance).

$$\text{PPIC (mg kg}^{-1}) = (B - S) \times 50/2 \times \frac{\text{Volume of } KMnO_4 \times 100}{1000 \times \text{weight of solid (g)}} \times 9$$

Where

B = concentration (m molar) of $KMnO_4$ in blank

S = concentration (m molar) of $KMnO_4$ in the sample 50/2 = Dilution factor

9 = mg carbon oxidized by 1 m mole $KMnO_4$

Cold Water Extractable Carbon (CWEC)

Estimation of cold water extractable carbon (CWEC) was carried out as perthe method described by McGill *et al*. (1986).

Weighed 10 g of field moist soil in a 50 ml centrifuge tube 20 ml of de- ionized water was added into a centrifuge tube. Contents were centrifuged at 1000 rpm for 30 minutes. The supernatant was filtered 10 ml of filtered extract was digested with 0.4N $K_2Cr_2O_7$ (2 ml), HgO (70 mg), 10 ml of concentrated H_2SO_4 and 5 ml H_3PO_4 taken in 500 ml conical flask. Two blanks were run with 10ml of distilled water each along with the acid mentioned above. The mixture was boiled gently on a hot plate at 105 ^oC for 60 minutes under reflux condition.

250 ml of distilled water was added and cooled at room temperature. The excess dichromate was determined by back titration against 0.35 N FAS

$$\text{CWEC}\left(\text{mg kg}^{-1}\right) = \frac{\text{Cold water extractable carbon}\left(\text{BTV} - \text{STV}\right)}{\text{X(g)}}$$

BTC = Blank tired value

$$\text{X(g)} = \frac{\text{Weight of wet soil (g)}}{[100 + \text{moisture (\%)}]} \times 100$$

Determination of Soil Microbial Biomass Carbon (SMBC)

The soil microbial biomass carbon was analyzed by following chloroform fumigation method.

Ten grams of soil sample was fumigated for 24 hours under vaccum in vaccum desiccator using ethanol free chloroform. After fumigation, chloroform fumes were removed by evacuation. Non-fumigated soil and fumigated soils were extracted using 50 mL. of 0.5 M K_2SO_4 and extracts were used for determining carbon (Vance *et al.*, 1987). Microbial biomass carbon in soil (SMBC):

$$\text{SMBC}\left(\text{mg kg}^{-1}\right) = \frac{E_{CF} - EC_{NF}}{K_E}$$

Where

K_{EC}= 0.25 ± 0.05 and it represents the efficiency of extraction of microbialBiomass carbon.

E_{CF} = Total weight of extractable C in the fumigated soil samples

EC_{NF} = Total weight of extractable C in non-fumigated (EC_{NF}) soil samples.

Total Carbon (TC), Total Inorganic Carbon (TIC) and Total Organic Carbon (TOC)

Estimation of total carbon and total inorganic carbon was carried out using total carbon analyzer. The commonly used method is the catalytic combustion or oxidation method. The total organic carbon was estimated by subtracting TIC from TC.

The catalytic combustion method achieves total combustion of samples by heating them to 680 °C in an oxygen rich environment inside total carbon combustion tubes in the presence of a platinum catalyst. One of the important features of this method is the capacity to efficiently oxidize hard to decompose organic compounds, including insoluble and macromolecular organic compounds. The carbon dioxide generated by oxidation is detected using an infrared gas analyzer (NDIR- non- dispersive infrared) which has high detection sensitivity with a detection limit of4 μg L^{-1} the highest level for the combustion catalytic oxidation method.

The sample was delivered at the combustion furnace which was supplied with purified air. There, it undergoes combustion through heating up to 680 °C with a platinum catalyst. It was decomposed and converted in to carbon dioxide. The carbon dioxide generated was cooled and dehumidified and then detected by the NDIR. The

concentration of TC (Total Carbon) in the soil sample was obtained through comparison with a calibration curve.

Total Carbon (TC)

About 50 to 80 mg of soil sample was weighed into a tin or silver boat. The boat was then placed into a quartz ladle which was introduced to the high temperature and oxygen atmosphere (typically 900 °C) within the sample combustion zone. At higher temperature, all the carbon within the soil sample got rapidly oxidized to CO_2. Interfering reaction products two (including sulphur oxides, halides, water and nitrous oxides) were removed by the post combustion scrubbers. The resulting carbon dioxidewas then swept into the Coulometer or detector where it was automatically measured.

Total Inorganic Carbon (TIC)

About 50 to 80 mg of soil sample was weighed into a silver boat then the soil sample was treated with the acid (HNO_3 80 %) then the boat was placed into a quartz ladle which was introduced to the high temperature and oxygen atmosphere (typically 200 °C) within the soil sample combustion zone. At higher temperature, all the carbon within the sample got rapidly oxidized to CO_2 and evolved CO_2 was carried to the detector two by the carrier gas and the concentration of CO_2 was read through the infrared detector.

Total Organic Carbon (TOC)

The total organic carbon was determined by subtracting the soil total inorganiccarbon from the total carbon content of soil as below;

Total Organic Carbon (TOC) = Total Carbon (TC) – Total Inorganic Carbon (TIC)

Determination of E4/ E6 ratio of Humic Acid (HA) and Fulvic Acid(FA)

Extraction and fractionation

10 grams of soil sample was weighed in a 250 ml Erlenmeyer flask and 50 ml of 0.1 N HCl was added to remove simple structural organic matter fraction namely sugars, polysaccharides, proteins, fats, waxes, cellulose *etc*., by oxidation. The soil acid mixture was boiled for 30 minutes and cooled. The suspension was decanted and the soil residue was retained for humic acid and fulvic acid extractions.

The soil residue was extracted with 50 ml of 0.1 M NaOH in 0.1 M sodium pyrophosphate and it was repeated thrice for complete extraction of humic fractions. The pooled alkali extract was acidified to pH 2 with 2 N HCl stirred well and allowed to stand at room temperature for 24 hours. The soluble fulvic acid was separated from

coagulate (humic acid fraction) by centrifugation. The absorbance values of HumicAcid (HA) and Fulvic Acid (FA) were recorded to determine the E4 / E6 ratios.

E4 / E6 ratio

The degree of humification and aromaticity of humic acid and fulvic acid was measured using E4/E6 ratios. A known quantity of the sample was taken and dissolved in 10 ml of 1×10^{-2} M $NaHCO_3$ solution. The absorbance at 465 and 665 nm was measured using UV-VIS scanning spectrophotometer and the absorbance ratio was recorded.

Soil Organic Carbon (SOC) storage

Changes in soil organic carbon generally occur over many years and it is often difficult to identify small changes. The TOC contents stored in soil (t ha^{-1}) was calculated using equation (Manjunatha *et al.*, 2012).

$$\text{Carbon storage (t ha}^{-1}) = \frac{\text{Area (m}^2) \times \text{BD (Mg m}^{-3}) \times \text{Depth (cm)} \times \text{TOC (g kg}^{-1})}{1000}$$

The data obtained were subjected to statistical analysis and correlation analysis was carried out to assess the relationship of soil carbon fractions with soil properties (Sundararaj *et al.*, 1972).

Results and Discussion

The distribution of soil organic carbon fractions varied markedly among agricultural land, coconut plantation, and forest land (Table 1), reflecting the strong influence of land use and management practices on soil carbon dynamics.

Labile Carbon Fractions (PDOC, PPOC, CWEC and SMBC)

Potassium dichromate oxidizable carbon (PDOC) was highest in agricultural land (410 mg kg^{-1}), followed by coconut plantation (355 mg kg^{-1}), and lowest in forest land (295 mg kg^{-1}). Higher PDOC values in agricultural soils indicate dominance of easily oxidizable organic carbon due to frequent soil disturbance, rapid residue turnover, and lower stabilization of organic matter.

Similar trends of elevated PDOC in cultivated soils have been reported by Blair *et al*. (1995) and Chan *et al*. (2001), who observed that intensive cultivation enhances the proportion of active carbon pools.

Potassium permanganate oxidizable carbon (PPOC), a sensitive indicator of management-induced changes in soil carbon, followed a similar trend, with agricultural land recording the highest PPOC (680 mg kg^{-1}), followed by coconut plantation (600 mg kg^{-1}) and forest land (515 mg kg^{-1}). Higher PPOC in agricultural soils reflects greater availability of partially decomposed organic substrates, whereas lower values under forest land indicate progressive transformation of labile carbon into more stable forms. These observations are in agreement with earlier findings reported in tropical and subtropical soils (Blair *et al*., 1995; Bhattacharyya *et al*., 2013).

Cold water extractable carbon (CWEC), representing readily soluble carbon available for microbial metabolism, was also highest in agricultural land (95 mg kg^{-1}), followed by coconut plantation (83 mg kg^{-1}) and forest land (70 mg kg^{-1}). Elevated CWEC in agricultural soils suggests rapid carbon cycling and frequent release of soluble organic compounds due to cultivation practices. Lower CWEC in forest soils may be attributed to immobilization of soluble carbon into microbial biomass and humified fractions, as reported by McGill *et al*. (1986).

In contrast to other labile fractions, soil microbial biomass carbon (SMBC) was highest in forest land (430 mg kg^{-1}), followed by coconut plantation (310 mg kg^{-1}), and lowest in agricultural land (215 mg kg^{-1}).

Higher SMBC in forest soils can be attributed to continuous litter input, diverse root systems, favorable microclimate, and absence of mechanical disturbance, which promote microbial proliferation. Lower SMBC in agricultural soils reflects reduced substrate availability and frequent disturbance, consistent with observations by Vance *et al*. (1987) and Six *et al*. (2002).

Distribution of Oxidizable Carbon Pools (Very Labile to Non-Labile Carbon)

Very labile and labile carbon fractions were predominant in agricultural land (24.63 and 28.94 Mg ha^{-1}, respectively), indicating rapid carbon turnover and limited stabilization. Coconut plantations showed moderate levels of very labile carbon (21.46 Mg ha^{-1}) but relatively higher labile carbon (38.12 Mg ha^{-1}), reflecting continuous organic inputs from perennial vegetation. Forest land recorded lower very labile carbon (18.72 Mg ha^{-1}) but substantial labile carbon (32.65 Mg ha^{-1}), suggesting efficient transformation of fresh residues under undisturbed conditions.

Less labile and non-labile carbon fractions increased markedly from agricultural land to forest land. Forest land recorded the highest less labile (41.18 Mg ha^{-1}) and non-labile carbon (53.49 Mg ha^{-1}), indicating greater carbon stabilization and long-term sequestration potential. Coconut plantation soils showed intermediate values, while agricultural land recorded the lowest values (14.27 and 10.04 Mg ha^{-1}, respectively). The accumulation of passive carbon pools under forest land is attributed to organo-mineral associations, aggregate protection, and reduced decomposition rates, as reported by Six *et al*. (2002) and Lal (2004).

Total Carbon, Inorganic Carbon and Organic Carbon

Total carbon (TC) and total organic carbon (TOC) were highest in forest land (17.86 and 14.60 g kg^{-1}, respectively), followed by coconut plantation (13.24 and 11.25 g kg^{-1}), and lowest in agricultural land (9.12 and 7.79 g kg^{-1}). Higher TOC in forest soils is associated with continuous biomass input and minimal anthropogenic disturbance, whereas lower TOC in agricultural soils reflects accelerated organic matter mineralization due to intensive cultivation. Similar land use-induced variations in TOC have been widely reported in Indian soils (Bhattacharyya *et al*., 2013; Guo and Gifford, 2002).

Humification Status (E4/E6 Ratio)

The E4/E6 ratio of humic and fulvic acids decreased from agricultural land to forest land. Agricultural soils recorded higher E4/E6 ratios (6.12 for HA and 9.84 for FA), indicating lower molecular weight and less humified organic matter. Forest soils recorded lower ratios (3.46 for HA and 5.92 for FA), reflecting higher aromaticity, molecular condensation, and degree of humification. Coconut plantation soils exhibited intermediate values. These results indicate progressive humification and stabilization of organic matter under perennial and forest land use systems, consistent with earlier reports on humic substance characterization.

Soil Organic Carbon Storage

Soil organic carbon storage followed the order: forest land (146.04 Mg ha^{-1}) > coconut plantation (112.38 Mg ha^{-1}) > agricultural land (77.88 Mg ha^{-1}). Higher SOC storage in forest land reflects dominance of passive carbon pools and efficient carbon stabilization mechanisms. Although forest soils store higher carbon per unit area, coconut plantations contribute substantially to landscape-level carbon storage due to their wider spatial extent. Similar watershed-scale observations have been reported by Manjunatha *et al*. (2012) and Wani *et al*. (2003).

Table 1: Distribution of Soil Organic Carbon Fractions under Different Land Use Systems

Carbon fraction	Agricultural land	Coconut plantation	Forest land
Potassium dichromate oxidizable C (PDOC) mg kg^{-1}	410	355	295
Potassium permanganate oxidizable C (PPOC) mg kg^{-1}	680	600	515
Cold water extractable C (CWEC) mg kg^{-1}	95	83	70
Soil microbial biomass C (SMBC) mg kg^{-1}	215	310	430
Very labile carbon mg kg^{-1}	24.63	21.46	18.72
Labile carbon mg kg^{-1}	28.94	38.12	32.65
Less labile carbon mg kg^{-1}	14.27	29.84	41.18
Non-labile carbon mg kg^{-1}	10.04	22.96	53.49
Total Carbon (TC) g kg^{-1}	9.12	13.24	17.86
Total Inorganic Carbon (TIC) g kg^{-1}	1.33	1.99	3.26
Total Organic Carbon (TOC) g kg^{-1}	7.79	11.25	14.60
SOC stock Mg ha^{-1}	77.88	112.38	146.04
E4/E6 ratio (Humic acid)	6.12	4.78	3.46
E4/E6 ratio (Fulvic acid)	9.84	7.63	5.92

Conclusion

The present study clearly demonstrated that land use systems exert a strong influence on soil organic carbon fractions and carbon stabilization in the Vitalapura sub-watershed of Chikkamagaluru District, Karnataka. Agricultural land was dominated by labile carbon fractions such as potassium dichromate oxidizable carbon, potassium permanganate oxidizable carbon, and cold water extractable carbon, indicating rapid carbon turnover and limited stabilization. In contrast, forest land recorded higher soil microbial biomass carbon and a greater proportion of less labile and non-labile carbon pools, reflecting enhanced carbon stabilization and long-term sequestration potential. Coconut plantation soils exhibited intermediate characteristics with a balanced distribution of active and passive carbon pools.

Total organic carbon and soil carbon storage increased in the order: agricultural land < coconut plantation < forest land, highlighting the role of perennial vegetation and reduced soil disturbance in carbon accumulation. Lower E4/E6 ratios in forest soils further indicated a higher degree of humification and organic matter maturity. Although forest land stored the highest carbon per unit area, coconut plantations contributed substantially to the overall soil carbon pool due to their wider spatial coverage. The study emphasizes that promotion of perennial land use systems and adoption of conservation-based soil management practices are essential for enhancing stable soil carbon sequestration, improving soil health, and ensuring long-term sustainability of agro-ecosystems in the region.

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