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# Impact of Different Land Use Systems on Soil Organic Carbon Dynamics

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Soil organic carbon (SOC) is vital for maintaining soil health, performing uninterrupted environmental functions and sustaining agricultural production. Soil management practices like land use changes, frequent tillage, improper fertilization and low or no exogenous carbon addition may lead to excess emission of $CO_2$ from soils, causing global warming and climate change. The soil organic matter (SOM) is considered as the most complex and least understood component of soil, because it is comprised of plant, microbial and animal bodies in various stages of disintegration and a mixture of heterogeneous organic substances closely associated with the inorganic constituents. The global soil carbon (C) pool of 2500 gigatons (Gt) includes about 1550 Gt of soil organic carbon (SOC) and 950 Gt of soil inorganic carbon (SIC). The soil C pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560). Global carbon cycle includes atmospheric pool biotic pool pedologic pool oceanic pool and geologic pool.

There are several pools and fractions of SOM with varying degrees of decomposition with stability and these fractions may be useful in the study of short-term as well as long-term influences of land use and management on SOC dynamics. Total organic carbon (TOC) is comprised of both labile and non-labile forms of SOC and has different degrees of sensitivity to various land use changes and management practices. Several studies have reported that labile fractions, such as the light fraction organic carbon (LFOC), particulate organic carbon (POC), readily oxidized carbon and microbial biomass carbon (MBC) are quickly changed and restored. Hence, compared to TOC, these labile SOM fractions can be used as sensitive indicators to study the effect of land use systems and management practices on soil quality and SOM changes in the short-term.

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When considering global climate change, land use has become a key factor that is directly related to food security, water and soil quality and other life support issues. Recently, the influence of land use change and management practices on SOC dynamics has gained scientific attention, because alteration in land cover, land use and management practices can have a significant impact on global carbon pools and fluxes (Sharma *et al*., 2014). Land use change could cause changes in soil quality and land productivity over time and space by altering the structure and functioning of ecosystems and biogeochemical cycles.

**Characteristics of Different Soil Organic Carbon Pools**

The active pools represent labile forms of carbon highly sensitive to alteration with a mean residence time of about 1-5 years. Being vulnerable to rapid oxidation, this pool poses the potential for rapid decomposition, thereby accentuating $CO_2$ effluxes to the atmosphere. However, this pool of carbon plays a pivotal role in fuelling the soil food web and influences a variety of soil functions and processes from nutrient cycling to maintaining. Impact of land use changes and management practices soil productivity and its quality. Slow pools of SOC have about 20-40 years of mean residence time while, for the passive SOC pools, it is about 200-1500 years. The stabilized carbon fractions are highly resistant to microbial activity and hence, they hardly serve as a reliable indicator of soil quality but contribute to overall carbon fixation.

**Different Soil Organic Carbon Fractions**

- **Total organic carbon (TOC):** TOC is referred to as the amount of carbon bound in organic compounds in soil. These organic materials can be derived from endogenous and exogenous sources. The carbon fraction stored in this organic matter represent the total organic carbon (TOC) in the soil, and for all practical purposes, it is assumed that SOM contains 58% carbon. TOC is measured by conventional colorimetric method via dichromate digestion and using a TOC analyzer. TOC is calculated by subtracting IC (inorganic carbon) from total carbon (TC) (TOC=TC-IC)
- **Particulate and mineral-associated organic carbon:** It is an intermediate portion of the SOM formed from new organic constituents or is derived from semi-decomposed aboveground organic residues near the surface soil or roots beneath the surface soil. Physical fractionation schemes generally classify SOM into three broad groups: coarse particulate organic matter containing organic fragments >250µm (cPOM), fine

particulate organic matter consisting of organic materials 53–250µm (fPOM), and mineral-associated organic matter (MinOM).

- **Dissolved organic carbon (DOC):** Continuum of organic Impact of land use changes and management practices 9 molecules of varying sizes, compositions, and structures that passes through a 0.45µm filter. Dissolved organic carbon (DOC) originates from a multitude of sources like plant litter, root exudates, soil humus, or from microbial biomass. The DOC fractions present in the macro- and meso-sized pores are subjected to convective transport (seepage) and represent the mobile forms, whereas the DOC components in micro-pores may be considered immobile. Low molecular weight substances, like amino acids, carbohydrates, and organic acids, and high molecular weight substances, like humic substances (i.e., fulvic, humic acids, and humin), are referred to as well-known DOC matrices.
- **Extractable organic carbon:** Dissolved organic matter has been further divided into labile, semi-labile, and non-labile parts. Labile carbon, called extractable organic carbon, is referred to as a primary energy source that can be readily degradable or consumed quickly (hours-weeks) by soil microorganisms. It is also identified as a short-lived carbon pool. For instance, simple sugars (*i.e.*, glucose, fructose) and protein degradation products (*i.e.*, amino acids) are labile carbon compounds. For the determination of labile carbon, oxidation with $KMnO_4$ is used and has been practiced successfully by many researchers. Breakdown of intermediate products of cellulose or hemicellulose is an example of a semi-labile organic compound. This fraction can be decomposed into the labile carbon fraction with time. Most of the high molecular weight humic substances are examples of the non-labile carbon fraction in soils. Determination of non-labile carbon can be performed by subtracting labile carbon from total carbon.
- **Microbial biomass carbon (MBC):** Microbial biomass carbon (MBC) represents the living SOC fraction and is considered as an estimate of biological activity in soil and is a major measurable carbon fraction included in several multi-pool models of SOC dynamics Determination of MBC by using chloroform fumigation extraction method.

## Factors Affecting Organic Carbon Dynamics

The amount of SOC that can be stored in a given soil is estimated by the difference between the rate of carbon input (vegetation, roots) and output ($CO_2$ emission to the atmosphere). Nevertheless, there are several controlling factors such as topography, climate, soil type, soil sampling depth, mineralogical composition, soil biota, land use and management practices and the interaction between them that affect the total amount of SOC in the soil profile.

### Climatic factors

- **Temperature:** Temperature, a key rate-determining factor of organic carbon decomposition is generally modeled by the Arrhenius equation or its mathematical derivatives. The biochemical decomposition of SOC is strongly temperature dependent in two ways: (i) the direct effects such as molecular attributes and temperature influences on enzyme kinetics and microbial metabolism (intrinsic temperature dependency); and (ii) indirect effects like temperature controls on carbon substrate solubility and diffusion (extrinsic temperature dependency)
- **Rainfall/moisture:** Rainfall is one of the major abiotic factors influencing SOC dynamics in soils under all land uses including agriculture, horticulture, forest, or grassland. Directly, it changes the environment for plant growth and species richness and, thus, determines the amount of above- and belowground biomass production. Increased biomass production has a positive impact on SOC storage through root induced protection of organic carbon in soil. Indirectly, it affects the biological processes responsible for changing the soil pH, redox potential, nutrient availability, soil weathering, and mineralogy. Srinivasarao *et al.* (2009) studied the influence of rainfall on soil carbon fractions under different crop productions in tropical India. They estimated SOC, soil inorganic carbon (SIC), and total carbon (TC) stocks under various rainfall ranges from 1100mm. They found that SOC had a significant correlation with mean annual rainfall, while SIC decreased with an increase in mean annual rainfall due to the dissolution and leaching of calcium carbonate down the soil profile.

### Soil-related factors

- **Parent materials/soil type:** Organic carbon characteristics are regulated by the soil type in various ecosystems that range along with clay content and are found in the order of desert > red > alluvial > laterite > saline > black soil. Black and forest soils are rich with clay (34.5%), and carbon availability is high due to the unhumified organic carbon. The SOC content varies with soil types based on the status of soil nutrients and other properties like mineralogy and texture, which determine biomass production. Soils with 1:1 clay mineral (e.g., kaolinite), 2:1 clay mineral (e.g., montmorillonite), and Fe and Al oxides and hydroxides vary with respect to the specific surface area and charge densities. These properties of the clay minerals determine the variation in the bond strength between the SOC and clay minerals. Srinivasarao *et al.* (2009), carbon stocks of four major soil orders/types under a tropical rain-fed production system were estimated. *vertisols* showed maximum SOC, SIC, and TC, while *Aridisols* had the lowest SOC, SIC and TC compared to other soil types.

- **Soil texture:** Soil texture refers to the relative size distribution of the sand, silt, and clay sized particles that make up the mineral fraction of the soil. It has been reported that soil texture plays an important role in carbon stabilization and the rate of SOC sequestration in soils. Sandy or sandy to loam soils do not hold SOC for long periods due to their low protective capacity with low clay content. A study based on soil micro-aggregates has revealed that the organic matter is physically protected with clay and silt aggregates and, hence, resists microbial attacks on carbon leading to its sequestration in soils. SOM tends to increase with the increase in clay content based on two mechanisms. Firstly, the complexation of organic and clay matter actively hampers decomposition. Secondly, enhanced clay content in soil increases the probability of aggregate formation.
- **Soil pH:** Soil pH can have a significant impact on the potential of agricultural soils to store SOC. Soil pH alters the decomposition and dynamics of SOC primarily via physical, chemical, or biological processes.
  - **Physico-chemical processes:** Soil pH can affect the solubility of humic SOC substances via protonation/ deprotonation reactions. The quantity of dissolved SOC (DOC) increases in response to lime-induced increase in soil pH, while it decreases following high acid deposition. Below pH 4, the solubility of SOC is relatively pH-independent due to a high degree of protonation. The protonation of functional groups such as carboxylate and phenolate decreases the electrostatic repulsion among the molecules and promotes the formation of intermolecular H-bonds and

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large humic aggregates. Enhanced SOC solubility at higher pH is attributed to the decreased occupation of binding sites with protons and hence, increased charge density.

- **Biological processes:** Soil pH can modify the decomposition of SOC via its effect on the activity of soil microbes. Directly, soil pH affects microbial growth with optimal pH ranging from 6.5 to 7.5. A positive correlation has been detected between soil pH and microbial biomass C or $CO_2$ evolution. Soil pH can also indirectly affect microbial growth and activity via influencing factors such as C substrate availability availability and solubility of metal ions.
- **Priming effect:** Soil pH can also affect the decomposition of SOC via the priming effect. The priming effect is a short-term change in microbial decomposition of SOC in response to labile-C inputs. Greater positive priming effects are frequently detected in soils with higher pH and the optimum pH for the priming effects lies in the range of 6–8. In acid soils, the magnitude and direction of the priming effect is also related to the liming effect of the organic material.
- **Soil moisture:** Moisture in soils is a key factor in decomposing SOC by soil microorganisms and carbon sequestration is moisture dependent. Microbial SOC utilization also depends on soil moisture and temperature condition. SOC redistribution and associated $CO_2$ emissions under soil erosion strongly depend on the temporal variability of environmental conditions such as initial soil moisture, location, soil management and rainfall. Increase in soil moisture provides food for soil biota by increasing microbial biomass content. In contrast, flooding or water saturation over long periods leads to poor aeration and causes a reduction in mineralization rates.
- **Soil structure:** Soil structure denotes the arrangement of soil particles into groupings such as peds or aggregates, which often form distinctive shapes typically found within certain soil horizons. Soil structure and SOC are interrelated. Briefly, SOC acts as a binding agent in the formation of soil aggregates, and soil aggregate stability is important in maintaining soil structure. Lal (2004) highlighted that well-stabilized soil structure avoids the loss of SOC by soil erosion, thereby increasing the rate of SOC sequestration in soils.

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- **Porosity:** Soil porosity refers to the fraction of the total soil volume that is taken up by the pore space. SOC derived from microorganisms within soils pores is bound and stabilized with aggregates, thereby affecting soil carbon sequestration. Hydrophobic SOC dominated by aromatic and aliphatic compounds (i.e., particulate carbon forms) has been shown to be physically bound in 2-5µm pore spaces in soils. In the same study, oxidized carbon fractions clogging pores and coating pore cavities on mineral surfaces have been reported to be in a nanoscale distribution for the organo-mineral assemblage of micro-aggregates in a heavy textured soils pores is bound and stabilized with aggregates, thereby affecting soil carbon sequestration.
- **Soil microbial community:** Soil microorganisms can be grouped into bacteria, actinomycetes, fungi, algae, protozoa, and nematodes. Soil Impact of land use changes and management practices 29 microorganisms are involved in the decomposition of soil organic matter, and the rate of decomposition depends both on the nature of microorganisms in soil and the nature of organic matter sources.

  Melanin, chitin, and glomalin are examples of fungal-derived recalcitrant residues that tend to exist for a long time in soils. Apart from the humification process, soil microorganisms are involved in mineralization of SOM, thereby resulting in the loss of carbon from soils. Soil microbes indirectly influence the physically protected SOM by improving soil aggregation, thereby enhancing carbon stabilization in soils
- **Topography:** Topography affects soil carbon budgets by way of erosion and subsequent redistribution of soil particles and organic matter across a landscape, and by way of water distribution that affects SOC dynamics. Topography is a key, passive soil forming factor and, thus, causes a strong relationship between SOC and terrain attributes at field scales.
- **Land uses and soil organic carbon dynamics:** Land use and management dictate whether the soil will be a source or a sink of atmospheric carbon (Lal, 2004). Generally, land management practices with less soil disturbance increase soil organic carbon accumulation. Soil organic carbon loss also occurs when native forest ecosystems are altered to cultivated systems. But, development of vegetation

on barren or abandoned agricultural land enhances its carbon storage capacity. Crop rotations, minimum tillage, intercropping, organic farming, and management of crop residue contribute to SOC build-up in the soil.

- **Forests:** Forest soils play a major role in the global carbon cycle and are major carbon sinks on earth. Sreekanth *et al*. (2013) studied organic carbon and its fractions under four typical forest types in Southwestern Ghats of India.

  The forest types included southern tropical thorn forest (TF), tropical riparian fingering forest (RF), southern montane temperate forest (SF), and southern dry mixed deciduous forest (DF). Forest types influenced the SOC and its various fractions like POC and labile and non-labile carbon. SF showed the maximum SOC, POC, and non-labile carbon fractions, while TF showed minimum values of POC and labile carbon fractions compared to other forest types.

- **Horticulture:** Horticultural lands have about the equivalent capacity to store as much carbon as do forest lands, horticulture lands have been given little attention with respect to soil organic carbon dynamics and global warming mitigation potential. In addition to enhancing soil attributes and good soil health, cultivation of perennial horticulture crops helps in sequestering more organic carbon and $CO_2$ compared to annual crops, and the perennials could provide a low-cost method for net emission reduction. Bhavya *et al*. (2017) compared three horticultural land use systems including mango orchard, cashew orchard, rose, vegetables, and medicinal and aromatic plants in India for their global warming mitigation potential through carbon sequestration in soil. They reported highest SOC stocks under the mango orchard, which was at par with the cashew orchard due to the continuous addition of organic matter under perennial orchards compared to annual crops including rose, vegetables, and medicinal and aromatic plants.

- **Agriculture:** Globally more than one-third of arable land is used for agriculture. Hence finding means to enhance SOC storage in agricultural systems will provide an option to mitigate rising atmospheric carbon. Several management strategies in agriculture appear to provide SOC sequestration by increasing organic inputs to soil and enhancing different soil processes that protect SOC from microbial decomposition

  SOC depletion in agricultural soils enhances soil degradation, which includes the following: (i) Physical degradation: decline in soil structure, reduction in aggregation, compaction, crusting, reduced water infiltration, anaerobiosis, and erosion; (ii) Chemical degradation: reduction in pH and subsequent acidification, nutrient depletion, nutrient imbalance, disruption in elemental cycles, and accumulation of salts in the root zone; (iii) Biological degradation: decline in diversity and activity of soil fauna and depletion of microbial biomass carbon.

Srinivasarao *et al.* (2009) investigated the impact of crop production systems, grown under various climates and soil types, on different fractions of SOC. They studied eight production systems, namely lowland rice-based, sorghum-based, maize-based, pearl millet-based, finger milletbased, soybean-based, groundnut-based, and cotton-based cropping systems. They found highest SOC stocks under the soybean-based production system (62.3 Mg C $ha^{-1}$) and lowest SOC stocks in the pearl millet- and finger millet-based production systems. The inorganic carbon stocks (SIC) were maximum under cotton (275.3 Mg C $ha^{-1}$) and sorghum-based production systems (243.7 Mg C $ha^{-1}$), while the lowest SIC was under lowland rice (18.15 Mg C $ha^{-1}$).

- **Grasslands:** Grasslands, including shrublands, rangelands, pastures, and croplands sown with fodder crops, have been reported to cover around 3.5 billion ha. On an average, temperate grasslands store about 331 Mg $ha^{-1}$ SOC and this constitutes 12% of the world's organic carbon in soil. SOC in grasslands can be strongly affected by management.

  Geraei*et al.* 2016 reported that higher labile C values observed in Forest and Pasture land uses can be explained by the relatively dense structure of plants and also the continuous deposition of organic matter via leaf litter and fine roots in the understory of forest and pasture soils, which would provide C compounds as sources of energy for soil organisms, to stimulate the activity and growth of microbial populations and consequently the accumulation of C in the microbial biomass in these soils.

**Managementpractices and soil organic carbon**

- **Nutrient management: -** Judicious use of nutrients and their management are crucial for SOC sequestration. In general, organic manures enhance SOC pools more compared to nutrient management with mineral fertilizers.

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Using groundnut-based cropping systems in tropical India, the effect of improved nutrient management practices on SOC and other C fractions was studied by Srinivasarao et al. (2014). Nutrient Impact of land use changes and management practices 57 management practices showed noteworthy effects on all the carbon fractions in the study. Application of 50% recommended doses of fertilizers (RDF) along with 4 Mg groundnut straw ha1 increased the SOC and MBC content 0.6 and 1.6 times, respectively compared to the control. Application of 50% RDF along with 4 Mg farm yard manure ha1 increased the POC content twofold compared to the control**.**

- **Irrigation and crop residue mulch:** Uncertainty in the SOC responses to future soil moisture changes occur due to unpredictability in (i) the relationship between microbial mediated carbon evolution and soil moisture and, (ii) the failure to assess the direction and size of soil moisture variations in the future, and (iii) the lack of a comprehensive understanding of the overall carbon response to climate change.

  Chatterjee *et al*. (2018) conducted an experiment on effects of irrigation, crop residue mulch and nitrogen management in maize (*Zea mays* L.) on soil carbon pools in a sandy loam soil of Indo-Gangetic plain region. The results showed that total organic carbon (TOC) increased by 40.5% in irrigation treatment compared to the rainfed treatment for the 0-5 cm soil depth after second year of cropping. Application of crop residue mulch significantly increased the TOC concentration by 14.9% at 0-5 cm soil depth compared to the no mulch treatment. The Carbon Lability Index (CLI) decreased whereas Carbon Pool Index (CPI) and Carbon Management Index (CMI) increased due to irrigation and crop residue mulch application.

**References**

Bhavya, V.P., Anil Kumar, S. and Shiva Kumar, K.M., 2017. Land use systems to improve carbon sequestration in soils for mitigation of climate change. *Int J Chem Stud*, *5*(4): .2019-2021.

Blair, G. J., Legroy and R. D. B., Lisle, L., 1995, Soil carbon fraction based on the degree of oxidation and development of carbon management index. *Aust. J. Agric. Res*. **47:** 1459-1478.

Cambardell, C. A. and Ellilot, E. T., 1992, Particulate organic matter changes across agrassland cultivation chronosequence. *Soil. Sci. Soc. Am*. J. **54:** 777-783.

Chatterjee, S., Bandyopadhyay, K. K., Pradhan, S., Singh, R. and Datta, S. P., 2018, Effects of irrigation, crop residue mulch and nitrogen management in maize (Zea mays L.) on soil carbon pools in a sandy loam soil of Indo-Gangetic plain region. *Catena*.**165**: 207- 216.

Geraei, D. S., Hojati, S., Landi, A. and Cano, A. F., 2016, Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran. *Geoderma*. **7**: 29-37.

Lal, R. 2008, Sequestration of atmospheric CO2 in global carbon pools. *Energy and Environmental Science*. **1**: 86-100.

Lal, R., Singh, B.R., Mwaseba, D.L., Kraybill, D., Hansen, D.O. and Eik, L.O., Eds., Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, Chapter 1, *Springer*, Berlin, 3-17.

Sharma, V., Hussain, S., Sharma, K.R. and Arya, V. M., 2014. Labile carbon pools and soil organic carbon stocks in the foothill Himalayas under different land use systems. *Geoderma*, **232**: 81-87.

Sreekanth, N. P., Prabha, S. V., Padmakumar, V. and Thomas, A, P., 2013, Soil carbon alterations of selected forest types in an environmental feed back to climate change. *Int. J. Environ. Sci*.**3**: 1514.

Srinivasarao, C., Lal, R., Singh, A. K. and Kundu, D., 2014, Soil organic carbon sequestration in rainfed production systems in semiarid tropics India. *Sci. Total environ.* ***487*****:**587-593.

Srinivasarao, C., Vittal, K. P. R., Venkateswalu, B., Wani, S. P., Saheawat, K. L and Marimuttu, S., Kundu, D., 2009, Carbon stocks in different soil types under diverse rainfed production systems in tropical India. *Commun. Soil. Sci. PLt Anal*. 40 **(15-17):** 2338-2359.