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Unveiling the Essence of Soil Organic Carbon: A Comprehensive Overview

Spoorthishankar, K. S.[1] and Praveen Kumar, M. B.[2]
[1]Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bengaluru.
[2]Ph.D. Scholar, Department of Forestry and Environmental Science, UAS, GKVK, Bengaluru.
*Corresponding Author: vidyaks153@gmail.com

The soil organic carbon (SOC) 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 SOC is a vital indicator of soil quality and, therefore, maintaining SOC quality and quantity is important for safeguarding long-term soil fertility. It has beneficial effects on soil physical, chemical, biological properties and thus it influences the productive capacity of the soil. Maintenance and improvement of SOM quality and quantity are the most essential criteria for sustainable soil management. The SOC has different pools and fractions including total organic carbon (TOC), particulate organic carbon (POC), microbial biomass carbon (MBC), dissolved organic carbon (DOC), permanganate oxidizable carbon ($KMnO_4$-C) and mineral associated organic carbon (MOC). Each has a varying degree of decomposition rate and stability.

Importance of soil organic carbon in soil

- Organic carbon enhances nutrient retention, transformations, and promotes soil micro-organism growth.
- It increases moisture retention capacity, aids in the degradation of pollutants, and contributes to carbon sequestration.
- For every ton of carbon in soil organic matter, approximately 100 kg of nitrogen, 15 kg of phosphorus, and 15 kg of sulfur become available to plants.
- Soil rich in organic carbon exhibits better structure, stability, aeration, water drainage, and retention, reducing erosion and nutrient leaching risks.
- Optimal organic carbon levels regulate pH, ion exchangeability, enhancing nutrient mobility and availability for improved crop productivity.
- Soil organic carbon is essential for crop nutrition, providing nutrients for plant growth and development, and facilitating nutrient cycling for sustained nutrient supply to crops.
- Soil organic carbon serves as a food source for soil microorganisms, stimulating microbial activity.
- Increased organic carbon levels enhance microbial activity, facilitating nutrient cycling and other vital soil processes.
- Heightened microbial activity ensures efficient and timely nutrient availability to plants, promoting optimal growth and development.

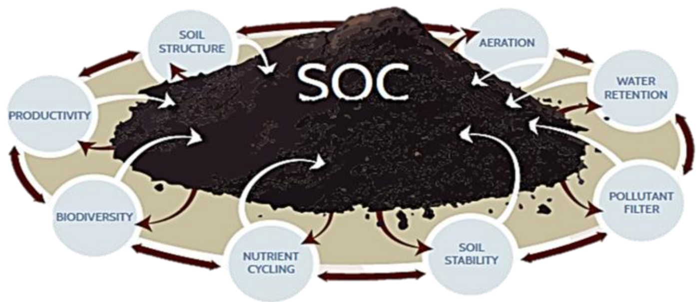

Fig 1. Role of soil organic carbon in soil

Factors affecting soil organic carbon

The Soil Organic Carbon (SOC) content in India has come **down to 0.3 per cent from 1 per cent in the past 70 years**. The factors affecting soil organic carbon (SOC) levels are numerous and interrelated, impacting both the storage and release of carbon in soil ecosystems. Here are some of the primary factors:

1. Land Use and Management Practices

Agricultural Practices: Techniques such as tillage, crop rotation, and the use of cover crops can significantly alter SOC levels. No-till farming, for instance, tends to increase SOC by reducing erosion and increasing soil aggregation.

Forestry Management: The way forests are managed, including harvesting methods and reforestation, affects the amount of carbon stored in soil.

2. Physical Properties

Soil Texture: Clay soils tend to have higher SOC concentrations due to their ability to bind and stabilize organic carbon within their structure.

Soil Structure: Well-aggregated soils provide protected environments for SOC against microbial attack, thereby enhancing carbon storage.

Depth and Profile: Deeper soils can store more carbon, particularly if they are undisturbed and have subsoil horizons that accumulate organic matter.

3. Geological Properties

Parent Material: The mineral composition derived from the geological parent material influences soil's physical and chemical properties, which in turn affect SOC stabilization.

Topography: Terrain features influence water drainage and erosion patterns, impacting how organic matter accumulates and decomposes in soils.

4. Biological Properties

Soil Microorganisms: Bacteria, fungi, and other microorganisms play critical roles in decomposing organic matter and cycling nutrients, influencing SOC dynamics.

Root Exudates and Litter Inputs: The type and amount of organic matter derived from plant roots and leaf litter are key to forming and maintaining SOC.

5. Climate

Temperature: Higher temperatures typically increase the rate of organic matter decomposition, reducing SOC, although this is also influenced by moisture availability.

Moisture: Water availability regulates microbial activity and decomposition processes; too much or too little can limit SOC formation.

Seasonal Patterns: Seasonal variations affect plant growth cycles and microbial activity, influencing the rates of carbon input and decomposition.

6. Chemical Properties

Soil pH: The acidity or alkalinity of soil affects microbial activity and the solubility of organic compounds, influencing SOC storage.

Nutrient Availability: The presence of essential nutrients like nitrogen and phosphorus can affect plant productivity and the decomposition rate of organic matter.

Cation Exchange Capacity (CEC): Affects the soil's ability to retain important nutrients and thus influences plant growth and residue return, impacting SOC.

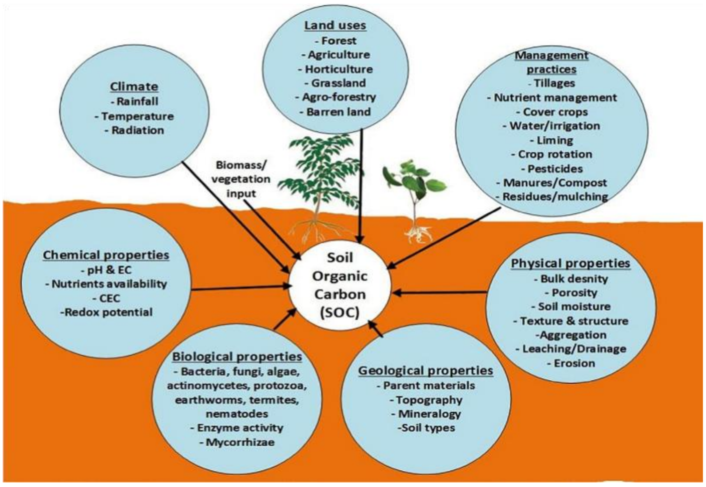

Fig. 2: Schematic diagram of the factors influencing organic carbon dynamics in soil

Soil organic carbon fractions

Total organic carbon

The carbon fraction stored in this organic matter represents the total organic carbon (TOC) in the soil. TOC is computed as the difference between the total carbon to total inorganic carbon.

TOC is broadly grouped into three major pools—active, slow, and passive carbon pools of SOC. 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. 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.

Particulate organic carbon

Particulate organic matter is composed of partially decomposed organic residues and is commonly considered an index of SOM lability. It is an intermediate portion of the SOM formed from new organic constituents or is derived from semi-decomposed above ground organic residues near the surface soil or roots beneath the surface soil.

Physical fractionation schemes generally classify SOM,

a) Coarse particulate organic matter - >250µm

b) Fine particulate organic matter – 53-250µm

c) Mineral associated organic matter -<53µm

Mineral associated organic carbon

Includes the carbon fractions of the SOM pools that are physically and chemically stabilized and are considered to represent the passive carbon pools with relatively longer turn over times.

SOC components can be stabilized in soil by,

- The intrinsic structural recalcitrance
- Interactions with mineral surfaces/ metal ions
- Physical occlusion within aggregates

Dissolved organic carbon

Organic molecules of varying sizes, compositions and structures that passes through 0.45µm filter. It is speculated to have its origin either from recent litter or from the relatively stable SOM usually found in lower parts of organic horizons.

Based on the soil pore size, the DOC pool can be further partitioned in to

1. Easily mobile fractions.
2. Immobile fraction.

DOM is dissolved organic matter. It consists of non-degradable and biodegradable parts. Based on degradation rates as measured by the amounts of DOC mineralized after a certain period, the biodegradable DOM 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. 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. This fraction is resistant to microbial decomposition and can persist in the soil environment for several years. Therefore, this fraction plays a crucial role in determining carbon sequestration in soils.

Microbial biomass carbon

Microbial biomass carbon (MBC) represents the living SOC fraction and has been studied extensively. MBC 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.

Conclusion

Soil organic carbon (SOC) is pivotal for soil health, fertility, and climate change mitigation. Its fractions, like total organic carbon, particulate organic carbon, and microbial biomass carbon, exhibit varying rates of turnover and stability. Sustainable land management practices are essential for enhancing SOC levels and maintaining ecosystem resilience. Moving forward, strategies should prioritize optimizing these practices to enrich SOC content, thereby fostering soil health, productivity, and global carbon cycle regulation.

References

Black, C. A. (1965). Method of Soil Analysis Part II Agronomy Monograph No. 9. *American Soc. Agron.*, Madison, Wisconsin, 148.

Cambardella, C. A. and Elliott, E. T. (1992). Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Sci. Soc. Am. J.*, **56** (3) : 777-783.

Carter, M. R. (1991). Ninhydrin-reactive N released by the fumigation-extraction method as a measure of microbial biomass under field conditions. *Soil Biol. Biochem.*, **23** (2) : 139-143.

Chan, K. Y. Bowman, A. and Oates, A. (2001). Oxidizible organic carbon fractions and soil quality changes in an *Oxic Paleustalf* under different pasture leys. *Soil Sci.*, **166** (1) : 61-67

Table 1: Determination of different carbon fractions in soil

Total carbon	CHN analyzer
Water soluble carbon McGill *et al*. 1986	10 grams of soil was shaken with 20 mL of deionized water for an hour, then centrifuged at 10,000 rpm for 30 minutes. The resulting supernatant was filtered, and 5 mL of it was used to determine organic carbon content using the Walkley and Black method from 1934.
Particulate organic carbon Cambardella and Elliot (1992)	20 g of air-dried soil was dispersed in 100 mL of sodium hexa-metaphosphate (5 g L^{-1}) with shaking by hand during first 15 min and then on a reciprocating shaker for 18 h the soil suspension was poured over a 53 µm screen using a flow of distilled water. All the material remaining on the screen, defined as the particulate organic carbon fraction and it was washed into a dry dish, oven dried at 60°C for 12 h, weighed and grounded to < 0.5 mm for determination of organic carbon.
Oxidizable organic carbon fractions (Chan *et al*., 2001).	-
Very labile	Organic C oxidizable under 12 N H_2SO_4
Labile	Difference in oxidizable organic C extracted between 18 N and 12 N H_2SO_4 (18 N–12 N H_2SO_4).
Less labile	Difference in oxidizable organic C extracted between 24 N and 18 N H_2SO_4
Recalcitrant	Difference in organic C extracted with 24 N H_2SO_4 and TOC determined by CHN analyzer (TOC–24 N H_2SO_4).
Microbial biomass carbon Carter (1991)	For the estimation of MBC two sets of samples have to be taken in the screw cap tube. weight 2.5 g of soil in each tube and add about 0.5 mL of methanol free chloroform in each tube and keep it for incubation at 40°C for five days. After five days of incubation add about 12.5 mL of 2 M KCl in each tube and keep it in the reciprocal shaker for 30 min. later filter the content. Pipette out 2 mL of filtrate in the test tube to this add 4 mL of ninhydrine and keep it in the boiling water bath for 20 min for color development. Purple color intensity was measured at 570 nm wavelength in spectrophotometer

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