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Increasing Soil Organic Carbon in Agricultural Soils: A Key to Sustainable Crop Production

*Harini V[1] and V. Sasikala[2]

[1]SMS (Agronomy), ICAR-KVK, TANUVAS, Namakkal, India

[2]Associate Professor and Head, ICAR-KVK, TANUVAS, Namakkal, India

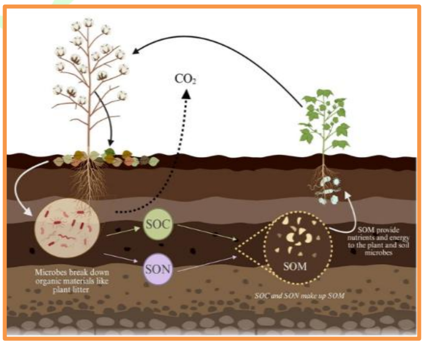
*Corresponding Author's email: harinivenkatesan49@gmail.com

Soil Organic Carbon (SOC) is one of the most important indicators of soil health and agricultural sustainability. It is the carbon component of soil organic matter derived from decomposed plant residues, animal wastes, microorganisms, and root biomass. Declining SOC due to intensive cultivation, excessive tillage, residue burning, and imbalanced fertilizer use has become a major concern in Indian agriculture. Increasing SOC improves soil physical, chemical, and biological properties, leading to enhanced nutrient availability, water-holding capacity, microbial activity, and crop productivity. It also contributes to carbon sequestration and climate change mitigation. Adoption of practices such as organic manure application, green manuring, crop residue incorporation, conservation agriculture, cover cropping, agroforestry, and integrated nutrient management can effectively restore SOC levels. This article highlights the concept, importance, types, methods of improvement, mode of action, and agricultural benefits of soil organic carbon for sustainable farming.

Keywords: Soil organic carbon, soil organic matter, carbon sequestration, green manure, conservation agriculture, biochar, compost, soil fertility, sustainable agriculture.

Introduction

Healthy soil is the foundation of sustainable agriculture. Among various soil quality indicators, Soil Organic Carbon (SOC) plays a central role because it influences nearly all soil functions. Soil organic carbon is derived from decomposed plant residues, animal manures, microorganisms, and root exudates and forms the major component of soil organic matter. Approximately 58% of soil organic matter consists of organic carbon (Brady and Weil, 2017). In India, continuous cultivation, removal or burning of crop residues, excessive tillage, soil erosion, and indiscriminate use of chemical fertilizers have resulted in a gradual decline in SOC. Low SOC reduces soil fertility, limits water availability, decreases microbial activity, and ultimately lowers crop productivity (Lal, 2004). Increasing SOC has therefore become an important strategy for maintaining soil health, improving nutrient-use efficiency, and mitigating climate change through carbon sequestration (Paustian *et al.*, 2016).



Definition of Soil Organic Carbon

Soil Organic Carbon (SOC) refers to the carbon fraction of soil organic matter originating from decomposed plant residues, animal wastes, microorganisms, root biomass, and humified organic substances. It is widely recognized as an important indicator of soil quality because it directly affects soil productivity and environmental sustainability (Lehmann and Kleber, 2015).

Importance of Soil Organic Carbon

SOC provides numerous agronomic and environmental benefits:

- Improves soil aggregation and structural stability (Six *et al*., 2002).
- Enhances water infiltration and increases water-holding capacity, reducing drought stress (Lal, 2004).
- Increases cation exchange capacity and nutrient retention (Brady and Weil, 2017).
- Promotes beneficial microorganisms and earthworm activity (Lehmann and Kleber, 2015).
- Improves root growth and nutrient uptake.
- Reduces soil erosion and surface crusting.
- Improves fertilizer-use efficiency.
- Enhances crop productivity and quality.
- Acts as a sink for atmospheric carbon dioxide through carbon sequestration (Paustian *et al*., 2016).
- Improves resilience of farming systems under climate change.

Types of Soil Organic Carbon

SOC is generally classified into three fractions.

Active (Labile) Carbon

Active carbon consists of fresh organic residues and easily decomposable compounds. It decomposes rapidly, supplies nutrients to crops, and serves as the primary energy source for soil microorganisms. It responds quickly to changes in management practices.

Slow Carbon

Slow carbon represents partially decomposed organic materials with moderate stability. It contributes to medium-term nutrient supply and improves soil fertility over several years.

Passive (Stable) Carbon

Passive carbon is composed mainly of humus and highly stable organic compounds protected within soil aggregates. It remains in soil for decades or even centuries and is responsible for long-term carbon sequestration and sustainable soil fertility (Six *et al*., 2002).

Methods to Increase Soil Organic Carbon

1.Application of Organic Manures

Regular application of farmyard manure (FYM), compost, vermicompost, poultry manure, and enriched compost increases soil organic matter and improves microbial activity. Annual application of 5–10 t ha^{-1} FYM significantly improves SOC and soil fertility (Lal, 2004).

2. Green Manuring

Growing green manure crops such as sunhemp (*Crotalaria juncea*) and daincha (*Sesbania aculeata*) and incorporating them into the soil before flowering adds organic biomass and nitrogen, thereby increasing SOC.

3. Crop Residue Recycling

Crop residues should be retained and incorporated into the soil instead of burning. Residue incorporation improves soil aggregation, microbial activity, and long-term carbon storage (Lal, 2004).

4. Conservation Agriculture

Conservation agriculture emphasizes minimum soil disturbance, permanent soil cover, and crop diversification. Reduced tillage slows organic matter decomposition and enhances SOC accumulation (Paustian *et al*., 2016).

5. Crop Rotation and Cover Crops

Including legumes and cover crops in crop rotations increases biomass production and root carbon inputs while improving soil fertility.

6. Biochar Application

Biochar is a stable carbon-rich material produced by pyrolysis of biomass. It increases carbon storage, enhances nutrient retention, and improves soil water-holding capacity (Lehmann and Joseph, 2015).

7. Integrated Nutrient Management (INM)

Combining organic manures, biofertilizers, and recommended doses of chemical fertilizers improves nutrient-use efficiency while sustaining SOC levels.

8. Agroforestry

Integration of trees with agricultural crops contributes leaf litter, root biomass, and organic residues, thereby increasing SOC over time.

9. Organic Mulching

Application of crop residues, straw, or dry leaves as mulch conserves soil moisture, suppresses weeds, and gradually enriches soil organic carbon during decomposition.

Mode of Action of Soil Organic Carbon

Organic materials added to the soil are decomposed by bacteria, fungi, actinomycetes, and earthworms. During decomposition, nutrients are mineralized and made available to crops. A portion of the decomposed material is transformed into stable humus, which binds soil particles into aggregates. Improved aggregation enhances aeration, infiltration, water retention, and root penetration. Stable carbon fractions remain protected within soil aggregates, thereby increasing carbon sequestration and long-term soil fertility (Six *et al.*, 2002; Lehmann and Kleber, 2015).

Uses of Soil Organic Carbon in Agriculture

- Maintains long-term soil fertility.
- Improves soil physical properties.
- Enhances microbial diversity.
- Improves nutrient cycling.
- Reduces fertilizer losses.
- Increases fertilizer-use efficiency.
- Improves drought tolerance.
- Supports sustainable crop production.
- Enhances crop yield and produce quality.
- Reduces greenhouse gas emissions through carbon sequestration.
- Improves resilience of agricultural systems to climate variability.

Conclusion

Soil Organic Carbon is the foundation of healthy and productive agricultural soils. Maintaining adequate SOC is essential for improving soil fertility, nutrient availability, water retention, and biological activity while ensuring sustainable crop production. Regular application of organic manures, green manuring, crop residue incorporation, conservation agriculture, crop diversification, agroforestry, and integrated nutrient management are practical approaches for increasing SOC. Adoption of these practices not only enhances farm productivity but also contributes to climate change mitigation through long-term carbon sequestration. Therefore, increasing soil organic carbon should be considered a key component of sustainable agriculture and soil health management.

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