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Soil Carbon and Its Importance in Agriculture Sector

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Soil carbon is a crucial element in the maintenance and production of agricultural soils. It is closely linked to organic matter present in soils, nutrient cycling, aquifer properties, soil aggregation and biological activities. Intensive tillage, burning of residues, high soil disturbance, and low organic matter incorporation can reduce the level of soil carbon in the soil with the passage of time. In contrast, practices such as crop residue management, growing cover crops, crop rotation, use of conservation agriculture, incorporating organic amendment into the soil, agroforestry, and appropriate nutrient management can lead to the increase of soil organic carbon. Soil carbon is also significantly important for climate change mitigation efforts since carbon which is kept in soils is carbon that has been taken out of the atmosphere. FAO considers soil organic carbon an important indicator of soil health and mentions its influence on food production.

Keywords: Soil Carbon, Agricultural Soil, Intensive Tillage, Burning Residue, Soil Organic Matter, FAO, Soil Health

Introduction

Soil exists not just to support plant roots. It is full of things such as minerals, organic materials, bacteria, gas, and water. Further, soil organic carbon is one of the significant parts of this composition because of its influence on certain physical, chemical and biological properties of soil. Soil organic carbon is the type of carbon that is contained in soil organic matter derived from plant crop remnants, roots of crops, microorganisms, animal crop remnants, and other biological substances at different stages of decay. FAO finds the presence of soil organic carbon very important as it shows how healthy soil is because organic matter presents in soil is responsible for water and nutrient retention and contributes to soil functions. Agricultural soils can lose carbon, especially if the land undergoes the process of intensive cultivation, and if organic matter is not replaced. FAO claims that all the soil carbon losses that have occured are caused by the changes in land use in history and improper soil management.

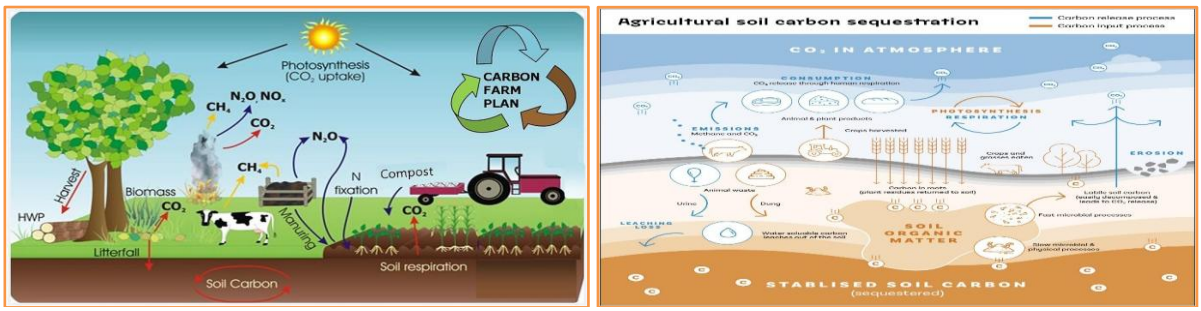

Image: Soil Carbon Cycle in Agricultural Ecosystem

What is Soil Carbon?

The entry of carbon into the agricultural soil is accomplished essentially by means of photosynthesis. The plants utilize carbon dioxide from the atmosphere for the synthesis of organic substances. Some of the carbon is transported into the underground part of the plant through its roots, root exudates, and plant residue. The microbes of the soil then decompose these plant parts, during which process some carbon is released into the atmosphere, while a part of it goes into the soil organic matter. The carbon in the soil is present in different states ranging from 'easy-to-decompose' organic substances to more resistant organic material associated with soil minerals. Whether the carbon going into the soil exceeds the carbon lost from the soil determines whether the SOC grows, stays the same, or decreases. According to FAO, even changes in land use and management have a particularly high influence on the upper soil layers, thus making the agricultural management of vital importance for existing SOC stocks preservation and the increase of the sequestered SOC.

Main Roles of Soil Carbon

Through a number of interconnected mechanisms, soil carbon improves agricultural production.

- Better Soil Structure
- Water Holding Capacity
- Nutrient Cycle
- Microbes
- Decrease of Soil Erosion

The significance of soil carbon can be presented in the following table.

Table 1: Major agricultural functions associated with soil carbon.

Soil carbon function	Importance in agriculture
Soil aggregation	Enhances soil properties and minimizes soil erosion
Water storage	Helps with water preservation
Nutrient circulation	Aids in availability and recycling of nutrients
Soil microbes	Function as a power source for soil organisms
Cation/ nutrient retention	Enhances efficiency of utilization of nutrients
Root zone	Provides a supportive environment for plant roots
Carbon storage	Plays a role in the removal of CO_2 from the atmosphere
Soil resilience	Helps maintain soils under impacts of various environmental factors

According to the FAO, the soils that are high in organic and carbon content possess major soil health and ecosystem functions related to food production and water benefits.

Soil Carbon and Crop Productivity

Crop productivity is a function of soil fertility, moisture availability, climate, crop species and management practices, with soil carbon influencing crop productivity indirectly by improving some of the properties leading to crop growth. Application of organic practices is one of the ways of increasing soil carbon. It was established as a result of a global synthesis that organic practices do increase SOC in agricultural lands. This conclusion was reinforced by a meta-analysis of several experiments on the effect of organic practices on crop yields, soil carbon and nutrient cycling processes, making the link between biological soil management and crop productivity. Therefore, soil carbon is not just a measure of carbon accumulated in the soil but an integral part of the soil health concept.

Major Sources of Soil Carbon

Agricultural soils obtain carbon from a wide variety of sources:

1. **Crop residues-** such as leaves, stems, roots, etc. left after harvesting the crops.
2. **Root biomass** – dead roots and root-derived carbon.
3. **Root exudates** – carbon-containing compounds released by living roots.

4. **Farmyard manure and compost** – organic materials applied to agricultural land.
5. **Green manure and cover crops** – biomass incorporated into or left on the soil.
6. **Agroforestry biomass** – leaves, roots and woody materials associated with trees.
7. **Organic amendments** such as suitable composted materials and biochar.

Approaches in Agriculture to Augment Carbon Content in Soil

Table 2: Management practices and their potential contribution to soil carbon

Management practice	Potential contribution
Crop residue retention	Returns carbon to soil
Cover cropping	Adds biomass and protects soil surface
Crop rotation	Diversifies carbon inputs
Reduced/conservation tillage	Can reduce disturbance and decomposition
Compost application	Adds relatively stable organic material
Farmyard manure	Increases organic inputs
Green manuring	Adds fresh biomass
Agroforestry	Provides continuous above- and below-ground carbon inputs
Balanced fertilization	Supports crop biomass production and residue return
Integrated nutrient management	Combines organic and mineral nutrient sources

The FAO has established conservation agriculture, use of soil cover and cultivation diversity as key management techniques for managing organic matter.

Relationship Between Soil Carbon and Climate Change

The interrelation between carbon in soil and climate change is an essential matter. Plants absorb carbon dioxide (CO_2) from the atmosphere during photosynthesis which is converted into organic carbon in the soil. Carbon sequestration in the soil signifies an increase in carbon captured in the soil per a certain starting point. FAO considers agricultural soil to be one of the most significant sources of carbon storage and practices emphasizing sustainable soil management. On the other hand, soil carbon sequestration is not **unlimited and irreversibly**. FAO states that sequestration is a slow and reversible process. Hence, all methods of increasing soil carbon should be regularly performed.

Factors Impacting on Soil Carbon

Various factors determine the level of carbon stored in the agricultural soil.

Climate

Temperature and precipitation affect both productivity and decomposition processes.

Soil Texture

Clay-rich soils can provide greater physical protection for some organic carbon compounds compared with coarse-textured soils.

Cropping System

Crop rotation, growing perennial plants, and diversified agricultural systems are influencing the quantity and the quality of carbon inputs. Tillage Repeated and heavily-using technology can lead to accelerated decomposition and allow soil organic matter to come to situations that favour carbon loss. According to FAO, intensive soil disturbance is one of the causes of agricultural soil organic matter depletion. Organic Matter Inputs Regular practice of returning crop residue, manure, compost and other kinds of suitable organic material can lead to increase in carbon input.

Proper Management of Soil Carbon in India

In India, enhancing soil carbon is more pertinent when it comes to keeping soil fertility high and increasing soil resilience in areas suffering from soil degradation, water shortages and high levels of agricultural intensity. The farming practices which include soil carbon through CV tree monoculture and the disposal of harvested residues can be less carbon-influencing than farming methods which make use of residue recycling and other organic amendments.

ICAR-IARI has noted carbon farming as a technique in which raising the level of SOC becomes a priority.

As for Indian farmers, some techniques are as follows:

- Retaining suitable crop residues in the field;
- Avoiding unnecessary burning of residues;
- Using compost and well-decomposed farmyard manure;
- Introducing legumes into crop rotations;
- Growing cover crops where feasible;
- Reducing unnecessary tillage;
- Adopting diversified cropping systems; and
- Integrating trees with crops where appropriate.

These type of soil, climatic conditions, crop, availability of water, and regional agricultural circumstances should be kept in mind to select the proper method.

Soil carbon, Climate-Smart Agriculture

The aim of climate-smart agriculture is the increased productivity and the likelihood of sustainable agriculture with lesser greenhouse-gas emissions where possible.Present studies still explore how some agricultural practices affect crop yield, SOC and greenhouse-gas emissions at the same time. The 2026 global synthesis has summarized that the impact of agricultural practices on yield, SOC and emissions differs from one management practice to another. Therefore, specific recommendations should be given instead of one method that is supposed to work always the same. Consequently, while it's important to keep in mind productivity, soil health and greenhouse-gas emissions, both farmers and agro-scientists shouldn't ignore the fact about soil carbon storage as well.

Challenges in Soil Carbon Management

Although increasing SOC has many potential benefits, several challenges remain:

- Soil carbon changes relatively slowly and may require several years to detect clearly.
- Carbon stocks vary considerably within the same field.
- To measure and monitor effectively, sampling and analytical techniques must be appropriate.
- Further, carbon accumulation is influenced by climatic conditions and soil type.
- In addition, some carbon-regulating practices may require more labor and funds.

For this reason, soil carbon management should be viewed as a long-term strategy in soil quality improvement.

Future Prospect

Soil carbon management will increasingly rely on methods such as precision agriculture, remote sensing, and digital mapping. An example of this development is represented by FAO's Global Soil Organic Carbon Sequestration Potential map which demonstrates the amount of soil organic carbon sequestered under different scenarios and emphasizes the need for monitoring and reporting. Technologies could also assist in identifying areas of low soil organic carbon and in increasing precision of management of the concerned zones.

Conclusion

Soil carbon is an important component in the existence of productive, healthy and sustainable soils. It affects key physical characteristics of the soil, the stability of soil structure, the capacity of the soil to retain water, nutrient circulation, microorganisms and general functioning of the soil ecosystem. At the same time, agricultural soils have great potential to capture carbon when correctly managed. There are many effective methods of improving the soil carbon management in practice that do not require special means or equipment, namely, maintaining crop residues in the soil, applying organic fertilizers and amendments, diversifying crop families and types, limiting the operations needed in farming, applying cover crops and adopting agroforestry solutions. However, the results may differ significantly

depending on climatic and management conditions. Therefore, the role of the soil carbon should be understood not only from the climate-change point of view; soil carbon provides a good opportunity to ensure the soil quality.

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