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## Role of Soil in Carbon Sequestration

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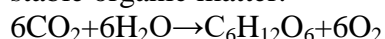
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Soil is one of the most important natural resources on Earth. Beyond supporting plant growth and agricultural production, soil plays a critical role in regulating the global climate system. One of its most significant environmental functions is carbon sequestration — the process of capturing atmospheric carbon dioxide (CO<sub>2</sub>) and storing it in the soil for long periods. In recent decades, climate change caused by increasing greenhouse gas emissions has become a major global concern. Scientists and policymakers now recognize that healthy soils can act as powerful carbon sinks capable of reducing atmospheric CO<sub>2</sub> levels and mitigating global warming. Carbon exists in the atmosphere, plants, oceans, rocks, and soils. Among terrestrial ecosystems, soil stores more carbon than vegetation and the atmosphere combined. According to FAO, soils contain approximately 1,500–2,400 gigatons of organic carbon globally, making them one of the largest carbon reservoirs on Earth. The growing interest in sustainable agriculture, regenerative farming, and climate-smart land management has increased attention toward soil carbon sequestration. Researchers are studying how agricultural practices, land restoration, and soil conservation can increase soil organic carbon while improving soil fertility and food security.

### Understanding Carbon Sequestration

Carbon sequestration refers to the capture and long-term storage of carbon dioxide from the atmosphere. It occurs naturally through biological, geological, and technological processes. In soil systems, carbon sequestration mainly happens through photosynthesis and the accumulation of organic matter. Plants absorb CO<sub>2</sub> from the atmosphere during photosynthesis and convert it into organic compounds such as sugars, roots, leaves, and stems. When plant residues decompose, part of the carbon becomes incorporated into the soil as soil organic carbon (SOC). Soil organisms such as bacteria, fungi, and earthworms help transform plant material into stable organic matter.

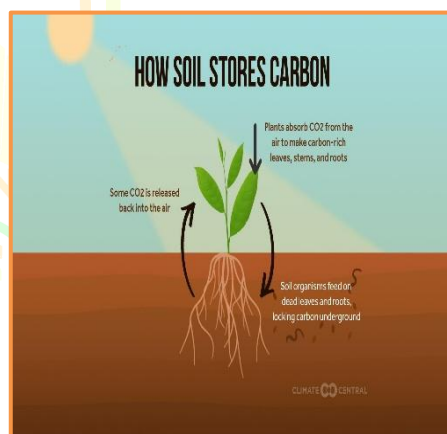


This equation shows photosynthesis, where plants capture atmospheric carbon dioxide and convert it into biomass.

### Soil as a Carbon Reservoir

Soils store carbon in two primary forms:

1. **Soil Organic Carbon (SOC)** – carbon derived from decomposed plant and animal materials.
2. **Soil Inorganic Carbon (SIC)** – carbon stored in mineral forms such as carbonates.



Among these, soil organic carbon is the most important for climate regulation and agricultural sustainability. Globally, soils contain more carbon than the atmosphere and vegetation combined. The upper 30 cm of the world's soils alone hold enormous amounts of carbon.

## Major Soil Carbon Pools

- Plant biomass
- Root biomass
- Soil microorganisms
- Soil humus
- Deep soil layers

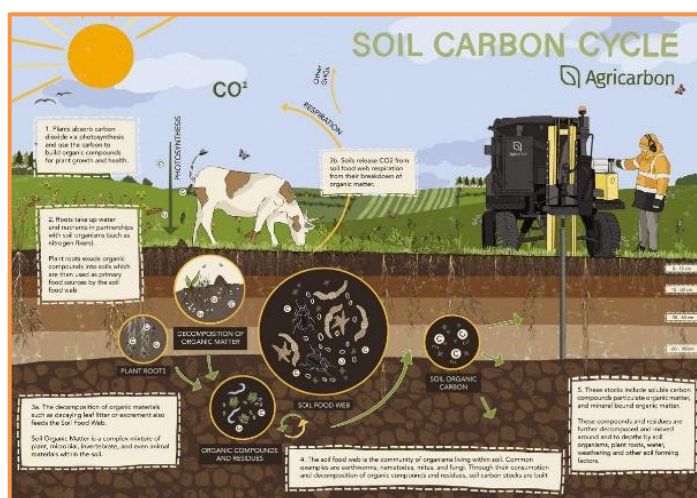
Deep soils are increasingly recognized as important long-term carbon storage zones.

## The Soil Carbon Cycle

The soil carbon cycle involves continuous movement of carbon between the atmosphere, plants, soil organisms, and soil organic matter.

### Steps in the Soil Carbon Cycle

1. Plants absorb  $\text{CO}_2$  through photosynthesis.
2. Carbon enters the soil through roots, leaf litter, and crop residues.
3. Soil microorganisms decompose organic matter.
4. Some carbon is released back into the atmosphere through respiration.
5. The remaining carbon becomes stabilized in soil aggregates and humus.



## Importance of Soil Carbon Sequestration

- 1. Climate Change Mitigation-** The most important role of soil carbon sequestration is reducing atmospheric  $\text{CO}_2$  concentrations. Carbon stored in soil remains out of the atmosphere for years or even centuries. Scientists estimate that improved soil management could significantly contribute to global climate mitigation strategies. The Food and Agriculture Organization has emphasized sustainable soil management as a key tool for achieving climate goals. (FAO)
- 2. Improvement of Soil Fertility-** Higher soil organic carbon improves: Nutrient availability, Soil structure, Water retention, Microbial activity. Carbon-rich soils are generally more fertile and productive.
- 3. Enhanced Water Holding Capacity-** Organic matter acts like a sponge, allowing soils to retain more water. This helps crops survive drought conditions and reduces irrigation requirements.
- 4. Reduction of Soil Erosion-** Healthy soils with higher organic matter have better aggregation and are less prone to erosion by wind and water.
- 5. Biodiversity Conservation-** Soils rich in carbon support diverse microbial communities, earthworms, fungi, and other organisms essential for ecosystem functioning.

## Current Global Status of Soil Carbon

The Food and Agriculture Organization developed the Global Soil Organic Carbon Sequestration Potential Map, which evaluates the potential of agricultural soils to capture additional carbon under sustainable management practices (FAO).

Research published in 2024 and 2025 shows:

- Soil carbon stocks vary greatly across regions.

- Tropical and peatland soils store massive amounts of carbon.
- Agricultural intensification has caused substantial carbon loss from soils.
- Regenerative practices can partially restore soil carbon stocks. (MDPI)

A major concern is that climate change itself may reduce soil carbon storage capacity. Rising temperatures accelerate decomposition and carbon release from soils. A recent Australian study warned that soils may become net carbon emitters under severe warming and drought conditions. (The Guardian)

### **Agricultural Practices that Enhance Soil Carbon Sequestration**

- Conservation Tillage
- Cover Cropping
- Crop Rotation
- Agroforestry
- Biochar Application
- Integrated Crop-Livestock Systems
- Role of Soil Microorganisms

### **Challenges in Soil Carbon Sequestration**

1. Carbon Saturation
2. Reversibility
3. Climate Change Effects
4. Measurement Difficulties
5. Economic Constraints
6. Scientific Uncertainty

### **Soil Carbon Sequestration and Sustainable Development**

Soil carbon sequestration contributes directly to several United Nations Sustainable Development Goals (SDGs):

- SDG 2: Zero Hunger
- SDG 13: Climate Action
- SDG 15: Life on Land

Healthy soils improve food security, water conservation, biodiversity, and ecosystem resilience.

### **Soil Carbon Sequestration in India**

India faces severe soil degradation due to erosion, intensive farming, deforestation, and overuse of chemical fertilizers. However, India also has strong potential for soil carbon sequestration through: Conservation agriculture, Agroforestry, Organic farming, INM. Recent studies in Rajasthan demonstrated significant variation in soil carbon sequestration potential across different land-use systems (PubMed). Government programs promoting natural farming and sustainable agriculture may help increase soil organic carbon while improving farmer livelihoods.

### **Conclusion**

Soil plays a vital role in carbon sequestration and climate regulation. Through photosynthesis, decomposition, and microbial activity, soils capture and store large amounts of atmospheric carbon dioxide. Healthy soils not only reduce greenhouse gas concentrations but also improve agricultural productivity, water retention, biodiversity and ecosystem sustainability. As the world faces increasing environmental and food security challenges, soil carbon sequestration offers a promising natural solution for mitigating climate change while supporting sustainable development. Protecting and restoring soils must therefore become a global priority for ensuring a healthier planet and a sustainable future for coming generations.

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