6. Soil's Organic Carbon - Environment

A comprehensive study by the ICAR has highlighted serious degradation of soil organic carbon (SOC) in India's arable lands

Background of the ICAR Study

The Indian Council of Agricultural Research (ICAR) conducted a 6-year nationwide assessment (2017–2023) of soil health. A total of 2.54 lakh soil samples were analyzed from 620 districts across 29 States, making it one of the largest soil carbon studies globally. The objective was to understand soil carbon distribution, its relationship with nutrient deficiencies, and the influence of climate, geography, and cropping systems.

Soil Organic Carbon (SOC) - Meaning, Role & Importance

SOC - SOC is the carbon component of soil organic matter, originating from decomposed plants, roots, crop residues, microorganisms, and soil fauna. Represents about 58% of total organic matter in soil.

Why SOC Matters – Foundational Role in Soil Health - SOC determines soil chemistry (nutrients), soil physics (structure, porosity), and soil biology (microbial activity). Acts as the "engine of soil fertility" and the backbone of long-term agricultural productivity.

Environmental Significance - SOC is a key carbon sink, storing CO_2 naturally in soils. Higher SOC levels reduce atmospheric carbon, supporting climate change mitigation.

Benefits of High Soil Organic Carbon

1. Improves Soil Structure - Enhances aggregation, reduces compaction, and improves root penetration.

2. Increases Water-Holding Capacity - SOC-rich soils act like sponges, retaining up to 20x more moisture; critical under drought conditions.

3. Enhances Nutrient Availability - Supports nutrient cycling of N, P, K, and micronutrients. Organic matter releases nutrients slowly, improving fertilizer-use efficiency.

4. Boosts Crop Yields - High SOC leads to stronger root systems, better nutrient absorption, and higher biomass.

5. Prevents Soil Erosion - SOC binds soil particles, reducing erosion from water and wind.

6. Reduces Greenhouse Gas Emissions - High SOC soils store carbon for decades, lowering CO_2 release.

Key Findings of the ICAR Study

1. Direct Link Between SOC and Micronutrient Deficiency - Areas with low SOC show high micronutrient deficiencies (Zn, Fe, Mn, Cu). High-SOC soils are nutritionally balanced, supporting healthy crop growth.

2. Heavy Use of Urea and Phosphorus is Depleting SOC - Unbalanced fertilizer practices reduce microbial diversity and degrade soil carbon stocks. Urea-heavy nitrogen fertilization accelerates organic matter decomposition.

3. SOC Distribution Follows Climate–Geography Gradients

Elevation - High-altitude areas (Himalayan states) have higher SOC due to cooler temperatures and slower decomposition.

Temperature - Hotter states (Rajasthan, Telangana) have low SOC due to fast organic matter breakdown.

Rainfall - Moderate rainfall facilitates decomposition and carbon buildup; erratic rainfall reduces SOC formation.

4. Cropping System Strongly Influences SOC

High SOC Systems -

1. Rice-based systems
2. Pulse-based systems
3. Multi-cropping
4. Crop rotations

Low SOC Systems -

1. Wheat monoculture

2. Coarse cereals in arid regions
3. Continuous single-crop cycles

Waterlogged and biologically rich rice–pulse systems promote more carbon storage.

5. Fertilizer Imbalance Causes Regional Variations

Low SOC regions - Punjab, Haryana, Western UP - Heavy urea/phosphorus usage, Intensive monocropping (wheat–rice), Over-irrigation

Higher SOC regions - Bihar, Jharkhand, Eastern India - More balanced fertilizer use. Mixed cropping and livestock integration

Agri-Ecological Base Map' – A Major Outcome of the Study

Purpose - A scientific tool linking climate, geography, cropping patterns, and fertilizer usage with SOC levels across India.

Key Functions

Identify High-Risk Areas - Pinpoints districts with declining SOC for urgent intervention.

Policy Planning - Helps plan carbon farming, soil restoration, and sustainable agriculture strategies.

Carbon Credit Implementation - Crucial for future carbon markets rewarding farmers for increasing soil carbon.

Scientific Land Management - Guides crop diversification, afforestation, and soil conservation programs.

Climate Change Impacts on SOC – Detailed Explanation

1. Temperature-Driven SOC Loss - High temperatures accelerate microbial decomposition of organic matter. Hot & arid regions lose SOC fastest, worsening desertification. More CO_2 is released, strengthening the greenhouse effect.

2. Rainfall and Moisture Effects - Adequate rainfall supports microbial life essential for SOC formation. Climate change causes erratic rainfall → reduced microbial activity → lower SOC formation.

3. Greenhouse Feedback Loop - Low SOC soils reflect more solar radiation and hold less moisture. This intensifies surface heating (albedo effect), raising ground temperatures. Higher heat causes faster SOC loss, creating a self-amplifying climate–soil degradation cycle.

Policy Recommendations and the Way Forward

1. Promote Organic Carbon Sequestration - Prioritize restoration in soils with very low SOC ($<0.25\%$). Encourage compost, farmyard manure, biochar, green manuring, and crop residues. Expand irrigation to support carbon-positive cropping systems.

2. Implement Carbon Credit Incentive Mechanisms - Reward farmers who enhance SOC through sustainable practices. Integrate SOC improvement into PM-PRANAM, National Mission on Sustainable Agriculture, and State Action Plans on Climate Change.

3. Encourage Balanced Fertilizer Use - Replace excessive urea with balanced N - P - K ratios. Promote soil testing, site-specific nutrient management, and bio-fertilizers.

4. Promote Carbon-Positive Cropping Systems - Encourage rice–pulse rotations, legumes, multi-cropping, and agroforestry. Discourage wheat–rice monocultures in low-carbon regions.

5. Maintain Vegetative Cover - Prevent bare soil through cover crops, mulching, and crop residue retention. Promote silvopasture, agroforestry, and tree plantation.

6. Integrate SOC into National Land and Climate Policies - Treat SOC as a key performance indicator in agricultural programs. Use the Agri-ecological Base Map for climate-smart agriculture planning.

Carbon Capture and Sequestration (CCS) – Expanded Notes

Definition - CCS is a technological process that captures CO_2 emissions at their source (industries, refineries, power plants) and stores them underground.

Difference Between CCS and Carbon Dioxide Removal (CDR)

CCS - Prevents new CO_2 from entering the atmosphere.

CDR - Removes CO_2 already present in the atmosphere (e.g., DAC, afforestation, soil carbon sequestration).

Types of Carbon Sequestration

1. Terrestrial Sequestration - Captures carbon in soils, forests, wetlands, and crop biomass. Includes afforestation, reforestation, conservation agriculture, soil carbon enhancement.

2. Ocean Sequestration - Injecting CO_2 into deep oceans. Fertilizing ocean waters to stimulate plankton growth that absorbs CO_2 (controversial due to ecological risks).

3. Geological Sequestration

Injecting compressed CO_2 into deep underground formations -

1. Depleted oil & gas reservoirs
2. Deep saline aquifers
3. Coal seams (ECBM)

Ensures long-term storage for thousands of years.

CCS Process – Step-by-Step

1. Capture

CO_2 is captured using techniques such as -

1. Pre-combustion
2. Post-combustion
3. Oxy-fuel combustion

Used in thermal power plants, refineries, cement, steel, and chemical industries.

2. Transport

CO_2 is compressed and transported through -

1. Pipelines
2. Rail
3. Ships
4. Trucks

3. Storage - Injected into stable underground formations. Long-term containment prevents leakage into the atmosphere.

Conclusion

The ICAR study highlights a critical national challenge - India's soils are rapidly losing organic carbon due to climate, fertilizer misuse, and unsustainable agricultural practices. SOC must become a central pillar of India's agricultural, environmental, and climate policies. Strengthening SOC is not only about soil health — it is essential for food security, climate mitigation, water conservation, and rural livelihoods.

Source - https - //www.thehindu.com/sci-tech/energy-and-environment/climate-change-imbalance-in-fertiliser-use-kill-soils-organic-carbon-icar-study/article70257059.ece