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Regenerating Agricultural Soils through Organic Carbon

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INTRODUCTION

Agricultural soils are central to food production, ecosystem services, and climate regulation. However, intensive farming practices, excessive use of chemical inputs, and deforestation have significantly reduced soil organic carbon levels. This not only affects crop productivity but also contributes to environmental degradation and greenhouse gas emissions.

Soil organic carbon, derived from decayed plant and animal matter, is the key component of soil organic matter (SOM). Its restoration and conservation are fundamental for improving soil structure, enhancing nutrient availability, and supporting beneficial microorganisms. Rebuilding organic carbon stocks is crucial to reversing land degradation and improving the long-term sustainability of agriculture.

2. Importance of Soil Organic Carbon (SOC)

2.1 Soil Fertility and Productivity

SOC plays a critical role in nutrient cycling, especially of nitrogen, phosphorus, and sulfur. It acts as a reservoir of nutrients that are slowly released to plants, ensuring steady crop growth and reducing dependence on synthetic fertilizers.

2.2 Soil Structure and Water Retention

Organic carbon improves soil aggregation, which enhances porosity, aeration, and water-holding capacity. This is particularly vital in dryland and semi-arid regions where water availability is a limiting factor for crop production.

2.3 Biodiversity and Microbial Activity

Healthy soils with higher SOC support diverse communities of soil organisms - including bacteria, fungi, nematodes, and earthworms - that contribute to nutrient recycling, pest control, and overall soil vitality.

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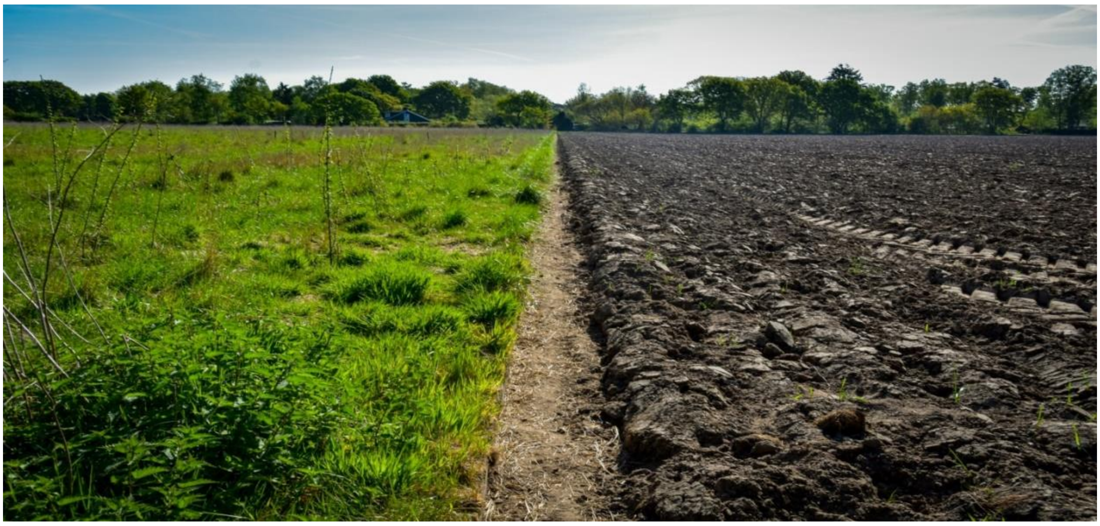

Source: https://regenerationinternational.org

2.4 Climate Change Mitigation

SOC acts as a carbon sink, helping to reduce atmospheric CO_2 levels. Globally, soil contains more than twice the carbon stored in the atmosphere, making it a critical component of climate-smart agriculture.

3. Causes of Soil Organic Carbon Depletion

Several human-induced and natural factors contribute to SOC loss:

- **Intensive tillage**: Frequent plowing exposes soil organic matter to oxidation and erosion.
- **Monoculture**: Reduces biomass input and disrupts soil microbial balance.
- **Overgrazing**: Leads to vegetation loss and compaction, limiting organic matter return to the soil.
- **Deforestation and land-use change**: Decrease plant biomass input and increase soil exposure to erosion.
- **Chemical dependency**: High inputs of synthetic fertilizers and pesticides can disrupt soil microbial ecosystems.

4. Strategies for Regenerating Soil Organic Carbon (SOC)

Regenerating SOC is central to improving soil health, increasing productivity, and building climate-resilient agricultural systems. Transitioning to regenerative agricultural practices is key to achieving this goal. Below are proven strategies that effectively enhance soil organic carbon levels:

4.1 Compost and Farmyard manure (FYM) Application

The application of compost and farmyard manure (FYM) is one of the most effective strategies for enhancing soil organic carbon (SOC). These organic amendments are rich in decomposed plant and animal residues, which improve soil structure, microbial activity, and nutrient availability. Compost and FYM contribute to humus formation, which enhances soil fertility and moisture retention. Regular use over time significantly boosts SOC levels. For example, long-term studies in India's Indo-Gangetic Plains have shown up to a 20% increase in SOC with continuous compost use, contributing to improved crop productivity and soil health.

4.2 Green Manuring

Green manuring involves growing leguminous plants like *Sesbania* or *Crotalaria* and plowing them into the soil while still green. These crops fix atmospheric nitrogen and contribute significant organic biomass, enhancing soil fertility and boosting SOC without synthetic inputs.

4.3 Cover Cropping

Cover crops such as clover, rye, vetch, and buckwheat are grown during off-seasons to protect soil from erosion and add organic matter. Their roots contribute to soil aggregation and carbon input, while their canopy suppresses weeds and enhances soil biodiversity.

4.4 Conservation Tillage

Minimal or zero tillage helps maintain soil structure and reduce oxidation of organic matter. It also conserves moisture, reduces erosion, and promotes gradual SOC accumulation.

4.5 Crop Rotation and Intercropping

Diverse cropping systems supply a continuous stream of root exudates and plant residues, enriching the soil with varied carbon sources. These systems also support beneficial microbial populations and reduce pest pressure.

4.6 Biochar Application

Biochar is a stable, carbon-rich material created from biomass pyrolysis. It resists decomposition and can remain in the soil for centuries, improving structure, water retention, and nutrient availability, particularly in degraded or sandy soils.

4.7 Agroforestry and Silvopasture

Integrating trees and shrubs into cropping or grazing systems increases above- and below-ground biomass, enhances biodiversity, and reduces soil erosion. Deep-rooted trees also contribute to long-term carbon sequestration in subsoil layers.

5. Monitoring and Management of Soil Organic Carbon (SOC)

Effective monitoring and management of SOC are essential to assess soil health and the success of regenerative practices. Regular measurement of SOC levels using standard techniques such as dry combustion (elemental analysis) and loss-on-ignition provides reliable data on carbon content. These assessments help guide land management decisions and track improvements over time.

Management strategies should be site-specific, considering soil type, climate, and cropping systems. A balanced nutrient approach is vital-while organic amendments such as compost or green manure are preferred, they may be supplemented with minimal and targeted chemical fertilizers to meet crop demands without harming soil microbes. Proper moisture management through irrigation scheduling or rainwater harvesting ensures that decomposition and microbial activity proceed optimally. Furthermore, strategic land-use planning plays a crucial role-avoiding cultivation on marginal or erosion-prone lands and implementing land-use systems like agroforestry or permanent cover cropping helps in building and maintaining SOC, thereby contributing to long-term soil regeneration and climate resilience.

6. Policy and Institutional Support

To scale SOC regeneration, government policies and programs must promote:

- Incentives for adopting organic and regenerative farming practices.
- Carbon credit schemes for soil carbon sequestration.
- Farmer training and extension services focused on soil health.
- Soil testing infrastructure and research support.

Programs like India’s National Mission for Sustainable Agriculture (NMSA) and international frameworks such as the “4 per 1000” initiative emphasize the global importance of increasing soil organic carbon stocks.

7. Challenges and Way Forward

7.1 Challenges

- **Lack of awareness** among farmers about SOC benefits.
- **Initial transition costs** for shifting to organic inputs.
- **Short-term yield variability** during transition to regenerative systems.
- **Inadequate infrastructure** for composting and organic input delivery.

7.2 Way Forward

- Develop region-specific soil carbon enhancement models.
- Promote public-private partnerships for organic input supply.
- Strengthen soil carbon accounting and carbon trading systems.
- Integrate SOC regeneration into agricultural education and policy.

8. CONCLUSION

Regenerating agricultural soils through organic carbon enrichment is a sustainable pathway to restore soil health, improve agricultural productivity, and combat climate change. By adopting science-based organic and regenerative practices, farmers can transform degraded lands into productive ecosystems. Collaborative efforts involving farmers, researchers, policymakers, and consumers are essential to mainstream this transformation and secure the future of agriculture.

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