



Soil-Based Climate Mitigation: Harnessing Soils for a Sustainable Future

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Introduction

Soils are a critical component of the global carbon cycle, storing more carbon than the atmosphere and vegetation combined. Proper soil management can significantly contribute to climate change mitigation by reducing greenhouse gas emissions and enhancing carbon sequestration. Soil-based climate mitigation encompasses practices that improve soil carbon storage, reduce nitrous oxide and methane emissions, and enhance overall ecosystem resilience. Leveraging soils for climate mitigation is a promising strategy to complement energy transition efforts and support sustainable agriculture [1,2].

Discussion

One of the primary mechanisms for soil-based climate mitigation is increasing soil organic carbon (SOC) through conservation agriculture, cover cropping, and organic amendments. Practices such as reduced or no-tillage preserve existing soil carbon by minimizing disturbance, while cover crops and crop residues add fresh organic matter that is stabilized in soil aggregates. Organic amendments, including compost, biochar, and manure, further enhance carbon storage, improve soil fertility, and promote microbial activity [3,4]. These approaches not only sequester carbon but also improve soil structure and water retention, enhancing resilience to climate extremes.

Nitrous oxide (N₂O) and methane (CH₄) are potent greenhouse gases often emitted from soils due to excessive nitrogen fertilization

and anaerobic conditions. Optimizing fertilizer application through precision agriculture, using slow-release or bio-based fertilizers, and improving drainage in wetlands and rice paddies can reduce these emissions. Integrating legumes into cropping systems decreases synthetic nitrogen demand, further limiting N₂O release. Similarly, managing wetland soils and incorporating rice–legume rotations can mitigate methane emissions from flooded soils.

Agroforestry and perennial cropping systems also contribute to soil-based climate mitigation. Tree roots and perennial vegetation increase belowground carbon inputs, enhance soil aggregation, and stabilize soils against erosion, while providing co-benefits such as biodiversity conservation, microclimate regulation, and additional income streams for farmers [5].

Emerging tools such as soil carbon modeling, remote sensing, and GIS-based monitoring enable assessment and verification of soil carbon sequestration at farm and landscape scales. These technologies facilitate adoption of climate-smart practices and help policymakers design incentive programs for soil-based mitigation strategies.

Conclusion

Soil-based climate mitigation offers a powerful, nature-based solution to reduce greenhouse gas emissions and enhance carbon sequestration. Conservation agriculture, cover cropping, organic amendments, precision nutrient management, and agroforestry systems collectively enhance soil carbon storage, reduce emissions, and improve ecosystem resilience. Implementing these strategies supports sustainable agricultural production, strengthens climate resilience, and contributes to global efforts to combat climate change. By prioritizing soils as a carbon sink, we can advance both agricultural sustainability and environmental stewardship.

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