UNLOCKING SOIL'S CARBON SEQUESTRATION POTENTIAL

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Unlocking soil's carbon sequestration potential is a multifaceted endeavor that requires a holistic approach to manage land and agricultural practices. One key aspect is adoption of regenerative agricultural techniques such as no-till farming, cover crops, crop rotation and agroforestry, which enhance accumulation of soil organic matter and promote carbon (C) storage in the soil. Improving soil health through balanced nutrient management, minimizing soil erosion, and enhancing biodiversity also contribute to higher C sequestration rates. Land restoration efforts, including conservation of wetland and reforestation projects, play a crucial role in maximizing soil's capacity to sequester C. Furthermore, incentivizing C farming and implementing policies that support sustainable land use practices can further unlock soil's potential as a valuable C sink, contributing significantly to the global efforts in mitigating climate change. Unlocking soil's C sequestration potential involves several strategies and practices aimed at enhancing C storage in soil, thus mitigating climate change. Here are some key approaches.

Cover Crops: Planting cover crops like legumes or grasses during fallow periods can increase soil organic matter, leading to higher C sequestration. Cover crops play a crucial role in soil C sequestration by increasing the soil organic matter through root biomass and crop residue deposition. Their extensive root systems and continuous growth contribute to improved soil structure, water retention, and microbial activity, facilitating C storage. Cover crops can capture around 60 million tons of CO_2 equivalent annually when grown on 20 million acres (8.1 million hectares), effectively compensating for the emissions produced by 12.8 million passenger cars (Environmental Protection Agency, 2019).

Reduced Tillage: Conservation agriculture practices such as no-till farming and reduced tillage can preserve soil organic matter and enhancing C storage through minimum soil disturbance. By leaving crop residue on soil surface or its shallow soil incorporation, these tillage practices promote accumulation of organic C in the soil. This not only enhances soil structure and water retention but also fosters microbial activity, which further contributes to C storage. Microbial activity plays a critical role in transforming plant residues into stable soil organic matter. In comparison with conventional tillage, conservation tillage reduces soil disturbance and soil erosion, thus enhancing soil aggregate formation and stability, which subsequently improve soil organic carbon (SOC).

Crop Rotation: It is a valuable practice for improving soil C sequestration as it improves soil health, promotes biodiversity, and reduces C losses from agriculture land. By alternating crops with different root structures, nutrient needs, and residue qualities, crop rotation enhances organic matter inputs into the soil. Deep-rooted crops can help break up compacted soil layers, facilitating water infiltration and root penetration, which in turn promotes microbial activity and C storage. Additionally, crop rotations can improve nutrient cycling, reduce pest and disease pressures, and enhance overall soil fertility, contributing to long-term C sequestration and sustainable land management. It can also reduce pest and disease pressure by disrupting their life cycles, thus reducing the need for chemical pesticides which negatively impact C sequestration. Healthy, less stressed plants contribute more effectively to C sequestration through increased photosynthetic activity.

Agroforestry: Introduction of trees and shrubs into agricultural landscapes through agroforestry systems can significantly increase C sequestration both above and below ground. Trees and woody vegetation add organic matter to the soil in the form of leaf litter, root turnover, and root exudates that contributes to the formation of stable SOC, enhancing soil fertility and structure. The deep root systems of trees also improve soil water retention and nutrient cycling, promoting microbial activity, and C storage. Agroforestry system is an effective strategy for sustainable land management and climate change mitigation as they can reduce soil erosion, mitigate greenhouse gas emissions, and enhance soil biodiversity. These systems have greater capacity for C sequestration compared to pastures or field crops. (Sharrow and Ismail, 2004).

Biochar Application: Biochar is a type of charcoal produced from organic materials through pyrolysis. Adding biochar to soil enhance C storage and improve soil fertility. Biochar application is a promising strategy for enhancing soil C sequestration and improving soil health. When applied to soil, biochar serves as a stable C pool, effectively sequestering C for hundreds to thousands of years. It enhances soil structure, water retention, and nutrient availability by providing a habitat for beneficial microorganisms and improving cation exchange capacity. Also, biochar reduces nutrient leaching and enhances soil fertility over time. Its use in agriculture can contribute significantly to mitigating climate change by sequestering C from biomass that would otherwise decompose and release CO_2 into the atmosphere. Biochar's capacity to sequester C in the soil for extended durations is due to its high C content, thermal stability, and resistance to decomposition. (Li and Chan, 2022; Elkhlifi *et al*., 2023). Figure 1. illustrates the significant impact of biochar on boosting soil C sequestration.

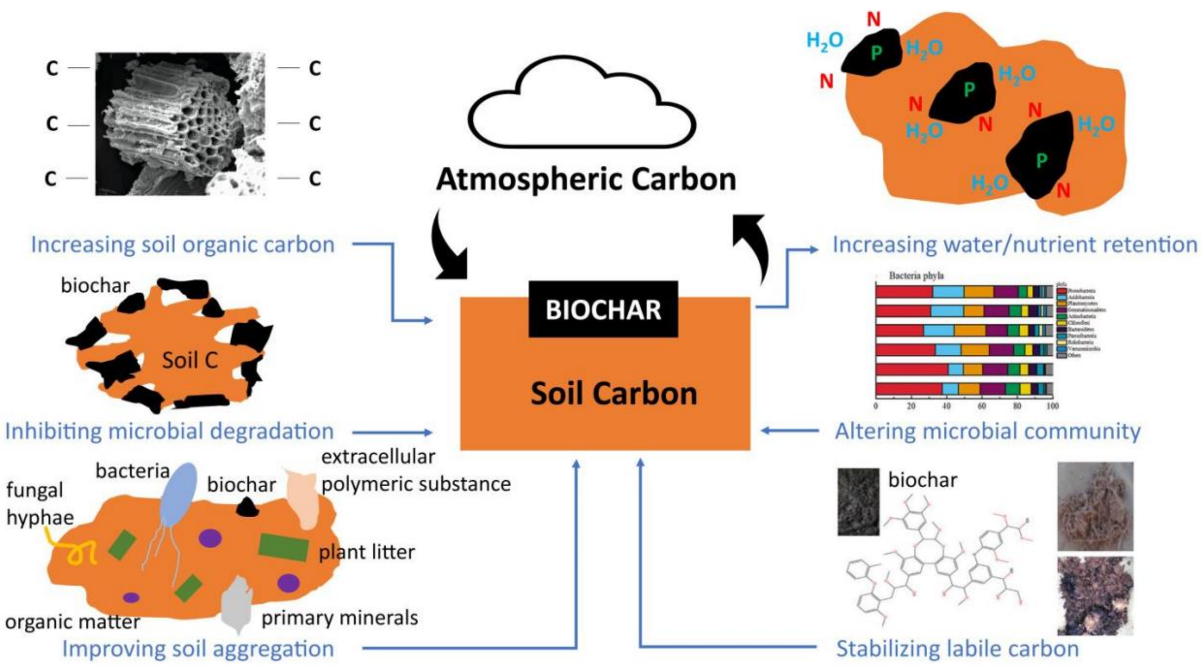

Figure 1. Major effects of biochar on enhancing soil carbon sequestration (Li and Tasnady, 2023).

Soil Amendments: Using soil amendments like gypsum or lime can improve soil structure, water retention, nutrient availability, and organic matter decomposition rates, thus creating favorable conditions for plant growth and C incorporation into biomass. Soil amendments, including compost, organic manure, gypsum, lime, and other materials, play a vital role in enhancing soil C sequestration by enriching the soil's organic matter content and supporting microbial activity. Compost and organic manure introduce substantial amounts of organic C into the soil, providing a substrate for microbes involved in the decomposition and C stabilization process. These practices not only increase C storage in soil but also contribute to improved soil health, resilience, and sustainable land management practices. Biofertilizers enhance soil C sequestration by promoting plant growth, improving soil structure, and stimulating microbial activity, leading to increased organic matter input and stable C compounds. They support sustainable agriculture by reducing the need for chemical fertilizers and enhancing soil health.

MONITORING AND MANAGEMENT

Regularly monitoring soil C levels and implementing management practices based on soil health assessments can optimize C sequestration efforts. The goal of monitoring, measurement, and verification (MMV) is to manage health, safety, and environmental risks, assess the effectiveness of sequestration, and demonstrate that the site is appropriate for closure. MMV is central to CO_2 sequestration risk management. Education, policy support, and stakeholder engagement further promote the adoption of sustainable practices that contribute to climate change mitigation and resilient agricultural systems.

Soil Sampling and Testing

- **Frequency:** Regular intervals (e.g., annually or biannually) to track changes in soil carbon levels.
- **Methods:** Core sampling, bulk density measurements, and soil carbon analysis (e.g., dry combustion method; wet oxidation method).
- **Parameters:** Soil organic carbon content, soil pH, nutrient levels, and microbial activity.

Remote Sensing and GIS

- **Technologies:** Satellite imagery, drones, and Geographic Information Systems (GIS).
- **Applications:** Monitor vegetation cover, land-use changes, and biomass production.
- **Benefits:** Provides large-scale and real-time monitoring of carbon sequestration activities.

Modeling and Simulation

- **Tools:** Process-based models (e.g., CENTURY, RothC) and carbon accounting frameworks (e.g., IPCC guidelines).
- **Purpose:** Predict the impacts of management practices on soil carbon stocks and project future carbon sequestration potential.
- **Inputs:** Climate data, soil properties, land-use information, and management practices.

Permanent Monitoring Plots

- **Setup:** Establish permanent plots for long-term monitoring of soil carbon and other parameters.
- **Data Collection:** Measure biomass, soil carbon, and other ecological indicators periodically.
- **Analysis:** Compare data over time to assess the effectiveness of carbon sequestration practices.

Public Awareness and Reporting

- **Communication:** Raise public awareness about the importance of carbon sequestration and sustainable land management.
- **Transparency:** Provide transparent reporting on carbon sequestration efforts and outcomes.
- **Impact:** Highlight the environmental, economic, and social benefits of carbon sequestration initiatives.

CONCLUSION

Regenerative agriculture practices are essential for unlocking the potential of soil to sequester C by improving soil health, soil biodiversity, and ecosystem resilience. Techniques such as cover cropping, reduced tillage, crop rotation, and agroforestry greatly enhance soil organic matter, allowing soils to capture and store more C. Cover crops help prevent soil erosion, improve nutrient cycling, and provide organic residues that increase soil C levels. Reduced tillage reduces soil disturbance, maintaining soil structure and microbial communities crucial for C storage. Crop rotation introduces diverse plant residues, enhancing soil fertility and C input. Agroforestry combines trees with crops and livestock, boosting C sequestration through increased biomass and soil organic matter. Together, these practices create a synergistic environment capable of combating the changing climate effects by storing C while enhancing soil fertility, water retention, and overall agricultural productivity. Effective monitoring and management of C sequestration integrate scientific methods, technological tools, stakeholder engagement, and adaptive management practices. By adopting these strategies, we can increase soil's capacity to sequester C, combat climate change, and promote sustainable agriculture.

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