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Mitigation of Greenhouse Gases by Effective Soil Management

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Soil health is related to soil carbon (which is closely related to soil organic matter) for assorted reasons, including enhanced water infiltration, enhanced water retention, decreased erosion, enhanced tilth, and enhanced biological activity. Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. This process is primarily mediated by plants through photosynthesis, with carbon stored as soil organic carbon. A key part of mitigating climate change is soils. On the one hand, soils are important carbon sinks that can store more carbon through the process of soil organic carbon (SOC) sequestration. However, soils also contribute to greenhouse gas emissions. This point focuses on the best management practices (BMPs) for soil health that farmers can adopt to lower CO_2 emissions. It's critical to cut GHG emissions to mitigate the severity and effects of climate change. Efficient soil carbon management can unfold assorted options for affordable GHG mitigation.

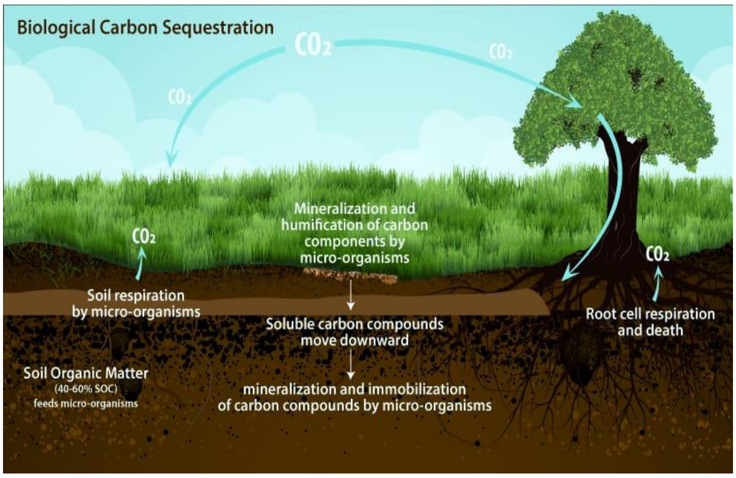
What is carbon Sequestration?

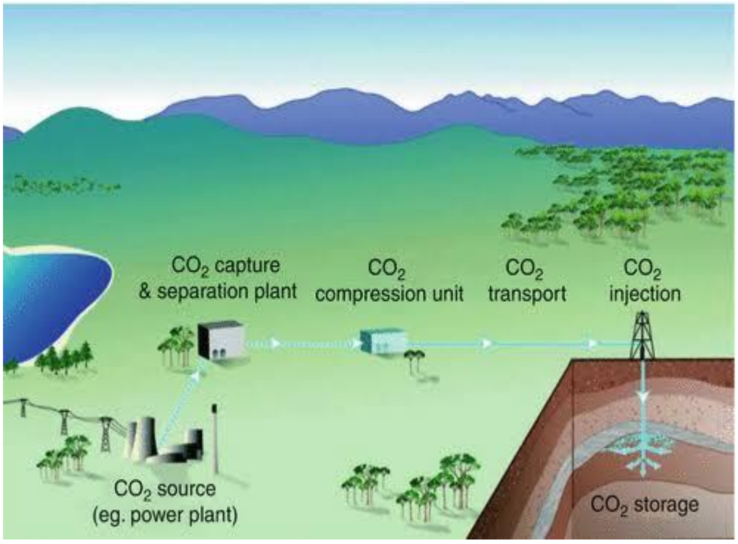
The process of drawing CO_2 out of the earth's atmosphere and storing it permanently is known as carbon sequestration. It is acknowledged as a crucial technique for cutting carbon from the atmosphere of the planet. This is crucial because, as a major contributor to global warming, about 45% of the CO_2 those humans emit stays in the atmosphere. Sequestering of sequestering carbon can stop new emissions from causing the earth to warm.

There are two main ways that carbon can be sequestered: geologically or biologically. In addition, even while it is artificially promoted by a variety of biological and geological techniques, it also occurs naturally in the environment on a large scale.

Biological sequestration: Carbon dioxide is sequestered biologically when it is left in its native habitat. This includes the so-called "carbon sinks," which include soil, meadows, oceans, and other bodies of water in addition to trees. Another name for this is an "indirect" or passive method of sequestration.

Geological sequestration: Geological carbon sequestration is the process of storing carbon dioxide





in subterranean geological formations or rocks. It is a largely manufactured or "direct" process that effectively offsets emissions from human activities like construction and manufacturing.

Soil carbon sequestration mechanisms

Photosynthesis and carbon storage: Carbon is continuously exchanged between plants and the atmosphere. During photosynthesis, plants accept carbon dioxide, which is after stored in large amounts in their roots, permafrost, grasslands, and forests. When they decompose, plants and soil release carbon dioxide. The primary carbon sequestered by forests is found in the soil and plants. Trees absorb carbon dioxide from the environment during photosynthesis to produce sugar, but they also release carbon dioxide back into the atmosphere during decomposition. Within forests, there is a cycle of gas uptake and release including carbon. Carbon capture can be improved, and these cycles can be influenced by forest management.

Soil organic matter formation and decomposition

Through the continuous release of exudates from plant roots, root tissue turnover, and the deposition of aboveground plant residues, plants are the primary source of organic matter in soils. The amounts of these materials vary widely in space and time and rely on the kind of habitat. Additionally, plants provide organic carbon to their mycorrhizal symbionts, which are among the soil's major sources of organic carbon. In ecosystems that are managed by people, the amount of organic matter that is added to the soil is mostly controlled by humans through crop selection, biomass harvesting, and the use of organic amendments, the latter of which can significantly increase the amount of carbon in crop soils. Reintroducing plant wastes into the soil causes a breakdown of different organic components. Decomposition is a biological process that results in simpler organic and inorganic molecules via the physical disintegration and biochemical conversion of complex organic molecules of dead material. The process of soil carbon cycling and biological activity is enhanced by the ongoing addition of decomposing plant stays to the soil's surface. The ongoing conversion of organic and inorganic carbon molecules by plants, micro and macro-organisms, and soil, plants, and the environment is known as carbon cycling.

Carbon stabilization in soil aggregates

Soil structure and aggregate stability were impacted by SOC. There are differences in the stability of organic carbon in aggregates of varied sizes. Compared to the macro-aggregates, the organic carbon in the micro-aggregates is less prone to alteration. The amount and quality of crop residue cover, as well as environmental factors, varied throughout cropping systems' soil organic materials, influencing the soil's organic carbon levels and aggregate stability. Cropping systems primarily alter soil aggregates by shifting the distribution of soil organic carbon and the active habitat of microorganisms, which eases the breakdown and transformation of soil organic matter.

Effective soil management practices

Conservation tillage and no-till farming

The goal of conservation tillage, an agricultural management strategy, is to reduce the frequency or intensity of tillage operations to support specific environmental and economic advantages. These include a decline in greenhouse gas emissions and carbon dioxide emissions, a reduction in the usage of farm machinery and equipment, and a general decrease in labor and fuel expenses. It is well known that conservation tillage, a general phrase for all tillage techniques that lessen soil erosion and flow when compared to plow-based tillage, raises the surface layer's SOC concentration. The two main ways that conservation tillage sequesters carbon is by deep burying SOC in the subsoil horizons and promoting micro-aggregation. By lowering the usage of fossil fuel-powered equipment and aiding soil in keeping carbon, no-till farming helps to minimize climate change by minimizing the release of greenhouse gas emissions during tillage. No-till farming reduces emissions by saving fuel because a tractor is not needed to draw a plough.

Cover cropping and crop rotation: Cover crops are tools to keep the soil in place, bolster soil health, improve water quality, and reduce pollution from agricultural activities. Sequestering atmospheric carbon (CO_2) in the soil helps to offset greenhouse gas emissions, such as the carbon dioxide emitted by cars, power plants, and other burning of fossil fuels. The soil has significant potential to store carbon and mitigate the effects of climate change.

Crop rotation plays a crucial role in carbon sequestration primarily through several mechanisms

- **Increased Soil Organic Matter**: Different crops have varying root structures and residue qualities. Rotating crops with deep-rooted plants (like legumes) and shallow-rooted ones (like cereals) helps diversify organic inputs into the soil. This diversity encourages microbial activity and enhances the accumulation of soil organic matter (SOM), which is rich in carbon.
- **Reduced Soil Erosion:** Continuous monoculture can lead to soil erosion due to reduced ground cover and root structure. Crop rotation helps keep soil structure and stability, reducing erosion and preserving organic carbon within the soil.
- **Improved Nutrient Cycling:** Rotating crops with different nutrient demands helps balance soil fertility and reduces the need for synthetic fertilizers. This practice fosters healthier soils that can keep more carbon.
- **Enhanced Soil Aggregation:** Diverse root systems and organic inputs from varied crops promote soil aggregation. Aggregated soils not

only sequester carbon effectively but also enhance water retention and nutrient availability.

- **Reduced Greenhouse Gas Emissions:** Certain crop rotations, such as including cover crops or legumes, can reduce the need for synthetic nitrogen fertilizers. This, in turn, lowers emissions of nitrous oxide, a potent greenhouse gas.

Organic amendments and composting

- **Animal manure:** Animal manure is the source of C and the addition of animal manure to different crop fields has effects on C contents of the soil. Improved soil properties refer to better C management. Animal manure also increases the salt concentration of the soil. The long-term application of manure increases the SOM significantly**.**
- **Crop residues:** The crop residues are the remains of the crops. The intensive agriculture system increases crop residue production significantly. This may increase the SOM and soil aggregation and hence storage. The degradation of crop residue depends upon its composition. There are three mechanisms, which are classified by different researchers based on the stabilization of SOM, including chemical, biochemical, and physical stabilization. Agricultural practices such as the addition of crop residues increase the SOM as well as nutrient contents in the soil by integrated nutrient management. Most studies focus on the fact that the change of crop residue traits has positive effects on the soil cropping system in the organic farming system.
- **Composting:** Composting is the systematic and controlled breakdown of diverse types of organic matter including animal manure, woody material, and other organic waste. The C content is available in the form of plant uptake in the composting. When the compost matures, 50% of C is available in the form of humic substances and is thought to be more stable practically.
- **Bagasse:** The application of diverse types of biomasses in the soil is the best technique to enhance CS in agricultural sites. The application of biochar produced from bagasse is a very authentic organic amendment to the soil for keeping its water content. Bagasse ash increases soil dehydrogenase and cellulose activity. Long-term investigations are needed to check the effect of ash effects on the soil's physical, chemical, and biological properties.
- **Wood chips:** Wood is mostly used as a fuel to cook food and is considered as a renewable energy source. Bamboo plantations can sequester C and fix it by producing high biomass. This biomass can be used to generate chips and pellets and as an alternative to fuel; as a result, it can sequester approximately 1.78 kg of C. Another research was conducted, and wood chips and straw were applied in the soil and the results showed that nitrogen mineralization and nitrification rates were higher significantly in the soil-applied wood chips.
- **Biochar:** Biochar is usually obtained by the breakdown of crop residues, and wood chips, at a low temperature range (350–600°C) in the atmosphere having extraordinarily little or no oxygen. It is resistant to microbial attack and hence when applied to the soil will remain stable for thousands of years and thus reduce the release of terrestrial C to the atmosphere in the form of CO_2. It has long-term benefits including an increase in soil pH, an increase in crop yield, keeping the cation exchange ability, nutrient retention, and water-holding ability. Biochar also reduces the emissions of other greenhouse gases like methane and nitrous oxides. Increased concentration of nitrogen oxides in the atmosphere affects plant growth by necrosis and slow photosynthetic rates.

Agroforestry

Because agroforestry techniques include trees in agricultural landscapes, they significantly contribute to carbon sequestration. Agro-forestry techniques aid in the sequestration of carbon in several ways:

- **Tree Biomass:** In agro-forestry systems, plants use photosynthesis to store carbon, which is then converted to biomass by the trees.
- **Below-ground Carbon:** Through the storage of carbon below ground, agro-forestry systems also aid in the sequestration of carbon. Deeply ingrained tree roots store carbon in the soil profile and deposit organic matter. Both soil fertility and soil carbon stores are improved by this.
- **Litter and Mulch:** The soil's organic matter content is increased by fallen leaves, tree branches, and other organic materials. Slowly breaking down, this organic matter releases carbon into the soil, effectively sequestering it.

- **Agro-forestry Interactions:** The combination of trees with crops or livestock in agro-forestry systems creates beneficial interactions.

Conclusion

Though several obstacles stand in the way of the entire biological potential being fulfilled, agricultural soils have a significant biological potential to reduce greenhouse gas emissions. It is crucial to consider all greenhouse gases when thinking about mitigation because a management strategy that is effective in lowering one gas may increase the emissions of another. Win-win methods should be prioritized, as successful greenhouse gas mitigation options for agricultural soils are likely to offer further economic and environmental benefits. Over an extended period, soil-based strategies for mitigating greenhouse gas emissions, such as carbon sequestration, have limited potential to close the gap between expected emissions and the emissions reductions needed to stabilize atmospheric CO_2. Therefore, soil-based greenhouse gas mitigation options should be a part of a broad portfolio of measures aimed at reducing greenhouse gas emissions, as there is no single solution, and it is imperative to reduce greenhouse gas emissions over the next 20–30 years to achieve CO_2 stabilization within a century.

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