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Agricultural Soil Carbon Sequestration: A Sustainable Solution to Climate Change

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Abstract

As far as we know, numerous effects of climate change are felt throughout the entire earth system, including the ecosystem supporting agriculture. Increased concentrations of carbon dioxide (CO_2) and other greenhouse gases are the primary cause of the earth's rising temperature, attributed to changes in land use, and the burning of fossil fuels. Hereby carbon sequestration has emerged as a solution with implications of different practices with increasing the carbon pools as a goal. This article aims to understand the impact of agricultural practices on climate change and soil carbon sequestration as a solution to address the changes. It also underscores the challenges faced and shortcomings of soil carbon sequestration.

1. Introduction

Climate change is characterised by long-term alterations in weather patterns and average temperatures, predominantly attributed to anthropogenic activities, including the combustion of fossil fuels, deforestation, and various industrial processes (Kumar, 2021). Climate change can have an impact not only on net primary production (NPP) but also on soil C inputs, soil C decomposition rates, overall soil health, and disease and pest attacks. Furthermore, climate-related changes like drought, flood, and storms destroy crops, and damage livestock and infrastructure, ultimately accelerating food insecurity. The effects of climate change on agriculture manifest in various forms, influencing crop yields, livestock productivity, fisheries, and many other agricultural sectors. These impacts are characterised by their complexity and interdependence, as alterations in climate conditions can lead to significant changes in agricultural outputs and practices (Bilali et al., 2020). In soil, increasing temperature causes a decrease in soil organic carbon as it accelerates the process of mineralization and SOM decomposition. Higher concentrations of atmospheric CO_2

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have shown more carbon fixation on soil and increased biomass by photosynthesis. However, it also shows increased carbon losses due to respiration and increased enzymatic activities. To address climate change different strategic measures have been taken, among which soil carbon sequestration is highly promising in the long run.

2. Carbon Sequestration

Carbon sequestration is used to describe the natural and anthropogenic process of removal of CO_2 from the atmosphere and emission sources and stored securely in the possible sinks *i.e.* terrestrial biosphere, oceans, plant biomass, pedological pools, and geological pools, which will reduce the concentration of CO_2 in the atmosphere. However, it has become common for the term sequestration to imply a contribution to climate change mitigation only by indulging land management practices and RMPs (recommended management practices) for secure sequestration of CO_2. The main aim of carbon sequestration by removing CO_2 from the atmosphere is reducing greenhouse gas concentration, mitigating, and contributing to climate equilibration but also improving soil health, air quality, conserving biodiversity, and sustainable practices. However, the rate of carbon sequestration will highly depend upon the different land uses and practices, soil characteristics, vegetation, topography, and climate, among other soil-forming factors and processes. The goal of deliberate carbon sequestration is to decrease the net flux of CO_2 to the atmosphere by sequestering carbon in the oceans, vegetation, soils, and porous rock formations. But, it also provides the benefit of enhanced ecology, food security, and profitability.

3. Types of Carbon Sequestration

3.1. Terrestrial C sequestration

Terrestrial sequestration also known as biological sequestration is the capture and storage of atmospheric carbon in soil and vegetation. Plants take atmospheric carbondioxide during photosynthesis and transform it into components that become part of the plant (Figure 1). Once the plant dies it decomposes and releases carbon which increases the SOC. Carbondioxide also enters the soil by dissolving with water and infiltrate, where it combines with calcium and magnesium and forms minerals (carbonates) that are capable of sequestering carbon for a long time. The capacity of forests to store carbon is generally regarded as superior; however, the unpredictable conditions induced by climate change have rendered grasslands a more resilient alternative.

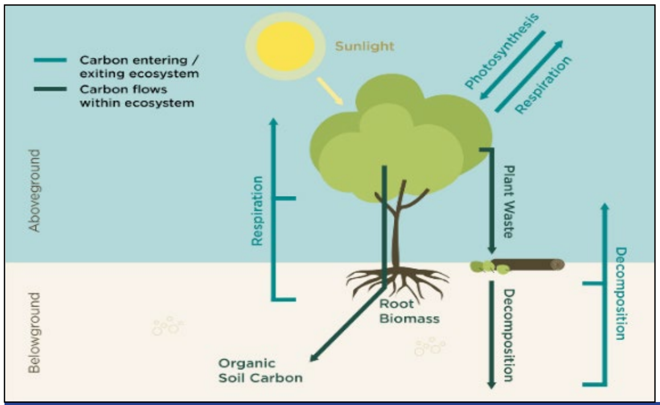

Figure 1: Terrestrial carbon fluxes. source: Michigan State University Forest Carbon and Climate Program

3.2. Geological C sequestration

Geological sequestration refers to the capturing of CO_2 from the point of emission like fossil fuel power plants and is injected deep into earth crevices, pore spaces within rock formations, or man-made structures like caverns and mines. It not only helps in storing carbon but also employs enhanced oil recovery and reduces greenhouse gas emissions. It also involves chemically binding CO_2 to underground substances like dissolving in fluids like water or reservoir oil and absorbing CO_2 in substances like coal which has a higher affinity to CO_2 and can retain CO_2 for thousands to millions of years.

4. Practices for Carbon Sequestration in Agricultural Soil

Humification, aggregation, deep soil carbon incorporation, and calcification are ways carbon can be stored in the soil. Besides managing agricultural soils, transforming agriculturally marginal lands into restorative is vital in altering soil organic carbon levels. By restoring degraded soils, converting agriculturally marginal soils to natural vegetation or replanting with perennial vegetation, and adopting recommended management practices on agricultural soils, the sink capacity of soil organic matter for atmospheric CO_2 can be significantly increased.

4.1. Conservation tillage and residue management

Conservation tillage is a practice in which the principle of no-tillage and crop residue management of about 30% is maintained that reduces soil and water losses and enhances carbon pools compared to conventional tillage which ultimately declines the production and degrades the soil health. With the implementation of conservation tillage, the soil organic carbon increases through the enhancement of soil aggrading processes and reversal of soil degrading processes. No-tillage along with crop residue can sequester more soil organic C by reducing the losses of soil and water, improving soil structure, enhancing SOC concentration, and reducing the rate of enrichment of atmospheric CO_2 (Lal, 2004). Therefore, conservation tillage will open doors for reducing the emission and storage of SOC.

4.2. Cover crops and crop rotation

Cover crops are generally grown to protect the soil surface from evaporation losses, maintain the soil temperature, reduce the impact of rainfall, minimize sheet erosion, and eventually become part of the soil by incorporation. Cover crops have been emphasized for their adaptive strategy as they increase the SOC level and maintain soil health. Incorporation of the biomass is the chief way for carbon sequestration. The incorporated biomass becomes a source and with further decomposition elevates the microbial population of the soil. Despite its benefits, the given results tend to lean on factors like soil, climate, management history, and cover crop species. Legume-based system of crop rotation increases the SOC. Growing soybean-wheat cropping in rotation for 2 years can increase SOC level by about 20-25% of C under rainfed and irrigated conditions, respectively (Bhattacharyya et al., 2009*)* and, he also recorded that SOC can sequester even without fertilizer. In tropical and sub-tropical regions like India, some of the cover crops used include pigeon pea, sun hemp, cowpea, alfalfa, sorghum, mustard, pearl millet etc.

4.3. Nanoparticles

Natural Nano Particles like allophane, a non-crystalline aluminosilicate found in Andisols have shown properties conducive to carbon storage and have the potential for further sequestration in the long term (Karthikeyan *et al* 2019). The presence of nanoparticulate Fe oxyhydroxides (ferrihydrite) in the allophane structure is associated with the formation of a stable organo-mineral complex which is attributed to long-term sequestration of SOC. Due to the unique feature of nanoparticles like a large specific surface area that provides stability to organic carbon, encapsulation, form stable complexes, etc. Other nanoparticles like nano-clays, hydrous Fe oxides, or oxyhydroxides have been documented for their positive effects on carbon stabilization in soil (Calabi-Floody et al., 2015).

4.4. Integrated nutrient management

Nitrogenous fertilizers can increase C sequestration by increasing the biomass of plants with positive results seen in N-limited soil than in N-rich soil. Indicating that N input in low-fertility soils can store more SOC. Phosphorus fertilizer application enhances the photosynthetic activity of leaves and thus, increases above-ground biomass, negatively impacting below-ground root production. Potassium fertilizer application induces stomatal regulation, metabolism, and mRNA translation, and it enhances stress tolerance, ultimately resulting in improved biomass production. Application of manure, compost, or biosolids along with recommended fertilisers as balanced nutrition into the soil is also very effective in addition to recalcitrant carbon which is not easily degraded by the microbial community and reduces the emission of greenhouse gas with long-time storage of the carbon. In addition the decomposition of compost is reduced which might be due to the microbes switching to decomposing N-rich SOM, with the possibility of protection of compost through adsorption onto soil minerals promoting carbon sequestration.

4.5. Soil-water management

Irrigation is necessary to achieve high yields in soils susceptible to drought, but over or improper watering can also raise the water table, result in waterlogging, and cause salinization. Soil salinization reduces biomass productivity and the SOC pool. Scheduled irrigation increased the amount of SOC in the pool earthworm introduction, irrigation, and conversion of cultivated lands to grassland produced significant increases in SOC (Conant et al., 2001). Reduced surface water levels may result in the use of groundwater, which when raised to the surface may release CO_2. The leaching of high-quality irrigation water may also help to sequester SIC. But at the same time, it might increase SOC mineralization (Zhou et al., 2016*)*.

4.6. Restoring degraded soils

Most degraded soils have lost a significant portion of their antecedent SOC pool, but this can be recovered by adopting wise land use practices. Effective conservation techniques can reduce erosion-related CO_2 emissions in degraded lands. Moreover, the restoration of degraded soils can replenish the exhausted SOC pool. Other processes that degrade soil include compaction, acidification, nutrient depletion, and salinization in addition to erosion. Though restoration of degraded soil increases the carbon pools more promising results are seen on fertile lands for their ability to sequester more carbon (Lal, 2004).

4.7. Management of grazing land and forest management

Desertification and land degradation are serious problems associated with grazing lands, especially in regions where excessive and uncontrolled grazing is prevalent. When grasses are subjected to burning, they enhance carbon storage in below-ground systems, particularly in the soil and root structures. In contrast, trees release a significant portion of their stored carbon into the atmosphere during combustion, making grasses more effective at concentrating carbon within the soil. Therefore, proper management of grass land and forests is important to increase the global carbon stock. Climate, soil type, species, and nutrient management all affect the amount and rate at which SOC is sequestered through afforestation. Afforestation, however, may not always enhance the SOC pool. Afforestation of pastures with radiata pine (*Pinus radiata*) decreased the SOC concentration by 15% to a depth of 12-18 cm.

5. Challenges

Rice is major crop in India, produces around 600 million tons of crop residue annually, out of which 34% (204 Mt) from rice. The quick utilization of the rice residue within 10-20 days can be a challenging task. Burning the crop residue which causes several adverse environmental and ecological impacts, by the release of CO_2 to the atmosphere and reducing the amount of C added in the soil going against the principle of decarbonization. Therefore, carbon farming/carbon crediting with provided incentives to the farmer by the amount of carbon they have farmed following various management practices is a win-win strategy for both the party. Restricted funding for climate-resilient agricultural practices and the lack of coordination of global plans to address climate change has been a challenge (Smith et al.,2020). Climatic constraints for carbon sequestration, though it is said that precipitation and clay content increase the total SOC pools. The limited availability of suitable locations in certain areas for CO_2 storage is another barrier. There is also the argument that the severe climate and resource-poor farming practices in tropical and subtropical areas make carbon sequestration a significant challenge. C secure efforts need to be expanded and expedited utilizing a range of tactics and practices. In the end, its effectiveness all lies in the devotion to the management practices by the farmers for a long time to achieve the global goals of comprehending climate change and food security.

6. Conclusion

Carbon sequestration is a win-win strategy, it gives the benefit of increasing the carbon pool along with mitigation, and food security and improves the overall soil quality. This article highlights different land use practices for C sequestering which helps to mitigate climate changes. Various approaches like CT, residue management, integrated nutrient management, restoration of degraded lands, etc. have shown positive impacts. Hence, proper management and implementation of practices to achieve the goals from the ground level is necessary.

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