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Investigating the Role of Microbiome in Soil Carbon Sequestration and Climate Change Mitigation

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Abstract: Complex plant and microbial cycles that regulate carbon pools and streams are involved in guiding ecological change in soil organic frameworks. The use of soil microbiome mediations in this special case to help increase soil carbon stocks and stop ozone-depleting chemicals from escaping from controlled soils. Presenting microbial strains, consortia, phages, and soil movements are examples of direct interventions; examining soil conditions or additional materials to alter the neighbourhood or its activities are examples of covert interventions. Using microbially catalysed processes, strategies to manage increased soil carbon stores include increasing plant carbon inputs, promoting the growth of soil normal matter, reducing SOM turnover, and reducing the production of various ozone-hurting chemicals. The biggest opportunities to increase global soil carbon reserves may be found in small or degraded soils. The cycles that influence the transition of plant-decided soil carbon inputs into SOM, as well as the characteristics of the microorganisms and microbial exercises that influence this transition, are the primary gaps in the information surrounding this area. We recommend expanding the regular, extensive screening of potentially beneficial soil microbes to include traits relevant to supporting soil carbon reserves as a first step. Furthermore, as we advance these interventions, we should consider the anticipated ecological risks and vulnerabilities, such as those encouraged by the unrestricted display of homogenous inoculants and consortia, as well as the necessity of site-explicitness due to the absurd diversity of soil natural environments.

Keywords: Aquaculture; Climate Change; Food Security; Agriculture.

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I. Introduction

In actuality, soil organic carbon, or SOC, is always growing but also continuously breaking down and being mineralized (Medhi et al., 2011). Although both SOC and soil inorganic carbon (SIC) occur in soils, SOC is the focus of this research because it is the main topic of discussion in both science and politics. All of the dead natural matter in soils is found in SOC. SOC stock changes are minimal when compared to the large SOC stocks that are currently in place. Woody debris, such as dead roots, is re-establishing parts of the SOC pool by entering the soil as biomass in the form of over-ground and subterranean litter. SOC is continuously broken down by organisms, which releases some carbon into the atmosphere as CO_2. The dirt's net C equilibrium is a reference to the difference between the two transitions. Transient variations in these two transitions, which depend on distinct factors, create a long-term shift in the net equilibrium (Chen et al., 2023). Soil absorbs carbon if the net C equilibrium is positive. C sequestration is achieved if soil C is increased relative to initial SOC due to decreasing barometric carbon (for example, through photosynthetic processes). Further, the agricultural sector has begun to experience discernible repercussions as a result of climate change. Optimal crop growth hinges on specific climate conditions, and shifts can adversely impact crops, thereby affecting the livelihoods of dependent communities. Agriculture, forestry, and land use collectively contribute significantly to greenhouse gas emissions, accounting for 27-31% of total annual emissions (IPCC, 2014). Roughly 17% of these are directly related to farming practices, and 7–14% are related to changes in land usage. Methane (CH_4) and nitrous oxide (N_2O) emissions from various agricultural sources have significant warming potentials; they are 80 and 300 times more potent than CO_2, respectively (Sheng & Zhu, 2018). Soil Organic Carbon shown in Figure 1.

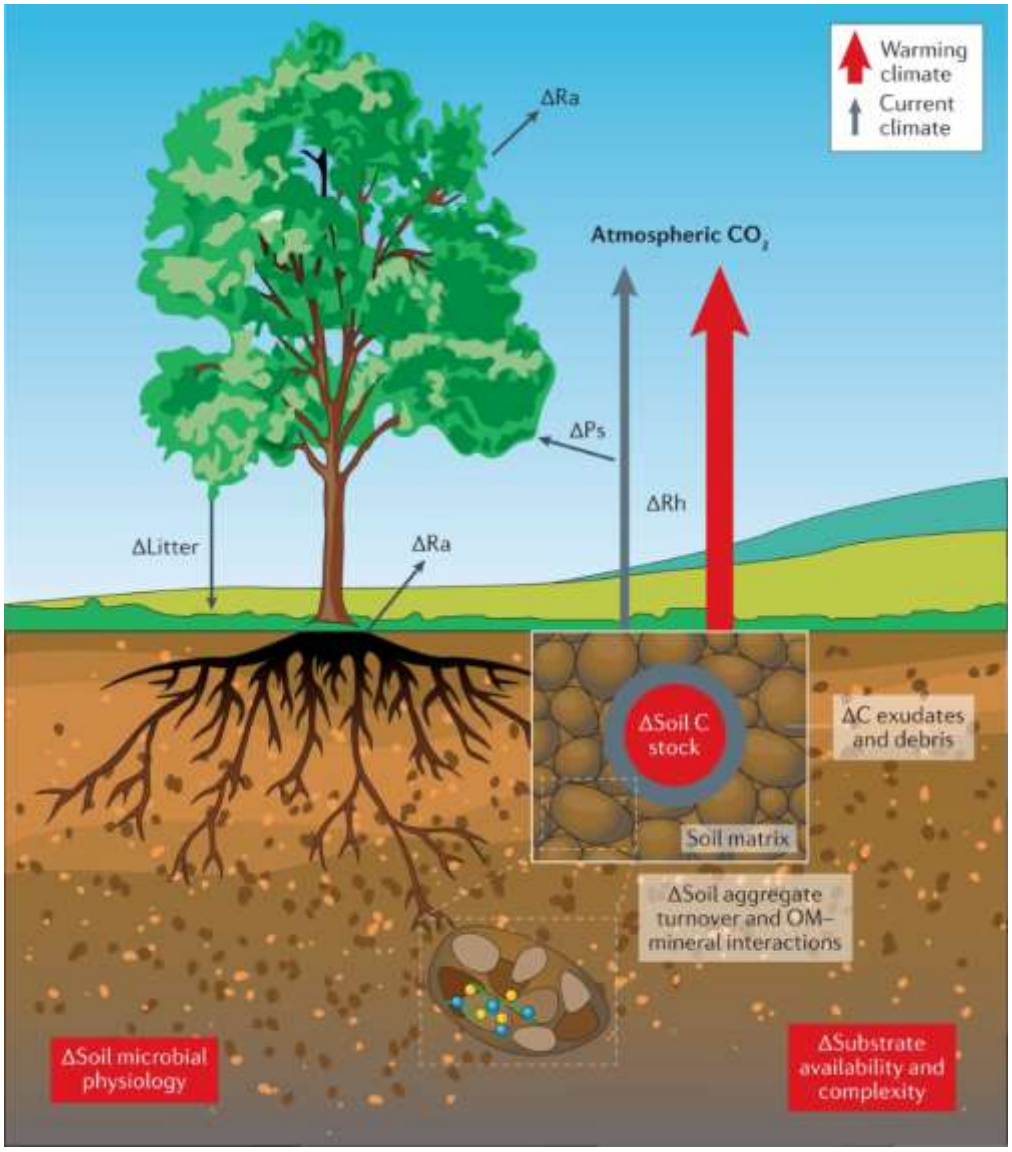


Figure 1: Soil Organic Carbon

The agricultural sector is responsible for 45% of CH4 emissions and 80% of N_2O emissions. Conventional soil management practices, including heavy tillage, burning crop residue, and frequent soil disturbance, can exacerbate greenhouse gas emissions. These practices hasten the decomposition of soil organic matter, thereby releasing carbon as carbon dioxide (CO_2) into the atmosphere. In addition, the extensive use of agrochemicals, the majority of which are fumigants, is responsible for the N_2O emission. Modern agriculture encounters a significant and pressing challenge on food security and economic prosperity, while also addresses the adverse environmental consequences associated with conventional farming practices. Conventional agriculture, characterized by intensive tillage without incorporation of organic residues has led to soil degradation, loss of soil organic matter, and increased susceptibility to erosion. Additionally, these actions exacerbate global climate change by making a substantial contribution to greenhouse gas emissions. Therefore, in order to feed the world's expanding population and address climate-related issues, it is essential to implement sustainable farming techniques (Purohit et al., 2024).

II. Conceptual Framework of the Study

Natural as well as anthropogenic factors both are responsible for depletion of soil C stock. Naturally occurring disturbances including drought, wind, and fire can become destructive and causes drastic changes in an ecosystem. Changes in soil moisture and temperature regimes brought on by natural disturbances may cause forest species to succession, which may alter the amount and quality of biomass that is returned to the soil. Soil disturbances and a decrease in forest cover have led to increased soil erosion, decreased soil carbon and nutrients, and a decline in biodiversity. Due to forest loss, carbon released by deforestation and degradation in tropical forests is probably going to become a carbon source. Natural disturbances such as fire have an impact on canopy cover and soil erosion, both of which have an effect on the upper layer SOC stock (Elbasiouny et al., 2022). Deforestation, afforestation of agricultural soils, forest management operations, and forest plantation management all have an impact on SOC in forests. However, through judicious and sustainable land management practices the depleted SOC stocks can be restored to some extent. The enhancement in SOC can be achieved by several management options. By establishing a continuous canopy cover and causing naturally occurring forest disturbances, forests can achieve high biomass and carbon stores. The SOC stock may be impacted by a number of management practices, including site preparation, harvesting, soil drainage systems, fertilizing, and planting species that are suited to environments with high NPP and higher below-ground biomass output. For SOC to accumulate, there should be a positive imbalance between the input and output of soil organic matter. Carbon accumulation could be achieved by increasing carbon inputs derived from photosynthesis and decreasing the carbon losses. SOC which is stored in soils is dynamic in nature as the carbon obtained from the atmosphere through photosynthesis by plants is again cycled to the atmosphere. The soil's resident time determines its ability to store carbon in the soil. It is possible to extend the residence period of soil organic carbon without increasing inputs (Bhattacharyya et al., 2022). Enhancing Soil Carbon Sequestration shown in Figure 2.

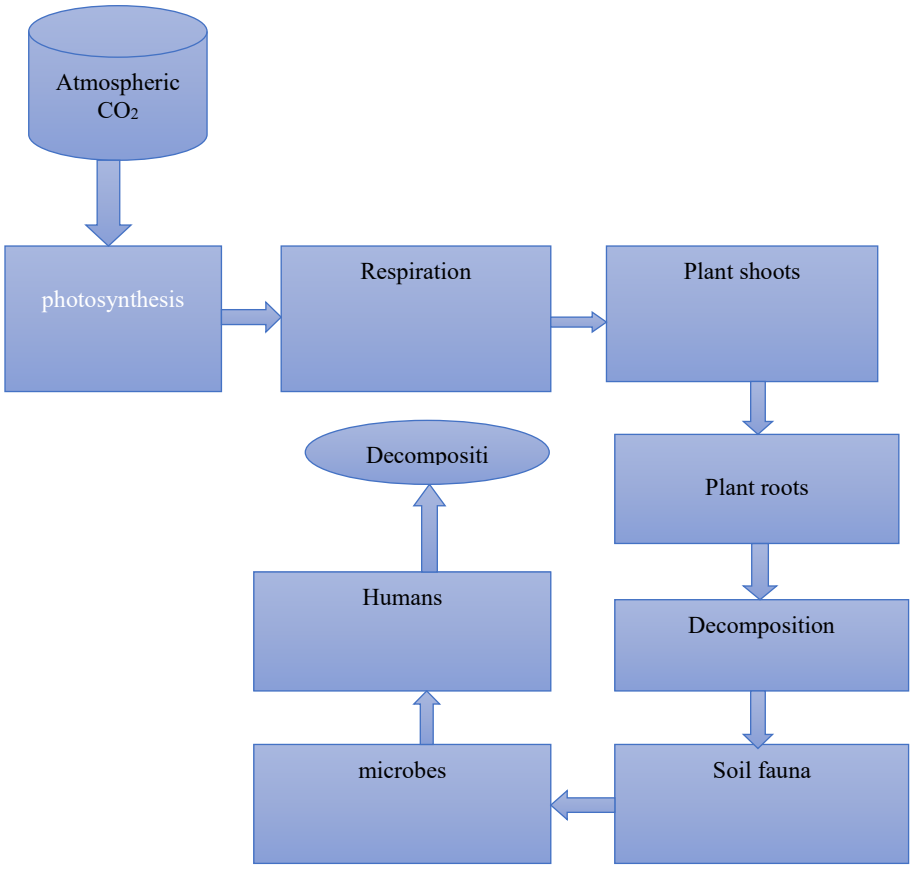


Figure 2: Enhancing Soil Carbon Sequestration

The extremes of pH, temperature, moisture and nutrient availability controls the rate of decomposition thus controlling the resident time of carbon in soil. Biochemical alternation and physiological protection are the two mechanisms which are involved in stabilizing soil organic carbon and control resident time of the carbon in soil. Biochemical alternation is the conversion of organic carbon forms which are more resistant to decomposition by abiotic and biotic processes commonly termed as humification and the products formed are known as humus (Naylor et al., 2020). In case of physicochemical protection the soil organic carbon is protected by organ mineral interactions at large sized to small sized molecules through absorption in soil surfaces, formation of complexes with soil minerals, deposition in pores and occlusion within soil aggregates which makes the soil organic carbon inaccessible to extracellular enzymes and decomposers (Kaur et al., 2021). The environmental conditions, vegetation, soil type and management practices are mainly responsible for the importance and saturation of the two stabilization mechanisms described

III. Role of Microbiome in Soil Carbon

The environment has many natural stores of carbon. Oceans, fossil fuel deposits, terrestrial systems, and the atmosphere are examples of natural stocks. Carbon is stored in the soils of forestland, grassland, and agricultural land, as well as in rocks, sediments, wetlands, and trees in the terrestrial system. Standing forests, understory vegetation, leaf and forest debris, and forest soils all store a significant portion of the world's terrestrial carbon. We refer to a stock that is absorbing carbon as a "sink" and one that is releasing carbon as a "source." Carbon "fluxes" are defined as carbon flows from one stock to another, such as carbon sequestration from the atmosphere to the forest. The process by which plants absorb carbon dioxide from the atmosphere and store it for a very long time in terrestrial ecosystems is known as carbon sequestration. As long as they are alive, plants store carbon in the form of live biomass. After they pass away, the biomass enters the soil as soil carbon and joins the food chain. The carbon is released back into the atmosphere as carbon dioxide and is free to travel through the carbon cycle if the biomass is burned. All methods that "transfer atmospheric CO_2 into long-lived pools and keep it stored securely so that it is not immediately re-emitted back to atmosphere" are referred to as carbon sequestration. Forest biomass builds up carbon over decades and centuries, in contrast to most crops and many plants, which have short lifespans or lose a large portion of their carbon at the end of each season (Kumari et al., 2023). A forest ecosystem stores carbon in four different ways. These include trees, under-storey phytogroups (plants that grow on the forest floor), leaf litter, and other decomposing materials found in forest soils and on the forest floor. As carbon is taken up in the creation of plant cells and oxygen is released, carbon is sequestered during the growth process. The carbon stored by the plant increases the forest stock as the biomass in the forest grows. On the forest floor, plants are growing at the same time, contributing to this carbon store. Branches, leaves, and other debris eventually fall to the forest floor, where they may hold carbon until they break down. Once more, through interactions between roots and soil, forest soils may retain a portion of the degrading plant litter. Both the assessment of biomass carbon and the measurement of the diurnal carbon sequestration rate were used in this study to assess the amount of carbon sequestered by plants. Static biomass carbon was used to estimate all previous investigations, and many assumptions and approximations were taken into account. However, the dynamic approach of measuring the rate at which plants sequester carbon during the day has not yet been used and is being tried for the first time in this field (Babaniyi et al., 2024). Layout of Comprehensive Methodology Used for the Collection of Soil Samples from Experimental Site shown in Figure 3.

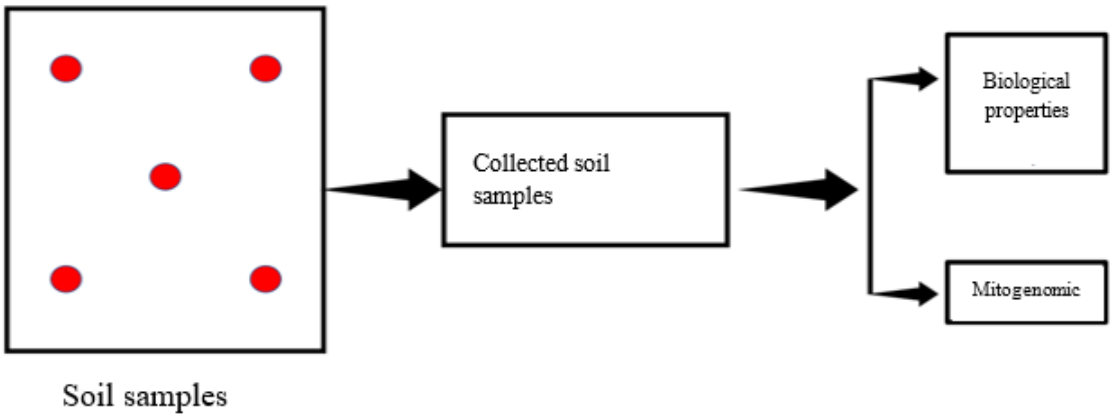


Figure 3: Layout of Comprehensive Methodology Used for the Collection of Soil Samples from Experimental Site

Exopolysaccharides (EPS) possessing bio emulsifying properties have been investigated for their potential to promote plant growth when produced by bacteria or their impact on the hydrological behavior of biological soil crusts. One of the critical strategies for mitigating soil water repellency has been recognized as the application of surfactants in soil.

IV. Conclusion

Ever since the industrial revolution in 1760, GHG emissions have been on the rise. In the late 20th century, global climate scientists acknowledged the seriousness of the damage and the threat posed. Despite mitigation measures being taken, the emissions continue to rise. The urban road transport sector is one of the primary contributors. Many researchers have proposed various methods and models to mitigate emissions from the urban transportation sector. But there are limitations associated with every method/model. While some models fail to capture the entire urban road transportation spectrum in the models, some lack robustness in the mitigation policy design. To reach the implementation stage, the policies should be designed to absorb the given locality's socio-economic conditions. The economic gains and losses associated with each mitigation strategy should also be included. But the models and methods currently existing are too constrictive to make proper judgments by the policymakers. Hence, there is a dire need for comprehensive mitigation strategies in terms of the number of policies considered.

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