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A Review: Role of Soil Carbon Sequestration in Climate Change and Impact on Plant Nutrition.

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ABSTRACT:

Plant growth, soil health, and environmental sustainability are just a few of the cycles in soil and plant systems that are greatly impacted by the climate. Climate factors like temperature, CO2 concentration, and rainfall patterns have changed due to human activity raising atmospheric CO2 levels. Through processes including mineralization, decomposition, leaching, and nutrient loss in the soil, these alterations have an impact on plant nutrition. In addition to helping to mitigate climate change, soil carbon sequestration is essential for enhancing soil fertility and plant nutrient availability. Thus, the goal of absorbing CO2 from the atmosphere and storing it in the soil through plants is being pursued worldwide. To achieve successful soil carbon sequestration (SCseq) and improved plant nutrition, it is imperative to implement efficient management techniques and increase soil carbon inputs while decreasing outputs. Food security still depends on increasing agricultural productivity, especially in developing countries. Future studies will address the numerous unknowns surrounding the effects of climate change on plant nutrition and world food production. This review highlights the value of soil carbon sequestration in reducing the effects of climate change as well as its advantageous function in enhancing plant nutrition through wise management techniques.

Keywords: Climate change, Plant nutrition, Soil carbon sequestration

1. Introduction:

Global warming and climate change are major environmental problems brought on by human activity's dramatic growth in greenhouse gas (GHG) emissions. Agroecosystems are directly impacted by variations in temperature, precipitation, and atmospheric CO2 levels. However, the use of nitrogen fertilizers, animal husbandry, rice cultivation, and tropical deforestation are the main causes of almost one-third of global GHG emissions that come from agroecosystems. The least developed and developing nations in the tropics and subtropics are the most exposed to the effects of climate change, which differ depending on the region. Changes brought on by the climate are expected to reduce crop productivity in these areas. By the end of the twenty-first century, atmospheric CO2 concentrations may reach 800 parts per million, according to projections. Although higher CO2 levels may promote photosynthesis and plant development, increasing biomass production, the wider agricultural ramifications are complicated. An essential part of soil fertility, soil organic carbon (SOC) is essential for enhancing the physical, chemical, and biological characteristics of soil. SOC is crucial for maintaining agroecosystems and agricultural productivity because of its intimate ties to nutrient cycles and crop field fertility. While increasing SOC inputs can guarantee long-term soil productivity and encourage soil carbon sequestration (SCseq), the efficacy of this strategy varies throughout studies. Microbial activity is affected by the availability of soil nutrients and the chemical makeup of organic inputs, both of which have an impact on SOC dynamics. Consequently, maintaining and improving SOC stocks in agricultural soils is crucial for sustainable land management, which benefits environmental health as well as agronomic productivity. This review emphasizes how important soil carbon sequestration is for enhancing plant nutrient uptake and stresses how important it is for sustainable farming methods.

2. Soil Carbon Sequestration and Plant Nutrition

2.1 Carbon Storage in the Soil

The atmosphere (780 Pg C) and vegetation (620 Pg C) combined cannot store as much carbon as soil (1500–1600 Pg C), making soil the planet's largest and most important carbon reservoir. About 75% of the carbon stock in terrestrial ecosystems is made up of it. Approximately 2500 Pg of carbon are thought to be stored in soil, of which 1550 Pg are thought to be soil organic carbon (SOC) and the remaining portion is thought to be soil inorganic carbon (SIC). Maintaining soil ecosystem services like nutrient cycling, soil health, microbial activity, and erosion control depends heavily on SOC. Liang et al. state that the top two meters of soil contain between 2376 and 2456 Pg C of SOC, the largest terrestrial carbon pool.

Research on soil carbon sequestration (SCseq) and SOC content at the national and regional levels is becoming more and more popular, especially in agricultural soils. SOC is essential for soil fertility, environmental quality, climate change mitigation, and sustainable crop production. Increasing soil organic matter (SOM) inputs, decreasing SOM decomposition, or combining the two approaches are ways to improve SOC. Maintaining higher SOM levels enhances soil fertility because plants receive their nutrients from the mineralization of organic matter. However, region-specific agricultural practices that raise soil carbon inputs while stabilizing or lowering carbon outputs are necessary to maximize soil carbon storage. Among the most dynamic elements of the global carbon cycle are agricultural ecosystems, which have net productivity levels that are higher than or comparable to those of natural ecosystems. These systems have the potential to cut CO2 emissions by 5.5–6.0 Gt CO2 annually by 2030, with organic carbon storage accounting for nearly 89% of this decrease. In these ecosystems, activities like fertilization, irrigation, and planting have a big impact on the net CO2 exchange. However, the advantages of carbon sequestration may be negated by overfertilization, which can contaminate water and degrade soil. About 50–60% of SOM, or soil organic matter, is made up of SOC. This encompasses all of the soil's organic materials, including humus, dead roots, plant waste, live biomass, and decomposed tissues. Together with plant and animal waste, SOM is essential to soil biological activity and provides soil organisms with their main supply of nutrients, energy, and habitat. SOC levels and soil biodiversity which include a wide range of species like bacteria, fungi, protozoa, worms, and insects are closely related. In order to maintain soil fertility and the general health of the environment, these creatures interact within a biological web.

2.2 Soil Carbon Sequestration.

An efficient method of addressing climate change is to increase soil carbon sequestration (SCseq), which lowers the buildup of greenhouse gasses (GHGs) in the atmosphere. Goh states that SCseq entails the medium- to long-term (15–50 years) storage of carbon in terrestrial ecosystems, marine environments, or subterranean carbonates [23]. The long-term storing of carbon in the earth's biosphere, subsoil, or oceans to slow the accumulation of atmospheric CO2, the main greenhouse gas, is also known as SCseq, according to Lal et al. and Stout et al., SCseq is the process by which atmospheric CO2 enters soils through crop residues, which are held in a stable form that deters its immediate release [36,60]. The significance of stabilizing carbon in solid forms to guarantee its preservation in the soil is emphasized by Sarfraz et al. Soil type, temperature, rainfall, biological activity, landscape features, SOM production and decomposition rates, and management techniques are some of the variables that affect the carbon sequestration process. SOM plays a major role in influencing changes in the SCseq potential and soil carbon storage. Inappropriate management techniques, like excessive residue removal or intensive tillage, can deplete both SOC and nitrogen pools, adversely affecting soil health. Variations in SOM brought on by soil physiochemical and biological characteristics can also affect SCseq results [61]. The equilibrium between carbon inputs (such as organic matter, crop residues, and root biomass) and losses (such as respiration and decomposition) is reflected in the SOC content. SOC levels, which are positively connected with crop productivity, can be raised by increasing organic carbon (OC) inputs. Higher biomass yields, for example, result in higher OC inputs, which improve soil quality and SOC sequestration. By enhancing agroecosystems' ability to absorb and store atmospheric CO2, SOC management also helps to slow down climate change. To preserve soil fertility, health, and ecosystem services, SOC is essential. Soil productivity decreases and yield potential is limited when SOC levels fall below 1%. The physical, chemical, and biological qualities of soil are improved by raising SOC. SOC enhances soil chemical, and biological qualities of soil are improved by raising SOC. SOC enhances soil structure, water retention, and erosion resistance on a physical level. In terms of chemistry, it raises cation exchange capacity (CEC), which helps the body hold onto vital nutrients like potassium, magnesium, and calcium. In a biological sense, SOC provides soil microorganisms with energy, promoting nutrient cycling and enhancing soil biodiversity.

The following are management strategies to improve SOC:

1. reducing soil disturbance to maintain aggregate carbon.

2. Improving the quality and quantity of biomass inputs.

3. Using organic amendments to promote harmful soil microorganisms.

4. Cover the soil surface with vegetation continuously.

Soil productivity can be increased and SOC restored with the help of certain techniques like integrated nutrient management, crop rotation, cover crops, agroforestry, and conservation tillage. In addition to influencing soil aggregation and nutrient availability, organic amendments like compost or manure directly increase SOC. Plants are involved in SOC dynamics in two ways. Their contributions as primary carbon sources include organic residues and root exudates, which nourish soil biota and boost microbial activity. Because they control erosion and form aggregates, they also help stabilize organic matter. Root exudates stimulate rhizosphere activity, which in turn supports microbial communities that control nutrient availability and enhance soil qualities. Though nutrient imbalances can cause microbial decomposition of resistant organic matter, turning carbon sinks into sources, long-term fertilization practices raise OC inputs and SOC levels. But over time, higher CO2 levels and more rhizodeposition can counteract these losses by increasing plant biomass and adding more carbon to the soil. Effective SOC management supports soil resilience and health, which in turn guarantees long-term climate advantages, increased agricultural yield, and sustainable soil fertility.

2.3 Relationship of Soil Organic Carbon Sequestration with Other Soil Essential Elements

According to Grovera et al.'s research [25], soil carbon inputs are important factors that promote soil organic carbon sequestration (SCseq) throughout plant growth. These inputs are impacted by nitrogen (N) availability and other vital nutrients. Synthetic fertilizers affect soil health and have a carbon footprint even if they don't add organic matter (OM). Improving SCseq in agroecosystems can affect soil health and their carbon footprint. Biological nitrogen fixers and nutrient solubilizers/mobilizers can be used to sustainably improve SCseq in agroecosystems. Furthermore, increasing soil carbon, enhancing soil quality, and increasing crop production are all possible by including green manure crops into traditional cropping systems through crop rotation and multiple cropping. These practices reduce soil erosion and improve soil through crop rotation and multiple cropping. These practices reduce soil erosion, improve soil structure and permeability, and increase microbial activity and SOM content. Leguminous green manure crops are particularly beneficial due to their ability to fix atmospheric nitrogen, which enhances biodiversity, increases soil carbon and nitrogen levels, and maintains soil fertility. Nitrogen and soil organic carbon (SOC) play a key role in controlling nutrient dynamics and affecting crop productivity. The patterns of their collection, deterioration, and transportation are frequently similar because of their interconnectedness. Through plant biomass and root turnover, for instance, nitrogen application can return absorbed CO2 to the soil, improving crop yield and supporting SOC stores. However, using nitrogen fertilizers excessively or inefficiently can raise greenhouse gas emissions, contaminate water, and acidify soil. In soil processes, the ratio of carbon to nitrogen (C: N) is crucial. Nitrogen fertilizer additions can increase carbon sequestration through plant biomass and rhizodeposition by lowering the C: N ratio and encouraging the development of non-N2-fixing bacteria. However, nitrogen alone does not supply organic matter, and its production has a carbon cost. Microbial biomass turnover also regulates the C: N ratio, influencing soil processes like mineralization and respiration, which are critical to long-term SOC dynamics. According to Lal et al. [37], SCseq is dependent on additional nutrients since SOM is derived from microbial and plant leftovers that need a variety of components. The stoichiometric ratios of SOM indicate that, for every unit of carbon sequestered in the soil, around 83 kg of nitrogen, 20 kilograms of phosphorus (P), and 14 kg of sulfur (S) are required. Controlling these nutrients is crucial for increasing soil carbon, especially from crop leftovers that are high in carbon. Crop residues like wheat stubble have higher nutrient-to-carbon ratios than SOM, where the ratios are less concentrated in relation to carbon (e.g., C: N:P:S = 12:1:0.5:0.14). This disparity impacts how well agricultural leftovers are converted into SOM. The ratio of carbon to nutrients in SOM is mostly constant across soils, ecosystems, and management eras worldwide. This equilibrium is intimately linked to the nutritional makeup of soil microbes, such as fungi and bacteria, which are essential for long-term carbon storage and nutrient cycling. As an illustration of their crucial involvement in carbon sequestration mechanisms, microbial biomass has nutrient-to-carbon ratios equivalent to those in SOM. Microbial deposition is becoming more widely acknowledged as a crucial process for the long-term storage of carbon in sedimentary and marine environments as well as in soils. The significance of microbial activity and nutrient interactions in improving soil carbon sequestration and preserving ecosystem sustainability is highlighted by this bio-sequestration route. Preserving ecosystem sustainability is highlighted by this bio-sequestration route.

2.4 Soil C Accumulation or Depletion

The main causes of soil carbon (C) losses include increased decomposition, decreased plant inputs, and erosion brought on by agricultural activities. The equilibrium between carbon inputs from photosynthesis and deposition and carbon losses from respiration, leaching, and erosion is what primarily governs the amounts of soil organic carbon (SOC) [49]. When comparing agricultural systems to natural ecosystems, De Oca [12] attributed SOC depletion to a number of factors, including reduced organic inputs, faster decomposition, changed soil moisture and temperature regimes, and losses from leaching and erosion. According to reports, tillage increases carbon losses by 28–77%, depending on the soil type and climate [5]. The organic matter content and nutrient-supplying efficiency of farmed soils are decreased by tillage, which breaks up macro-aggregates and creates nutrient-poor micro-aggregates [6]. Since a large amount of organic carbon has already been lost from agricultural soils, methods to restore these stocks are essential for reducing atmospheric CO2. Global agricultural soils have the potential to sequester between 0.4 and 0.9 Pg C per year [61]. To do this, though, the delicate balance between carbon imports and outputs must be addressed, since this may have a big impact on the biological carbon sink. The SOC stock's volatility makes it difficult to identify these developments. Carbon loss from soils has been increased by human activity; in recent decades, cultivated agricultural soils worldwide have lost 41 to 55 Pg C. Forest conversion to agricultural land drastically lowers SOC supplies, which first fall quickly before slowing down and stabilizing over the course of 30 to 50 years [4]. SOC may be improved by expanding cropping systems by reintroducing more biomass into the soil, according to some research, however, exploitative farming may result in increased carbon loss [1]. Its distribution into labile (active) and recalcitrant (passive) fractions determines the SOC level. While refractory SOC aids in long-term carbon sequestration, labile SOC is susceptible to management techniques and is essential to soil nutrient cycling and production [9]. A balance between these fractions promotes soil sustainability and long-term productivity [55, 9]. Effective SOC management involves combining organic and inorganic nutrient sources, which not only improve soil carbon stocks but also support soil physical, chemical, and biological health [14]. Particulate organic carbon (POC), microbial biomass carbon (C) and nitrogen (N), and perhaps mineralizable carbon are examples of active SOC fractions that are more sensitive to management changes and represent changes in soil quality and nutrient cycling. Future variations in SOC and total nitrogen may be predicted by these fractions [55]. On the other hand, resistant SOC fractions provide the possibility of long-term carbon sequestration due to their slower turnover rates. With or without organic manure, balanced fertilizer applications can change soil dynamics, increase soil microbial biomass, and improve SOC storage [55]. Carbon inputs and outputs are related to calculating the carbon balance of the soil. Plant tissues absorb carbon during photosynthesis; some of this carbon is then exhaled back into the atmosphere, while the remainder decomposes and adds to soil carbon. The main type of soil carbon storage is soil organic matter (SOM). Developing countries might increase their yearly food output by 30–40 Mt by increasing SOM by 1 t C ha^{-1} [35]. But during the last millennium, soil degradation has decreased worldwide SOC supplies by 16–20%, which poses a serious obstacle to sustainable land management [59]. Since the middle of the 18th century, mechanization alone has reduced soil carbon by 78 ± 12 Tg, contributing to the continuing depletion of SOC reserves. Forests being turned into farms has resulted in a 22% decrease in SOC stocks [36,59]. To guarantee food security and environmental health, sustainable resource management must place a high priority on maintaining soil quality. Practices including conservation tillage, balanced fertilization, the use of compost, cover crops, organic and inorganic mulches, biofertilizers, and diverse cropping systems can all improve the storage of SOC in agricultural soils [62, 42, 63]. Degraded land rehabilitation and the integration of crop leftovers are also successful strategies [56, 61].

Long-term experiments conducted in India showed that nutrient balancing increased SOC concentrations, with cropping systems based on legumes having a higher carbon content than those based on cereals [14]. In addition, the kind and quality of inorganic and organic fertilizers affect the amount of SOC sequestration [9].

3. Conclusion

Soil organic carbon (SOC) is essential for preserving soil health and productivity as well as reducing climate change by storing carbon dioxide from the atmosphere. However, the world's SOC supplies have been severely reduced by agricultural practices like tillage, deforestation, and soil degradation. Restoring SOC levels and balancing carbon inputs and outputs in soils require sustainable management techniques. SOC storage can be improved by techniques like conservation tillage, crop variety, the use of cover crops and biofertilizers, and the use of both organic and inorganic fertilizers. Maintaining soil quality and long-term productivity requires a balance between labile and recalcitrant organic carbon components.

In the end, using sustainable soil management techniques can lessen environmental effects, improve soil fertility, address SOC depletion, and support global food security.

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