Harnessing Carbon Sequestration to Tackle Climate Change in Agriculture

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ABSTRACT

Global climate change is an important problem in this time. It leads to a gradual increase in the average annual temperature of the planet, which began with the industrial revolution in the beginning of the 20th century. Extreme weather in recent years has made the talks about the growth of earth's temperature more intense. The change in temperature is explained by high levels of manufacturing and economic activity that includes emissions of main greenhouse gases: carbon dioxide, methane, etc. Carbon dioxide, a greenhouse gas, has the ability to trap heat in the atmosphere and contributes to global warming. Carbon sequestration is the process of capture and long-term storage of atmospheric carbon di oxide to mitigate global warming and to avoid dengerous impact of climate change. Soil carbon sequestration, the process of capturing and storing carbon in the soil, plays a crucial role in reducing atmospheric CO^2. Process-based models such as the DeNitrification-DeComposition (DNDC) model have been increasingly used to understand the complex interactions between climate, crop and soil management through integration of the primary SOC turnover mechanisms. While carbon sequestration is important, the development of carbon-neutral technologies and alternatives to fossil fuels is also crucial. There is need for research, education, outreach and policy interventions to restore SOC pool, improve quality of soils of agro-ecosystems, increase productivity, and improve environment quality.

INTRODUCTION

In the modern world, humanity is increasingly concerned about the issue of global climate change on the earth. Climate change issues especially human impact on the earth's climate system are the topic that has been very actively discussed in recent years. Though there are still lot of not fully explored "white spots" in it. Climate change refers to change in long term weather patterns. It is measured usually in major shifts in temperature, rainfall, snow and wind patterns. Global surface temperature has increased 0.8^0c since the late 19^{th} century. Global warming, greenhouse gases are the important phenomenon that increase temperature of the earth. In addition, analysis of geological samples, ocean sediments and other data shows that warm periods coincide with the periods of high atmospheric carbon di oxide concentration. Greenhouse gas levels have increased substantially since pre industrial era. In pre-1850 the concentration of carbon di oxide was 280 parts per million which increased by 50% and become 419 parts per million. Similarly in case of methane the concentration was 722 parts per billion which increased by 150% and become 1923 parts per billion and for nitrous oxide the concentration was 270 parts per billion which increased by 25% and become 337 parts per billion (NOAA and CRIES, 2024). The global warming potential of methane is 30 times more than carbon di oxide and nitrous oxide is 300 times more potent than carbon di oxide. The mean residence time of carbon di oxide is 120 years and for methane it is 12 years and 11 years for nitrous oxide. Due to high global warming potential and long mean residence time these gases cause global warming.

Ways of carbon sequestration

Carbon sequestration, the process of capturing and storing carbon dioxide (CO_2) from the atmosphere, has become a crucial strategy in addressing climate change and mitigating the impacts of greenhouse gas emissions (Roy *et al*. 2023). This mechanism involves oceanic, petrologic, biotic, and geological components, with the primary objective of slowing the net emission rate into the atmosphere (Lorenz and Lal, 2014).

1) Geological sequestration:

Geological sequestration involves three main processes capturing carbon dioxide, transporting carbon dioxide and placing the carbon dioxide in a geological formation for permanent and semi-permanent storage by means of system of injection wells.

2) Ocean sequestration:

Carbon sequestration by direct injection into the deep ocean involves the capture, separation, transport, and injection of CO_2 from land or tankers. 1/3 of CO_2 emitted a year already enters the ocean. Ocean has 50 times more carbon than the atmosphere.

3) Terrestrial sequestration:

The process through which CO_2 from the atmosphere is absorbed naturally through photosynthesis & stored as carbon in biomass & soils. Tropical deforestation is responsible for 20% of world's annual CO_2 emissions, though offset by uptake of atmospheric CO_2 by forests and agriculture. Carbon seq. rates differ based on the species of tree, type of soil, regional climate, topography and management practice. Pine plantations in SE United States can accumulate almost 100 metric tons of carbon per acre after 90 years (~ 1 metric ton/1 year).

Promising agriculture techniques to increase carbon content in soil:

Land managers can increase soil carbon sequestration by using a variety of strategies.

These strategies include increasing the rates of organic matter input, directing carbon into carbon reservoirs that are more resilient, and extending the life of individual carbon reservoirs or the lifespan of all carbon reservoirs. It is possible to reverse past processes that have led to the depletion of soil carbon stocks that were previously accumulated under native perennial vegetation by putting a variety of agricultural management techniques into practice. Extensive studies of soil management techniques have produced important new understandings of the mechanisms underlying increasing soil carbon content.

1) Cropping intensification: Using high-yielding crop varieties, removing fallow periods, and adding fertilizers and soil amendments greatly boost the amount of organic matter that is produced and added to the soil. Moreover, precision farming increases soil carbon inputs. Nevertheless, some of the extra crop residue breaks down quickly and doesn't add to the long-term buildup of carbon in the soil. However, some residue turns into humus, which encourages the long-term accumulation of organic carbon in the soil. Although the use of manures or biologically modified inputs can result in greater enhancements, cropping intensification alone has limited effects on soil carbon. These amendments contain materials that are more resistant to decomposition and increase the input of organic carbon. Applying manures as soil amendments increases the amount of organic carbon in the soil and promotes long-term carbon storage.

2) Conservation tillage: Soil organic carbon (SOC) decreases as a result of mechanical soil disturbance that happens when natural vegetation is removed to make way for row crops. Because the soil structure controls microbial access, turnover processes, and interactions within the decomposer food web, it is essential for maintaining soil organic matter (SOM). Labile organic matter is prevented from decomposing by the incorporation of organic material into soil aggregates or micropores. The relationship between micro aggregate formation, macro aggregate turnover, and carbon stabilization within micro aggregates is intimately related to the rise in SOC. Restoring aggregation processes can rebuild the physical protection mechanism by lowering the intensity of tillage. Additionally, conservation tillage reduces wind and water erosion, which breaks up soil aggregates and causes particulate organic matter to be lost. These losses impair the ability of the soil to retain water, obstruct the regeneration of nutrients, and may lower crop productivity. Increased irrigation or fertilizer application is required to maintain or improve soil organic carbon (SOC) levels because erosion, both directly and indirectly, contributes to the loss of soil carbon.

3) Lime, irrigation water, fertilizer application: Increased resistance of organic matter to decomposition is largely dependent on transformations involving the production of humic compounds that resemble melanin. These changes are facilitated by abiotic oxidants and phenoloxidase enzymes. According to recent research, the stability and activity of these oxidants and enzymes are increased when the pH of the soil is kept neutral or higher. Humic compounds' ability to withstand chemical reactions speeds up formation and decreases mineralization, which raises the amount of organic carbon in soil. Wetting and drying cycles encourage the oxidative polymerization reaction, which stabilizes carbon and keeps it from stagnating in oxidizing or reducing environments. Enhancing the availability of iron and manganese oxide-containing minerals can also promote the development of humic materials.

4) Perenial vegetation: The carbon levels in the soil significantly rise when perennial vegetation grows on previously plowed cropland. Remarkably, the rate of soil carbon increase after perennial vegetation establishment, even in the absence of additional management, is on par with or higher than that seen when converting to no-till cropland. Similar to the processes involved in conservation tillage, this increase is attributed to improved soil aggregate formation, a shift towards fungal-dominated decomposition pathways, increased organic matter inputs (especially belowground through roots and mycorrhizal fungi), and decreased erosion.

CONCLUSION

Practices in agricultural management that increase carbon inputs and reduce SOC losses can improve soil carbon sequestration. Using additional biomass through techniques like crop rotation, agroforestry, cover crops, deep-rooting crops, and the application of compost and biochar are examples of carbon input strategies. By leaving crop residues on the field and minimizing soil erosion with practices like cover crops and notillage, farmers can minimize SOC losses. But it's crucial to take into account the drawbacks and compromises of various approaches. Compost, farmyard manure, and biochar are examples of organic fertilizers whose availability is limited by transportation-related CO_2 emissions and local availability. Sometimes the additional CO_2 emissions from the production of mineral fertilizers and irrigation pumping activities exceed the beneficial contributions of these activities to the carbon sink. We need sustainable practices that weigh the advantages and disadvantages of these actions. Reduced nutrient availability, pH shifts in the soil, irrigation-induced leaching, and a rise in weed diversity are among the disadvantages. Furthermore, the SOM (CO_2) mineralization or denitrification (N_2O) of ammonia or nitrate contents of nitrogen-applied fertilizers is enhanced by greenhouse gas emissions linked to soil activities. In order to fully assess the carbon sequestration potential of relatively new management practices, like the application of inorganic carbon, more investigation and extended field testing are required. Notwithstanding these difficulties, sequestering SOC is essential for soil fertility, soil health, and ecosystem services because it preserves soil productivity, reduces the effects of climate change, and supports ecosystem services. Sustainably managed agriculture and ongoing research are essential to maximize carbon sequestration potential, overcome obstacles, and create practical plans for preserving.

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