A comprehensive review on Carbon sequestration potential and addition of organic carbon to soil

Abstract

A variety of soil management techniques can be used to sequester carbon on agricultural fields, and with widespread application, the amount of sequestered carbon might be large. Historic carbon emissions must now be sequestered because mitigation is unlikely to be sufficient to stabilise our atmosphere on its own. For the purpose of removing carbon from the atmosphere and storing it in the soil, various management techniques exist. The efficacy of these tactics varies depending on the region, soil type, and climate. The longevity of soil sequestration and the ideal circumstances for maximising the reduction of carbon emissions remain topics of discussion. This essay examines the process by which soil stores carbon, the current status of soil carbon research, and the controversy surrounding the potential of soil carbon. It emphasises the numerous side advantages of raising soil carbon and provides a set of suggestions for further investigation.A substantial amount of soil organic carbon (SOC) might be sequestered by switching from conventional to conservation tillage, although this change would only have a long-term impact on tillage practices. Crop rotation based on legumes is more effective than that based on grass in converting biomass carbon to soil organic carbon. Rotational grazing lowers the overall quantity of CO2 released into the atmosphere while improving the quality of the grass. Producing biochar and incorporating it into soil is an additional strategy for storing carbon from the atmosphere.

Keywords

soil carbon, carbon sequestration, carbon emission, soil organic carbon, conservation agriculture

Introduction

By volume, the earth's atmosphere (dry air) is made up of 0.04% carbon dioxide, 20.95% oxygen, 78.09% nitrogen, and trace amounts of other gases. All living things contain carbon, which is the primary component of life as we know it on Earth. Carbon is cycled amongst several reservoirs, the atmosphere, the seas, the land biota, and the marine biota in the forms of carbon dioxide, carbonates, organic compounds, etc. The natural processes of photosynthesis (the uptake of carbon dioxide by plants), respiration (the release of energy and carbon dioxide), dissolution, and carbonate precipitation, according to Grace (2001), enable carbon exchange.

The rising concentration of greenhouse gases (GHGs) in the atmosphere is making climate change an increasingly serious problem. It might be managed by reducing greenhouse gas emissions, particularly carbon dioxide, and storing carbon in the soil and vegetation. The three main greenhouse gases are nitrous oxide (N_2O), carbon dioxide (CO2), and methane (CH_4).Human activity has caused the concentration of CO2, CH_4, and N_2O in the atmosphere to rise by 30, 145, and 15%, respectively, during the Industrial Revolution (IPCC, 2007).

Since it is the only GHG that is known to play a significant part in plant physiology, CO_2 is a special kind of greenhouse gas that traps long-wave radiation reflected from the earth's surface.

A rise in CO_2 levels may cause plants' stomata to partially close, reducing transpiration. Approximately 7.5% of global warming is caused by CO_2.Because of the significant amounts of carbon dioxide that are now stored in these pools and their capacity to absorb more, soil, plants, and the ocean are all regarded as potential carbon dioxide sinks.Carbon dioxide is taken up by photosynthesizing plants and stored as biomass carbon in the terrestrial carbon pool.As dead biomass breaks down through the roots, carbon dioxide is released into the soil carbon pool. Even though the majority of the carbon on Earth is stored in the ocean, soils hold about 75% of the carbon pool on land, which is three times more than the amount stored in living things like plants and animals.Thus, soils are essential to preserving a healthy global carbon cycle.

After natural land was turned into farmed agricultural land, it is estimated that around 50 Pg C of carbon had been released into the atmosphere globally from soils (Paustian et al., 2000).The physical basis for this is that increased soil aggregate turnover and accelerated soil organic matter (SOM) breakdown are caused by disturbances related to intense soil tillage. The agricultural system releases carbon dioxide (CO_2) through a variety of processes, including plant respiration, crop residue and soil oxidation, the use of fossil fuels in agricultural machinery, and the manufacture of agricultural inputs like pesticides and fertilisers.

Carbon Sequestering

In order to slow down or prevent global warming, carbon dioxide or other forms of carbon can be permanently stored in soils, oceans, forests, and other types of plants. This is an approach to mitigate the build-up of greenhouse gases, which are emitted as a result of human activity.C sequestration is defined as the long-term storage of carbon by the Ecological Society of America (ESA, 2000). The IPCC (2000) defines carbon sequestration by terrestrial ecosystems as the net removal of carbon dioxide (CO_2) from the atmosphere or the prevention of CO_2 emissions from terrestrial ecosystems into the atmosphere. All chlorophyllous plants absorb CO_2 from the atmosphere during photosynthesis as part of the elimination process. Plant biomass, which is found in the roots, branches, leaves, and trunks of plants, and soil organic matter are where this C is kept. The land use practices and various ecosystem conditions that support established vegetation over longer periods of time are what determine the terrestrial carbon sequestrations.According to Izaurralde et al. (2007), carbon sequestration is the application of a land management strategy that raises ecosystem C storage, lowers the rate of heterotrophic respiration, or both. Planting trees, lessening cropland's tillage, or re-establishing grasslands on degraded areas will all enhance the amount of carbon stored in soils, plants, or both.

Soil carbon sequestration, according to Sundermeieret al. (2005 a), is the process of removing carbon dioxide from the atmosphere and storing it in the form of crop residues and other organic substances so that it is not released back into the atmosphere right away.The process of "sequestering" carbon helps reduce emissions from burning fossil fuels and other carbon-emitting activities while improving soil quality and long-term agronomic productivity. One way to achieve this is through soil carbon sequestration is through management practices that add large amounts of biomass to the soil, cause minimal disturbance, conserve water and soil, improve soil structure, and increase soil fauna activity. One such practice is continuous no-till crop production. The largest terrestrial pool is the soil organic carbon (SOC) pool, which is more than three times the size of the atmospheric pool (760 Gt) and about 4.5 times the size of the biotic pool (560 Gt). Globally, the soil carbon pool, also known as the pedologic pool, is estimated to be 2,500. Metz et al. (2005) listed seven options for mitigating climate change, including carbon capture and storage (CCS), energy efficiency, switching to lowcarbon fuels, nuclear power, renewable energy, enhancement.

The projected global soil carbon pool, also known as the pedologic pool, is 2,500 Gt down to a depth of 2 m. Of this, 1,550 Gt is the soil organic carbon pool, while the remaining 950 Gt is made up of the soil inorganic carbon and element pools (Batjes, 1996).Arable lands' regeneration of their SOC pools offers a potential sink for atmospheric CO_2. Agricultural activities have a significant impact on the change in SOC over the long and short terms. The density and dispersion of soil SOC are increased by a variety of land use and soil management techniques. These methods include cover cropping, mulch farming, conservation tillage, and crop rotation using legumes (Lal, 2004).The main source of carbon dioxide in the soil is soil organic matter (SOM), a complex mixture of carbon compounds that includes decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and carbon associated with soil minerals. Other than plants, carbon dioxide can be captured as a pure by-product in processes related to petroleum refining or from flue gases from power generation. Through the process of photosynthesis, plants absorb carbon and return some of it to the atmosphere through respiration. The carbon that remains in plant tissue is subsequently consumed by animals or added to the soil as litter when plants die and decompose.The quantity and duration of carbon sequestered in soil are determined by a number of factors, including drainage, natural vegetation, soil texture, and climate.

The estimated 39–52 million tonne C/year of soil C sequestration potential in India is divided into five categories: 5–7 Tg C/year for erosion control, 6–7 million tonne C/year for the adoption of improved management practices (IMP) on agricultural soils, and 22–26 million tonne C/year for secondary carbonates. This breakdown includes 7.2–9.8 million tonne C/year for the restoration of degraded soils and ecosystems (Lal, 2004). An estimated 121 million hectares of degraded land, including salt-affected wasteland, exist in India, according to estimates from the Indian Council of Agricultural Research (ICAR) and National Academy of Agricultural Sciences (NAAS) (Maji et al., 2010).

Inorganic chemical processes that transform CO_2 into soil inorganic C molecules like calcium and magnesium carbonates are the mechanism responsible for direct soil C sequestration.

The process by which plants photosynthesize atmospheric CO_2 into their biomass is known as indirect plant C sequestration. During the decomposition process, some of this plant biomass is indirectly sequestered as SOC. The removal of CO_2 from the atmosphere is just one important advantage of improved soil carbon storage. The following are some advantages of atmospheric carbon sequestration into SOM:

i. Better soil quality as a result of increased aggregate stability, soil structure, and fertility;
ii. Greater ability to retain water;
iii. Diminished loss of nutrients;
iv. Lessened soil erosion;
v. Enhanced ability to eliminate harmful substances from the soil; and
vi. Enhanced crop yield.

The effect of increased atmospheric CO_2 levels on soil microorganisms' ability to sequester carbon was investigated by the researchers. More carbon was broken down by bacteria in nitrogen-rich soils, which increased the amount of CO_2 released into the atmosphere. The season and species had an impact on this CO_2 output as well. Under trees, in an elevated CO_2 atmosphere, microorganisms stored more carbon in unfertilized soil with little nitrogen. Increased CO_2 leakage from soils results from the application of nitrogen-based fertilisers, which are occasionally used to promote the growth of young trees (Lagomarsino,2007).

Strategies for managing soil carbon sequestration

The loss of soil carbon contained in it can result from changes in land management practices as well as climate change. Restoring damaged soils and implementing improved management practices (IMPs) for agricultural and forestry soils are two crucial soil C sequestration techniques.

The following management strategies are effective in creating a net carbon sink in soils:

Agriculture for conservation

Hobbs (2007) defines conservation agriculture (CA) as permanent soil cover (mulch) and minimal soil disturbance (no-till) paired with rotations. Compared to current cultivation methods, it is a more sustainable strategy for the future.The United Nations Food and Agriculture Organisation (FAO) defines conservation agriculture as a concept for resource-saving agricultural crop production that aims to achieve high and sustained production levels along with acceptable profits while also protecting the environment and reducing or eliminating soil manipulation for crop production. Unlike traditional methods, which primarily strive to maximise yields frequently at the expense of the environment, it incorporates the application of current agricultural technology to increase productivity, by maximising yields as well as protecting the health and integrity of the ecosystem (Dumanski et al., 2006).By storing carbon in the soil, conservation agriculture has the shown ability to transform many soils from sources of carbon to sinks of atmospheric carbon (FAO/CTIC, 2008; Lal et al., 1998). By lowering erosion, raising water infiltration, enhancing soil surface aggregates, promoting biological tillage to lessen compaction, raising the organic matter and carbon content of surface soil, regulating soil temperatures, and controlling weed growth, California enhances agriculture. Additionally, it lowers production costs, saves time, boosts output through timely planting, lowers pests and illnesses by promoting biological variety, and lowers greenhouse gas emissions (Hobbs, 2007).

Zero or minimum tillage

The primary goal of tillage is to create a soil environment that is conducive to plant growth.It is one of the main causes of the decline in soil carbon stores.If more organic matter (OM) is not added back to the soil as residues, compost, or through other methods, SOM is oxidised when it is exposed to the air during tillage, which lowers the amount of OM content. Tillage messes with the pores that microbes and roots have left behind. It's unclear how this will affect biology below ground. As raindrop energy dissipates, soil aggregates are more likely to break down on the bare surface left following tillage.Soil erosion is caused by this, which clogs soil pores, decreases water infiltration, and increases runoff. The surface crusts and prevents plant emergence when it dries (Hobbs, 2007).The primary cause of soil C loss is believed to be the use of disc harrows and mould board ploughs, which break up soil aggregates and hasten the breakdown of plant waste.C sequestration in agricultural soils may result from modifications to tillage techniques.According to Uger (1990), conservation tillage consists of mulch tillage, reduced tillage, and no tillage. The development of new crop production technologies that are typically associated with some degree of tillage reductions, for both pre-plant as well as in-season mechanical operations that may result in some level of crop residue retention on the soil surface, is characterised by Govaertset al. (2009) as conservation tillage.

The practice of using crops like legumes and small grains for soil enhancement and protection in between conventional crop-production periods is known as "cover cropping." Through the improvement of soil structure and the addition of organic matter, cover crops increase carbon sequestration. In a study conducted by Wang et al. (2010), six winter and summer cover crops were grown in two different soil types gravelly loam soil (GL) and fine sandy soil (FS) in phytotrons at three different temperatures. Of the winter cover crops, the ones with the highest and lowest amounts of carbon accumulation were Viciafaba L. at 0.597 kg/m2 and white clover (Trifolium repens) at 0.149 kg/m^2 in the FS soil, respectively.

Sunhemp (Crotalaria juncea L.), one of the summer cover crops, accumulated the most carbon (0.481 kg/m2), whereas castor bean (Ricinus communis) produced 0.102 kg/m2 at 30º C in the GL soil. After growing a full cycle of winter and summer cover crops, the mean SOC in the GL and FS soils rose by 13.8 and 39.1%, respectively, in comparison to the corresponding soils.

Due to their capacity for atmospheric nitrogen fixation, their propensity to shed leaves, and their higher below-ground biomass, pulses contribute a considerable amount of organic carbon to the soil (Ganeshamurthy, 2009).After seven cropping cycles, the effects of adding pulses to an upland maize-based farming system in the inceptisols of the Indo-Gangetic plains were examined in terms of the changes in the soil organic carbon pool (Venkateshet al., 2013).

According to the findings, adding pulses increased the overall amount of organic carbon in the soil. It decreased as soil depth increased and was higher in surface soil (0–0.2 m).Comparing the maize-wheat-mungbean and pigeonpea-wheat systems to a traditional maize-wheat system, the results showed a significant increase in total soil organic carbon of 11 and 10%, respectively, and in soil microbial biomass carbon of 10 and 15%, respectively. More amounts of carbon fractions and a higher carbon management index were obtained from the application of crop residues, farmyard manure at a rate of 5 mg/ha, and biofertilizers than from the control and recommended inorganic fertiliser treatment (N, P, K, S, Zn, B), especially in the system that included pulses.According to McCalla's 1958 research, fields with residue mulched had larger concentrations of bacteria, fungus, actinomycetes, earthworms, and nematodes than those with residue incorporation. Thus, it may be said that through their roots, cover crops assisted in promoting biological soil tillage.
For the earthworms, arthropods, and microscopic animals below ground that also biologically till soils, the surface mulch supplied food, nutrients, and energy.

Crop sequencing or rotation

Crop rotation is the practice of growing a variety of crops on the same plot of land in successive years. Through the alternate planting of shallow- and deep-rooted plants, it enhances the fertility and soil structure.A crop that removes a particular type of nutrient from the soil is succeeded by another type of crop that either replenishes the nutrient back into the soil or extracts a different combination of nutrients during the subsequent growing season. The amount of organic matter in the soil can be raised by changing the crops that are planted. Crop rotation's efficiency, however, varies with crop type and crop rotation intervals.The primary goal of crop rotation is to replace nitrogen by planting green manure after cereals and other crops. The cultivation of deep-rooted legumes, which boost the carbon content in deeper soil layers through rhizo-deposition and deep root biomass, is a part of organic crop rotation. Moreover, it results in integrated livestock production and the more efficient use of nitrogen.

Numerous long-term field experiments were carried out to compare crop sequencing with mono-cropping. Gregorich et al. (2001) studied continuous maize cultivation with a legume-based rotation; after 35 years, the difference between the rotation and monoculture maize was 20 tonne C/ha. Furthermore, the SOC present below the ploughed layer in the legume-based rotation appeared to be more biologically resistant, indicating the deep-rooted plants were useful for increasing carbon storage at depth. It was determined that shoot residues were not as important in increasing soil C stocks in no-till Ferralsol as roots, whether in rotations based on cover crops or forages.

Crop residue

The Ministry of New and Renewable Energy (MNRE, 2009) estimates that the Indian government generates 501.76 million metric tonnes of crop residues annually. The production and final usage of these crop wastes vary greatly between Indian regions, contingent upon the crops cultivated, cropping intensity, and productivity. The state of Uttar Pradesh generates the most crop leftovers (60 Mt), followed by Punjab (51 Mt) and Maharashtra (46 Mt).An estimated 92.81 million tonnes of crop residues go unexamined in India each year; these leftovers are mainly burned on farms to make way for the sowing of new crops (Pathak et al., 2010).

Due to the increased usage of combines for harvesting and the high expense of labour for removing crop residues using conventional methods, the issue of on-farm burning of agricultural leftovers has gotten worse recently (NAAS, 2012).In addition to numerous other gases, burning crop residues releases CO, CH4, N2O, NOx, NMHCs (nonmethane hydro carbons), and SO2. (Anonymous, 2012). In India, the burning of crop residue produced about 0.23 million tonnes of CH4 and 0.006 million tonnes of N2O in 2007.Burning alters the soil's microbial population, causes moisture loss, and raises the pH of the soil because it produces ash, which contains ions of calcium, magnesium, and potassium. One such technique that will have a significant effect on the sequestration of carbon is leaving agricultural residue on the field. An estimated 3.4×109 tonnes of crop residue are produced annually worldwide.

C sequestration of 0.2 × 1015 g/year could result from the conversion of 15% of the carbon in the residues to passive organic carbon portion (Lal, 1997).According to Siligrams and Chambers (2002), the plough layer with incorporated straw had a higher level of organic carbon (10.9 g/kg) compared to burnt straw (8.9 g/kg).It is better to turn the wastes into biochar than to burn them. Based on agricultural residue management studies carried out at Bhairahawa, Nepal, Duxbury and Lauren (2004) revealed that carbon stocks ranged between 26.9 and 28.8 t/ha at a depth of 40 cm. The improved productivity of rice and wheat (average of 5.1 against 3.4 t/ha for rice and 3.0 versus 1.2 t/ha for wheat for fertilised and control treatments, respectively) did not affect soil C contents, as evidenced by the fertiliser input without residue having no influence on the soil carbon store. The addition of residues raised the soil C stock by 1.48 t/ha on average. Over the course of seven years, 29.5 t/ha, or 14.75 tC/ha, of residues were added in total.As a result, C retention was 0.21 tC/ha/year, or 10% of that added.

Carbon Dioxide Emission Measurement

Field CO2 measurements

Following crop emergence, four 10-cm-diameter PVC rings two in each row and two in between are positioned in each plot. Every PVC ring's carbon dioxide emissions are measured using a Li-Cor 6400 (Li-Cor Corp., Lincoln, NE) that has a 6400-09 soil chamber attached.

Up to harvest, measurements of the soil's CO2 emission rate are made every seven to ten days. At the time of monitoring CO2 emission, soil temperature and moisture were recorded in the top 5 cm outside the ring. Using the thermometer that came with the Li-Corr 6400, the temperature of the soil was determined.

CO2 measurements in forests

Nondestructive morphometers and the Allometric Equations approach (IPCC, 2003; USDA, 2007) are used to measure the following parameters: a) total ground biomass; b) carbon percentage; and c) density of plant wood.
The relationship between an organism's size and the size of any of its parts is known as allometry. An allometric equation is typically stated in power-law or logarithmic form. The combined analysis of the above ground biomass (AGB), below ground biomass (BGB), and tree canopy biomass data corresponding to each species of tree measured yields the total ground biomass.

Conclusion

There is a strong correlation between soil and management systems and carbon sequestration.In addition to increasing water use efficiency and decreasing the use of fossil fuels, zero or no tillage in conjunction with crop residue retention on the soil surface aids in the sequestration of carbon. Only a small portion of residues that are left on the soil surface come into touch with the soil and microorganisms. Because there is less oxygen available, breakdown proceeds slowly. Crop residue should not be added to the soil because doing so causes it to decompose quickly and produce carbon dioxide. Because different crop species have varying root depths, crop rotation can accelerate the rate of SOC accumulation at different soil profile depths, which helps with carbon sequestration.

The greatest way to add organic matter to the soil and raise the carbon pool in the soil is through manures.Compared to plant residues, they are more resistant to microbial breakdown. Therefore, applying manure increases carbon storage for the same amount of carbon input compared to applying plant residue.

A production method that maintains the wellbeing of people, ecosystems, and soils is organic agriculture. Instead of using inputs that have negative impacts, it makes use of biological processes, biodiversity, and cycles that are tailored to the particular environment. It blends science, creativity, and tradition to improve everyone's quality of life, equitable relationships, and the environment as a whole.For a considerable amount of time, applying FYM has been considered a beneficial way to improve soil fertility.Biogas can also be produced from dung, and the leftover slurry can be applied to fields as manure. Utilising FYM also encourages aggregate formation and stabilisation, which aids in C's long-term storage. However, the primary drawback of utilising manures in the system is the carbon loss that results from the cattle's growth and breathing needs. The ruminants even produce a considerable amount of CH_4, a powerful GHG. This could be managed by using organic agricultural methods in conjunction with balanced NPK and micronutrient fertilisation.

To boost the amount of carbon stored at deeper soil layers, deeprooted grasses and crops should be produced through hybridization in addition to various conservation techniques.Up to 30–50% of the carbon fixed in photosynthesis in many plants is first moved below ground. A portion is utilised for the root system's structural growth, while the remainder is lost to the surrounding soil in organic form by autotrophic respiration (rhizo-deposition). For thousands upon thousands of years, carbon can be stored in the soil via biochar. It contributes to increased soil fertility, which in turn promotes plant development and, in turn, raises biomass and CO2 consumption.

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