

Soil Carbon Sequestration: A step towards sustainability

Abstract

Nowadays, sustainable agriculture is a major concern of the whole world, all leading agricultural countries like China, USA and India etc. are working together in several organizations such as FAO, World Food Organisation to overcome the problem of environmental health and food security in upcoming years to meet the food demand goal in 2050 in sustainable manner. Carbon present in soil naturally is termed as soil carbon which is directly related to organic matter present in soil, higher the soil carbon more will be the crop yield. Most of the soil carbon has been released in the atmosphere due to conversion of uncultivated land into cultivated agricultural land. Bringing back that released carbon back to the soil with several methods is known as soil carbon sequestration. In this paper, relation of soil carbon sequestration has been discussed with respect to organic farming, natural farming respectively. Changes carried out in traditional agronomical practices have potential in enhancement of soil carbon sequestration. Practices such as conservation tillage, growing cover crop, proper nutrient management, residue management etc. have significant capacity to sequester carbon in the soil, along with that various challenges which are being faced during carbon sequestration are also considered in this paper. **Soil carbon sequestration is a temporary solution to Carbon dioxide enrichment, but it is challenging to operationalize due to obstacles such as measuring the soil's carbon stock, permanence, carbon pools, separation, and the soil's propensity to approach saturation levels. This chapter aims to raise knowledge of the capability of soils to absorb and store atmospheric carbon dioxide in long-lasting pools, reducing climate change.**

Keywords: Agronomic Practices, Carbon Sequestration, Natural Farming, Organic Farming, Sustainable Agriculture

Introduction

Soil Carbon

Soil carbon refers to the carbon that is kept in soils all over the planet. This is composed up of carbonate minerals produced from soil-found organic and inorganic carbon. In the context of the global carbon cycle, soil carbon functions as a carbon sink for biogeochemistry, climate change mitigation, and the creation of global climate models. Although the majority of the carbon on Earth exists in the seas, three times as much of it is stored in soils, which make up around 75% of the carbon pool on land. Soils are essential for maintaining a healthy global carbon cycle. According to Paustian et al (2000), around 50 Pg C are thought to have been released into the atmosphere from soils globally as a result of the conversion of natural land to cultivated agricultural land. For forests, wetlands, and farmland and grasslands, the mitigation potential from soil carbon is 9%, 72%, and 47%, respectively. In addition to helping to mitigate climate change, soil carbon is crucial to land-based initiatives to reduce atmospheric carbon dioxide, stop carbon emissions, and provide ecosystem services. Globally, soils contain three times as much carbon as the atmosphere, and scientists have known for decades that soil organic matter regulates climate. The historical loss of carbon from this pool and the potential for future accelerated loss under warming scenarios have both been noted in recent study. Thus, in response to anticipated land use change and climate change, soil organic carbon (SOC) plays a role in both repairing a carbon sink and preventing future CO₂ emissions.

Soil Carbon Sequestration

Carbon sequestration involves the long-term storage of carbon dioxide or other forms of carbon in the oceans, soils, vegetation (particularly forests), and geologic formations in order to prevent or delay global warming. It is a means of reducing the **build-up** of greenhouse gases, which are emitted as a result of human activity. The net removal of carbon dioxide (CO₂) from the atmosphere or the prevention of emission of carbon dioxide (CO₂) into the atmosphere by terrestrial ecosystems is referred to as carbon sequestration. All chlorophyllous plants absorb CO₂ from the atmosphere during photosynthesis as part of the elimination process. The soil's organic matter and the biomass of plants (their trunks, branches, leaves, and roots) are where this carbon is kept. The terrestrial carbon sequestrations are dependent on various ecosystem conditions and land use strategies that support established plants for longer periods of time. During photosynthesis, plants take in carbon, and during respiration, they release some of it back into the atmosphere. When plants die and decay, the carbon that is still present in their plant tissue is then devoured by animals or given to the soil as litter. As soil organic matter, carbon is mostly kept in the soil (SOM). SOM is a complex mixture of carbon compounds that includes bacteria, fungi, protozoa, nematodes, decomposing plant and animal tissue, and carbon bonded to soil minerals. Carbon can be swiftly released back into the atmosphere or can be trapped in soils for ages. The quantity and duration of carbon storage in soil are both influenced by climatic factors as well as by natural vegetation, soil texture, and drainage.

Potential of Soil Carbon Sequestration to Reduce the Impact of Global Warming

According to Ruddiman (2005), soils have lost between 140 and 150 Gt C (or 510 and 550 Gt CO₂; Sanderman et al., 2017) due to cultivation since the beginning of agriculture roughly 8,000 years ago. It has been argued that soil C sequestration might be a substantial greenhouse gas (GHG) removal technique because it is known that optimum management practises can restore some, if not all, of this lost carbon (Lal et al., 2018). (also called negative emission technology, or carbon dioxide removal option; Smith, 2016). Nevertheless, a recent systematic assessment by Fuss et al. (2018) predicts a yearly technical capacity of 2–5 Gt CO₂/year. Worldwide estimates of soil C sequestration potential vary significantly. Economic potential estimates are at the lower end of this range (Smith, 2016; Smith et al., 2008).

Soil Carbon Sequestration in relation to Organic Farming

The greatest terrestrial carbon resource is represented by soil organic carbon (SOC) reserves, albeit these stocks normally drop once natural regions are converted for agricultural use (Guo & Gifford, 2002). As agricultural soils make up a large amount of the planet's land area, reestablishing SOC sequestration in these systems is crucial for reducing climate change (Lal, 2004). Moreover, enhancing the quick cycling of particulate organic matter, a source of nutrients for crop output, may be accomplished by speeding up the sequestration of SOC (Janzen, 2006). The ecological intensification of agricultural systems makes the assertion that maintaining food production while boosting SOC sequestration may be achieved by optimising vital ecosystem processes like soil C cycling (Bommarco et al. 2013). In fact, compared to conventional farming (CF), organic farming (OF), one of the major ecological intensification methods now in use globally in terms of surface area (Tittonell, 2014), boosts top SOC stocks by 3.50 Mg C/ha on a worldwide average (Gattinger et al., 2012). The causes of this rise are unclear, but it is clearly influenced by the large rates of external C inputs (such as manure) that are generally used in OF (Kirchmann et al. 2016; Leifeld & Fuhrer, 2010). However when contrasting conventional and organic farms with low manure application rates (LMR; European livestock units per hectare 1, Gattinger et al., 2012), increases in SOC stocks are also found. Additionally, because crop output is on average 20% to 25% lower in OF, C inputs to the soil via primary crop leftovers are reduced (Ponisio et al., 2014; Seufert et al. 2012). Hence, the higher SOC stocks observed under organic management of agricultural areas cannot be entirely explained by changes in farming systems in the quantity of C inputs entering the soil (manure and crop output).

The overall impact of long-term changes in soil carbon inputs and outputs is represented by soil organic carbon stocks (Crowther et al., 2016). As a result, variations in SOC losses from organic matter decomposition in farming systems may be changing SOC sequestration by increasing the SOC stores found under OF. According to Garca-Palacios et al. (2016) and Parton et al. (2007), the morphological and chemical quality of plant residues, soil decomposers, and site climate all play major roles in the breakdown of soil organic matter. The quality of plant residues (such as leaf and root N concentrations) feeding soil decomposers may be a primary driver of soil C losses when comparing SOC sequestration in OF vs. CF under the same climatic circumstances (Faucon et al. 2017). In this line, labile plant residues (e.g., greater N content) are often associated with quicker breakdown rates and consequently increased soil C losses (Cornwell et al., 2008; Garca-Palacios et al., 2016). Yet, the stability of biological materials might potentially have the opposite effects. According to the Microbial Efficiency-Matrix Stabilization framework, the breakdown of labile litter increases the amount of microbial residues that are chemically bound to the mineral soil matrix, enhancing the stability of the soil organic matter (Cotrufo et al. 2013). In order to understand the mechanisms governing SOC sequestration reactions to OF, it may be helpful to take into account crop residue features critical for decomposition (Faucon et al., 2017). To assess whether ecological intensification should be pursued as an effective land management technique helping to reduce climate change through these greater SOC sequestration rates, a thorough knowledge of the processes behind enhanced SOC sequestration is essential.

An increase in SOC could facilitate soil carbon sequestration. According to Iwasaki, Endo, and Hatano (2017), adding organic matter over a lengthy period of time boosts soil carbon sequestration. According to Li et al. (2016), SOC sequestration rises with addition of plant-derived C. In order to boost soil fertility, SOC sequestration must often be accompanied by increased soil P and S retention in addition to N. These are the other essential nutrients needed to create a pool of SOM that was more stable (Kirkby et al. 2013). Natural farming, which entails low-input organic farming with weed cover management, has the potential to boost soil carbon sequestration, but attention must be paid to the nutrient balance for long-term management.

Soil Carbon Sequestration in relation to Natural Farming

Analytical report of Gurukul Farm Kurukshetra on affect of natural farming in organic carbon sequestration.

According to preliminary research and observations at the 180-acre Gurukul farm in Kurukshetra, natural farming may serve as a potential model for Indian agriculture. There has been a remarkable improvement of soils in respect to organic carbon (OC), nutrients, and biological health, according to the analytical findings from the several establishments (CCS HAU Hisar, PAU Ludhiana, IIFSR Modipuram, and Kurukshetra University). The analysis at CCS HAU in Hisar and IIFSR in Modipuram revealed that the average amount of organic carbon in soil samples taken from Gurukul Farm in June 2017 amounted 0.61 and 0.62%, respectively. In the IIFSR and CCS HAU analyses, the 19 and 30% soil samples were found to be suffice/rich in OC (>0.75%). In June 2018, a year after the crops had been planted, soil samples were once more taken and examined at CCS HAU Hisar. It was found that 95% of the soil samples had high OC concentrations, with a mean OC percentage of 0.91% falling within the 0.82-1.12% range. Following the Kharif season in October 2018, more soil samples were taken for analysis at CCS HAU Hisar and PAU, Ludhiana, in order to corroborate the results. These findings showed that the average OC in the soil analysis reports by the various institutes was 0.84 and 0.78%. On a 180-acre farm, the effects of LBNF practises can be seen in the 49% rise in OC (from 0.61 to 0.91%) in only one year of operation and the continual preservation of average OC at a level of over 0.75% throughout the season. On the OC content of soil, changing seasons and crop management techniques may have an impact.

Sr. No	Organic Carbon %		
	June 2017	June 2018	October 2018
1	0.82	1.12	0.82
2	0.82	1.05	0.52
3	0.75	1.05	0.82
4	0.67	0.97	0.82
5	0.60	0.97	0.75
6	0.60	0.97	1.12
7	0.52	0.97	0.82
8	0.52	0.97	0.82
9	0.45	0.97	0.97
10	0.37	0.97	0.97
11	-	0.90	-
12	-	0.90	-
13	-	0.90	-
14	-	0.90	-
15	-	0.82	-
16	-	0.82	-
17	-	0.82	-
18	-	0.82	-
19	-	0.45	-
Average	0.61	0.91	0.84

Table:1 Organic Carbon status of Gurukul Farm (Samples analysed at CCS HAU Hisar, Haryana)

Organic Carbon Content: Ten soil samples were randomly selected from Gurukul Farm and examined at CCS HAU Hisar during the summer/Kharif season of 2017. Similarly, 16 soil samples were collected by the IFSR, Modipuram scientists for study of organic carbon, macronutrients, and micronutrients. found that 19% of the soil samples examined at IIFSR and 30% of those examined at CCS HAU Hisar fell into the rich group (>0.75%) for organic carbon.

Similar findings from the respective institutions showed that 10 and 12% of the soil samples had low levels of organic carbon (0.40%). The remaining samples were classified as having a medium level of OC concentration. The two universities' combined average OC was 0.61%.

In June 2018, 19 samples were once more randomly selected from 180 acres of Gurukul Farming Land and were evaluated in the soil testing lab of CCS HAU, Hisar, after a year. The astounding findings showed that 95% of the soil samples fell into the category of rich soil, with an average OC of 0.91% in the range of 0.82 to 1.12%. One-fourteenth of the soil samples tested had OC levels above 1.0%. Only one sample, with an OC of 0.45%, fell into the medium category.

The soil samples were again randomly collected from the farm in October 2018, and they were examined at soil testing facilities run by CCS HAU in Hisar and PAU in Ludhiana. The OC state of Gurukul Farmland was once again verified by these results, though on a considerably smaller scale, which may have been caused by seasonal changes. In the samples examined at CCS HAU Hisar and PAU, Ludhiana, the average OC was 0.84 and 0.78%, respectively.

90% (CCS HAU) and 70% (PAU Ludhiana) of the samples from the wealthy category (>0.75%) respectively. Only one sample out of twenty analysed at CCS HAU and PAU falls into the low category (less than 0.40%), while 30% of samples examined by both of the universities had OC more than 0.90%.

Agronomic Practices followed to enhance Soil Carbon Sequestration

CO₂ levels are rising at a pace of 2.3 ppm annually, which is contributing to more environmental damage and global warming. Up to 30% of GHG emissions are caused by the agricultural sector. For humanity to survive, sustainable agriculture is crucial. Utilising various agronomic management techniques can aid in the sequestration of carbon. No-till or reduced-till techniques, nitrogen management, cover crops, crop rotations, green manuring, the use of animal manures, agroforestry, etc. are some examples of these techniques. Adoption of these many agronomic techniques will increase farmer revenue in addition to crop production. [Anonymus, Minnesota Board of Water and Soil Resources]

1. Conservation Tillage

Especially in corn and soybean rotations, Minnesota farmers are utilising conservation tillage more often than in the past. Numerous environmental and financial advantages of conservation tillage practises include reduced production costs, improved water quality, better nutrient retention, and reduced soil erosion. No-till as well as conservation tillage techniques have been shown to be effective at reducing soil erosion and offering other advantages. As an added bonus, conservation tillage techniques sequester more carbon than traditional agricultural tilling techniques. There are a variety of advantageous tilling techniques; the most advantageous include no-till and strip till, which disrupt soils the least.[Mbuthia et al. (2015), Reicosky et al. (2015)] The amount of microbial biomass in the soil has evolved into a sign of improved nutrient retention, soil structure, and soil quality. Additionally, research has shown that tillage has a negative impact on beneficial microorganisms like bacteria and fungus, which are particularly good at storing carbon.[Mbuthia et al. (2015), Zucker et al. (2016)] The only way to increase the retention of carbon in agricultural systems, however, is through the use of conservation tillage techniques. In addition to benefits like greater infiltration, nutrient retention, and decreased erosion potential, it has been demonstrated that coupling conservation tillage and cover crops greatly increases soil organic carbon.Landscapes are transformed by soil health practises and no-till farming (2019), according to Mbuthia et al. The benefits of no-till and cover crops are greater when used jointly than when used separately.In 2015, Mbuthia et al. Despite concerns about carbon sequestration, BWSR promotes conservation tillage and cover crops to preserve soil health, prevent soil erosion, and enhance water quality in nearby streams.

2. Cover Crops Store Carbon

When the land would otherwise be bare, such as before the main crop appears in springtime or after the autumn harvest, cover crops are sown to offer seasonal soil cover. By generating biomass on the soil's surface and below, cover crops sequester carbon. According to research, root biomass is where the majority of the soil's organic carbon is found. Carbon buried underneath lasts longer than it does in deposits on the surface. In the long run, cover crops safeguard soil carbon by producing aggregates that improve the general health and productivity of the soil by fostering beneficial root-zone fungi, bacteria, and invertebrates that also contribute to soil carbon. In 2015, Mbuthia et al.

Introducing cover crops to all tillage treatments improved soil organic carbon stock increases by 30% for no-till, 10% for chisel ploughed plots, and 18% for moldboard ploughed plots, according to a 12-year University of Illinois study. [Olson et al. (2014)]

By being planted in the late summer, cover crops can produce a significant amount of biomass both in the autumn and the following spring. A suitable option is winter rye since it resists decay better compared to other cover crops like oats or barley.

3. Management of the necessary nutrients

Chemical fertilisers, notably N₂O, are a major cause of GHG emissions. In addition to this, the manufacture of fertiliser and the transportation of it are linked to GHG emissions. Using fertilisers wisely boosts crop yields and profitability, and through the process of soil organic carbon (SOC) mineralization, farmed soils have contributed roughly 50 Pg of CO₂ to the atmosphere [Lal R. Sequestering carbon in soils of agro-ecosystems(2011)]. Although studies show that nitrogen fertilisation reduces soil microbial activity over time, they also show that the use of fertilisers has significantly enhanced agricultural output [Frey SD et al. (2014)]. For sustainable soil fertility and crop output, balanced fertilisers must be used continuously. According to Windeatt JH et al. (2014), crop residues and nutrients, particularly N, aid in the storage of up to 21.3–32.5% of carbon. The long-term impacts of nitrogen fertilisation on soils, however, are complex and still unknown. For instance, in the long-term trials conducted in Canada, SOC sequestration rates ranged from 50 to 75 g cm² per year in soils with ideal cropping systems. Long-term tests in the Northern Great Plains (ND) have also demonstrated that N fertiliser boosted crop residue returns but generally did not increase SOC sequestration, which is the opposite of what research in the Great Plains has revealed. Liu Enke and others. A long-term study that was started in Northwest China in 1979 to determine the effects of fertilisation on SOC and SOC fractions across the entire soil profile, such as (0-100 cm) soil depth, was published by [Liu E et al. (2013)]. Six treatments made up the experiment: unfertilized (control), N fertiliser, NP fertiliser (nitrogen and phosphorous), straw plus N and P fertilisers (NP + S), farmyard manure (FYM), and NP fertiliser plus FYM (farmyard manure plus N and P fertilisers). As compared to the control treatment, the results showed that SOC storage in the 0–60 cm increased by 41.5, 32.9, 28.1, and 17.9% in the NP + FYM, NP + S, FYM, and NP treatments, respectively. The labile pool in the 0–60 cm of soil depth was also increased by the addition of organic manure and inorganic fertiliser. These findings demonstrate that among the forms of fertilisation under investigation, prolonged use of organic manure has the most advantageous effects on creating carbon pools. It may be inferred that the proper application of fertilisers in accordance with soil conditions can help to maximise carbon sequestration together with crop production and reduce emissions of various GHGs.

4. Application of compost and animal manure

Compost is a substance that mostly consists of organic matter that has decomposed and is utilised to fertilise and condition agricultural soil. Animal manure is the animal excreta that is gathered from livestock ranches and barnyards and used to improve the soil. Manure application affects the C content of different agricultural fields and is crucial for maintaining the health of the soil as it is a source of carbon. Green manuring, as compared to applying a mixture of FYM along with green manure, stored more carbon in a maize-wheat cropping system, while FYM application alone increased carbon sequestration in the cropping system consisting of rice and wheat [Naresh RK et al. (2017)]. Composting improves the soil's C levels while simultaneously increasing net primary output [Baldi E et al. 2018]. According to a paper by Ren T et al. (2014), limiting the application of manures and organic fertilisers has an impact on soil microbes, nutrient regimes, and stable organic compounds in addition to stable organic compounds. The beneficial effects of mixing mineral fertilisers with organic manures were supported by Liu et al. Similarly, application of various organic materials, i.e., municipal solid waste (MSW), farm yard manure (FYM), sugar industry waste (filter cake), and maize cropping residuals, at 3 t C ha⁻¹ alone and with a full or half dose of NPK mineral fertiliser demonstrated that the utilisation of organic material (filter cake or MSW) has the best potential to improve improving SOC retention, WUE, and wheat yield in an irrigated maize-wheat cropping system [Shehzadi S et al. (2017)].

All of this suggests that using organic fertilisers like compost and animal manure alongside synthetic ones is good for the environment and the health of the soil.

5. Performing Crop rotations

The succession of crops cultivated in regularly occurring successions on the same plot of land is referred to as crop rotation. The subsequent crops could last for two or more years. Carbon sequestration is also impacted by variations in crop rotations, soil types, temperatures, and crop management techniques. Intensive cropping systems deplete soil organic matter (SOM), but balanced NPK fertilisation, the usage of organic amendments, and in a similar way the application of crop residues may boost carbon sequestration levels to 5-10 Mg ha¹ annually as these amendments contain 10.7-18% C, which can also aid in the retention of carbon [Manadal B et al.]. Alternative sources of nitrogen include peas, lentils, alfalfa, chickpeas, sesbania, and other legume crops. Soil carbon can be stabilised by the use of crop rotations, particularly with legume cover crops, that contain carbon molecules that are probably more resistant to degradation by microbes. Syswerda et al. published the findings of a 12-year study of an organic management system which utilised different crop rotations. They claim that despite substantial weed control tillage, a rise in soil carbon sequestration was observed. The findings of a lengthy study that was carried out in Dingxi, Northwest China, between 2013 and 2015 were displayed in a rotation of spring wheat and peas in a semi-arid environment that was rain-fed. The different treatments included no-till with stubble retained (NTS), conventional tillage with stubble incorporation (TS), conventional tillage with stubble removed (T), and no-till with stubble retained (NTS). In addition, the average grain output over the course of the 3 years in NTS was higher than T and NT [Yeboah S et al. (2016)]. The SOC, microbial biomass carbon, and root biomass in NTS rose above T and NT. Alternative tillage and cropping methods have recently received a lot of interest as a way to reduce agricultural CO₂ emissions. Different cropping techniques, such as cover cropping, ratoon cropping, and companion cropping, may aid in the sequestration of carbon. Row intercropping, strip intercropping, mixed cropping, and relay intercropping are all types of intercropping that can boost income and improve soil fertility.

Wheat + mustard, cotton + peanut, peanut + sunflower, wheat + chickpea, etc. are some examples of intercropping [Anon, "Mixed Cropping"]. Compared to conventional farming, organic farming may additionally boost soil organic carbon. According to research on the restoration of grasslands, legume species have more advantageous impacts on the restoration of grasslands than the use of mineral fertilisers due to their biotic and abiotic effects [De Deyn GB et al. (2011)].

The information above demonstrates how choosing the right crop rotations for the soil and environmental conditions can be beneficial in the storage of carbon, which not only improves soil fertility but also lowers CO₂ emissions into the atmosphere and increases farmer income. This is done while keeping in mind economic considerations.

6. Management of residues

Following crop harvest, crop residues—detached vegetative components of crop plants—are purposefully left in agricultural fields to decompose. A tonne of cereal residue, for example, comprises 12–20 kilogramme N, 1-4 kg P, 7–30 kg K, 4–8 kg Ca, and 2-4 kg Mg. The yearly production of agricultural residues over the world is around 3.4 10⁹ tonnes. If 15% of these total residues are applied to the soil, it can boost the C levels of the soil. Mulching is the practise of covering plants with detachable vegetation, such as compost, wheat straw or plastic sheets, in order to shield them from excessive evaporation and cold stress as well as to increase the amount of SOM in the soil.

Crop leftovers are crucial to managing SOC and enhancing the condition of the soil. Mulching increases soil moisture, decreases soil erosion, and, in a similar manner, decreases the depletion of carbon from the soil and agricultural leftovers, which are integrated into the soil to increase its organic matter. Due to higher carbon inputs and less soil disturbance, a direct seedling mulch-based farming

strategy enhances soil organic matter. In the top 0–5 cm of the soil, mulch can improve soil organic matter (SOM) and carbon sequestration. It enhances the physical and chemical characteristics of the soil and can boost the annual carbon sequestration in soils used for agriculture by 8–16 Mg ha⁻¹.

Because of higher carbon inputs and reduced soil disturbance, mulch-based cropping techniques promote the development of soil organic matter. Direct seedling straw mulch has a potential to lessen heat stress because it increases soil organic carbon and N efficiency, decreases evaporation, boosts infiltration rate, and minimises tillage in lowland rice-based cropping systems. Increased net primary productivity (NPP) results from adding more residues to the soil. Many agricultural soils will exhibit C growth proportionate to increases in C inputs, despite having had their initial C levels drastically lowered by agriculture. The equilibrium between the the inputs of C from crop residue and the losses of C, which primarily occur through decomposition, determines the amount of C in the soil.

Soil C can be raised by increasing inputs of residues or by slowing down decomposition (hétérotrophic soil respiration). Decomposition rates of litter are also impacted by its quality. Results of a 4-month study were added to uncultivated and agricultural soils over three rates of straw residue and farm yard manure under controlled greenhouse conditions. The application of organic matter, particularly the incorporation of farm yard manure, led to a significant increase in the final soil organic carbon content, and a higher amount of soil organic carbon were stored in the cropland soil than in the uncultivated soil. Two treatments of straw residue and farm yard manure incorporation were used into: a soil surface layer and a 0-20 cm soil depth. The findings demonstrated that agricultural soil and farmyard manure were more effective at storing carbon than uncultivated soil. According to the findings [Mahmoodabadi et al. (2014)], it is important to pay closer attention to how organic residue management affects carbon sequestration.

All of this demonstrates how using crop waste and applying mulch can enhance soil microbial activity, reduce heat stress, aid in water storage, and increase soil organic carbon.

7. Using improved crop varieties

The soil organic carbon can be increased by choosing enhanced crop varieties that can increase both above- and below-ground biomass. According to Machado et al. [Machado et al. (2006)], crop species with extensive root systems have the ability to enhance SOC in soils subject to NT. Similar to this, Kell [Kell DB. (2012)] asserts that by enhancing root development in crops used in agriculture, soil carbon storage can balance greenhouse gas emissions for the ensuing 40 years. All of this suggests that using crop types with superior root systems and higher yields can boost soil fertility while also increasing agricultural yields.

Challenges in Carbon Sequestration

Although there are many chances to use the carbon stock and sequestration capacity of various ecosystems' soils, there are also many obstacles that make this challenging in practise. Many of these difficulties include:

1. Measurement and verification

It is challenging, time-consuming, and expensive to measure the carbon stock in soils. Due to sample mistakes, small-scale variability, and difficulties with measurements and analysis, changes within the range of 10% are exceedingly challenging to detect [Sparling et al. (2006)]. The annual increase in soil carbon stock is quite minimal, typically between 0.25 and 1.0 t/ha [Ravindranath et al. (2007)]. Due to methodological challenges with monitoring, verification, sampling, and depth, it is particularly harder to account for tiny gains or losses in soil carbon at different scales. Even if these little adjustments It is difficult to connect such changes to management or land use practices in a specific

context when (gains or losses) are found. When the soil eventually reaches a stable state, its ability to sequester and hold carbon is likewise limited.

Sequestered carbon is found in the soil in a variety of pools with variable lengths of time spent in the ecosystem. These pools consist of:

Organic carbon stored in a passive, recalcitrant, or refractory pool has an extremely long residence time, ranging from decades to thousands of years.

Carbon stored in an active, labile, or rapid pool decomposes quickly, causing it to remain in the soil for a significantly shorter time. The typical residence period is between one day and one year.

Due to the slow rate of decomposition, carbon stored in a sluggish, stable, or humus pool has a lengthy turnover time. The typical length of stay is one year to ten years. [Abdullahi et al. (2018)]

2. Permanency

As the sequestered carbon can be quickly released back into the atmosphere as a result of breakdown or mineralization, this presents another difficulty with carbon sequestration in soil. Sequestered carbon is regarded as a temporary solution for reducing atmospheric carbon because of this. A number of meteorological, agrarian, and managerial factors influence the rate of carbon loss. [Abdullahi et al. (2018)]

3. Separation

It is exceedingly challenging to identify and distinguish between the amounts of carbon that has been naturally sunk into the soil as a result of land use or management actions. The notion of separation calls for a distinction to be made between carbon sequestered or GHG emissions avoided owing to management intervention and those that would have happened because of natural events. Hence, methodologies to distinguish between carbon that is naturally sequestered and carbon that is captured as a result of human management are needed.

Conclusion

The extent and duration of the potential for SOC sequestration are limited. It is merely a temporary solution to the CO₂ enrichment caused by anthropogenic activity. Even with soil C sequestration, the atmospheric CO₂ concentration will keep rising. Thus, creating fossil fuel substitutes is necessary for a long-term solution. Although this concept seems interesting in theory, it is challenging to operationalize in practise due to a number of obstacles. Among these are the challenges associated with measuring the soil's carbon stock, permanence, the presence of carbon pools with varying carbon residence durations, separation, and the soil's propensity to approach saturation levels once the maximum amount of carbon that can be harvested has been attained. The majority of these issues have seen progress, but deliberate initiatives to improve carbon absorption and sequestration in the soil ecosystem have not yet gained widespread recognition among practitioners and policymakers. The purpose of this chapter is to raise knowledge of the capability of soils to absorb and store atmospheric CO₂ in long-lasting pools, hence reducing climate change. Researchers must to put up a lot of effort in addressing the issues preventing the general implementation of this endeavour.

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