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.

Add result/outcome of analytic report (field observation in india)

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

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Introduction

Soil Carbon

The carbon stored in soils around the world is known as soil carbon. This contains carbonate minerals made from both organic and inorganic carbon found in soil. In terms of the global carbon cycle, soil carbon is a carbon sink that contributes to biogeochemistry, the mitigation of climate change, and the development of global climate models.Although the majority of the carbon on Earth is stored 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.Soil carbon comprises 9% of the mitigation potential of forests, 72% for wetlands and 47% for agriculture and grasslands. Soil carbon is important to land-based efforts to prevent carbon emissions, remove atmospheric carbon dioxide and deliver ecosystem services in addition to climate mitigation. 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 buildup 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. Plants absorb carbon during photosynthesis and release some of it back into the atmosphere during respiration. 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

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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 sequestrsation.

On the basis of initial investigation and observations at 180 acres of Gurukul farm Kurukshetra, it appears that natural farming may be a promising model in Indian agriculture. The analytical results from the different institutions (CCS HAU Hisar, PAU Ludhiana, IIFSR Modipuram and Kurukshetra University) have reflected that there was incredible enrichment of soils in terms of organic carbon (OC), nutrients and biological health. The results indicated that the average organic carbon in soil samples collected from fromGurukul farm in June 2017 and analysed at CCS HAU, Hisar and IIFSR, Modipuram was 0.61 and 0.62%, respectively. The 19 and 30% soil samples in the analysis of IIFSR and CCS HAU were found sufficient/rich in OC (>0.75%). After one year of cropping i.e. in June 2018, soil samples were again collected and analysed at CCS HAU Hisar. It was observed that 95% soil samples were rich in OC with average OC value of 0.91% in the range of 0.82-1.12%. For confirmation of results, soil samples were further drawn in October 2018 after Kharif season and analysed at CCS HAU Hisar and PAU, Ludhiana. These results indicated that the average OC was 0.84 and 0.78% in the soil analysis reports from the respective institutes. The increase in OC by 49% (from 0.61 to 0.91%) in a period of only one year and the maintenance of average OC at the level of more than 0.75% across the season on a farm of 180 acres exhibit the impact of LBNF practices. Seasonal variation and crop management practices may exert influence on OC content of soil.

Sr. No	Organic Carbon %		
	June 2017	June 2018	October 2018
1	0.82	1.12	0.82

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

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Organic Carbon Content: In summer/Kharif season of 2017, 10 soil samples were drawn at random from Gurukul farm and got analysed at CCS HAU Hisar. Likewise 16 soil samples were taken by the scientists of IFSR, Modipuram for analysis of organic carbon, macro and micronutrients. These analytical results presented in Table 4 and 5Where are those tables?? (revealed that 30% soil samples analysed at CCS HAU Hisar and 19% of those analysed at IIFSR were in rich category(>0.75%) with respect to organic carbon.(Table 2 & 3 : not found)

Similarly 10 and 12% soil samples represented poor status of organic carbon (<0.40% in the results registered by the respective institutions. Rest of the samples were categorised in the medium range of OC content. The average OC from both of the institutions was 0.61%.

After one year in June 2018, nineteen samples were again drawn randomly from 180 acres of Gurukul Farmland and got analysed in the soil testing laboratory of CCS HAU, Hisar. The results were incredible which depicted that 95% soil samples represented in rich category with average OC of 0.91% in the range of 0.82 to 1.12% (Table 4). Sixteen percent soil samples had OC more than 1.0%. Only one sample was in medium category with OC of 0.45%.

Again in October 2018, the soil samples were drawn at random from the farm and got analysed in soil testing labs of CCS HAU, Hisar and PAU, Ludhiana. These results again confirmed the OC status of Gurukul Farmland, although at somewhat lesser scale might be due to seasonal variations. The average OC was 0.84 and 0.78% in the samples tested at CCS HAU Hisar and PAU, Ludhiana, respectively.

The figures of the samples representing rich category (>0.75%) were 90% (CCS HAU) and 70% (PAU Ludhiana). Only one sample out of 20 samples tested at CCS HAU and PAU fall under poor category (<0.40%) whereas 30% samples analysed by both institutions had OC more than 0.90%.

Agronomic Practices followed to enhance Soil Carbon Sequestration

CO_2 is increasing at the rate of 2.3 ppm per year, which is resulting in the increase of global warming and environmental pollution. Agriculture sector is responsible for up to 30% emission of GHGs.

Sustainable agriculture is essential for the survival of humankind. Adoption of different agronomic management practices can be helpful in the sequestration of carbon. Such practices include no-tillage or reduced tillage, nutrient management, cover crops, crop rotations, green manuring, application of animal manures, agroforestry, etc. Adoption of these different agronomic practices will not only improve the crops yields but will also improve farmer’s income.[Anonymus, Minnesota Board of Water and Soil Resources]

1. Conservation Tillage

Minnesota farmers are using conservation tillage more frequently than in the past, particularly in corn and soybean rotations. Soil erosion control, water quality improvement, increased nutrient retention, and lower production costs are among the many environmental and economic benefits associated with conservation tillage practices. No-till and other conservation tillage practices have proven successful in controlling soil erosion and providing other benefits. Conservation tillage practices have the additional benefit of sequestering more carbon than conventional agricultural tilling practices. There is a range of beneficial tilling practices; the most beneficial are those that disturb soils the least, including no-till and strip till.[Reicosky et al. (2015), Mbuthia et al.(2015)] Soil microbial biomass has become an indicator of soil quality and increased nutrient retention and soil structure. Additionally, studies have found that beneficial micro-organisms including bacteria and fungi are especially effective in storing carbon, and they are negatively affected by tillage.[Zuber et al.(2016), Mbuthiaet al.(2015)] But conservation tillage practices alone are not the solution to greater carbon sequestration in agricultural systems. Combining conservation tillage with cover crops has been proven to significantly increase soil organic carbon in addition to benefits that include increased infiltration, nutrient retention and decreased erosion potential.[Soil Health Practices and No-till Farming Transform Landscapes(2019), Mbuthiaet al.(2015)] No till and cover crop practices together provide greater benefits than either practice does individually.[Mbuthiaet al.(2015)] Issues of carbon sequestration notwithstanding, BWSR encourages the use of conservation tillage and cover crops to protect soil quality, reduce soil erosion and improve water quality in local waterways.

2. Cover Crops Store Carbon

Cover crops are grasses, legumes and forbs planted to provide seasonal soil cover when the soilwould otherwise be bare - before the main crop emerges in the spring or after fall harvest. Covercrops sequester carbon by adding biomass both on the soil surface and below-ground. Researchsuggests that the majority of soil organic carbon originates from root biomass. Underground carbonpersists longer than above ground depositions.Cover crops encourage beneficial root-zone fungi,bacteria and invertebrates who also contribute to soil carbon and protect it over time by formingaggregateswhichincreaseoverallsoilhealthandproductivity.[Mbuthiaetal.(2015)]

A 12-year University of Illinois study showed that adding cover crops to all tillage treatmentsincreased soil organic carbon stock gains by 30% for no-till, 10% for chisel plowed and 18% formoldboard-plowed plots. [Olson et al. (2014)]

Planting in late summer allows cover crops to generate substantial biomass throughout the fall andagaininthespring.Winterryeisagoodchoicebecauseitismoreresistanttodecaythanothercovercrops such as oats or barley.

3. Nutrient management

Chemical fertilizers are a source of emission of GHGs, especially N2O. In addition to it, fertilizerproduction and its transportation are also associated with the emissions of GHGs. Judicious use offertilizers increases crop yields and profitability, and about 50 Pg CO2 additions to the atmospherehasbeencontributedbythecultivatedsoils[LalR.Sequesteringcarboninsoilsofagro-

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ecosystems(2011)], through the process of mineralization of soil organic carbon (SOC). The use offertilizershasdramaticallyincreasedagriculturalproductivity,butstudiesrevealthatthechronicuse of nitrogen fertilization decreases soil microbial activity [Frey SDet.al. (2014)]. Continuous use of balanced fertilizers is necessary for sustainable soil fertility andproductivity of crops. Crop residues andnutrients, especially N, help in carbon sequestration up to 21.3–32.5% [Windeatt JHet.al (2014)]. However, ultimate effects of continuous nitrogen fertilization on soils are complicatedand remain unclear. For example, in the long-term experiments in Canada, SOC sequestration were50–75 g cm^{-2} per year in well-fertilized soils with optimum cropping systems .ResearchintheGreatPlainsshowsthatSOCsequestrationisimproved by the application of N fertilization, but opposite to it, long-term experiments in the Northern Great Plains (ND)have also shown that N fertilizer increased crop residue returns but generally did not increase SOCsequestration Liu Enke et al. [Liu E et al. (2013)] reported the results of a long-term study which was initiated inNorthwest China in 1979, to find out the effects of fertilization on SOC and SOC fractions for thewhole soil profile such as (0–100 cm) soil depth. The experiment included six treatments, i.e.,unfertilized (control), N fertilizer (N), nitrogen and phosphorous fertilizer (NP), straw plus N and Pfertilizers(NP + S),Farmyardmanure(FYM),andFarmyardmanure(FYM)plusNandPfertilizers (NP+ FYM). Results showed that SOC storage in 0–60 cm in NP + FYM, NP + S, FYM,and NP treatments increased by 41.5, 32.9, 28.1, and 17.9%, respectively, as compared to controltreatment.Applicationoforganicmanureplusinorganicfertilizeralsoenlargedlabilepoolin0–60cmsoildepth.Theseresultsshowthatlong-termapplicationsoforganicmanurehavethemostbeneficial effects in buildingcarbon pools among the investigatedtypes of fertilization.

It can be concluded that the appropriate use of fertilizers according to the soil condition can behelpful in the maximum sequestration of carbon along with maximum crops production and in thereductionsof emissions of different GHGs

4. Animalmanureandcompostapplication

Animal manure is animal's excreta which is collected from livestock farms and barnyards and isused to enrich the soil, while compost is the material which largely consists of decayed organicmatter and is used for fertilizing and conditioning of agricultural soil. Application of manures isimportant for the maintenance of soil health and is the source of C, and its application to different crops fields has effects on Ccontents. As compared with theapplication of only NPK, application of FYM along with NPK increased C sequestration in the rice-wheatcroppingsystem[NareshRKet.al.(2017)],whilegreenmanuring,ascompared with the application of FYM along with green manure, sequestered more C in a Maize-Wheatcroppingsystem. Compostingnotonlyincreases the net primary production but also enhances the C contents of the soil [Baldi Eet al. (2018)]. It has been reported thatdecreasingofmanuresandorganicfertilizersapplicationinfluencesnotonlystableorganiccompounds but also soil microorganisms and nutrient regimes [Ren Tetal. (2014)]. Liu et al. supported the positiveeffectofincorporationofmineralfertilizerswithorganicmanures.Similarly,applicationofdifferent organic wastes, i.e., municipal solid waste (MSW), farm yard manure (FYM), sugarindustry waste (filter cake), and maize cropping residues, at 3 t C ha^{-1} alone and with a full or halfdose of NPK mineral fertilizer showed that the addition of organic wastes (filter cake or MSW) hasthe best potential for improving SOC retention, WUE, and wheat yield in an irrigated maize-wheatcroppingsystem [Shehzadi S et al.(2017)].

This all indicates that the use of animal manure, compost, etc. along with other inorganic fertilizersis beneficial for both soil health and environment.

5. Croprotations

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Crop rotations mean the sequence of crops grown in regularly recurring successions on the samearea of land. The succeeding crops may be for 2 or more years. Differences in crop rotations,climates, soils, and different crop-related management practices also affect carbon sequestration.Intensive cropping systems result in the depletion of SOM, but the use of balanced fertilization withNPK, application of organic amendments, and similarly application of crop residues can increasecarbon sequestration levels to 5–10 Mg ha−1 per year because these amendments contain 10.7–18%C, which can also be helpful in the sequestration of carbon [Manadal B et al.]. Different legumecrops, such as peas, lentils, alfalfa, chickpea, sesbania, etc., can serve as substitute sources fornitrogen. Applications of crop rotations especially by using legume cover crops, which containcarbon compounds that are likely more resistant to microbial metabolism, can make soil carbonmore stable. Syswerda et al. reported the results of a long-term study(over a 12-year period) of an organic management system that involved various crop rotations.Accordingtothemdespiteofextensivetillageforweedcontrol,increaseinsoilcarbonsequestration was recorded. The results of a long-term study, which was conducted in Dingxi,Northwest China, during 2013–2015, were shown in-spring wheat-field pea rotation in a rain-fedsemi-arid environment. The treatments were: conventional tillage with stubble removed (T); notillagewithstubbleremoved(NT);no-tillwithstubbleretained(NTS),andconventionaltillagewith stubble incorporation (TS). The SOC, microbial biomass carbon, and root biomass in NTSincreased over T and NT, and similarly, average grain yield across the 3 years in NTS was betterthan T and NT [Yeboah S et al. (2016)]. Recently, muchattention has been given to alternate tillage and cropping systems as a means to mitigate theagricultural emissions of CO2. Different types of cropping systems, i.e.,cover cropping, ratoon cropping, and companion cropping, can be helpful in carbon sequestration.Intercropping which includes row inter cropping, strip inter cropping, mixed cropping, and relayintercroppingcanincreasetheincomeandcanalsoraisesoilfertility.

Some of the examples of inter cropping are wheat and mustard, cotton and peanut, peanut andsunflower, wheat and chickpea, etc. [Anon, “Mixed Cropping”.]. Organic farming can alsoimprove soil organic carbon as compared with the conventional farming. Research regarding the restoration of grassland alsoshows that through their biotic and biotic effects, legume species have more positive effects on therestoration of grasslands as compared with the application of mineral fertilizers [De Deyn GBet al. (2011)].

This above shows that keeping in view the economic considerations, selection of appropriate croprotations according to the soil and environmental conditions can be helpful in the sequestration ofcarbon,whichnotonlyimprovesoilfertilitybutalsoreducetheemissionsofCO2intotheatmosphere and increase farmer’s income.

6. Residues management

Crop residues are detached vegetative parts of crop plants that are intentionally left to decay inagriculturalfieldsaftercropharvesting.Worldwide,theannualproductionofcropresiduesisabout

3.4 × 109 tones, and if 15% of these total residues are applied to the soil, it can increase the Ccontents of the soil, because, for example, one ton of cereal residue contains 12–20 kg N, 1–4 kg P,7–30 kg K, 4–8 kg Ca, and 2–4 kg Mg. Mulching is detached vegetation, which includes wheatstraw, compost, or may be plastic sheets, which are spread around plants to protect them fromexcessive evaporation and cold stress and similarly to promote SOM contents in soil.

Crop residues play an important role in the SOC management and improvement of soil quality Mulchingimprovessoilmoiture, reduces soil erosion, and similarly reduces the loss of carbon from the soil and cropresidues, which are incorporated into the soil to enhance the soil organic matter. A direct seedlingmulch-based cropping system increases soil organic matter, as a result of increased carbon

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inputsanddecreasedsoildisturbanceMulchcanincreasesoil organic matter (SOM) and carbon sequestration in the top 0–5 cm soil depth. It improves soil'sphysical and chemical properties and can increase carbon sequestration in agricultural soils up to8–16 Mg ha−1 per year. Mulch-based cropping systems enhance the buildup of soil organic matter,principally as a result of increased carbon inputs and decreased soil disturbance. Direct seedling straw mulch has the potential to ameliorate the heatstress, and it improves the infiltration rate, reduces evaporation [Lal R. Tillage in lowlandrice-based cropping systems.], and similarly increases soil organic carbon and N efficiency. Increasing residues inputs to soils entails increasing net primaryproductivity (NPP). Many agricultural soils, which have been significantly reduced from theiroriginalClevelsthroughcultivation,willshowCgainsinproportiontoincreasesinCinputs.SoilC levels are governed by the balance between the inputs of C through plant residues and the lossesof C basically through decomposition. Therefore, C can be increased in soil by increasing residuesinputs and or reducing decomposition rates (i.e., heterotrophic soil respiration). Litter quality alsoaffects rates of its decomposition. The results of a4-monthstudy,whichwasconductedinagreenhousecontrolledconditionandinthreeratesofstraw residue and farm yard manure, were added to uncultivated and cropland soils. Two treatmentsofstrawresidueandfarmyardmanureincorporationwereusedinto:asoilsurfacelayeranda0–20 cm soil depth revealed that the application of organic matter, especially the incorporation offarm yard manure, led to significant increase in the final soil organic carbon content, and higheramount of soil organic carbon were stored in the cropland soil than in the uncultivated soil. Theresults showed that carbon sequestration ranged farm yard manure > straw residue and cropland soil>uncultivatedsoil.Theresultsrevealedpayingmoreattentiontotheroleoforganicresidue management in carbon sequestration [Mahmoodabadiet al. (2014)].

This all shows that the application of mulch and the use of crop residues can improve soil microbialactivity, ameliorate the heat stress, and help in water storage and improvement of soil organiccarbon.

7. Useofimprovedcropvarieties

Selection of improved varieties of different crops, which can improve both above and below groundbiomass, can also improve the soil organic carbon. Machado et al. [Machado et al. (2006)] reported that crop species that have massive rooting systems have the potential toimproveSOCinsoilsunderNT. Similarly,accordingtoKell[KellDB.(2012)]byimproving root growth in agricultural crops, soil carbon storage can match anthropogenic emissionsfor the next 40 years. This all indicates that the use of improved crop varieties having extensive rootsystemsand better yields canincrease both yields andsoil fertility.

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 [Ravindranathet 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

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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. [Abdullahiet al. (2018)]

2. Permanentity

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 managemental 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 due to natural causes. Hence, methods that can 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, theoretically this idea sounds appealing, however it is difficult to operationalize it in practice due to a number of challenges. Some of these include difficulties in measurement of soil carbon stock, permanence, carbon pools with different carbon residence times, separation, the tendency of the soil to reach saturation level when the maximum attainable carbon that could be captured is reached. Advances have been made in tackling most of these challenges, however, deliberate actions to enhance carbon capture and sequestration in the soil ecosystem is yet to get wide acceptance by practitioners and policy makers alike. This chapter is written in an attempt to create more awareness on the potential of soils in capturing and storing atmospheric CO2 in long lived pools thereby mitigating climate change in the process. Researchers should also work assiduously in finding solutions to the challenges making widespread adoption of this initiative difficult.Add result/outcome of analytic report (field observation in india) so as to support the findings.

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