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Soil carbon sequestration through various agronomic practices: A way to mitigate climate change impacts

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Abstract
Climate change is among the emerging global issues of the 21st century. Carbon sequestration stands as a strategic principle for mitigating the adverse effect of changing climate as it removes CO_2 from atmosphere and stores in soil, plant or in water bodies. In simpler terms, it is a process of capturing CO_2 and storing them in forest, ocean or in deep geological formations for long term and thereby reducing the concentration of CO_2 in the atmosphere. Soil can be considered as the largest carbon reservoir of the terrestrial carbon cycle for storing large amount of soil organic carbon. Agronomic practices such as reduced tillage, manuring, residue incorporation, crop rotation and mulching play important roles in sequestering soil carbon. Growing crops in rotation provides advantage of storing more Carbon in soil as compared to mono cropping. Minimum tillage practices as well as incorporation of residues increases the soil carbon content significantly. Adding organic manures and fertilisers to soil, Growing forest trees, revegetation of degraded land and following various land use options also adds to the soil carbon storage. Applying soil amendments not only improves soil characteristics but also checks CO_2 and methane emissions. Many of the practices that facilitate carbon sequestration are also found to improve soil aggregate formation, water holding capacity, fertility status of soil and food security. Therefore, Soil Carbon sequestration can be considered as a key principle for improving soil health, enhancing crop yield as well as reducing the adverse effects of climate change.

Keywords: Carbon sequestration, agricultural practices, mitigate climate change

Introduction
Climate change can be considered as a main issue today as the amount of green-house gases (GHGs) is increasing in the atmosphere. Anthropogenic activities are the key reasons for earth's climate change thereby increasing global temperature over the years. According to the data of The Inter-governmental panel on climate change (IPCC), the atmospheric temperature will rise from 0.5-1.2 ˚C by 2020, 0.88-3.16 ˚C by 2050 and 1.56-5.44 °C by 2080 for India. The CO_2 concentrations for these years are estimated to be 393, 543 and 789 ppm in year 2020, 2050 and 2080, respectively (IPCC, 2007). Climate change is attributed to increase in atmospheric concentration of several GHGs by fossil fuel combustion, land use change and deforestation and human induced soil degradation. Recent reports from the Intergovernmental Panel on Climate Change (IPCC) reflects that in near future we may reduce anthropogenic carbon emissions but efforts are required to be performed to sequester the carbon which was previously emitted to have atmospheric carbon within safe limits and to diminish climate change.

The CO_2 as a GHG traps long wave radiation reflected back from the earth's surface and also plays a major role in governing plant physiology. CO_2 contributes about 7.5 percent of the total global warming. Soil, vegetation and the ocean can act as a probable reserviour of carbon dioxide as much of the carbon dioxide can be stored in them. The living plants can also absorb carbon dioxide from the atmosphere and sequester it as biomass carbon in the terrestrial carbon pools of the soils.

Carbon Sequestration
Soil C sequestration can act as an additional tool to counter the emerging climate change issue. In present scenario, greenhouses are of major concern that has led to several studies on the qualities, kinds and behaviours of Soil Organic Carbon. Carbon sequestration is absorption of carbon from the atmosphere and its storage in a terrestrial or aquatic body. Carbon sequestration in terrestrial ecosystems is basically the withdrawal of CO_2 from the atmosphere and transferring them into nearly stable pools of carbon.

There present five major carbon pools namely oceanic pool (38,000 pg); largest one, then comes geological pool (5000 pg), soil carbon pool (2500 pg), biotic pool (560 pg) and the atmospheric pool (760 pg). The average life span of an carbon atom varies from 5 yrs in the atmosphere, 10 yrs. in vegetation, 35 yrs. in soil to 100 yrs in the sea.

Ways that carbon can be sequestered

- Geological sequestration
- Ocean sequestration
- Terrestrial sequestration

Geological sequestration

Geological carbon sequestration is a method of preserving carbon dioxide in deep geologic formations and hence blocking it from getting released to the atmosphere. CO_2 can be collected from sources such as large industries, converted to a fluid state, and placed deep underground into permeable geological formations.

The geologic strata in which the gas are stored must have another layer of impermeable rock above it to seal the stored CO_2 . As per the IPCC estimates in a well constructed and managed geological storage CO_2 can be kept for millions of years, and the sites can store about 99 percent of the inserted CO_2 over 1,000 years.

Ocean sequestration

One of the most secured places to stock carbon is in the deep oceans, which currently store about one third of the carbon released due to anthropogenic causes which is about two billion metric tons per year. Carbon is naturally retained in the ocean by solubility and biological pumps and also can be stored by human interventions such as injecting it directly or by ocean fertilisation. According to the estimates the amount of carbon that would double the load in the atmosphere would increase the concentration in the deep ocean by only two percent.

The tiny planktons that are present on the ocean surface convert carbon dioxide into carbohydrates by the process of photosynthesis. Other sea creatures feed on these phytoplankton and hence also consume the sugars contained in them. When these creatures die, they sink at the bottom and the carbon contained in their body is retained as sediments. This carbon may under go chemical process along with water to form calcium carbonate or may get used by some organisms to built up their skeletons.

Terrestrial Carbon Sequestration

It is the process through which CO_2 from the atmosphere is trapped and stored as biomass & soil carbon by the process of photosynthesis.

Soil Carbon Sequestration

Soils have the potential to extract carbon from the atmosphere and store in it. Agricultural activities are performed in about one third of arable land globally (World Bank, 2015) so creating ways to increase carbon sequestration in agricultural systems will be a key factor to counter the climate change issue. Several agricultural management strategies are identified that could sequester carbon in soil.

Soil: the largest terrestrial carbon pool

- Soil is a store house of carbon with about 60% organic carbon as soil organic matter (SOM), and the rest are inorganic carbon stored as inorganic compounds (e.g., limestone, or $CaCO_3$).
- The global soil carbon pool contains 2500 (Gt) carbon. The total soil carbon pool is four times that of biotic pool and three times that of atmospheric pool.
- If 1 tonne of carbon is lost from soil, it is equivalent to 3.7 tonnes of CO_2 from the atmosphere. (Climate change and agriculture 2012)
- In India the Soil Organic Carbon stock is estimated to be 21 Pg (upper 30 cm) and 63 Pg (upper 150 cm).

Agronomic practices for soil carbon sequestration

- Tillage & Residue management
- Crop management
- Nutrient management
- Agro forestry
- Soil amendments

Tillage & Residue Management

Conservation tillage (CT) has three major principles such as minimal soil disturbance (no-till), permanent soil cover (mulch) and crop rotation. It means reduction in ploughing frequency and intensity as well as leaving crop residues on the soil surface which will act as mulch. It is one of the key strategy to surplus the SOC content and organic matter. Under zero tillage system soil microbial biomass carbon was often found to be higher and CO_2 evolution was found to be lower than conventional tillage system thereby increasing additions but lowering losses of labile C under zero tillage system which ultimately gives rise to higher C sequesteration in it. Growing crops without tillage along with residue mulching and eliminating summer fallowing enhance soil structure, lowers bulk density and improves infiltration capacity in arid and semi-arid regions (Shaver *et al*., 2002) [65]. Smith *et al*. (1998) [69] concluded that following conservation tillage can sequester about 23 Tg C/year.

Adopting Conservation Tillage system has the potential to increase SOC content which may enhance soil quality and resilience (Blevins and Frye, 1993) [9, 10]. Conventional tillage practices which involve ploughing usually hamper Soil organic carbon storage. Turning over soil through ploughing decreases particulate SOC (Beare *et al*., 1994a; Beare *et al*., 1994b; Camberdella and Elliott, 1992; Robertson *et al*., 1991; Angers *et al*., 1993) [6, 7, 11, 26, 62, 2].

The shifting from Conventional agriculture to Conservation Tillage may improve macro aggregation as well as aggregate stability and carbon is stored in between the macro aggregates (Haynes and Swift, 1990; Elliott, 1986; Haynes *et al*., 1991) [39, 26, 41]. Conservation tillage practices has resulted in increasing SOC content near the soil surface as compared with conventional tillage (Lal, 1989; Carter, 1992; Dick *et al*., 1986a,b) [50, 12, 22, 23].

Soils in arid regions or having course texture may have less impact on Soil Organic Carbon content while converting from conventional to conservation tillage (Powlson and Jenkinson, 1981; Haynes and Knight, 1989) [60, 38]. A pasture land or land with vegetation when converted to cultivable land a decline in SOC is found which is more with conventional than with a Conservation Tillage system (Blevins *et al*., 1983a; Blevins *et al*., 1983b; Dick, 1983; Beare *et al*., 1992) [9, 10, 21, 3]. Higher SOC content under Conservation tillage may lead to higher and stable aggregate formation (Home *et al*.,1992; La1 *et al*., 1994) [6, 7], because of increase in microflora population (Beare *et al*., 1993) [4], higher earthworm activity (Edwards *et al*., 1993) [25] and formation of platy structure with greater bulk density. Ploughing causes breakdown of aggregates, and CT leads to increase in aggregation (Hamblin, 1980; Ike, 1986) [36, 49].

Managing crop residues and incorporating them in soil has found to increase soil organic matter levels. Amalgamating crop residues in a rice-wheat cropping system has increased soil organic C content when practices in a long term basis. Cereal crop residues with having higher C: N ratio contributes more towards the soil carbon pool. Due to use of combine harvesters for harvesting and higher cost of labours for removing crop residue, residue burning has emerged as a serious issue now a days (NAAS, 2012) [57]. Burning of residues has several demerits such as decrease in microbial population in the soil, increase moisture stress and increases soil pH as ash is produced that contains Ca, Mg and K ions. Leaving crop residues in the field as such is another practice is an effective strategy to sequester carbon in soil. (Lal, 1997) [52] reported that the annual production of crop residue in the world is approximate to be about 3.4×109 tonnes and as because 15 percent of the C present in the residues can be converted to storable carbon, this may lead to C sequestration of 0.2 × 1015 g/year. The use of crop residues as mulches has been found useful as it reduces maximum soil temperature and conserves water. Using Happy seeder in rice-wheat cropping system helps in zero till sowing of wheat on rice residue as surface mulch which saves time, reduces tillage cost, avoids residue burning and maintains yield (Singh and Sidhu, 2014) [67].

Crop Management

Crop management strategies include crop rotation rather than mono cropping and inclusion of cover crops in cropping system. Cover crops helps in carbon sequestration by enhancing soil structure and adding organic matter to the soil. Pulses add a notable quantity of organic carbon to soil as of their ability for atmospheric (Ganeshamurthy, 2009) [32] nitrogen fixation, leaf shedding ability and better below-ground biomass (Ganeshamurthy, 2009) [32]. Venkatesh *et al.*, (2013) [75] conducted a study on seven cropping cycles and found the changes in soil organic carbon pools due inclusion of pulses in an upland maize-based cropping system in Inceptisols of Indo-Gangetic plains. Presence of pulses improved the total soil organic carbon content which was found highest in surface soil (0-20 cm) and subsequently went on decreasing with increase in soil depth. Maize-wheat-mungbean and pigeonpea-wheat systems found to increase total soil organic carbon percent by 11 and 10 percent, soil microbial biomass carbon by 10 and 15 percent respectively, as compared with a conventional maize-wheat system. Growing pod legumes along with food crops is an effective strategy to enhance SOC and soil quality (Entry *et al.*, 1996) [27].

Growing legume crops as cover crops increases biodiversity, the quality of residue input and ultimately the SOC pool. Ecosystems with higher biodiversity can absorb and sequester more C as compared to those with reduced biodiversity. In Georgia, USA, Sainju *et al.* (2002) found that practicing no till with hairy vetch can improve SOC. Franzluebbers *et al.* (2001b) also observed in Georgia, USA that improved forage management can also enhance the SOC pool. Enhancement of SOC pool by growing cover crops has been reported from Hungary by Berzseny and Gyrffy (1997) [8], U.K. by Fullen and Auerswald (1998) [31] and Johnston (1973), Sweden by Nilsson (1986), Netherlands by Van Dijk (1982) and Europe by Smith *et al*. (1997).

Hence, it may be concluded that cover crops helped encourage biological soil tillage through their roots. The surface mulch provides food, nutrients and energy for earthworms, arthropods and other below ground micro organisms who help in biological tillage of soil.

Crop rotation is a growing crops in a returning succession on the same piece of land. It improves the soil structure and fertility of soil by growing deep rooted and shallow rooted plants one after other. A crop that leaches out one type of nutrient from the soil is followed by a deep rooted crop in the next season that collects and returns that nutrient to the soil. Growing crops of different physiological pattern can enhance the level of soil organic matter. However, getting the benefits of crop rotation depends on the kind of crops and number of times the rotation has been done. The common crop rotation practice includes creals with legume crops or green manure crops which aims at refilling nitrogen by fixing it from atmosphere. Organic crop rotation practices include cultivation of deep rooted legumes which increase the carbon content in deeper soil layer. Different long term field experiments were conducted to compare different cropping patterns with mono-cropping. An experiment was done to compare the soil carbon deposition for a long term basis between continuous maize cultivation and with a legume-based rotation was by Gregorich *et al.*, (2001) [35]. After 35 years, the difference in carbon storage between monoculture maize and the rotation was about 20 tonne C ha-1. It was also observed that the SOC present below the ploughed layer in the legume-based rotation appeared to be more biologically stable, as the deep rooted plants were responsible for increasing carbon storage at deeper zone. Cropping systems provide an opportunity to produce more biomass C than in a monoculture system and to thus increase SOC sequestration. Chander *et al.*, (1997) [13] studied the deposition of soil organic matter under different crop rotations for 6 years and found that inclusion of green manure crop of *Sesbania aculeate* in the rotation improved the soil organic matter status and microbial Carbon content.

Nutrient Management

Judicious nutrient management is crucial for SOC sequestration. In general, the use of organic manures and compost enhances the SOC pool more as compared to application of the same amount of nutrients as inorganic fertilizers (Gregorich *et al*., 2001) [35]. The role of fertilizers on enhancing SOC pool depends on the amount of biomass C produced and its humification. Applying manures on a long term basis may enhance the SOC pool and improve aggregation (Sommerfeldt *et al*., 1988; Gilley and Risse, 2000) [66, 34]. The capacity of conservation tillage to store SOC is greatly affected where soils are amended with organic manures (Hao *et al*., 2002) [37]. Smith and Powlson (2000) reported that 820million metric tons of manure are produced each year in Europe, and 54% is incorporated into agricultural and the remaining is applied to non-arable pasture land. They found that enhancement in SOC content after incorporation of manure is more in case of crop lands than pasture lands. They estimated that if all manure were applied into crop land in the European Union, there would be a net addition of 6.8 Tg C/year.

A long-term field experiment performed by Lal *et al.*, 1998 [53] revealed that the enhancement in SOC was found more under judicious fertiliser application as compared to no fertiliser. This study concluded that fertility management practices can increase the SOC content at the rate of 50-150 kg ha[-1] yr[-1]. Adding superior levels of nitrogen dose enhances organic matter quantity in soil and applying phosphatic fertilizer also has a beneficial impact on soil organic C. Integrated nutrient management practices including farmyard manure, green manure and crop residues are found to add organic matter to soil.

Agroforestry

Growing of multipurpose trees along with agricultural crops; Agroforestry, is one of major principles for controlling elevating hunger, malnutrition, poverty and deterioration of the environment (Garrity 2004) [33]. Agroforestry is found to increase the soil organic carbon (SOC) through litter fall, control soil erosion (Escobar *et al*. 2002) [28], improve land productivity (Noble *et al*. 1998) [58] and diversify the farm income. Presence of trees on a piece of land can increase it's Water Holding Capacity due to activity of roots (Pereira 1979) [59], just as deforestation increases the run-off (Lal 1981) [51]. Thus Agroforestry has emerged as a key principle to deal with land degradation and there by conserving the physico-chemical properties of soil.

There are several negative points which need to be addressed seriously like competition for nutrients and other resources between the tree and crop species, allelopathic effect of tree, occupation of space by tall trees thereby leaving less space for crops, tree species that serve as host for harmful insect and pest (Kohli *et al*. 2006) [46]. The maximum benefit from this system can be obtained if the positive interaction surpasses the negative interactions (Jose *et al*. 2000) [43]. Generally the root system of trees go beyond the crop zone and thus they use water from lower zone without interfering with the crop water need (Jose *et al*. 2006) [46]. Roots of the trees can collect nutrient from the deeper zone which otherwise may have lost by leaching (van Noordwijk and Hairiah 2000) [74]. Tree litters adds organic matter to the soil when undergo deposition and also help in release of nutrients by the process of mineralization (Kohli *et al*. 2007) [47].

Agroforestry system can serve as great sink for carbon as it can store it in both above and below ground parts and hence can reduce global warming by collecting CO_2 from atmosphere (Albrecht and Kandji 2003) [1]. A better understanding of agroforestry systems has emerged as new research interest as it involve greater diversity and can play a major role in carbon sequestration (Puriand Nair 2004) [61]. After a long term study of 5 years Swamy and Puri (2005) [70] observed 3.5 Mg ha[-1] more C was stored under *Gmelina arborea* than agr-isilviculture system. Planting forest trees on intensively cultivated lands may sequester SOC where it has been depleted dur to continuous cultivation (Johanson 1992) [42].

Soil amendments

Soil amendments are basically organic and inorganic materials that helps to improve the fertility status of soil. The left over crop residues can also be used as soil amendments by incorporating them in soil as they enhance fertility status of soil when undergo decomposition. Some common substances which are used as soil amendments include municipal bio-solids, composted bio-solids, animal manures and litters, wood ash, soil ash and other composted agricultural by-products. Adding them in soil helps in restoring soil quality by balancing pH, increasing organic matter, improving water holding capacity, re-establishing microbial communities, and decreasing compaction in soil. Along with enhancing soil properties they can also help in preventing CO_2 and methane emissions. Evidences are also there for increase retention of nutrients and water and improvement in soil physical characteristics as well as crop growth by addition of biochar (Major *et al*., 2010; Sohi *et al*., 2010).

Benefits of Soil Carbon Sequestration

- Changes in soil properties: The different management options which are followed for storing carbon, also adds several benefits to soil. Due to presence of soil cover, surface soil becomes less prone to erosion and surface crusting, hence stable soil structure is maintained. As surface run off is reduced it leads to higher infiltration and more ground water recharge. Due to incorporation of residues soil organic matter status increases hence soil water content and nutrient retaining capacity increases.
- Due to diversified cropping soil biological population and also organic matter content increases. Organic matter also has the capacity to bind pesticides, suppress disease causing organisms and improve crop vigour.
- Moreover it improves soil, air and water quality. Due to trapping of carbon the air quality is enhanced. Water quality is improved as surface runoff and therefore sediment load is less in surface water.

Limitations

- The amount of C which has been stored is limited. The increase in SOC content stops as soon as a new equilibrium value is approached.
- The process of C sequestration is reversible: The management strategies which are followed to increase the soil C status must be continued for a indefinite period to maintain the sequestered Carbon for longer period. Carbon accumulated in forest trees are lost when the trees are cut down or fell down.

Conclusion

- Soil carbon sequestration is an more practical as well as effective approach to sequester atmospheric CO_2 than any other possible approaches. As it removes CO_2 from the atmosphere it has emerged as an important strategy to mitigate climate change impacts.
- Many of the management strategies which helps in sequestering carbon also improve soil aggregation, water retention and soil fertility. These key benefits associated with it must be considered thoroughly to adopt these management strategies.
- For formulation of policies that are taken up for mitigating climate change it is necessary to include the estimates of soil C sequestration and these information should be based on true evidence because over emphasizing soil C sequestration is may under-emphasize other measures which may become more significant.

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