Impact of carbon sequestration in soil

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Abstract

The need to stabilize the greenhouse gas concentrations of the atmosphere is the great environmental challenge of this century. To control these concentrations, humanity can reduce fossil fuel emissions and/or identify mechanisms to remove greenhouse gases once they have been emitted. Therefore, carbon capture is vital to reduce release of carbon emissions and other GHG's to the atmosphere thereby mitigating global warming. Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in reservoirs. Basically it is the process of capturing of atmospheric carbon dioxide and storing it to mitigate global warming and climate change. This presentation is a review of the role of agriculture and soils in carbon capture. In this light, this paper will discuss - what is carbon sequestration? Mechanism, benefits and recommended management practices of carbon sequestration.

Key words: Greenhouse gas; Global warming; Carbon sequestration

Introduction

Earth is getting more and more warmer than ever, reason is human activities. Human activities have caused an imbalance in natural carbon cycle, consequently greenhouse effect and global warming came into being. When fossil fuels are burnt for transportation, heating, cooking, electricity, and manufacturing, we are effectively realizing more carbon into the atmosphere than it is being removed naturally. Ultimately we are causing more carbon concentration into atmosphere. As a result we are proceeding on the path of global warming and climate change. Global warming and climate change refer to an increase in average global temperatures. Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily by increases in "greenhouse" gases such as Carbon Dioxide (CO_2).

Carbon Sequestration

Carbon sequestration is the process of capture and long-term storage of atmospheric carbon dioxide to mitigate global warming and to avoid dangerous impacts of climate change. In other words, it also refers to the process of removing carbon from the atmosphere and depositing it in a reservoir. This carbon storages or reservoirs are also known as carbon pools. Carbon pool refers to a system or mechanism which has the capacity to accumulate or release. It can be natural or human induced.

Carbon sequestration refers to the capture and long-term storage of carbon in forests, soils or in the water body, so that the build-up of carbon dioxide (one of the principal greenhouse gases) in the atmosphere will reduce or slow. Managing land and vegetation to increase carbon storage can buy valuable time to address the ultimate challenge of reducing greenhouse gas emissions.

There are three main types of carbon sequestration:

● **Oceanic Carbon Sequestration -** Enhancing the net uptake of carbon from the atmosphere by the oceans, through fertilisation of phytoplankton with nutrients and injecting carbon dioxide to ocean depths greater than 1000 meters; and

● **Geological carbon sequestration-**The subsurface sequestration of carbon dioxide in underground by geological repositories.

● **Terrestrial or biological carbon sequestration -** Increasing the amount of carbon stored in vegetation and soils;

Mechanisms of Carbon sequestration

Soil organic matter (SOM) is protected against decomposition by various mechanisms. Soil organic matter can be: (1) physically stabilized, or protected from decomposition through microaggregation, (2) intimate association with silt and clay particles, and (3) biochemically stabilized through the formation of recalcitrant SOM compounds. In addition to this each SOM pool changes in land management by which SOM compounds undergo protection and release. The characteristics and responses to changes in land use management are described for the light fraction (LF) and particulate organic matter (POM-C). If LF and POM-C is not occluded within microaggregates (53-250 μm) then such carbon is unprotected. Physicochemical characteristics inherent to soils define the maximum protective capacity of these pools, which limits increases in SOM (i.e., C sequestration) with increased organic residue inputs. Some long-term experiments showed that little or no increase in soil C content was observed in imbalanced application of N or NP fertilizer under different soil and cropping systems in India (Manna *et al*., 2005a).

Physically protection Physical protection by aggregates is indicated by the positive influence of aggregation on the accumulation of SOM. The physical protection exerted by macro and micro-aggregates on particulate organic matter carbon (POM-C) is attributed to (1) the compartmentalization of substrate and microbial mass, (2) reduced diffusion of oxygen into aggregates, which leads to reduced activity within the aggregates, and (3) compartmentalization of microbial biomass and microbial activities. Many studies have documented positive influence of aggregation on the accumulation of SOM under different soils and cropping systems (Hati *et al*., 2008; Manna *et al*., 2005b; Manna *et al*., 2007a; Manna *et al*., 2007b). Cultivation causes release of C by breaking up the aggregate structures, thereby increasing availability of C. More specifically, cultivation leads to loss of C-rich macro-aggregates and an increase of C-depleted micro-aggregates (Hati *et al*., 2008).

In general, the occluded light fraction had higher C and N concentrations than the free light fraction and contained more alkyl C (i.e., long chains of C compounds such as fatty acids, lipids, cutin acids, proteins and peptides) and less O-alkyl C (e.g., carbohydrates and polysaccharides). During the transformation of free light fraction into intra-aggregate light fraction, there is selective decomposition of easily decomposable carbohydrates (i.e., Oalkyl C) and preservation of recalcitrant long-chained C (i.e., alkyl C) and that cultivation decreased the O-alkyl content of the occluded SOM. This difference is the result of continuous disruption of aggregates, which leads to faster mineralization of SOM and preferential loss of readily available-C (Manna *et al*., 2005b). Hence, the enhanced protection of SOM by aggregates in less disturbed soil results in accumulation of more labile C than would be maintained in a disturbed soil. Other studies also indicated that the macro-aggregate (>250 μm) structure exerts minimal amount of physical protection whereas SOM is protected from decomposition in free micro-aggregates

(<250 µm) and in micro-aggregates within macro-aggregates (Six *et al*., 2000).They reported that C mineralization increased when macro-aggregates are crushed, but the increase in mineralization accounted for only 1-2% of the C content of the macro-aggregates. These studies clearly indicate that C stabilization is greater within free micro-aggregates than within macro-aggregates. The general characteristics of LF are: (i) consists of plant residues in various stages of decomposition; (ii) presence of charcoal; (iii) contain various sugars (mannose + galactose/Arabinose + Xylose); (iv) high O-alkyl content; (v) high C/N ratio; (vi) low net N mineralization potential; (vii) contain labile SOM pool (viii) high lignin content; in high phenyl propenoic acid/benzoic acid ratio. We have studied LF and POM from >2000 µm size classes from three soil types under long-term fertilizers experiment. It was observed that long-term application of manure and fertilizers improved the LF-C, which varied from 1.1 to 2.7 % of SOC in Inceptisols and 1.3 to 3.9 % of SOC in Vertisols. POM-C varied from 10.6 to 27 % of SOC in Inceptisols, 10.3 to 39.7 % of SOC in Vertisols and 10.3 to 31.2 % of SOC in Alfisols. The acid hydrolysable carbohydrates were substantially improved in the NPK+FYM treatment compared to inorganic fertilizer application in all these three type of soils.

Chemical stabilization: silt and clay-protected SOM The protection of SOM by silt and clay particles is well established. Basically the retention of specific microbial products (amino sugars such as glucosamine, muramic acid etc.) chemically protect the C that is associated with primary organo-mineral complex. Many researchers observed that mineral associated carbon (MAC) with 20 µm size classes of silt +clay have higher potential of C stabilization capacity than sand size fraction of C associated with macro-aggregates (53-2000 µm).

Biochemical stabilization Biochemical protection of SOM occurs due to the complex chemical composition of the organic materials. This complex chemical composition can be an inherent property of the plant material (lignin, hemicelluloses, etc. referred to as residue quality) or be attained during decomposition through the condensation and complexation of decompositing residues, rendering them more resistance to subsequent decomposition. Therefore, this pool is stabilized by its inherent or acquired biochemical resistance to decomposition. This pool is referred to as the passive SOM pool (Parton *et al*., 1987) and its size has been equated with the nonhydrolyzable fraction. Several studies have found that the non-hydrolyzable fraction in temperate soils includes very old C and acid hydrolysis removes proteins, nucleic acids, and polysaccharides (Schnitzer and Khan, 1972) which are believed to be chemically more labile than other C compounds, such as aromatic humified components and wax-derived long chain aliphatic compound.

Benefits of carbon sequestration

Carbon sequestration builds soil fertility, improves soil quality, improves agronomic productivity, protect soil from compaction and nurture soil biodiversity. Increased organic matter in soil, improves soil aggregation which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality. It is also helpful in the protection of streams, lakes, and rivers from sedimentation, runoff from agricultural fields, and enhanced wildlife habitat. Besides these, it has major roles in mitigating GHG gas emissions and in tackling the effects of climate change.

Management options for enhancing Carbon sequestration

The technological options for sequestration of atmospheric CO_2 into one of the global C pools can be broadly grouped into two categories:

(a) Abiotic and (b) Biotic sequestrations.

(a) Abiotic sequestration: It is based on physical and chemical reactions and engineering techniques without intervention of living organisms (e.g., plant and microbes). The abiotic strategy of C sequestration in oceanic and geological structures has received considerable attention (Freund and Ormerod, 1997) because theoretically abiotic sequestration has a larger sink capacity than biotic sequestration. It includes (i) Oceanic injection (ii) Geological injections (iii) Scrubbing and mineral carbonation.

(b) Biotic sequestration: It is based on management intervention of higher plants and micro-organisms in removing CO_2 from the atmosphere and also the anthropogenic interventions to reduce emissions or offset emissions. Increasing use efficiency of inputs (e.g., water, nutrient, energy) also contributes to increasing terrestrial C sequestration. The biotic sequestration includes C sequestration in forest ecosystem, wetlands and soil carbon sequestration.

Soil carbon sequestration implies removal of atmospheric CO_2 by plants and storage of fixed C as soil organic carbon. The strategy to enhance soil carbon sequestration involves increase of SOC density in soil, improve depth distribution of SOC and stabilizing SOC by encapsulating it within stable micro-aggregates so that C is protected from microbial processes or as recalcitrant C as humus with long turn over time. The management options for increasing SOC sequestration includes (i) conservation tillage (ii) cover crops (iii) efficient nutrient management (iv) efficient water management (v) restoring degraded soils (vi) practicing crop diversification and efficient cropping system (vii) minimizing soil and water erosion (viii) efficient pasture management (ix) afforestation and efficient forest management (x) efficient management of urban soils etc.

Recommended management practices for soil carbon sequestration

Lal (2011) has suggested following recommended management practices over traditional practices in order to facilitate soil organic carbon sequestration. Therefore, conversion to restorative land uses (e.g., afforestation, improved pastures) and adoption of recommended management practices (RMP) can enhance SOC and improve soil quality. Important RMP for enhancing SOC include conservation tillage, mulch farming, cover crops, integrated nutrient management including use of manure and compost, and agroforestry.

The restoration of wastelands, degraded/desertified soils and ecosystems (e.g., afforestation, improved pastures) and adoption of improved farm management practices can enhance soil organic carbon and improve soil quality and soil health. Such management practices include organic agriculture, conservation tillage, mulching, cover crops, integrated nutrient management and agro-forestry, including improved management of pastures and rangelands (FAO, 2007).

Crop management

Results from several field experiments under various climatic conditions revealed that crop rotations, in combination with tillage, sequestered more soil carbon (Yang and Kay, 2001; Campbell *et* *al*., 1995). Meyer-Aurich *et al*. (2006) conducted an experiment with two levels of tillage and eight different corn-based crop rotations. They found that continuous alfalfa rotation had the highest sequestration rates (513 kg C ha^{-1} yr^{-1}). Carbon storage of soils in the corn-corn-alfalfa-alfalfa rotation was significantly higher than in the corn-corn-soybean-soybean rotation. Rotations which included cereals and red clover, had soil carbon levels that were between those observed for continuous alfalfa and corn-corn-soybean-soybean rotation. Crop rotation is very effective in carbon sequestration than continuous cultivation of single crop every year. Mandal *et al*. (2007) reported that rice mustard-sesame registered significantly higher rate of carbon sequestration (1.91 Mg C ha^{-1} yr^{-1}) than that of rice-fallow-rice (0.28 Mg C ha^{-1} yr^{-1}) and rice-wheat-fallow (0.27 Mg C ha^{-1} yr^{-1}) system. Inclusion of crops which leave behind higher amount of crop residues and/or root carbon facilitate higher SOC sequestration. They observed that besides quantity, the quality of residue also decide the rate of SOC sequestration. The residues with wider C:N ratio (rice and wheat) facilitate higher SOC sequestration than residues with narrower C:N ratio (jute, berseem etc.).

Tillage and residue management

The impact of conservation tillage and crop residues incorporation have shown remarkable potential in C sequestration as compared to conservation tillage alone. Conservation agriculture using crop residue as mulch and no till farming can sequester more SOC through conserving water, reducing soil erosion, improving soil structure, enhancing SOC concentration, and reducing the rate of enrichment of atmospheric CO_2 (Lal, 2004). Doraiswamy *et al*. (2007) reported that ridge tillage in combination with fertilizer and crop residue is very effective in SOC sequestration through erosion control. Ghimire *et al*. (2008) reported that SOC sequestration could be increased with minimum tillage and surface application of crop residue and SOC sequestration was highest in top 0-5 cm soil depth irrespective of the tillage and crop residue management practices. Suman *et al*. (2009) reported that changes in residue management and incorporation of organic manures may help in carbon sequestration by restoring soil organic carbon (SOC).

Incorporating plant residues is one means by which we can add organic matter to soil. Removal of crop residues from field is known to hasten SOC decline especially when coupled with conventional tillage. Incorporation of crop residues favours immobilization because of wide C/N ratio in the crop residues. The extent of residue or crop cover left on the soil surface depends on the availability. In our country, there are competing uses such as fuel, thatching material, feed for crop residues. Therefore, crop residues are mostly disposed off from crop fields. In some situations, where they are available in abundance, crop residues are considered as waste material and disposed-off by burning such as in the rice-wheat growing areas of north India.

Application of biochar

Biochar is a carbon reach material produced by incomplete combustion of biological materials in absence of oxygen or with limited amount of oxygen. It is believed that biochar can store carbon in soil for hundreds to thousands of years and thus level of green house gases like CO_2 and methane can be reduced significantly (Lehmann, 2007).

Nutrient management

It is interesting to note that efficient management of inputs leads to carbon sequestration that helps in increasing the agricultural inputs use efficiency. Sequestration of soil organic carbon helps in improving the physical, chemical and biological health of soil. The agricultural inputs include water, nutrient, energy and agrochemicals. There is continuous decline in the factor productivity of these inputs due to their inefficient use and deterioration of soil health. Efficient use of these inputs helps in reducing the cost of cultivation, sustaining agricultural productivity at higher level with minimal environmental pollution.

Judicious nutrient management is crucial to SOC sequestration. Use of organic manures and compost enhances the SOC pool more than application of the same amount of nutrients as inorganic fertilizers (Gregorich *et al*., 2001). The fertilizer effects on SOC pool are related to the amount of biomass C produced/returned to the soil and its humification. Adequate supply of N and other essential nutrients in soil can enhance biomass production under elevated CO_2 concentration (Van Kessel *et al*., 2000).

Modified land use system

Alternate landuse systems like agroforestry system (AFS) has become an established approach to integrated land management, not only for renewable resource production, but also for ecological considerations. It represents the integration of agriculture and forestry to increase the productivity and sustainability of the farming system. Agroforestry (also known as multistrata tree gardens or analogue forests) and homegardens are other variants of these complex systems, but involve higher plant diversity. Trees play an important role in soil C sequestration (Takimoto *et al*., 2009); with an increase in the number of trees till complete stocking (high tree density) in a system, the overall biomass production per unit area of land will be higher, which in turn may promote more C storage in soils. In fact, recent research has reported higher soil C stock (amount of carbon stored in soil) under deeper soil profiles in agroforestry systems compared to treeless agricultural or pasture systems under similar ecological settings (Haile *et al*., 2008; Nair *et al*., 2009). Multipurpose trees (MPTs) form an integral component of different agroforestry interventions and models. MPTs, besides furnishing multiple outputs like fuel, fodder, timber, and other minor products, also help in the improvement of soil and other ecological conditions. Trees play various functions, including shading crops to reduce evapotranspiration, erosion control and nutrient cycling (Young, 1997).

Challenges in soil carbon sequestration

Soil carbon has gained increased interest in the recent past owing to its importance in carbon sequestration studies and its potential impact on sustainable crop production. Carbon sequestration implies removing atmosphere carbon and storing it in natural reservoirs for extended periods (Lal, 2011). Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately emitted. This transfer or sequestering of carbon helps to off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity. However, accuracy in estimating soil carbon sequestration to determine best management practices is hindered by inherent variability of soil properties Maintaining or arresting the decline in soil organic matter (SOM) is the most potent weapon in fighting against soil degradation and for ensuring sustainability of agriculture in tropical regions. In India nearly 60 per cent of agriculture is rainfed, covering the categories of arid, semi-arid and sub-humid climatic zones. Consequences of depletion of organic matter are poor soil physical health, loss of favorable biology and occurrence of multiple nutrient deficiencies. In the rainfed arid, semi-arid and sub-humid tracts, apart from poor rain water management, depletion of nutrients caused by organic matter deficiency is one of the important causes of soil degradation. Improving organic matter is, therefore, crucial to sustenance of soil quality and future agricultural productivity. Humus is known to favor many useful physical, chemical and biological processes that occur within the soil. Accordingly, soil organic matter is the key element of soil management that prevents erosion and improves water availability. Other soil physical characteristics that are linked to soil organic matter are: infiltration, water retention, bulk density and soil strength. When spread on the surface as mulch, organic matter moderates the bomb-like effect of falling rain drops and prevents dispersion-mediated erosion, surface crusting, and hard setting. Deforestation, residue burning, conventional tillage, imbalance use of fertilizers are some of the challenges of carbon sequestration in soil.

Conclusion

Carbon Sequestration can assist significantly in maintaining the natural carbon cycle. Therefore, requirement is that we need to implement this practice properly. There is a need to go for natural sequestration first, thus conservation of existing forests and more and more reforestation is required. Only then we will be able to reduce carbon emission and corresponding harmful impacts. Later on there is an immigrate requirement to install carbon capture and store mechanism in every thermal power plants. So that carbon emission can be managed at its point source.

Sequestering carbon in soil and biota can mitigate climate change. Recommended management practices like conservation tillage, crop rotation, residue management and integrated nutrient management have good potential in improving soil carbon sequestration. Efficient use of agricultural inputs would reduce greenhouse gas emissions and result in carbon sequestration. Sequestration of carbon in soil can improve soil health which will help in improving input use efficiency in agriculture.

From the above considerations, it can be concluded that SCS is desirable, both for its beneficial effects on GHG reduction and climate change, and for its wider environmental and economic implications. In particular, an increase in the levels of SOM is necessary to cover the loss of organic C in agricultural soil. The decrease in SOM content led to the decline of several soil properties that are essential for soil protection and conservation from both the agronomic and environmental points of view. Proper SOM management is also a prerequisite of a sustainable agriculture capable of dealing with the increasing demand of food and the maintenance of the environment. Appropriate SOM management is therefore an essential turning point for the equilibrium of natural systems and the future of the entire human society. For this, countries should unilaterally desire to undertake policies that have beneficial effects on the productivity and long-term sustainability of agricultural production systems.

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