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Review article

SOIL CARBON SEQUESTRATION: AS A CLIMATE CHANGE ADAPTATION AND MITIGATION STRATEGY – AN OVERVIEW

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ABSTRACT: Sequestration of atmospheric carbon is one of the mitigation measures for countering anthropogenic climate change due to excessive emission of greenhouse gases. However, soil carbon sequestration measures need to be sustainable and significant, without substantial conflict between groups with diverse priorities. Carbon sequestration potential of soils in reduced clearing of primary ecosystems has attained substantial importance in modern agricultural farming systems apart from climate change adaptation. The adoption of diverse management strategies of carbon sequestration in croplands, grasslands etc., may provide potential estimation of carbon sequestration potential. Thus?, the identification of any system for efficient land-based carbon sequestration therefore requires a quantitative estimate on a regional setting. Research needs to be done to identify both horizontal and vertical agricultural technologies that restore carbon pools and soil quality and create tools to measure, monitor and verify soil-carbon pools and fluxes of greenhouse gas emissions.
Key words: Carbon sequestration, Greenhouse gases, Soils, Technologies

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INTRODUCTION

According to Intergovernmental Panel on Climate Change, [1] average global surface temperature is likely to rise a further by 1.4 to 5.8 °C or even warmer during the 21st century. The increase in temperature is well correlated with anthropogenic activities and especially with the increase in the concentration of greenhouse gases (GHG's) [2]. Increasing concentration of GHGs, particularly CO_2 in the atmosphere could lead to a rise in average earth surface temperature by 0.17 °C per decade [2] and 0.5–1% of precipitation per decade in most of the Northern Hemisphere and 0.3 % in tropics and sub-tropics (Wang et al., 2010). Anthropogenic activities such as fossil fuel combustion, fertilizer production and land-use changes have dramatically increased the global CO_2 concentration which is expected to reach 600 ppm before the middle of this century [3]. Fossil fuel combustion is the prime cause of rising CO_2 level followed by changes in land-use pattern. Deforestation accounts for an annual release of carbon between 0.9 × 1012 and 2.5 × 1012 kg, about one third of which comes from the oxidation of soil carbon in the tropics mainly linked with changes in land-use pattern [4]. A substantial amount of global CO_2 comes from soil through decomposition, mineralization and soil respiration [5]. Over the past decade, the direct agricultural emissions have increased about one per cent a year, reaching 4.6 Gt CO_2 yr^{-1} in 2010, or about 10% of total annual emissions [6]. The food system at large, including feed, fertilizer and pesticide manufacture, processing, transportation, refrigeration and waste disposal, accounts for 30% or more of total annual global GHG emissions [7].

The global warming as a result of increased GHG emissions especially that of CO_2 will result in rapid effects (IPCC, 2007), as follows

1. Large scale disruption of forestry, agriculture and fisheries.
2. Extinction of many plant and animal species on land and oceans.
3. Changing rainfall and snowfall pattern.
4. Loss of huge tracts of coastal lands under rising seas as the oceans expands due to melting of polar ice.
5. Less assess to less reliable water supplies in many parts of the world.

Rising levels of CO_2 leading to global warming has triggered a search for methods to control and bring down the levels of atmospheric carbon. These concerns have led to a question about the role of soils as a carbon source or sink [8]. Knowledge of relative C storage and flux characteristics of converting ecosystems is essential for predicting global geosphere-biosphere modelling and for amelioration of increased atmospheric CO_2 levels through C sequestration. Carbon sequestration in soil and its biomass has been proposed to be a key strategy to reduce atmospheric CO_2 [9] suggested that increases in SOC should normally be termed 'accumulation' and that 'sequestration' be reserved for situations where there is an additional transfer of C from the atmosphere and thus a genuine contribution to climate change mitigation.. Soil C sequestration is expected to account for about 90% of the total global mitigation potential available in agriculture by 2030 [10]. Direct soil carbon sequestration occurs by inorganic chemical reaction that converts CO_2 into soil inorganic carbon compounds such as Ca and Mg carbonates and indirectly as plants photosynthesize atmospheric CO_2 into plant biomass; subsequently some of the plant biomass is indirectly sequestered as soil organic carbon during decomposition process. The amount of carbon sequestered at a site reflects the long term balance between carbon uptake and release mechanisms.

Many best soil management practices have been proven to help in sequestering soil carbon including, restoration of degraded soils and ecosystems, the adoption of recommended agricultural practices on prime land and retiring marginal agricultural lands to restorative land uses, conversion of croplands to grasslands, no-till farming, nutrient management, improved grazing, water conservation and harvesting, agro-forestry practices [4].Through these healthy practices, forest vegetation can be maintained; thereby increasing the carbon stock of forest soil by reducing direct loss to the atmosphere [11]. There is a large potential of restoration of degraded soils in South East Asia, which ranges from 18.3 to 35.0 Teragram carbon per year (TgC/yr). These estimates are attainable potentials provided that regional governments adopt appropriate policies and implement plans to restore degraded soils through forestation, establishing planted fellows and improving grazing lands [12]. Various attempts have been made to estimate the potential of SOC sequestration globally as well as in different countries based on different scenarios as a result of changing management practices and land use (Table 1).

Table 1: Estimates of potential SOC sequestration globally and in selected countries as compared to total carbon emissions

	Total C emission/yr	**C sequestration rate due to improved management, Gt/yr**		**% of total C emission**	**Reference**
		Current	Potential		
Global -(1)	9.1 Gt*	0.4	0.44-0.88	5-10 %**	Paustian *et al* (2004)
Global -(2)	13.4 Gt	-	1.50-1.63†	11-12%	Smith et al. (2007)
USA	2.00 Gt*	0.017	0.288	14 %	Lal *et al.* (2007)
Europe	1236 Mt	˜0.0	104	8.3 %	Smith *et al.* (2000)
Australia	154 Mt*	?	?	?	AGO (2007)

* Total GHG emission; ** for up to next 50 years; †by 2030

There has been considerable interest in carbon sequestration through iron fertilization in the oceans, forest and agricultural lands may also play a key role in the overall strategy for slowing the atmospheric accumulation of carbon [13]. However, ocean fertilization to sequester CO_2 by phytoplankton can be ecologically disruptive and is unlikely to be effective for climate mitigation [14] although land-based carbon capture and storage has been proposed the high cost involved is often used as an argument against it [15]. The global carbon sequestration potential by improved pasture management practices was calculated to be 0.22 t C per ha per year. Assuming 0.2 t C per ha per year for organic farming practices, the total carbon sequestration potential of the world's grassland would be 1.4 Gt per year at the current state, which is equivalent to about 25% of the annual GHG emissions from agriculture [16,17]. Soil carbon sequestration in some soils in India from last 20 years is given in Table 2.

Table 2: Soil C sequestration through INM for 20 yrs in some soils of India

Location	Soil system	SOC after 20yrs.(gm/Kg)				
		Cropping	Initial SOC	Control	NPK	NPK+FYM
Bhubneshwar	Inceptisol	Rice-rice	2.7	4.1	5.9	7.6
Pantnagar	Mollisol	Rice-wheat	14.8	5.0	9.5	15.1
Pantnagar	-	Rice-wheat-cowpea	14.8	6.0	9.0	14.4
Faizabad	Inceptisol	Rice-wheat	3.7	1.9	4.0	5.0
Barrakpore	-	Rice-wheat-jute	7.1	4.2	4.5	5.2
Palampur	Alfisol	Maize-wheat	7.9	6.2	8.3	12.0
Karnal	Alkali soil	Fallow-rice-wheat	2.3	3.0	3.2	3.5
Nagpur	Vertisol	Cotton-cotton	4.1	-	-	5.5
Trivandrum	Ultisol	Cassva	7.0	2.6	6.0	9.8

The mechanism and potential of C-sequestration in converted ecosystems are still not well understood and due to this and other uncertainties, predictions made for global carbon balance remain uncertain [18]. The soil C pool reflects a balance between the input and output, and if the carbon flux is low relative to storage it leads to sequestration in soil but a higher flux cause C loss. Most agricultural soils have lost 30% to 70% of their antecedent SOC pool [19]. FAO has prepared a Global Carbon Gap Map that identifies areas of high carbon sequestration potentials (FAO, 2008). India, representing almost all major climatic zones and wide range of land use systems, has vast opportunities for soil carbon sequestration.

Carbon Sequestration in Crop Lands

Organic farming practice like cultivation of cash and cover crops, intercropping and manure is becoming increasingly important for carbon sequestration in the soil. Several field studies have proved the positive effect of organic farming practice on soil carbon pools. In the USA, a field trial showed a fivefold higher carbon sequestration in the organic system (i.e., 1218 kg of carbon per hectare per year) in comparison with conventional management. The potential of carbon sequestration rate of organic farming for European agricultural soils has been estimated at 0–0.5 t C per hectare per year [12] calculated the sequestration potential of organic croplands to be 0.9–2.4 Gt CO_2 per year (which is equivalent to an average sequestration potential of about 0.2–0.4 t C per hectare and year for all croplands), which represents 15–47% of total annual agricultural GHG emissions. Some farming and farming related practices currently discussed for their high sequestration potential, such as no-tillage, are so far poorly applicable in organic systems [20]. Conservational no tillage systems perform well in terms of carbon sequestration but can increase N_2O emissions. In the long term, the removal of GHGs from the atmosphere through soil carbon sequestration is limited [21]. The level of soil organic matter does not increase indefinitely in any soil, but reaches certain equilibrium, depending on the soil and climatic conditions and management practices. Lal et al., (2004) estimates the carbon sink capacity of the world's agricultural soils by enhanced management practices to be 21–51 Gt carbon, which is equivalent to all anthropogenic GHG emissions over 2–3 years.

Tillage Practices

A recent research review found that almost all studies to-date indicates that switching to conservation tillage not only improves soil structure, but also reduces carbon dioxide emissions and contributes to increases in soil organic carbon [22]. But, reduced or no-till is only a boon to greenhouse gas emissions reduction when it is practiced within organic systems: the soil carbon gains achieved under conventional no-till agriculture are countervailed by the greater area-scaled N_2O emissions from nitrogen fertilization [23]. Thus, carbon sequestration in soils can compensate inevitable agricultural emissions until more neutral production practices are developed and widely used. There are scientific results showing that the carbon stored by no-tillage systems is released by a single ploughing, presumably because of its labile quality.

Carbon Sequestration in Grasslands

Grasslands and savannas cover 20% of the earth's land surface [24] and store 30% of global soil organic carbon [25]. Grassland ecosystems managed for livestock production represent the largest land-use footprint globally, covering more than one-quarter of the world's land surface [26]. Global estimates of the relative amounts of carbon in different vegetation types suggest that grasslands probably contribute >10% of the total biosphere store [27]. Plant diversity greatly influences carbon accumulation rates in grasslands. The presence of species with differing functional traits increases soil carbon and nitrogen accumulation [28]. Carbon from plants enters the SOC pool in the form of either aboveground litter or root material. Greater carbon accumulation is associated with greater root biomass (i.e. greater carbon and nitrogen inputs in the soil) resulting from positive interactions among legumes and C4 grasses and the greater soil depths through which their roots are located at higher diversity [28]. The global carbon sequestration potential by improved pasture management practices was calculated to be 0.22 t C per ha per year. The conversion of arable agriculture to perennial plants (trees, grasses, shrubs) can also contribute to sequestration of carbon. It is, however, important to carefully identify the plant/crop in planning C- sequestration through vegetation.

Land Uses Practices

Any modification of land use and management practise can change soil C stocks [29]. Faulty land use practices like shifting cultivation, free-range grazing by cattle, growing crops along with the slope, cultivation of erosion permitting crops etc. may cause removal of top soil by erosion [30]. Organic matter has lower density than soil solids hence are easily subjected to losses through wind and water erosion. It is clear that the OM loss under 3% slope is around 46 kg/ha in Kerala [31,32] (Table 3).

Table 3: Organic carbon losses under different slopes and slope length (this is showing the impacts of slope on loss not the impacts of land use practices)

Slope (%)	Loss of Organic Carbon (Kg/ha)
0.5	6.6
1.5	13.9
3.0	46.0
Slope length	
18.3	13.8
36.6	7.1
54.9	4.9

Cultivation of soil and consequent aeration stimulate more microbiological activities and promote the oxidation of organic matter i.e. increase the rate of disappearance of soil organic carbon. Intensive cultivation stimulates decomposition of SOM [33-37]. Organic carbon status usually remains low in cultivated soils. It is clear that in all the soil zones, the organic matter content is very high in virgin soil (Table 4).

Table 4: Organic matter content (%) in virgin and cultivated soils

Soil zone	Virgin	Cultivated
Brown	3-4	2-3
Dark brown	4-5	3-4
Black	6-10	4-6
Dark grey	4-5	2-3

Issues on Soil Carbon Sequestration

There are numerous issues related to soil carbon sequestration. SOC sequestration requires input of crop residues/biosolids and of fertilizers/manures to enhance biomass production. The efficacy of SOC sequestration in view of the hidden costs of the input involved is one of these concerns. Judicious use of cost intensive fertilizers and pesticides with high use efficiency and other improved management options and use of manure for nutrient additions are efficient means of SOC sequestration [38-40]. Concern about the lack of response of SOC sequestration to conservation tillage and the permanence of sequestration in the soil needs to be addressed. SOC sequestration is a major challenge in soils of the tropics and subtropics, where the climate is harsh and resource-poor farmers cannot afford the off-farm input.

CONCLUSION

However, the sequestration of CO_2 in soils is not included in the clean development mechanism (CDM) agreed to in Kyoto protocol. The FAO should play a leading role in this process, including the establishment of this process, including the establishment of a global soil carbon sequestration initiative, entrusted with the promotion of agricultural technologies that restore carbon pools and soil quality (*e.g.* organic agriculture, conservation agriculture) and to create tools to measure, monitor and verify soil-carbon pools and fluxes of greenhouse gas emissions (*viz.* nitrous oxide) from agricultural soils, including crop lands and pastures.

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