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Potential carbon sequestration methods of agriculture: A review

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Abstract
Carbon is the non-metallic element that exists in our environment in various forms. Our environment is made up of 0.03-0.04% of carbon dioxide by volume. This gas is a major greenhouse gas and plays an important role in earth carbon cycling. The combustion of any substance including fossil fuels, respiration by living beings leads to the production of this gas. The soils are having the ability to sequester carbon with proper management it is obvious that we can use this resource as a sink for carbon. The carbon capture and sequestration (CCS) technology is done to induce carbon into the soil from carbon generating point sources. It is the process of capturing waste CO_2 from larger sources example fossil fuel power plants than its transportation was done to the storage site, and finally depositing it from where it will not enter back to the atmosphere, generally in underground geological formations. India is one among 24 developing countries that are having CCS activity, recognizing the importance of CCS for energy security. On agricultural soils adoption of conservation tillage, conventional no-till, and organic no-till, crop rotations including cover crops, rotational grazing-like practices must be adopted to increase sequestration of carbon in farmer's field. As stated by Lal, 2004 in the table that the potential is about 39.3 to 49.3 Tg carbon per year, and the above discussion clearly states that the agricultural soils of India are having better potential for more carbon sequestration.

Keywords: Carbon capture and sequestration (CCS), carbon sequestration, conservation tillage

Introduction
Carbon is the non-metallic element that exists in our environment in various forms. The carbon dioxide, carbon monoxide like gases are the forms of carbon element found freely in the environment. Our environment is made up of 0.03-0.04% of carbon dioxide by volume. This gas is a major green house gas and plays an important role in earth carbon cycling. The meaning of green house gas refers in the positive term as it works to trap heat close to Earth that is the energy it receives from the Sun so that all the energy doesn't escape back into space and the Earth's ocean would not get frozen to solid. The combustion of any substance including fossil fuels, respiration by living beings leads to production of this gas. Increase in the emission of global CO_2 concentration presented its adverse effects on our environment. Melting of glaciers, increase in the level of oceans, and increase in global temperature are all the outcome of increase in global CO_2 content mainly due to surge of human activities. The industrialization leads to rise in CO_2 levels in the atmosphere which was initially of about 270ppmv, from that time a rise in that level was upto 40% which made this gas a troublemaker. To combat this problem we had to find ways by capturing excess carbon from the atmosphere and store it in the soils.
The soils are having the ability to sequester carbon with proper management it is obvious that we can use this resource as a sink for carbon. Since one-third of the world's land was agriculturally occupied (World Bank, 2015) [6], hence we have to consider agricultural carbon management strategies, which increases carbon input to soils and protects its turn over into soils. This method not only benefits our environment but also benefits soils by improving soil fertility, structure, water holding capacity.

Carbon sequestration in soils
Soil carbon sequestration refers to the removal of CO_2 from the atmosphere and stored in various carbon sinks. Carbon cycling between soil and environment forms a source-sink dynamics. The sequestration process is primarily mediated by plants through photosynthesis and with the carbon stored in the form of soil organic carbon. In arid and semi-arid climates it can also occur due to the conversion of CO_2 into an inorganic form of carbon such as secondary carbonate but the rate of inorganic carbon formation is relatively low (Lal, 2008) [5].

Carbon changes its molecular form and cycles between the atmosphere, oceans, and forests. Nowadays scenario indicates that soils under croplands, grasslands, and forests have lost much more carbon as there is more of it in the atmosphere and oceans. There are three types of carbon pools found in our soils: fat or labile pool, slow pool, and stable pool. The fast pool can return carbon to the atmosphere in a few days or few years, while the slow pool takes years to decades for degradation. If the carbon pools into the soils under stable pool form, then its "mean residence time" increases into the soil from centuries to millennia. This stable pool is generally called humus, a term for a group of carbon compounds that are resistant to decomposition, and well protected from microbial decomposition (Six *et al.*, 2002) [7]. Hence, we have to focus more on increasing the stable pool of soil carbon.

There are five sinks of carbon on earth namely: biosphere, pedosphere, lithosphere, hydrosphere, and atmosphere and the content of present in them is specified in Table 1.0.

Table 1.0: The amount of carbon sequestered in various environmental sinks

Sr. No.	Sinks of Carbon (C)	Amount of carbon (Giga tones GT)
1.	Lithosphere and Pedosphere (Soil)	
	a. Organic Carbon	1550
	b. Inorganic Carbon (Calcite, Dolomite, Gypsum)	950
2.	Biosphere (Plants and Animals)	560
3.	Hydrosphere (Oceans)	38,400
4.	Atmosphere	800

The sequestration potential of agricultural soils globally on annual basis lies in the range from 0.4 to 1.2 gigatons per year (Gt/yr) (Lal, 2004) [4]. The sequestration of carbon in the soils takes place in four ways:

1. Decreasing soil disturbance (i.e. tillage) to enhance the physical protection of soil carbon.
2. Increasing the quality and mass of animal and plant inputs to soils.
3. Improving microbial diversity in soils.
4. Maintaining year-round plant cover on soils.

Soil carbon saturation

We know that soil has immense capacity to sequester carbon, but everything has its limits. Soil is a carbon sink that also pertains to a certain limit, that limit is called soil carbon saturation. The saturation point for carbon was described by Six *et al.*, 2002 [7] as a limit of decreasing soil aggregation of carbon, decrease in carbon adhesion to mineral particles, and cessation of biochemical protection to new carbon. If the soil is carbon saturated then the vulnerability to attack by microbes increases. The carbon saturation is influence by inherent soil characteristics like clay content and type. Generally, the majority of soils around the world are likely below their saturation limit due to poor management and land degradation (Lal, 2004) [4].

Carbon capture and sequestration technique (CCS)

The carbon capture and sequestration (CCS) technology is done to induce carbon into the soil from carbon generating point sources. It is the process of capturing waste CO_2 from larger sources example fossil fuel power plants than its transportation was done to the storage site, and finally depositing it from where it will not enter back to the atmosphere, generally in underground geological formations. The main objective of this technique is to prevent the discharge of large quantities of carbon dioxide into the atmosphere from fossil fuels which was produced during power generation and by industries as well. CCS is a crucial climate protection technology for coal-rich countries like India, which can massively reduce CO2 emission compared to any other present technology for sequestering carbon directly.

This method involves three major steps (Gupta and Paul, 2019) [2]; the first one is Capturing it refers to the separation of CO2 from other gases which were produced at large industries such as coal and natural gas power plants, steel mills, oil and gas plants, cement plants, etc. The second step is the Transportation of separated CO2 which was compressed and transported through pipelines, ships trucks, and other methods to a site for geological storage. The last step is the Storage or Sequestration of carbon dioxide into deep underground rock formations, this is done at the depth of 1 km or more.

India is one among 24 developing countries that are having CCS activity, recognizing the importance of CCS for energy security. Together with other industries like National Aluminum Company (NALCO), ONGC, Bharat Heavy Electrical Ltd. (BHEL), and APGENCO, NTPC, The Indian fertilizer sector has also adopted carbon capture technology (Table 1.1). The captured CO_2 is said to be of 99% purity which will be recycled again to be used in the production of urea from ammonia.

Table 1.1: The use CCS technology by various fertilizer plants

Sr. No.	Fertilizer Plants	Developer	Technology for carbon capturing	Industry	CO_2 absorption capacity Tonnes per day (TPD)
1.	Aonla (U.P.) urea plant	Indian Farmers Fertilizer Co-Operative	Amine Based (Post-Combustion Capture)	Chemical Production	450 TPD
2.	Phulpur (U.P.) urea plant	Indian Farmers Fertilizer Co-Operative	Amine Based (Post-Combustion Capture)	Chemical Production	450 TPD
3.	Jagdishpur (Orissa) urea plant	Indo Gulf Corporation	Amine Based (Post-Combustion Capture)	Chemical Production	150 TPD

Source: Sood *et al.*, 2017

Agricultural techniques to promote carbon sequestration

The tropical soils, particularly arid, semiarid, and sub-humid climates contributing to the lower status of SOC. The Land-use change (LUC) is the second important factor which contributes to 20% of global emission after the burning of fossil fuels. The Land-use change refers to the conversion of more and more natural or forest areas to be brought under agricultural uses particularly for intensive crop cultivation, to sustain the food needs of an ever-growing population. The LUC leads to a decrease in average C stocks of 25–30% (Badole *et al.*, 2020) [3]. The intensive cropping and cultivation may disturb soils and leads to oxidative loss of SOC but also tends to huge additions of carbon by crop residue biomass that results in a net buildup or depletion of soil organic carbon stocks. Therefore, cropping systems together with other management practices under soil environment plays a crucial role in carbon stabilization and maintaining SOC stock. Certain examples are there such as rice with forestry (*Madhuca longifolia* and *Diospyros melanoxylon*) or rice with horticulture (guava) system conserves the organic carbon into the soil at a desirable level so that ecosystem functions and helps to increase food and timber production. Generally, soil C sequestration focused on the top 0–30 cm of the soil profile and ignores subsoil horizons which may also respond to carbon management. As we know even if that the subsoils are having low carbon content then also contributes more than half of the total soil carbon stocks, hence we have to consider subsoil as a more important sink of CO_2 than the topsoils. Various agricultural systems have emerged which are having the ability to increase soil carbon which maintains soil fertility, productivity, and sustainability of the soil system. Some of them are discussed below:

Conservation Tillage, Conventional No-Till and Organic No-Till

Conservation tillage means the conservation of at least 30% crop residue over the surface of the soil. The process of no-till includes specializes planting equipment, chemical herbicides, a genetically modified seed that reduces or eliminates the need for tillage equipment. Here, the soils remain undisturbed and soil aggregate remains intact as well as physically protected to preserve carbon. This practice can increase soil carbon rapidly at the soil surface (West and Post, 2002) [15]. Conservation tillage and no-till utilize tillage implements that are less aggressive than the classic moldboard plow, it requires fewer tillage passes per season so that more residues remain on the soil surface and minimizes the disruption of soil aggregates. It is also concluded that these practices together can increase soil carbon by protecting carbon, but in conservation tillage sequestration generally occurs at rates lower than no-till (West and Post, 2002; Halvorson *et al.*, 2002) [15, 16]. The Rodale Institute and numerous other institutes have been experimenting with the organic no-till system. As we know the organic production system not allowed the use of herbicides or chemical fertilizers they depend on cultivation to control weeds. The system relies on an implement called a roller-crimper that is used to roll over a standing cover crop in spring which can increase OC of soils. Researchers at the Rodale Institute and several other institutions have been experimenting with an organic no-till system by reducing tillage and flattening or crimping plants which when died creates mulch over the soil surface that will continuously suppress the weeds during the growing season (Rodale Institute, 2015) [14].

Rotational Grazing

The herd of grazing animals increases annual pasture biomass production and can also redistribute carbon over the pastures in the processed form of manure which leads to rapid increases in soil carbon content ultimately supports carbon sequestration. Methods like management of intensive grazing, frequent movement of cattle to the new pastures, higher stocking densities, and the preventing of overgrazing were also adopted for more ground carbon preservation. The rotational grazing was further enhanced by the addition of compost and amendments to rangelands. Studies by Marin Carbon Project in the University of California, Berkeley demonstrated that thin applications of compost to grasslands in managed grazing pattern leads to the substantial increase in plant biomass, therefore the net increase in carbon sequestration was registered (Ryals and Silver, 2012; Ryals *et al*., 2014) [13]. Therefore, the meta-analysis of present grassland improved management under the majority of the studies found that during conversion from croplands to grasslands and there is greater carbon sequestration (Conant *et al.*, 2001) [11]. The researchers in the southeastern US also reported that the conversion of land from row crops to management-intensive grazing increases soil carbon to an apparent saturation point (Machmuller *et al.*, 2015) [10].

Perennial Cropping Systems

The majority of crop systems are dominated by annuals which depend on repeated tillage cycles for the planting of seeds for obtaining desired productivity but perennial plants can survive for several seasons and require fewer disturbances. Hence, the recently proposed for more and more planting of perennial crops can protect soil carbon well due to more extensive roots systems and more below-ground biomass (Cox *et al.*, 2006) [8]. According to Albrecht and Kandji, 2003 [9] the agroforestry system shows potential carbon sequestration value because it utilizes tree crops and also mimics forest systems by doing considerable food production as well but this system for a long time remains largely underutilized and understudied. The description of various cropping systems used in various parts of India and the technology involved in it is represented in Table 1.2.

Table 1.2: Technological options for soil carbon sequestration

Technology	Cropping system	Regions of India
1. Green manuring	Sugarcane	Tropical
	Rice-wheat	Northwestern, Northern, Punjab
	Rice	Tropical
2. Mulch farming conservation tillage	Rice-wheat	Punjab
	Pearl millet	Arid
	Soybean-wheat	Central
	Arable land	Northern
	Sugarcane	Tropics
3. Afforestation/ agroforestry	Silviculture	Northern
	Acacia nilotica	Central
	Agroforestry	Tropical

4. Grazing management/ley farming	Grassland	U.P., M.P.
	Mixed farming	Arid
5. Integrated nutrient management/ manuring	Arable land	Tamil Nadu, Northeast, Northern
	Rice-wheat	Northwest, Northern
	Cotton	Central India
	Rice-rice	Northern
	Maize-wheat-cowpea	Semi-arid
	Wetland rice-wheat	Northern
	Maize-wheat	Northern
6. Cropping systems	Pearl millet	Arid
	Fallowing/ecological approach	Humid/sub-humid
	Mint-mustard	U.P.

Source: Lal, 2004 [4]

Conclusion

As stated in Table 1.3 that the potential is about 39.3 to 49.3 Tg carbon per year and the above discussion clearly states that the agricultural soils of India are having better potential for more carbon sequestration. The process is not only favorable for environmental well-being but also for restoring soil quality which thereby reducing the problem of soil degradation and finally ensures food security. The change in the patterns of the cropping system by including more of the green manuring and leguminous crops into it as well as adopting practices of minimum soil disturbance also gives long-lasting benefits to the environment and farmers.

Table 1.3: Total Potential Carbon Sequestration potential of Indian soils (Tg C yr-1)

A. Soil Organic Carbon (SOC)	
• Restoration of degraded soils	7.2-9.8
• Agricultural intensification	5.5-6.7
B. Secondary Carbonates	21.8-25.6
C. Erosion Control	4.8-7.2
Total	39.3-49.3

Source: Lal, 2004 [4]

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