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Soil carbon sequestration enhancement techniques: an emergent technology to mitigate climate change

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ABSTRACT
The purpose of this paper is to review the various techniques and methodologies related to increase the residence time of carbon in soil by enhancing carbon intake rate and reducing the soil respiration rate. The uptake and loss of carbon by land plants and soils were closely balanced before human intervention but due to ignorance of various factors according to Schlesinger (1997) the global flux of CO2 from soil has become approximately $75*10^{15}$gC/yr, roughly 2.5 times larger than the total Net Primary Productivity (NPP) of carbon in soil. Through this paper it is tried to make people aware and encourage to minimize the gap of intake and release of carbon by soil and utilize its huge potential of carbon sequestration via adopting various techniques and proper land management practices, in this way we could not only offset the CO2 concentration in atmosphere but will also increase the soil fertility, water retention capacity and crop productivity.

Keywords: Carbon sequestration; Soil respiration; Carbon residence time; Soil fertility

1. INTRODUCTION

As according to Intergovernmental Panel on Climate Change (IPCC, 2001) and the UN Framework Convention on Climate Change (Macilwain 2000) the increasing concentration of CO2 is a worldwide threat leading to global warming, thus mitigation measures of it is one of the challenge in front of all over the world which requires a sustainable, significant, cost-effective, environmentally sound and viable approach. Three strategies are available for lowering CO2 emissions to mitigate climate change (Schrag, 2007): (i) reducing global energy use; (ii) developing low or no-Carbon fuel; and (iii) sequestering CO2 from point sources using natural and engineering techniques. As per capita energy consumption is directly proportional to the development of a country, so reducing global energy use means decreasing the development globally, developing low or no-C fuel requires time for modification of technology and commercializing innovative and cost effective techniques, which can be earned only by sequestering CO2 by engineered technology or by enhancing the natural process of it. One of the engineering techniques of C capture and storage (Lackner, 2003; Koonin, 2008; Broecker, 2008; Kasahun Kitila Hunde, 2015a; Eludoyin. 2015) involve injection of compressed and liquefied CO2 beneath the ocean, into a saline aquifer or into a stable rock strata (Chu, 2009; Haszeldine, 2009) is a costly devises associated with many negative ecological impacts like increase in acidity of sea water, resulting death of fish and other aquatic lives and change in physiochemical behavior of aquatic organisms. The other option is Geological Sequestration the principal concerns about it is the relatively high cost (McKinsey and Co., 2009; Al-Juaied and Whitmore, 2009), and the need for an established protocol for measurement, monitoring and verification (MMV) along with possibility of earthquake and geological disturbances. Thus there is requirement of such a technology which should be not only economical but also environmentally compatible and it can be achieved through Soil carbon sequestration, it is a natural, cost-effective, and ecofriendly process, (Watson et al., 2000) It is a win-win option because while mitigating climate change by off-setting fossil fuel emissions, it also improves quality of soil and water resources, enhances agronomic productivity, and buys us time to identify and implement viable alternatives to fossil fuel.

2. CARBON SEQUESTRATION POTENTIAL OF SOIL

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 reemitted. Worldwide, SOC in the top 1 meter of soil comprises about 3/4 of the earth's terrestrial carbon; nevertheless, there is tremendous potential to sequester additional carbon in soil. Soil stores three times more carbon than living vegetation. Carbon residence time i.e maintenance of stored carbon over an extended period is a key factor affecting sequestration potential in different soils (*Luo et al*., 2003). Even with constant input, conditions or manipulations that increase residence time can effectively sequester C. Thus, strategies to increase both input rates and residence time lead to enhanced sequestration. Under more biologically favorable environmental conditions, biochemical alteration and physicochemical protection are the primary mechanisms controlling SOC residence time (*Jastrow et al*., 2007; Luo, 2003; Kasahun Kitila Hunde, 2015b).

3. SOIL CARBON CYCLE

Lehman *et al.,* (2008) noted that soil C cycling has an important role in the global C cycle because soil organic carbon (SOC) stocks are almost four times greater than C in the atmosphere, and annual emissions of CO2 from soil are one order of magnitude greater than all anthropogenic CO2 emissions. Therefore, small uncertainties in soil processes may have large effects on climate-change predictions for those general circulation models that incorporate terrestrial biogeochemical cycles.

Figure 1. shows that soil C inputs can be from crop residues, cover crops, litter and soil amendment such as compost and manure. The amount of input is under the control of photosynthesis and residence time in soil is determined by the rate of SOM decomposition. SOM decomposition is largely determined by litter quality, specific climatic and soil conditions, soil disturbance and soil microbial activity. The result is short term SOM which had a quick turn over rate. The loss of carbon can be a result of erosion processes and respiration by soil microorganisms. The remaining un-degraded material as humus remained as long term SOM, while some soluble organic C can leach through the soil into aquatic systems. Respired CO2 can be recaptured during the next photosynthetic processes.

4. BASIC MECHANISMS BEHIND INCREASING CARBON RESIDENCE TIME

Residence time of carbon in soil could be increased by adopting such methodology or techniques which would prevent the biochemical alteration of Soil Organic Carbon (SOC) and the Black Carbon of the soil by microbial attack or exposure of these to atmosphere. SOC, also called as Humus is a dynamic cluster of chemically altered and unaltered organic compound, more resistant to decomposition and held together by hydrophobic interaction and hydrogen bonding (Piccolo, 2002; Sutton and Sposito, 2005) while Black carbon is a recalcitrant aromatic compound ranges from partially charred plant material to char & charcoal to graphite & soot particles, formed by periodic in situ burning or by atmospheric deposition from natural fires & industrial sources (Schmidt and Noack, 2000). Most black C forms are more recalcitrant than biogenic C in soil, and mean residence times can be hundreds to thousands of years (Glaser et al., 2002; Laird et al., 2008). The methodologies targeting to this task involves various processes that depends upon the type of soil, their climatic conditions, chemical composition, Characteristics etc. These processes are:-An array of molecular association with mineral surface, providing physical obstruction of the micro-organisms to the substrate of carbon compounds (SOC, black carbon etc.), Inhibiting decomposition action by soil structure control on gas exchange and moisture conditions.

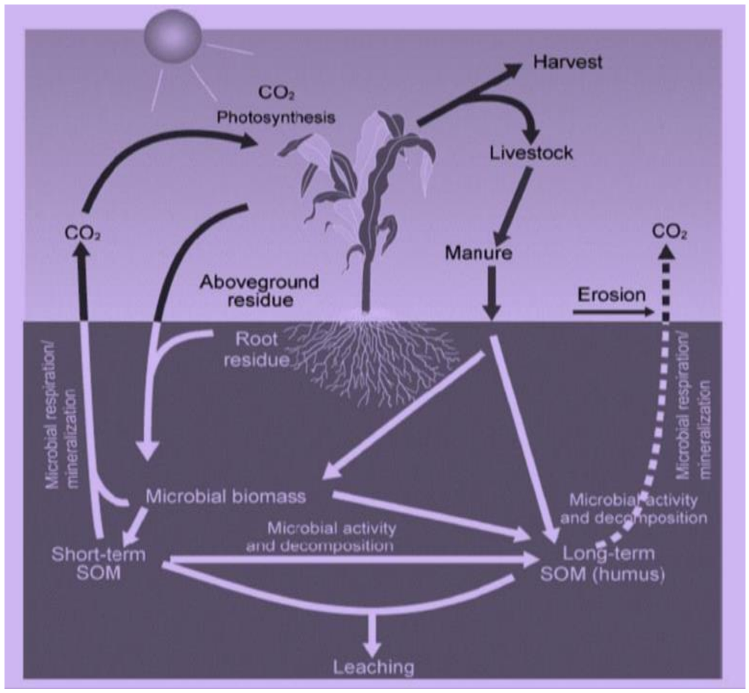

Figure 1
Soil carbon cycle (adapted from Robertson and Grandy, 2006

Physical protection of soil can be provided by creation, turnover and stabilization of soil aggregates (Six et al., 2004). Even greater increase in C residence time is achieved by locking of C in silt and clay sized aggregates which are mostly form within micro-aggregates (Balabane and Plante, 2004). Soil porosity which depends upon the aggregates structure and dynamics also control the attack of decomposers and their enzyme to the carbon substrate of soil Substrates inside pores with necks <0.2 μm are not accessible to microorganisms, and extracellular enzymes are excluded from nano scale pores (Zimmerman et al., 2004; Chenu and Plante, 2006). Interactions between water films and small pore necks can lead to anaerobic spaces within largely aerated aggregates and to localized limitations on decomposer activity (Young and Ritz, 2000).

5. PROMISING TECHNOLOGIES AND METHODOLOGY FOR SOIL CARBON SEQUESTRATION

This technology have target of both increasing the total concentration of Soil Organic Content (SOC) and other form of recalcitrant form of carbon in soil as well as reducing their exposure to microorganism and environment to increase their residence time in soil.

5.1. Enhancement of Soil Carbon Sequestration by Amendment with Fly Ash

The carbon sequestration Potential of degraded lands (e.g.,mine sites, Highway rights of way, eroded lands) could be enhanced by increasing their rate of humification by adding with Fly Ash of specially of sub-bituminous and lignite fly ashes (Amonette et al., 2003) and thus we could reclaim these land for useful purpose too by increasing the fertility of soil.

5.2. By Recommended Management Practices of Agriculture

Potential of soil carbon sequestration can be enhanced by using recommended management practices which are:-

- Reduction or elimination of mechanical tillage and adoption of no-till (NT) or minimum till;
- Use of crop residues or synthetic materials as surface mulch in conjunction with incorporation of cover crops into the rotation cycle;
- Adoption of conservation-effective measures to minimize soil and water losses by surface runoff and accelerated erosion bioengineering;
- Enhancement of soil fertility through integrated nutrient management (INM) that combines practices for improving organic matter management (in situ), enhancing soil biological processes involving biological nitrogen fixation (BNF), and mycorrhizae, and additions of organic wastes (biosolids, slurry) and synthetic fertilizers;
- Conservation of water in the root zone to increase the green water component by reducing losses through runoff (blue water) and evaporation (grey water), and increasing use efficiency through application of drip irrigation/fertigation techniques;
- Improvement of grazing systems that enhance the diet of livestock and reduce their enteric emissions; and
- Better use of complex farming systems including mixed crop-livestock and agro forestry techniques that efficiently use resources, enhance biodiversity and mimic the natural ecosystems.

5.3. Through Adopting Biotechnology

Additional Carbon could be sequestered if genome-enabled modification of root turnover times could be achieved. Application of modern system biology approaches and other advanced methodologies to improve fundamental understanding of soil microbial communities and their habitats is another approach that could further enhance the potential for soil sequestration. Such information could lead to new management practices and production of organic matter materials that optimize microbial activities for the transformation of residues specifically to enhance sequestration.

5.4. Biomass Carbonization

Converting harvestable biomass to more recalcitrant C rather than completely combusting it offers a new approach to terrestrial sequestration as a potential side benefit of bio energy production. With low-temperature pyrolysis, biomass is carbonized by heating under low-oxygen conditions while producing liquid and gaseous biofuels. Since combustion would not be complete, char-like substances would also be produced. The nature and yield of the solid product obtained depends on the feedstock and temperatures and pressures employed (*Antal and Gronli*, 2003; *Röthlein*, 2006) and ranges from a lignitic material produced under hydrothermal conditions to a series of chars whose porosity increases with temperature from 250° to 800°C. The carbonized biomass could then be incorporated in soil to protect it from further oxidation where, depending on the nature of the product, it may also improve nutrient- and moisture-holding properties while decomposing at a much slower rate than unconverted biomass (*Lehmann*, 2007a, 2007b).

5.5. Deep-Soil Sequestration

One third of the 2300 Gt C stored in soils is located at depths greater than 1 m (*Batjes*, 1996), where because of low oxygen levels and strong stabilization on mineral surfaces, C half-lives are measured in millennia (*Trumbore*, 1997). The lower horizons of widespread, mature soils, such as Alfisols, Ultisols, and Oxisols, have a tremendous capacity to absorb organic C because of their vertical extent, acidic pH, and abundant clay and iron oxide contents (*Jardine et al*., 1989; *Benke et al*., 1999; *Kong et al*., 2005). Results from sorption experiments (*Jardine et al*., 2006] suggest that the maximum for increasing this sequestration reservoir is 165 pg C for each meter of soil depth. Common fertilization methods in agriculture and silviculture may, in fact, already be enhancing the downward vertical spread of organic carbon through the soil profile with the benefit of long-term carbon protection. The application of nutrient sources is typically performed to enhance growth and biomass of crops and trees (*Allen et al*., 1990).

6. CONCLUSIONS

The idea of using intentional sequestration of carbon in soil through land management to mitigate rising atmospheric CO2 concentration is relatively recent. Not much is known at this point about the ease of accomplishing significant mitigation and the amount of CO2 that might be mitigated. The technological capability for increasing carbon sequestration is at hand, many co-benefits seem likely, the potential magnitude of the results appears promising, and initial cost estimates appear to be low. As a result, there is a rising demand to know precisely how much carbon may be sequestered in soil, how quickly this sequestration can take place, and what other environmental and economic impacts will occur as a result. There are, however, many considerations beyond the technological capability and potential benefits that will determine the rate and cumulative magnitude of soil carbon sequestration. Researchers understanding of the biological, edaphic, and physical environmental conditions that influence the potential amount and permanence of soil carbon is growing rapidly. This knowledge is being incorporated into mathematical models of soil carbon dynamics that allow the extrapolation of information across many conditions and provide a basis for predictions of future soil carbon sequestration. The net greenhouse gas emissions of different soil carbon sequestration methods, the costs of delivering offsets to buyers, and the ancillary environmental issues must also be evaluated. Finally, the acceptance of sequestration methods by land managers and the public will be a significant factor in determining the rate of soil carbon sequestration. The willingness of public and private buyers to use soil carbon sequestration methods to achieve net greenhouse gas reduction in the atmosphere will depend on the costs and economic benefits, which include unpriced environmental benefits. The main thrust areas in this field are:-

1. To identify site-specific technologies that creates a positive soil carbon budget.
2. Adequate understanding of biogeochemical, microbial and plant processes responsible for ecosystem storage, particularly as they influence storage in soils.
3. Needs research in context of Indian Agricultural fields in different climatic conditions especially on the degraded land or waste land for e.g. land near mining area which has huge carbon sequestration potential and needs reclamation too.

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