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Soil Carbon Sequestration in a Challenging Environment

Gayatri Sahu and Suchismita Mohapatra
Assistant Professor, Department of Soil Science & Agricultural Chemistry, Institute of Agricultural Sciences, Siksha 'O' Anusandhan, Bhubaneswar, Odisha

SUMMARY

Recently, the contributions of the soil in various ecosystems have become more prominent with the recognition of its role as a carbon sink and the potential of that in reducing the concentration of carbon dioxide (CO2), which is a vital greenhouse gas, from the atmosphere. Conversely, the soil capacity to increase the concentration of CO2 in the atmosphere through mineralization of organic matter is also a source of concern. Globally, the soil contains a large carbon pool estimated at approximately 1500Gt of organic carbon in the first one meter of the soil profile. This is much higher than the 560 Gt of carbon (C) found in the biotic pool and twice more than atmospheric CO2. By holding this huge carbon stock, the soil is preventing carbon dioxide build up in the atmosphere which will confound the problem of climate change. There are a lot of strategies used in sequestering carbon in different soils, however, many challenges are being encountered in making them cost effective and widely acceptable.

INTRODUCTION

The role of soil the ecosystem is increasingly being recognized with the realization that it has the capacity of reducing the concentration of carbon dioxide (CO_2) in the atmosphere (through sequestration of organic carbon in the soil) and also by releasing this CO_2 back into the atmosphere (through mineralization of soil organic matter). It has been reported that mineralization of only 10% of the soil organic carbon pool globally can be equivalent to about 30 years of anthropogenic emissions (Kirschbaum, 2000). This underscores the need to preventing carbon loss (emission) from the soil resource. Globally, the soil contains a large carbon pool estimated at approximately 1500 Gt of organic carbon in the first 1 m of the soil profile. By holding this huge carbon stock, the soil is preventing carbon dioxide build up in the atmosphere which will compound the problem of climate change. Despite the huge carbon deposit in soil ecosystem globally, research efforts in sequestration has been primarily focused on geological and vegetation carbon capture and storage while giving less attention on the role of soil as a viable carbon sink (Kane, 2015).

Basic Concepts of Carbon Sequestration

Atmospheric enrichment of GHGs can be moderated by either reducing anthropogenic emissions, or sequestering C in plant biomass or the soil. Transfer of atmospheric CO_2 into other pools with a longer mean residue time, in such a manner that it is not re-emitted into the atmosphere in the near future, is called sequestration. Depending on the processes and technological innovations, there are three main types of C sequestration: (i) those based on the natural process of photosynthesis and conversion of atmospheric CO_2 into biomass, soil organic matter or humus and other components of the terrestrial biosphere; (ii) those involving engineering techniques; and (iii) those involving chemical transformations (Lal, 2008). The rate of enrichment of atmospheric CO_2 concentration can be reduced and moderated by its transfer to other pools by mitigative and adaptive options.

Mitigative strategies involve those options that either reduce emissions or sequester C. Sequestration of CO_2 by plants occurs both in terrestrial and inland aquatic ecosystems. CO_2 sequestration in terrestrial ecosystems is significant in protected areas and in extensively and intensively managed land-use systems, but to different degrees depending on vegetation, soil types and conditions. Restoration of degraded lands, and drastically disturbed ecosystems (i.e. mined lands) comprise an important sink for atmospheric CO_2. Important strategies for aquatic ecosystems are the management and restoration of wetlands (peat soils and their permanent vegetation).

Mechanisms of Carbon Capture and Sequestration

Soil carbon is originally derived from the CO_2 assimilated by plants through photosynthesis and converted to simple sugars and eventually returned to the soil as soil organic matter. Photosynthesis is the process where plants produces organic compounds such as carbohydrate by using solar energy to convert CO_2 and water into organic compounds such as carbohydrates. These organic compounds are then used in making the plants structural components (also known as biomass) and generating the energy needed for metabolic activities. The maximum amount of carbon that can be produced, otherwise known as gross primary productivity (GPP), depends on the plant's ability to produce these compounds through photosynthesis.

The biomass produced through photosynthesis is utilized by the plants themselves in generating the energy needed for metabolic activities in a process called respiration. The difference between the GPP and respiration is called the net primary productivity (NPP). NPP is generally believed to be 45% of the GPP (Gifford, 2003). NPP is determined by the potion of solar radiation captured by the plants and used for the photosynthesis (also known as photosynthetically active radiation (PAR), the leaf area index, the light use efficiency (the ratio of primary productivity to absorbed PAR) of the vegetation and autotrophic respiration (Sanderman *et al.,* 2010). The higher the NPP the more carbon is transferred to stable pools in the soils (Sitch *et al*., 2008).

Challenges of Carbon Sequestration in Soils

Although there are a lot of opportunities in leveraging carbon stock and sequestration potential in the soil of different ecosystems, there are numerous challenges making this difficult in reality. Some of these challenges include:

a. Measurement and Verification

The stock of carbon in soils is difficult, time-consuming and expensive to measure. It is even more difficult to account for little gains or losses in soil carbon at various scales due to methodological difficulties such as monitoring, verification, sampling and depth (Trumbore and Torn, 2003). Even if these small changes (gains or losses) are detected, it is not easy to link such changes to management or land use practice in a given context. The capacity of the soil to sequester and retain carbon is also finite as it reaches a steady state after sometime.

b. Carbon Pools

Sequestered carbon exists in the soil in different pools with varying degree of residence time in the ecosystem. These pools include: i) Passive, recalcitrant or refractory pool: organic carbon held in this pool has a very long residence time ranging from decades to thousands of years. ii) Active, labile or fast pool: carbon held in this pool stays in the soil for much shorter period due to fast decomposition. The residence time normally ranges from 1 day to a year. iii) Slow, stable or humus pool: carbon held in this pool has long turnover time due to slow rate of decomposition. The residence time typically ranges from 1 year to a decade.

c. Permanence

Another challenge of carbon sequestration in soil is non-permanence of the sequestered carbon as it can be released back to the atmosphere as easily as it is gained as a result of decomposition or mineralization. It is for this reason that sequestered carbon is considered a short-term option for removing carbon from the atmosphere. The rate of carbon loss depends on several climatic, land use and management factors.

d. Separation

It is very difficult to isolate and differentiate the portion of carbon sequestered in the soil as result of management activities or land use and that which occurred naturally. The principle of separation requires that the carbon sequestered or GHGs emission prevented as a result of management intervention be distinguished from that which would have occurred due to natural causes. Methods are therefore needed that can differentiate naturally sequestered carbon from that captured due to human management (Swift, 2001).

CONCLUSION

There has been increasing interest on carbon capture and storage in the soils of different ecosystems as a climate mitigation measure. However, enhancing the carbon stock of soils also have ancillary benefits such as improving soil health and productivity, water retention, fertility enhancement among others. Some of these include difficulties in measurement of soil carbon stock, permanence, carbon pools with different carbon residence times, separation, the tendency of the soil to reach saturation level when the maximum attainable carbon that could be captured is reached. Advances have been made in tackling most of these challenges, however, deliberate actions to enhance carbon capture and sequestration in the soil ecosystem is yet to get wide acceptance by practitioners and policy makers alike. This chapter is written in an attempt to create more awareness on the potential of soils in capturing and storing atmospheric CO2 in long lived pools thereby mitigating climate change in the process.

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