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Management of Soil Organic Carbon through Agricultural Practices

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Abstract

Soil organic carbon (SOC) is the most important indicator of soil quality and agricultural sustainability. It an important constituent describing soil fertility/soil health and contributes to macro and micronutrients turnover. In arid and semi-arid region, there is a rapid decline of soil organic carbon levels with continuous cultivation and less or negligible use of organic manure. Decline of organic carbon stock in the soil affects soil fertility status and climate change regulation capacity. Accordingly, decreasing level of SOC in soil creates widening of nutrient deficiency specially N across the worldwide and other nutrients. Negligible use of organic manures, green manure and extensive tillage usually expose surface soil to water loss; and favour the breakdown of SOC into carbon dioxide. Resultant decline in SOC encourages poor water holdings of soil, encourages nutrient leaching and global warming. All these changes are responsible for decline in the potential productivity of a soil. Soil productivity is closely linked to soil organic matter (SOM) and its primary component soil organic carbon (SOC). To maintain food production for a rapidly growing population, application of mineral fertilizers and the effective recycling of organic amendments such as crop residues and manures are essential especially in the smallholder farming systems that rely predominantly on organic residues to maintain soil fertility.

Keywords

Soil organic carbon; Soil quality; Climate change; Management.

Introduction

Soil organic carbon (SOC) is the primary constraint on agricultural production. It is the carbon that remains in the soil after partial decomposition of any material produced by living organisms. It is a key factor in land valuation schemes, soil fertility and quality evaluation, and climate change investigations. Carbon is found in soil as organic matter and carbonate minerals ($CaCO_3$). It is the main component of soil organic matter (SOM) and as such constitutes the fuel of any soil. Soils represent the largest terrestrial organic carbon reservoir.

Across the world, soil organic carbon is decreasing due to changes in land use such as the conversion of natural systems to food or bioenergy production systems. The losses of SOC adversely affect crop productivity and ecosystem services. Soil carbon dynamics play a vital role in sustaining soil quality, crop productivity and protecting the environment (Doran and Parkin 1994, Bauer and Black 1994, Robinson *et al*. 1996). The soil organic

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carbon (SOC) has many direct and indirect effects on soil quality. Increases SOC pool in soil improves soil structure and tilth, counter soil erosion, raise water holding capacity and plant nutrient stores, provide energy for soil macro and microbiota, purify water, denature pollutants, enhance soil biodiversity, improve the crop/crop residue ratio and mitigate the effects of climate (Lal 2007).

Depending on local climatic conditions, geology, land use and management and other environmental factors, soils hold different amounts of SOC. Total soil organic carbon can be storage by adoption suitable soil management practices, including conservation tillage and annual cropping practices (Franzluebbers *et al*. 1995, Halvorson *et al*. 2002). It can also be increased by retention crop residue near the surface of the soil and adoption of crop rotation; and conservation tillage (especially no-till) procedures (Lal *et al*. 1998, Allmaras *et al*. 2000, Reicosky and Allmaras 2003). The adoption of minimum tillage practices and the growing of high biomass crops having potential for contributing to C biomass are prerequisites for SOC accumulation (Sisti *et al*. 2004). Soil organic carbon in soil may depend on quality and quantity of crop residues, type of crop, crop rotation, tillage operation etc. (Wright and Hons, 2005).

Arresting the decline of soil organic carbon by use of organic sources is the most potent weapon in fighting unabated soil degradation. Organic matter helps in improving soil quality to sustain biological productivity, maintain environmental quality and promote plant and animal health (Parewa *et al*., 2015). Increasing soil organic matter content can both improve soil fertility and reduce the impact of drought, improving adaptive capacity, making agriculture less vulnerable to climate change, while also sequestering carbon. Increase levels of soil carbon in farms, improves soil fertility, hence improves food security, increases economic returns from carbon revenues and creates business development opportunities for farmers to diversify income-generating activities. The aim of this chapter is to identify suitable agricultural practices that can be used for maximizing the benefits of soil organic carbon in soil, improve soil health and maintain agricultural productivity.

Why soil organic carbon is important

Soil organic carbon is one of the principal constituents of soil fertility and trigger for nutrient availability through mineralization. SOC is a main source of energy and nutrients for soil organisms. It is believed to play an essential role in increasing crop production and soil resilience to climate change. It releases nutrients for plant growth, promotes soil structure, physical, chemical and biological health of soil, and is a buffer against harmful substances. Humus play an important role in aggregate stability, nutrient and water holding capacity. General role of soil organic carbon in biosphere is depicted in figure 1. Organic carbon compounds, such as polysaccharides bind soil particles into aggregates. During the decomposition of organic residues and manures different kind of organic acids (oxalic acid) released in soil, which prevents phosphorus fixation in soil and improve its availability. For restoration

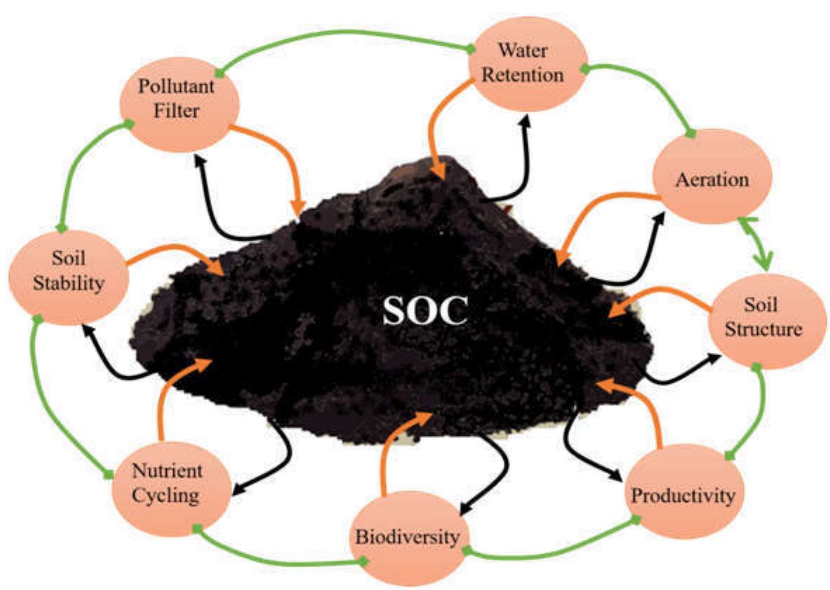

Fig. 1: Role of soil organic carbon in biosphere

of the soil health, soil organic carbon is important and hence it is a prerequisite for sustainable crop production and soil health.

Causes of declining soil organic carbon

Mismanagement of sources and resources is the root cause of ongoing decay in soil health since 1960s. Overexploitation due to transgressed carrying capacity, deforestation, shift to non-sustainable intensive farming practices like, heavy tillage, removal of crop residues, negligible use of organic manures elimination of legume catch and intercrops, inefficient handling of agrochemicals, water, energy and weakened technology transfer system have contributed to degradation in quality of soils and other natural resources. All these deteriorating SOC content. Unsustainable management practices such as excessive irrigation or leaving the soil bare endanger these soils, causing SOC loss and massive erosion. The burning of crop residues or stubble in open fields also results in the loss of soil organic carbon to the atmosphere as CO_2 and many nutrients (Gupta and Sahai 2005, Heard and Hay 2006, Singh *et al*., 2008, Kumar *et al*., 2015).

Climatic conditions, such as rainfall, temperature, moisture and soil aeration affect the decomposition rate of organic matter. Organic matter decays more rapidly at higher temperatures, so soils in warmer climates tend to contain less organic matter than those in cooler climates. Negligible use of organic manures, adoption of cereal - cereal cropping system and knocking out the intervening catch crop are other elements decreasing SOC and deteriorating soil health (Antil *et al*. 2011). Similarly, removal of huge amounts of above ground biomass and poor grazing management practices are important human-controlled factors that influence grassland production and have led to the depletion of soil carbon stocks (Conant and Paustian, 2002; Ojima *et al*. 1993).

Table 1: Management practices that can increase soil organic carbon levels in agricultural soils

Management category	Impact	References
Crop residue management	Proper crop residue management add soil organic carbon in soil which improves soil aggregates and physical, chemical and biological properties of soil. It also partially substitute the fertilizer requirement and increased the crop productivity	Arshad and Coen 1992, Magdoff and van Es 2000, Bahadur *et al.*, 2015
Crop selection and management	Perennial crops increases soil organic carbon by root and litter decomposition. Using annual crops having high residue can also help to reduce net carbon loss from cropping systems.	Becker *et al.* 1995 Talgare *et al*. 2012
Conservation tillage	Conservation tillage practices avoids rapid decomposition of soil organic matter and improves soil quality indices including soil organic carbon storage. Soil organic carbon can increase over time when reduced-till systems are adopted combined with residue management	Murungu *et al*. 2010, Musunda, 2010, Zibilske *et al*., 2002, Dick 1983, Yeboah *et al*., 2016
Biofertilizer	PGPR mitigate climate changes and sequester C through several ways. The PGPR and Azolla play an important role on nutrient cycles (C and N), availability of nutrients and enrichment of carbon and nitrogen in soil. They enhance glomalin (reservoirs of C and N) production in rhizosphere by increasing mycorrhizal colonization.	Dębska *et al*., 2016, Kaushik and Prasanna 1989, Bhuvaneshwari and Kumar 2013, Wang Zhi-Gang *et al*., 2016
Pasture management	Development of perennial pastures & their grazing management; and introduction of improved leguminous crops enhances soil organic carbon, nutrient availability and soil fertility	Conant *et al*. 2001
Organic amendments	Application of organic amendments such as organic manures or compost, biuochar in soil increases soil fertility through improves nutrient availability, soil aggregate stability, soil organic carbons and soil physical properties. This enhances the biological buffering capacity of the soil, resulting in greater yields and yield stability over time. It also provide additional nutrients supplements (calcium, copper, zinc, and potassium) to the microbes.	Huang *et al*. 2014, Mekki *et al*. 2017, Yadav *et al*., 2019
Cover crops	Cover crops increases nutrient cycling and soil carbon pools by providing additional below and above ground biomass. It minimise soil erosion.	Wander and Traina, 1996, Kuo *et al*., 1997, Dinga *et al*. 2006, Steenwerth and Belina, 2008
Revegetation	Revegetation and other perennial vegetation can increase SOC storage in soil and prevent soil from erosion	Li *et al*., 2016, Yang *et al*., 2015

Management practices that increase soil organic carbon

There is a large number of literature describing the beneficial effects of SOC on aspects of soil quality. Managing soil organic carbon (SOC) through improved management practices is one strategy to enhance soil ecosystem services. Various management options and farming practices can enhance SOC levels either by increasing inputs or decreasing losses, e.g. conservation tillage, crop management, stubble retention, pasture and grazing management (Table 1). Inputs can also be augmented by direct additions of organic materials, FYM, composts, manure, farm waste and other recycled organic materials. In general, SOC increases when inputs of plant residue carbon to the soil are greater than carbon losses through decomposition, erosion, and leaching (Huggins and Fuchs 1997, Paustian *et al*. 1997). Cover crops are normally grown during fallow periods of cropping systems, the addition of cover crops to a cropping system can increase total residue carbon inputs to soil and has the potential to increase SOC (Table 2).

Table 2: Cover crops increases soil organic matter or soil organic carbon in soil.

Cover crops	Depth of sample	Increase in SOM or SOC	Reference
Vetch and rye	0.13 m	31%	Beale *et al.* 1955
Hairy vetch	0.07 m	85%	Patrick *et al.* 1957
Rye	0.30 m	7%	Kuo *et al.* 1997
Rye	0.20 m	12%	Sainju *et al.* 2002
Rye & hairy vetch	0.30 m	9%	Villamil *et al.* 2006

Cover crops have the potential to increase soil organic C in agricultural soils (Karlen and Cambardell 1996, Lal *et al*. 1998, Jarecki and Lal 2003). The primary general strategies for improving soil organic carbon are as follows:

1. Adoption of improved irrigation techniques (e.g. regulated deficit irrigation) can reduce soil CO_2 emissions and enhance C sequestration in soils by decreasing microbial activity (Qureshi, 2014; Zornoza *et al*. 2016).
2. Growing perennial crops including intercrops or cover crops in the crop rotation can improve C inputs into the soil.
3. Maximizing the return of carbon, by minimizing crop residue removal or burning can boost soil carbon.
4. Strategies should be implemented to preserve SOC rather than to restore.
5. Soil organic carbon can be enhanced by growing crops having high biomass production capacity or by using deep rooted crops and by reducing the fallow period.
6. Conservation practices that prioritize the maintenance of crop residues, such as no-tillage, are considered one of the principal strategies for soil C accretion. Hence, conservation agriculture production systems have the potential to improve soil quality if appropriate cropping systems are developed (minimum soil disturbance, continuous ground cover and diversified crop rotations or mixtures). Many researchers reported that organic carbon enhanced by adoption of conservation agriculture production systems (Murungu *et al*. 2010, Musunda, 2010, Zibilske *et al.*, 2002, Yeboah *et al.*, 2016).
7. Adoption of crop rotation diversity increased soil organic carbon. Crop rotation, especially combined with conservation tillage, will lead to higher soil-carbon content in soil.
8. Application of bio-fertilizers is one of the management practices that can help to maintain or increase the organic matter (OM) content, sequester C through several ways and improve soil fertility. The soil micro-organisms are the agents of transformation of soil organic matter in the soil. (Dębska *et al.*, 2016, Wang Zhi-Gang *et al.*, 2016).
9. Add plentiful amounts of soil organic matter from crop residues as well as off field organic materials such as manures and composts. Use a variety of sources of organic materials because they have different effects on physical, chemical and biological properties of soil. Improved use of composts and amendments can help to maintain or build soil carbon.
10. Biochar is another option being considered to increase soil carbon. The conversion of vegetative biomass waste to biochar (biologically derived charcoal) is a source of carbon (C) that can be used to increase the level of soil organic carbon in agricultural soils (McHenry, 2011).
11. Another option to enhance SOC concentration and improve soil properties is to cover crops. Cover crops reduces off-site sediment transportation, leaching or runoff losses of nutrient and protect the soil from erosion. It can also be used strategically to boost organic matter and carbon input to the soil (Table 2). Cover crops can produce bulk organic matter

where it is need and through the action of the roots and root exudates can have a bigger impact on the soil than just the amount of organic matter produced.

12. Green manures are a gift from nature, being a suitable alternative to increase the organic matter content of the soil. Increases soil organic matter as a result of green manure improves soil physical properties by increasing the distribution and stability of soil aggregates and decreasing soil bulk density (MacRae and Mehuys, 1988).
13. Good grassland management and prevention of open grazing can possibly converse soil carbon losses and sequester considerable amounts of carbon in soils.

Conclusion

Soil organic carbon management is a primarily prerequisite under changing climate. A number agricultural management practices have been proving useful to increase soil organic carbon in soil over time and minimise the rate of its loss. It can be enhanced by adoption of followings: (1) decreasing carbon loss by least disturbance to soil from tillage, and eliminating residues burning and overgrazing (2) increasing carbon inputs by retaining stubble or crop residues and adding organic amendments, biofertilizers, changing cropland to mixed crop-pastures and agroforestry, and increasing crop rotation.

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