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REVIEW ARTICLE

Organic farming practices as a modulator of soil carbon- A review

[*1]D. Udhaya Nandhini, [2]E. Somasundaram, [3]S. Somasundaram and [4]K. Arulmozhiselvan
[1]Post Doctoral Fellow, Centre of Excellence in Sustaining Soil Health, ADAC & RI, Trichy
[2]Professor & Head, Department of Sustainable Organic Agriculture, TNAU, Coimbatore-3
[3]Associate Professor, Department of Agronomy, ADAC & RI, Trichy
[4]Project Director, Centre of Excellence in Sustaining Soil Health, ADAC & RI, Trichy
[*]Corresponding author email: udhaya.jeni@gmail.com
Contact number: +91- 94861 55964

ABSTRACT

Changes in the crop management practices have intensive impact on soil organic carbon. Soil organic carbon (SOC) content is an important index in determining and maintaining the important physical conditions, properties and functions of soil. Maintaining the soil organic carbon is the key factor for sustaining the soil health and crop productivity. Organic practices that maintain or enhance SOC affect soil quality and may favour the capacity of soils to sequester further organic carbon. Converting the natural agricultural systems have caused substantial depletion of SOC pools stored in soils across the globe, with an estimated loss of about 78 Pg C. However, management practices increases organic C inputs into soil systems, by increasing plant productivity and diversity, or through the application of external sources of organic C through amendments can increase SOC storage. Hence, this review is framed to outline the influence of organic farming practices in the dynamics of soil carbon.
Keywords*: Soil organic carbon, soil quality, depletion, management practices, crop productivity*

INTRODUCTION

The awareness of climate change and its consequences have claimed the sequestration of carbon (C) in soils [4]. Carbon dioxide is the most important concern with respect to climate change; hence, this can be removed from the atmosphere and stored as carbon in permanent sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis. Of which, soil, an important terrestrial pool of global C cycle has twice the capacity to store C compared to the atmosphere [15], holds around 1417-1500 Giga tones (Gt) of C in the first meter of soil and about 716 Gt in the top 30 cm [37]. This is 3.3 times more than the size of atmospheric pool (760 Gt) and 4.5 times more than biotic pool (560 Gt) [41]. Carbon sequestration potential is influenced by many factors such as climate and soil conditions [11], cropping systems [34], managements including tillage [56] and fertilization [7]. A relatively faster rate of decomposition is induced by the continuous warmth in tropical agro-ecosystems, as a result high equilibrium levels of organic matter are difficult to achieve. In these conditions, large annual rates of organic inputs are needed to maintain an adequate labile SOC pool in comparison to cooler climates where soils have more organic carbon because of slower mineralization rates.

SOIL CARBON AND IT POOLS

Soil organic carbon (SOC) is the carbon associated with soil organic matter (45–60%), is an important soil quality index as it is directly related to crop productivity [43] which plays pivotal roles in deciding and maintaining the overall soil functions [67].

Soil C is found as either inorganic (i.e. mineral) or organic materials (Fig. 1). Soil inorganic carbon consists of carbonates and bicarbonates of Ca^{+2}, Mg^{+2}, K^{+} and Na^{+} [44]. Soil organic carbon includes live plant roots, humus, charcoal and other recalcitrant residues of organic matter decomposition. It also includes the organisms that live in the soil that are collectively called the soil biota (e.g., fungi, bacteria, mites, earthworms, ants and centipedes). SOC is a heterogeneous mixture of organic materials including fresh litter, carbohydrates, and simple sugars, complex organic compounds, some inert materials, and pyrogenic compounds [42]. Total organic carbon can be further defined as fractions that vary in size and decomposability. The passive fraction is chemically stable and can take more than 2500 years to turnover, which is the largest pool and the least likely to be influenced by management practice.

The slow fraction, with a turnover rate of 20-40 years, composed of organic compounds that are either resistant to decomposition or physically protected. Management practices through soil manipulations may disrupt soil aggregates (e.g. tillage) which influences this pool, by exposing previously protected organic material to microbial decomposition. The active or labile fraction is readily utilised by micro-organisms and emanated from new residues and living organisms which last for about 2 – 3 years. Management practices can influence this pool at very large and significant differences can be measured. The capacity of a soil to supply nutrients is often defined by the proportion of total soil organic carbon that is labile.

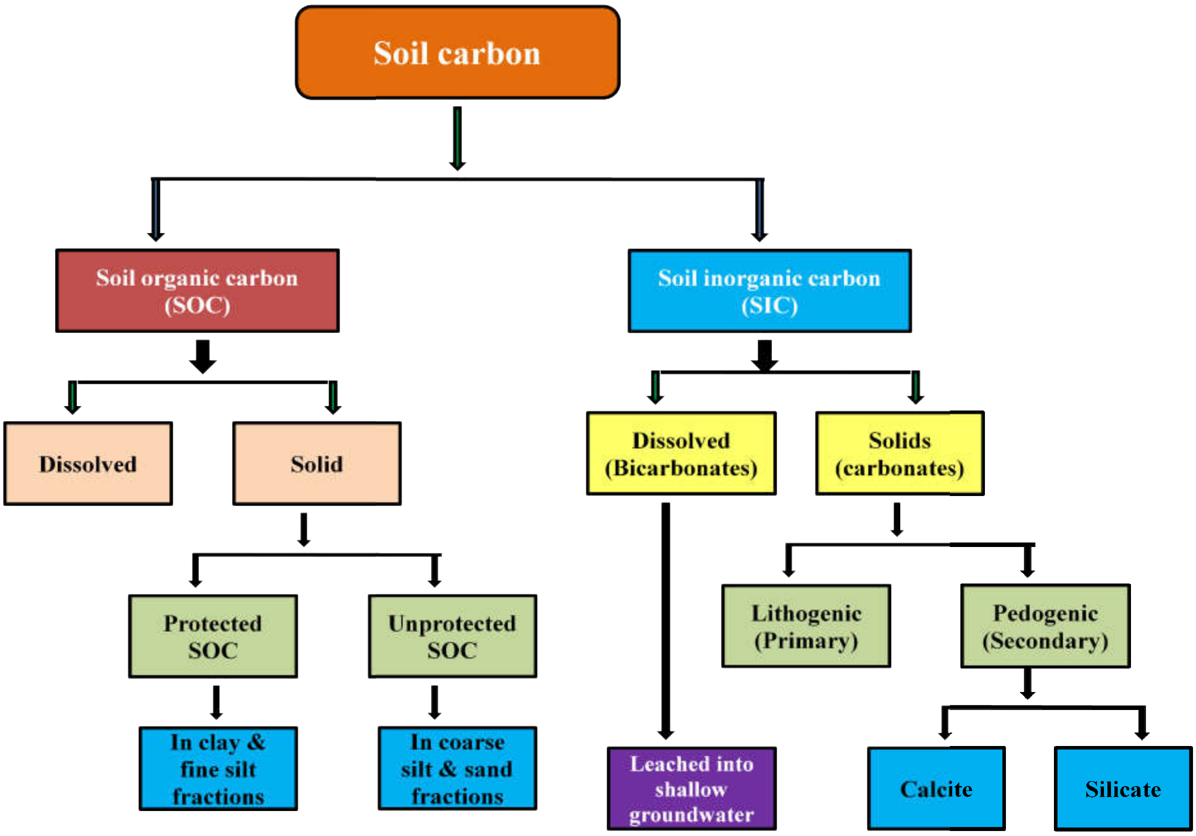

Figure 1. Types of organic and inorganic carbon pools in soil

SOIL CARBON DYNAMICS

Soil carbon dynamics play a crucial role in sustaining soil quality, promoting crop production and protecting the environment [19]. Worldwide stocks of SOC are under risk from multiple climate change drivers includes dramatic changes in land use, increase in GHG emissions and hastening of global warming [45, 46]. A recent study predicts that for 1^{o}C of warming, about 30 Gt of soil C will be released into the atmosphere for the temperature increment of 1^{o}C [12]. The current rate of SOC loss due to land use change (deforestation) and related land-use activities (tillage, biomass burning, residue removal, excessive fertilizers, erosion, and drainage of peatlands) is between 0.7 and 2.1 Gt C year^{-1}. Conversion of natural vegetation cause depletion of 60% and 75% of SOC stocks in soils of temperate and tropical regions, respectively [21, 22]. SOC levels result from the interactions between several ecosystem processes. Soil carbon results both from growth and death of plant roots and indirectly from the transfer of carbon-enriched compounds from roots to soil microbes [57]. Maintenance of soil organic carbon is essential for long-term sustainable agriculture, since declining levels generally lead to decreased crop productivity [2]. Organic farming derives its fertility from healthy, living soil with humus levels. Organic farming involves many practices that protect and build-up soil carbon levels, including ones that promote the overall carbon input into the soil, which increases the supply of mores resistant organic matter inputs that promotes soil aggregation and the retention of carbon in the soil. Basic principle of organic farming is "to feed the soil", which will feed the crop.

SOIL CARBON DYNAMICS UNDER ORGANIC FARMING

Soil organic carbon is the basis of sustainable agriculture. Soil health can be improved by increasing SOC and it can help to mitigate climate change. The actual amount of SOC that can be stored depends on management practices, type of soil, climatic conditions and in addition underlying initial soil carbon level of the site. There has been a concern that modern agricultural practices have prompted a decrease in soil quality and SOC in particular [60]. Organic farming practices are known to exert significant influence on soil organic carbon. The fourth Assessment Report of Inter-governmental Panel on Climate Change (IPCC) reported that 89 per cent of mitigation technologies will increase the soil carbon pools through crop land management, grazing land management, restoration of degraded lands, bio-energy and water management. The common organic farming practices leading to improve soil C sequestration *viz*., use of manures, compost, crop residues and biosolids, mulches, conversation tillage, agro-forestry, diverse cropping systems and cover crops [41]. All these organic practices have the potential to modify carbon storage capacity of agricultural soil [61, 30]. In general, management practices are aimed to enhance and/or to maintain soil C, but their effectiveness depends upon both the soil characteristics (i.e. soil quality) and the current SOC content. Udhaya Nandhini *et al*. [78] reported that organic farming practices like multi varietal seed technique and mulching with crop residues increased the carbon content in soil over a period of years.

Fallow period

From the findings of Feng and Li [23], it is clear that the rate of soil organic carbon decomposition during the fallow is approximately 2 to 2.5 times quicker than in the year of cultivation. Soil organic carbon (SOC) and soil nutrient (N, P, and K) concentrations significantly increased with increasing fallow duration up to 7 years. These increases have been attributed to the decay of above-ground and root biomass of fallow vegetation and the presence of native leguminous species among the vegetation [65]. In Andean highlands, crop rotations are often initiated with potato followed by 2 to 3 years of cereal crops, barley, oats and then an uncultivated fallow period that can last 1–15 years [17] or even 20 years [52]. These extended periods of natural fallow are expected to restore soil fertility mainly through the addition of organic matter due to the decomposition of both above- and below-ground plant biomass of native vegetation.

Conservation tillage

Conservation tillage is defined as any tillage or planting system, in which at least minimum of 30% of the soil surface covered with residues after planting, with the aim to reduce erosion by wind and water [13]. Therefore, conservation tillage is one of the practicable choices to magnify the soil organic matter for the sustainable production [22]. Reduced oxygen supply in the soil subsurface under no-till systems which affects rate of decomposition [81] and the distribution of microbes and its activity [18, 19] by which soil organic matter is retained in the soil and enhance SOC sequestration [82].

SOM is more protected in no-till farming due to higher aggregate stability [3] and larger proportion of carbon associated with micro-aggregates than in conventional tillage [31]. Microaggregates play a crucial role for the longterm stabilization of soil organic matter [76] whereas, macroaggregates (soil particles>250 μm) ensures minimal physical protection [38]. In general, soil aggregates are disrupted under conventional tillage in the various plough layers and thereby it decreases the soil organic carbon [64].

Conservation tillage improves the structure of soil and enhances pool of soil organic carbon [58]. Smith *et al*. [70] estimated that adoption of conservation tillage has the potential to sequester about 0.023 Pg carbon year^{-1} in the European Union. According to Franzluebbers [25] the impact of conservation tillage on SOC sequestration is greater in degraded soils than in fertile soils. Dao [14] states that no-tillage system increased soil organic carbon to the tune of 65, 17 and 7% over conventional tillage soil in the 0–5, 5–10, 10–20 cm depths, respectively in Texas after 11 years of experiment, [14]. West and Post [82] estimated that conservation tillage increased the amount of C sequestered by 0.57± 0.14 t C/ha/yr compared to conventional tillage. Nevertheless, soil organic carbon improvements not only rely on tillage practices, but also soil texture, climate, topography and other controlling factors of soc formation.

Organic manures

Industrial revolution led to intensive farming have caused decline in soil health and soil carbon [46]. Nevertheless, the use of organic amendments such as farm manure (FYM), green manure, composts and crop residues in farming systems proves to be useful in the refinement of soil quality and augmentation of SOC storage.

However, the soil carbon increase not only depend on organic manures apply and also determined by climate [77], amount of application [25], manures [29], soil texture [27], initial SOC stock, land use, and time of application.

Soil amended with recycled organic manures such as compost and biosolids, where organic C is in relatively stable forms, have proved more effective than fresh plant residues and animal / plant manure in increasing SOC storage [85]. Additions of organic sources of nutrients along with high inputs of NPK fertilizers to soil have reported an increase in SOC [5]. Swarup *et al*. [72] found out similar type of pertinence amidst SOC. Application of external organic manures such like FYM, vermicompost results in an enhancement of OC storage as well as improves other soil functions related to the presence of organic matter [54].

Further, Bharani *et al*. [6] demonstrated through a 6 years of study that loss or gain of SOC stocks for various organic amendments in rice based cropping systems of Coimbatore was related to initial SOC level, with potential for 33% increases in SOC when compared to control at the end of the cropping cycle Kundu *et al*. [40] also justified a similar increase in SOC stock. The use of organic amendments such as FYM, rice straw and green manure is known for improving soil productivity and can increase the amount of SOC [28]. Mandal *et* al. [50] have reported that application of FYM and green manure adds organic carbon in the soil. The increase in organic carbon content in the organic manures applied soil is attributed to the direct incorporation of organic matter followed by subsequent decomposition of these materials might have resulted in the enhanced organic carbon content of the soil [68].

Kukal *et al.* [38] observed a higher SOC sequestration in a rice-wheat system due to application of FYM and the cropping system had greater capacity to sequester carbon because of high carbon input through enhanced productivity.

Continuous addition of organic manures viz. vermicompost and FYM under organic management resulted in higher organic carbon, indicating soil as best carbon sink even in sub arid conditions also the labile carbon pool was 12.1% higher in organic management compared to inorganic management [20]. Similar increases in SOC content due to addition of FYM in irrigated system were also observed by Swarup and Yaduvanshi [72] and Yadav *et al*. [83] in India.

Sainju *et al.* [63] observed an increase of soil surface (0–20 cm) SOC stock of about 3.2 Mg C ha^{-1} after 10 years of poultry litter application in comparison to mineral fertilizer plots. In Nepal, after 25 annual cattle manure applications, surface (0–30 cm) SOC stocks were higher by about 19.1 Mg C ha^{-1} than control (unfertilized) plots [27]. In China, after 22 years of pig manure application, the surface soil layer (0–15 cm) accumulated 3.8 Mg C ha ha^{-1} more than mineral fertilizer alone [33].

Mulching

Application of crop residue as mulches enhances SOC stock. Effect of mulching on soil carbon depends on the type of organic mulch, climate and edaphic factors. Increasing the amount of SOC and SOM is regarded as the main advantage of organic mulch [66]. Mulch can increase carbon sequestration in agricultural soils up to 8–16 Mg ha^{-1} yr^{-1} and additionally, the soil's physical and chemical properties are also improved. Total SOM by using mulch increased from 1.26 to 1.50% [35]. Mulch also plays a key role in supplying nutrients, playing a role in the C and N cycle and the sink of C. It can significantly increase SOM and carbon storage in the topsoil layer of 0–5 cm. This variation in the CS is attributed to the mulch rates. As more is the mulch and time after applying mulch, more will be the CS rate. For example, there will be 41% more CS after 4 years of mulching and 52% more CS after 11 years of mulching [66]. Blanco-Canqui and Lal [8], mulching with straw during 10 years increased SOC by 33%.

Mulching with straw can enhance the carbon stock by adding c input from straw compared with no mulching [53]. Particulate organic carbon was increased from 7 to 13% [47] and labile C fractions [48] when straw mulching was done than no mulching

Residue management

Crop residue retention has been identified as an effective strategy to improve soil organic carbon [79]. The rate of residue decomposition is influenced by residue quality as defined by C/N ratio, lignin and polyphenol concentrations. Generally, plant residues with higher C/N ratios, such as cereal crop residues, decompose more slowly than residues with lower C/N ratios such as those derived from legumes [9].

Crop residues include stems, leaves, roots, chaff, and other plant parts that remain after the economic parts are harvested or grazed [24]. Globally, 84% of residues are produced by seven major crops: wheat, rice (*Oryza sativa* L.), corn, sugar cane (*Saccharum officinarum* L.), barley, cassava (*Manihot esculenta* L. Crantz), and soybeans [43].

The aboveground components of crop residues include shoot, leaves, cobs, husk, etc. The main aim of residue retention in field is to obtain better soil structure, improved water holding capacity and less risk of erosion. Residue as surface mulch provides a pleasant environment for soil biodiversity that significantly improves SOC [75].

Cover crops

Cover crop is defined as a "crop that provides soil protection, seedling protection, and soil improvement between periods of normal crop production or between trees in orchards". Growing of leguminous cover crops enhances the quality of residue input, soil biodiversity and SOC pool [69]. Hu *et al*. [32] reported that cover crop incorporation increased labile SOC pool and coarse organic debris by two- to threefold, whereas the total SOC pool increased by 20%. Inclusion of green manures in the cropping season increased 15% in the soil carbon level after 21 years compared to conventional system (only 8.6 % increase) at USA, Rodale trial. Soil organic carbon was increased 120 - 130 kg N ha^{-1} yr^{-1} at 0 - 30 cm depth by using cover crops, whereas in no cover crop treatment the SOC content have not had changes [62, 63]. In the 54 years study, when cover crops used in rotation, annual SOC changes was at the rate of 0.32 ± 0.08 Mg ha^{-1} yr^{-1} [59].

Crop rotation

Crop rotation is the practice of growing a sequence of different crop species on the same land [84]. The SOC sequestration depends on quantity of residues returned to the soil through crop rotation. In a recent meta-analysis, researchers found that more diverse crop rotations consistently have higher soil carbon and soil microbial biomass than less diverse systems, especially when cover crops were included in the rotation [51]. Diversity in crop rotation enhances the soil carbon stock through increased root carbon input, soil microbes and aggregate stability [74]. Crops with deep root system encourages better soil carbon storage as they retain 2.3 times more carbon input through roots than aboveground biomass. [36].

Agroforestry

Agroforestry refers to the practice of purposeful growing of trees and crops and/or animals, in interacting combinations, for a variety of benefits and services such as increasing crop yields, reducing food insecurity, enhancing environmental services, and resilience of agroecosystems [1]. Besides C fixation in tree biomass, agroforestry systems efficiently accumulate C both in topsoils and subsoils in several ways. Quantitatively, the C inputs from trees, shrubs, and under storey vegetation in the form of litter fall, roots and rhizodeposition make the most important contributions to increases in SOC stocks, mostly within woody components. Moreover, SOC stocks can be increased in adjacent agricultural land by agroforestry-induced yield increases associated with higher C inputs [49]. Carbon sequestering potential of any agroforestry system depends on type, tree & crop species, climate conditions, soil conditions and management practices.

Singh *et al*. [68] reported a 33%–83% increase in SOC to depths of 45 cm relative to controls under *Populus* and *Eucalyptus* canopies intercropped with grasses and which was attributed to differences in leaf litter inputs.

Rate of soil carbon sequestration in the tropics and subtropics, ranges 0.1 and 4.2 Mg ha^{-1} per year [55] where as in temperate agroforestry systems, it is in the range of 0.1-6.4 Mg ha^{-1} per year [10].

Integrated farming system

Crop-livestock farming systems integrate fodder, livestock and crop production activities on the same farm, where the resources such as crop/pasture residues (feed base), animal manure (nutrient input), power and cash are exchanged to gain benefits from the resulting crop-livestock interactions [73]. The integration of a crop-livestock system in agricultural areas in Brazil, formerly cultivated under no-till crop succession, acted as a sink of C with accumulation rates ranging from 0.8 to 2.6 Mg ha^{-1} year, depending on the crops introduced, the edapho-climatic conditions, and the time periods (over 1-8 years) of the crop-livestock integration [16].

CONCLUSION

Organic and traditional farm management practices have been proving useful to increase SOC storage over time and slow down the rate of SOC loss. However, the effectiveness of the above practices is highly variable and the actual amount of SOC sequestration seems to be dependent on factors such as soil type, climate, topography and the initial C level in soils. Hence, research is required to identify an improved crop management practices and technologies that enhance SOC storage.

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