

Effects of Tillage, Residue and Nutrient Management on Soil Organic Carbon Dynamics and its Fractions, Soil Aggregate Stability and Soil Carbon Sequestration: A Review

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Abstract

Crop and soil management practices such as tillage, residue or nutrient management, could alter soil organic carbon (SOC) and its sequestration. However, their effects on SOC dynamics and its sequestration have shown inconsistent results in different soil/climate/cropping systems. There are several studies to assess the effects of different tillage (conventional and conservation) methods combined with straw or residue return on SOC, its sequestration and the SOC fractions in various crops and cropping systems. This review synthesizes the much-needed state of knowledge of different conventional and conservation tillage practices and crop residue retention, and their interactions and effects on soil aggregate stability, total and labile organic carbon, microbial biomass carbon, particulate organic matter, SOC dynamics and sequestration and productivity of important crops and cropping systems across several climates and locations. SOC can be best preserved by crop rotations with conservation tillage practices such as no or reduced tillage, and with additions of residues, chemical fertilizers and manure. More research on the influence of alternative tillage, crop residue, and nutrient management systems on SOC and its sequestration, and development of SOC monitoring system through carefully-designed long-term experiments combined with simulation modelling approaches will advance our understanding of the SOC dynamics and sequestration in major crops and cropping systems across representative climates and locations which will help improve agricultural system sustainability and global food security.

Keywords: Soil Organic Carbon; Aggregate Stability; Soil Microbial Biomass; System Productivity; Soil Carbon Sequestration; Tillage and Residue Management Practices; Cropping Systems

Introduction

Soil organic matter/carbon (SOM/SOC) has profound effects on soil physical, chemical and biological properties [1]. Maintenance of SOM/SOC in cropland is important, not only for improvement of agricultural productivity but also for reduction in C emission [2]. However, short- and medium-term changes of SOC are difficult to detect because of its high temporal and spatial variability [3]. On the contrary, soil labile organic C (LOC) fractions i.e. microbial biomass C (MBC), dissolved organic C (DOC), and easily oxidizable C (EOC) that turn over quickly can respond to soil management intervention more rapidly than total organic carbon (TOC) [1,159]. Therefore, LOC fractions have been considered as early sensitive indicators of the effects of land use change on soil quality and soil health [4,5,159]. Agricultural practices such as tillage methods are conventionally used for loosening soils to grow crops. At the same time, long-term soil disturbance by tillage is believed to be one of the major factors reducing SOC in agriculture [6]. Nevertheless, SOC pool plays a significant role in the global carbon cycle and is a key determinant of the physical, chemical and biological properties and is required for the proper functioning of the soil system.

Soil aggregation (macro- and micro-) and stability can have a large effect on SOC dynamics and sequestration, and C availability. Soil macro-aggregates affect C storage by occluding organic residues, making them less accessible to degrading organisms and their enzymes [8]. The SOC protection by soil aggregates has been extensively studied [9]. Christensen BT [10], considered the structural control of soil aggregates as the accessibility of decomposers for the SOC, diffusion of oxygen, degradation of products, transport of moisture, etc. Beare MH., *et al.* [11] showed that macro-aggregates (> 0.25 mm) in non-tilled soils provide an important mechanism for the SOC protection. Six J., *et al.* [12] asserted that SOC protection is greater within free micro-aggregates (< 0.25 mm) than within macro-aggregates. The fractionations of water-stable aggregates and density may thus be helpful for an improved understanding of C dynamics affected by soil management, since aggregate and density fractions are more sensitive to changes in soil management than TOC. Table 1 shows commonly used terms in SOC and soil aggregate and stability studies.

Soil properties, such as clay content, are hypothesized to control decomposition of SOC. However, the hypothesis regarding soil property-C decomposition relationship has not been explicitly tested in large spatial scales [13]. A data assimilation approach has been used to evaluate the roles of soil properties and environmental factors in regulating decomposition of SOC. In that approach, multifactor regression and structural equation modeling (SEM) analyses showed that clay content is the most important variable in regulating SOC decomposition. In contrast to the active and slow C pools, soil properties had little effect on the decomposition of the passive C pool.

Frequent tillage usually destroys SOM and speed up the movement of SOM to deeper soil layers [14]. Therefore, agricultural practices such as reduced tillage (RT) that reduce soil disturbance are essential to improve soil quality and health and agricultural sustainability. Likewise, retention or incorporation of crop residues can also play an important role in increasing SOC sequestration, increasing crop yield, improving SOM/SOC, and reducing the greenhouse gases [15-17,160]. As an important agricultural practice, straw return to soil is often implemented with tillage in the production process. Although numerous studies have indicated that RT methods combined with straw return had a significant effect on labile SOC fractions, the results varied under different soil/climate conditions. The distribution of the TOC stock between soil and vegetation may also vary with latitude. In the temperate forests of northern latitude, around 72% of the TOC is found in the soil, with the remainder (~28%) in the plant biomass. In the tropical forests, however, the distribution is reversed, with around 38% of the organic C stored in the soil and around 62% in the vegetation. This difference can be explained by slower decomposition rates in the cold temperate climate than in the tropics. For example, both no tillage (NT) and shallow tillage with residue cover resulted in significantly higher SOC than conventional tillage (CT) without residue cover in the temperate Loess Plateau of China [18], while [19] reported that the difference between plowing with straw return and NT with straw return treatments was not significant on TOC in the sub-tropical Central China. Likewise [2], showed that in the sub-tropical Chitwan Valley of Nepal, NT with crop residue application at upper soil depth had distinctly higher SOC sequestration than CT with crop residue.

The effects of tillage on soil LOC can vary with regional climate, soil condition, residue management practice, and crop rotation [20,21,160]. Therefore, the investigation on soil LOC for specific soil, climate, and cropping system is necessary to improve the soil quality, soil health and soil productivity. However, it becomes clear that experimental approach alone will not provide enough information on the SOC components and SOC sequestration. Appropriate simulation models will be necessary to predict SOC dynamics, including soil microbial biomass, and SOC sequestration in response to varying pedoclimate and agriculture systems so as to adapt to relevant management practices. Thus, the objective of this review was to improve our understanding on the effects of tillage, residue and nutrient management practices on SOC fractions, soil aggregate distribution and stability, SOC sequestration, and productivity of important crops and cropping systems across important climates and locations. This review focuses on the effects of soil and crop management practices on LOC, which is an important fraction of SOC, soil aggregate stability, particulate organic matter, and microbial biomass carbon.

Total organic carbon (TOC): TOC is a measure of all carbonaceous material that is derived from living organisms. TOC may also refer to the amount of organic carbon in soil (SOC), or in a geological formation, particularly the source rock for a petroleum play; 2% is a rough minimum. For marine surface sediments, average TOC content is 0.5% in the deep ocean and 2% along the eastern margins. The percent OM is determined by the mass of oven dried soil lost on combustion in a 500°C furnace or by any other method [22].

Active or labile organic carbon (LOC): It is also called activated charcoal, a form of C processed to have small, low-volume pores that increase the surface area available for adsorption or chemical reactions. Activate C has an incredibly large surface area per unit volume, and a network of submicroscopic pores where adsorption takes place. Activate C is a material that is produced from carbonaceous source materials, such as coal, coconuts, nutshells, peat, wood, and lignite. The primary raw material used for active C is any organic material with a high carbon content [23]. The C-based material is converted to activate C through physical modification and thermal decomposition in a furnace, under a controlled atmosphere and temperature. The finished product has a large surface area per unit volume and a network of submicroscopic pores where adsorption takes place. LOC is a measure of the small portion of the organic matter that can serve as an easily available food source for soil microbes, thus helping fuel and maintain a healthy soil food web. LOC declines faster but is also restored faster than non-labile C or total C. LOC is a more sensitive indicator of the C dynamics of the system. LOC sources serve as nutrient source for microbes and plants.

Soil nitrogen: It is a measure of the fraction of the SOM which contains much of the organically bound N. Microbial activity can mineralize this N and make it available for plant uptake. This is measured by extraction with a citrate buffer under high temperature and pressure [24].

Non-labile carbon: It is the difference between TOC and LOC.

Particulate organic matter (POM): SOM particles less than 2 mm and greater than 0.053 mm in size constitute the POM. POM is biologically and chemically active and is part of the labile (constituted by partially decomposed plant material, fungal hyphae, spores, and pollen grains and is easily decomposable) pool of SOM. It is measured by quantifying 20 mm KMnO_4 oxidation with a spectrophotometer. This fraction has a fast recycling rate and is associated with soil microbial activity and soil particle aggregation and aggregate stability. Thus, POM is very sensitive to the changes in soil use and management and, therefore, its variation throughout time is more indicative of the effect of management practices than TOC [25]. Likewise, its content can indicate the size of the easily mineralizable organic content and thus contribute to estimate potential nutrient (e.g. N) supply by soil.

Microbial biomass carbon (MBC): Microbial biomass carbon is an early indicator of changes in TOC. MBC responds quickly to the management changes, and is usually 'starved' because soil is too dry or does not have enough organic C [26]. The amount of LOC is of particular importance as this provides a readily available carbon energy source for microbial decomposition. Soils with more labile C tend to have a higher microbial biomass. Important sources of organic carbon as food for the microbial biomass are crop residues and soluble compounds released into the soil by roots (root exudates) [159].

Micro/macro aggregate size: Macro-aggregates are quantified by means of "water stable aggregates" (WSA) defined as the percentage of total aggregates that remain stable (aggregates > 250 μm) following slow-wetting and shaking and chemical actions [27]. Micro-aggregates, on the other hand, are quantified by measuring clay-size particles (≤ 2 mm diameter), specific silt-size (≤ 5 and/or ≤ 20 mm), or specific sand size (≤ 125 mm), although it is best quantified by analyzing the overall size distribution of the fragments that result from the breakdown of aggregates in the macro-aggregate tests.

Aggregate stability: Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied. Aggregate stability is not the same as dry aggregate stability, which is used for wind erosion prediction [28].

Table 1: Commonly used terms in soil organic carbon, and soil aggregation and stability studies.

Aggregate distribution and stability

Soil aggregation is a process that binds together soil particles as their inner maintenance force is more powerful than forces of adjacent particles. This process depends on time, place, application and soil management. Oades JM and Waters AG [29] reported that an aggregate

hierarchy is not evident in soils where oxides are the dominant aggregate stabilizing agents (e.g. Ferralsols with high clay content). It is commonly understood that in such soils, aggregate between 0.02 and 0.25 mm are highly stable and are not destroyed by agricultural practices.

Fresh residues are C source for microbial activity and nucleation centers for aggregation when returned to cropland [160]. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates [30] which could increase aggregates stability and fix the unstable C, thus improving the SOC concentration [31] and increasing C sequestration [18]. Koushwaha CP, *et al.* [32] revealed that larger aggregate size fractions had greater amount of organic carbon (OC) than smaller aggregate size fractions. This may be due to either an increased aggregates' stability and strength caused by the addition of zeolitic materials, or because the humification of plant residues can increase the amount of OC in macro-aggregates during incubation in the treated soil. Hao XY and Chang C [33] reported that fertilization improves soil structure and mean weight diameter (MWD), increases macro-aggregation and resistance to slaking but may decrease stability of soil aggregates to dissolution and dispersive actions. They further reported that the stability of structure macro-aggregates was higher in treatment without fertilizer than in treatment consisting of crop residue (CR) together with NPK fertilizers (CR + NPK) or NPK alone. Also, the MWD was higher in NPK than in CR + NPK. Munkholm LJ, *et al.* [34] also reported that unmanured soil is denser than manured soil, and aggregates are stronger when dry and weak then wet.

Hao XY, *et al.* [35] showed that in aggregate size fraction (>2 mm), the amount of OC increased from "10% nanozeolite 3.27 ($\text{g K}_{\text{gsoil}}^{-1}$) and zeolite 2.91 ($\text{g K}_{\text{gsoil}}^{-1}$)" in the "10% zeolitic materials plus 5% alfalfa straw" treatment to "30% nanozeolite 3.93 ($\text{g K}_{\text{gsoil}}^{-1}$) and zeolite 3.54 ($\text{g K}_{\text{gsoil}}^{-1}$)" in "30% zeolitic materials plus 5% alfalfa straw" treatment. The amount of OC in > 2 mm size fraction) increased with additions of "5% alfalfa straw in 3.93 or 3.54 ($\text{g K}_{\text{gsoil}}^{-1}$)" in "30% zeolitic materials plus 5% alfalfa straw" treatment toward "5% wheat straw 3.69 or 3.31 ($\text{g K}_{\text{gsoil}}^{-1}$)" in "30% zeolitic materials plus 5% wheat straw" treatment in nanozeolite and zeolite, respectively. Zotarelli I, *et al.* [37] showed that MWD_w and OC contents in each aggregate size fraction increased with the additions of nanozeolite, zeolite, and plant residues. This study also revealed that nanozeolite and alfalfa straw were more effective for increasing the MWD_w and OC contents in aggregate size fractions than zeolite and wheat straw, respectively. In other words, higher percentage nanozeolite, zeolite, and plant residues resulted in increasing the MWD_w and OC in aggregate size fractions.

Blair N, *et al.* [38] observed slower decomposition and greater aggregate stability following the addition of intermediate quality *Flemingia macrophylla* (> 4% polyphenols) versus the addition of high quality *Medicago truncatula*. The most probable reason for the stability of the aggregate hierarchy is the continuous incorporation of young organic matter. De Gryze S, *et al.* [39] showed that macro-aggregates had a linear relationship with wheat straw incorporation, but no relationship with the soil texture. Helfrich M, *et al.* [40] found that among the various components of SOM, carbohydrates have particular importance in increasing aggregate stability, and to a certain degree could protect SOC against mineralization. Hati KM, *et al.* [41] reported that the SOC is closely related to the formation and stability of soil aggregates. Thus, the amendment of organic residues can improve soil structure and increase aggregate stability. Song MW, *et al.* [42] reported that straw return plays a very important role in increasing soil TOC and labile OC fractions. Simansky V, *et al.* [43] observed higher total carbon (C_t) and labile carbon (C_L) contents in water-stable micro-aggregates (WSA_{mi}) and macro-aggregates (WSA_{ma}) in the size fractions from 25×10^{-4} to 3×10^{-3} m in RT compared to CT. There were also higher concentrations of C_t and C_L in WSA_{ma} in the size fractions $>3 \times 10^{-3}$ m in CT. The application of crop residues together with NPK fertilizers increased the concentration of C_t in all fractions of WSA_{ma} . On the other hand, C_t concentration decreased by 7% in WSA_{mi} . In crop residues with NPK fertilizers (CR + NPK), the highest concentration of C_L was observed in WSA_{ma} in the size fraction 2×10^{-3} to 3×10^{-3} m. Chung H, *et al.* [44] revealed that organic matter in the soil is frequently occluded within macro-aggregates where it is protected from decomposition. Tillage operation exposes this protected organic matter and enhances its decomposition. Thakuria D, *et al.* [45] also observed that the application of bio-inoculants and retention of crop residues conjointly help maintain C and N balance in soil and can enhance labile C pool in rice-legume cropping systems. Lahmar R reported that conservation tillage such as NT increases topsoil aggregate stability, which could be explained by an increase in SOC at the soil surface.

Simansky V., *et al.* [43] found that WSA_{ma} was higher by 9% in RT, which led to an increase in mean weight diameter of water-stable aggregates by 11% and increasing of index stability (Sw) by 12%. Chen HQ., *et al.* [18] found that RT practices allow C to build-up in the plow layer by enhancing soil aggregation and reducing oxidation. Yang Y., *et al.* [82] also observed that the soil LOC is a sensitive indicator for evaluating changes in the soil quality, because the LOC plays vital role in nutrient cycling and microbial activity energy uptake. Lewis DB., *et al.* [83] reported that increasing tillage intensity could reduce $KMnO_4$ -C levels in soils as a result of destruction of macro-aggregates and elevated respiration. Under CT, due to increased soil disturbances, aggregated and protected SOC fraction can subject to rapid decomposition via oxidation lowering the amount of $KMnO_4$ -C under CT.

Naresh RK., *et al.* [56] also observed that macro-aggregates are less stable than micro-aggregates and more susceptible to the disruptive forces of tillage, and > 2 mm size macro-aggregates showed the lowest percentage distribution across depths. This might be attributed to the mechanical disruption of macro-aggregates with frequent tillage operations and reduced aggregate stability. The proportion of the micro-aggregates in all treatments was small and they had the lowest OC content. However, micro-aggregates formation and the micro-aggregates within the macro-aggregates can play an important role in C storage and stabilization in the long term [70]. Xue J., *et al.* [71] found that over time, CT generally exhibits a significant decline in SOC concentration due to destruction of the soil structure, exposing SOM protected within soil aggregates to microbial organisms. Thus, the adoption of no-till system can minimize the loss of SOC leading to higher or similar concentration compared to CT. Zhou H., *et al.* [51] found that, compared to CT, macro-aggregates in RT in wheat coupled with unpuddled transplanted rice (RT-TPR) was increased by 50.1% and micro-aggregates in RT-TPR decreased by 10.1% in surface soil. Surface residue retention (50%) caused a significant increment of 15.7% in total aggregates in surface soil (0 - 5 cm) and 7.5% in sub-surface soil (5 - 10 cm). In surface soil, 19.2% of total aggregate C was retained by > 2 mm and 8.9% by 0.1 - 0.05 mm size fractions. RT-TPR combined with ZT on permanent wide raised beds in wheat (with residue) had the highest capability to hold the OC in surface (11.6 g kg⁻¹ soil aggregates).

Bandyopadhyay KK., *et al.* [47] reported significant positive correlation for SOC between WSA_{ma} and MWD in vertisols. Removal of residues from the surface and plowing through tillage accelerated decomposition which reduced aggregate stability in CT. Huang S., *et al.* [48] observed significantly more macro-aggregates and higher SOM content in the bulk soil and > 2 mm aggregate fraction for the NPK plus OM treatment compared with other treatments. Li CF., *et al.* [49] showed that MBC was affected by straw return with an affecting force of 96% at 0 - 7 cm depth and 98% at 7 - 14 cm depth. The probable explanation maybe that crop residue may enter the labile C pool, provide substrate for the soil micro-organisms, and contribute to the accumulation of labile C. Mandal S., *et al.* [50] found that soil aggregation at 0 - 15 cm depth was not affected by cropping systems, but was affected by tillage. The ZT with residue and ZT without residue had 12 and 33% larger MWD than CT with residue and CT without residue, respectively, indicating the tillage effect dominating the residue effect.

Zhou H., *et al.* [51] concluded that the application of NPK plus OM increased the size of sub-aggregates that comprised the macro-aggregates. Also, they observed that long-term application of NPK plus OM improves soil aggregation and alters the three-dimensional microstructure of macro-aggregates, while NPK alone does not. Zhang-liu DU., *et al.* [52] showed that NT and RT significantly increased the proportion of macro-aggregate fractions (> 2000 and 250 - 2000 μ m) compared with the moldboard plow without residue (MP-R) and moldboard plow with residue (MP + R) treatments. Averaged across depths, MWD of aggregates in NT and RT were 47 and 20% higher than that in MP+R. Hati KM., *et al.* [53] revealed that the MWD of the top 15 cm soil under NT (1.05 mm) was significantly higher than that under RT and MB (moldboard tillage) and the MWD was least under CT (0.71 mm). Similarly, $\%WS_{ma}$ was maximum under NT (63.5%) and minimum under CT (50.2%). Liqun Zhu., *et al.* [54] showed that soil LOC fractions were significantly and positively correlated with TOC concentrations at 0 - 21 cm soil depth. Such correlations suggested that TOC was a major determinant of soil LOC fractions. The formation of micro-aggregates occurs in advanced stages of organic matter decomposition, so the OC in the micro-aggregates is more stable or recalcitrant compared to the OC found in other aggregates, thereby favoring aggregate stability and C retention [55,56].

Madari Beata, *et al.* [36] also observed that the most pronounced difference between tillage systems was observed in the surface soil layer (0 - 5 cm), where NT had higher aggregate stability (AS_{NT} : 96%; AS_{CT} : 89%), larger aggregate size distribution (MWD_{NT} : 7.9 mm, MWD_{CT} : 4.3 mm), and about 28% greater TOC in all aggregate size classes than in CT. Soil under NT had greater TOC in micro-aggregates than under CT (NT: 22 g kg⁻¹; CT: 13 g kg⁻¹). Zotarelli I, *et al.* [37] revealed that the MWD of aggregates was on average 0.5 mm greater in NT than in CT in the 0 - 5 cm layer in oxisols. Sandeep S., *et al.* [58] reported that tillage and its interaction were found to significantly influence only those SOC fractions closely associated with aggregate stability, viz, labile polysaccharides and glomalin. The highest amount of C₄-derived carbon was found to be in plots receiving recommended doses of N as urea (29%) followed by control (25%). Naresh RK., *et al.* [59] showed significantly higher TOC and SOC content of 11.9 and 10.7 g kg⁻¹, respectively in wide raised beds transplanted rice (RBTPR) and ZT with 100% residue retention and 11.0 and 9.4 g kg⁻¹, respectively in RBTPR and ZT with 50% residue retention. They also reported that irrespective of residue incorporation/retention, wide raised beds with ZT wheat enhanced 53.6%, 33.3%, 38.7% and 41.9% of TOC, total inorganic carbon (TIC), SOC and OC, respectively, in surface soil as compared to CT with transplanted rice. Simultaneously, residue incorporation caused an increment of 6.4%, 7.4%, 8.7% and 10.6% in TC, TIC, SOC and OC, respectively over the treatments with no residue management in wheat.

The above results reveal that decreasing micro-aggregates under NT would seem natural because of the different aggregate sizes present in the soil implying that increased share of larger aggregates would result in decreased share of smaller aggregates.

Particulate organic matter

Particulate organic matter (POM) fraction comprises of all SOM particles less than 2 mm and greater than 0.053 mm in size. POM is biologically and chemically active and is part of the labile (easily decomposable) pool of SOM. Franzluebbers AJ., *et al.* [60] found that the crop residues persist longer at the soil surface under NT, thus differences in soil C and N levels between cropping sequences were more apparent under NT compared to CT. Organic matter turnover, mineralizable C, and soil microbial biomass were greater for high-intensity sequences than for monoculture. This suggests that higher crop residue inputs from intensive cropping were offset by any practice that enhances organic matter decomposition under CT. Stimulation of residue and organic matter decomposition under CT could mask the effects of cropping intensity on soil C and N levels, but under NT, their greater effects could be observed. Thus, both residue quantity and quality could serve important roles in C and N accumulation in these soils. Manjaiah K and Singh D [61] also observed stratified particulate organic carbon (POC) along the soil depth. A higher accumulation of POC was found in surface soil that reduced to half at 15 - 30 cm depth. Overall, the super-optimal dose as well as balanced application of NPK enhanced POC in soil. The POC contents in 100 and 150% of the recommended rates of NPK in 0 -45 cm depth were increased by 9 and 22%, respectively, over 50% of the recommended rates. The POC content in 100% NPK + FYM increased by 38 and 23% over 100 and 150% NPK, respectively.

Bhattacharyya R., *et al.* [67] reported slower macro-aggregates turnover in ZT compared with CT. This phenomenon might lead to micro-aggregate formation within macro-aggregates formed around fine intra-aggregate POM and to a long-term stabilization of SOC occluded within these micro-aggregates. Duval ME., *et al.* [68] reported that of the two POM fractions isolated in their study, fine POM (f_{POM}) was, in general, more sensitive to soil tillage and land use than coarse POM (c_{POM}). On the other hand, c_{POM} is more dependent on plant derived C inputs and, therefore, more variable in time and space (also in depth) than f_{POM} . Liu E., *et al.* [69] revealed that the average concentrations of POC, DOC and MBC in organic manure plus inorganic fertilizer treatments (NP+S and NP+FYM) in 0 - 60 cm depth were increased by 65 - 92%, 43 - 57%, and 75 - 99%, respectively, over unfertilized control.

Microbial biomass carbon

The microbial biomass consists mostly of bacteria and fungi, which decomposes crop residues and organic matter in soil. This process releases nutrients, such as N, into the soil that are available for plant uptake. About half the microbial biomass is located in the surface 10 cm of a soil profile and most of the nutrient release also occurs here. Generally, up to 5% of the TOC and N in soil is in the microbial biomass. When microorganisms die, these nutrients are released in forms that can be taken up by plants [159].

Hopkins DW and Shiel RS [72] reported that the microbial biomass was greater in soils receiving annual additions of FYM for nearly 100 years in addition to inorganic NPK application. However, in a different study, a significant increase in MBC was found only in soils fertilized with compost, while treatment with mineral fertilizers was characterized by a small MBC, as small as in the unfertilized soil. Similarly, Omay AB [73] reported a significant decrease in MBC due to fertilizer applications, particularly N. The imbalanced use of fertilizers also decreased MBC due to limitation imposed by major nutrients like P and K, which are essential for higher crop production as well as for microbial cell synthesis. Wani SP, *et al.* [74] also reported that the highest increase in MBC (147%) was observed in 50% recommended dose of N (RDN) through fertilizer (F) + 50% RDN through FYM followed by 79% increase in 50% RDN through FYM, 74% increase in 100% RDN through F and 37% increase in 50% RDN through F.

Ghani A., *et al.* [75] reported that the fresh residues are C source for microbial activity and nucleation centers for aggregation when returned to cropland. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates [30], which could increase aggregate stability and fix the unstable C, thus increasing the SOC concentration and C sequestration [18,31]. Haynes RJ [1] observed that DOC consisting of organic compounds present in soil solution acts as a substrate for microbial activity and is the primary energy source for soil micro-organisms. Spedding TA, *et al.* [76] found that residue management had more influence than tillage on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0 - 10 cm layer.

Tresder KK, *et al.* [77] reported a complementary interaction between pigeon pea (a legume) root system and rhizo-bacteria. Pigeon pea has a prolific root system, which releases an array of organic compounds viz. Psidic acid and oxalic acid. Gloumalin content is generally increased in the rhizosphere, which can stimulate and diversify the growth of the microbial biota and enzymatic activity, and thus, can increase nutrient cycling and especially N and P acquisition to the crop [78]. Retention of crop residues at 3 t ha⁻¹ under ZT and an association of pigeon-pea leaf litter fall can stimulate the growth of microbial population by providing continuous supply of food. Rudrappa L, *et al.* [4] reported that application of NPK (50 to 150% of recommended rates) significantly enhanced other organic C fractions like MBC, POC and KMnO₄ oxidizable C (KMnO₄-C) in soil. The TOC in 0 - 45 cm depth in 150% NPK (63.5 Mg C ha⁻¹) was increased by 39% over that in 50% NPK (51.5 Mg C ha⁻¹) and 29% over that in 100% NPK (54.1 Mg C ha⁻¹).

Six J., *et al.* [79] reported that under intensive tillage a decline in microorganisms with soil aggregation can occur because of the inhibition of fungal growth and activity due to reduced establishment and maintenance of extensive hyphal networks, or because of the changes in soil moisture that may differently influence bacteria and fungi either by directly affecting survival and growth or indirectly by shifting substrate availability. Mandal A, *et al.* [80] also reported that the microbial biomass was greater in soils due to addition of straw plus inorganic NPK for 34 years than that with NPK fertilizers alone in rice-based cropping system. Hao XH., *et al.* [81] also observed that the microbial biomass was considerably greater in soils receiving FYM along with NPK fertilizers than in soils receiving merely NPK fertilizers in three subtropical paddy soils.

Wang J., *et al.* [84] reported increased MBC with crop residue application in comparison to no residue application. Moharana PC., *et al.* [85] reported that highest values of TOC (11.5 g kg⁻¹) and black organic carbon [WBC] (7.9 g kg⁻¹) were maintained in FYM treated plots, while the highest LBC (1.36 g kg⁻¹) and MBC (273 mg kg⁻¹) were found in FYM + NPK plots. The magnitude of change in SOC pools in sub-surface (15 - 30 cm) soil was lower as compared to the surface (0 - 15 cm) soil. Significant increase in all SOC pools under FYM indicates the importance of organic manure application in maintaining OC in pearl millet-wheat cropping systems in the *inceptisol of subtropical India*.

Awale R., *et al.* [86] found that the trends for soil CO₂-C mineralized at 21 or 30 days were similar. Hurisso TT, *et al.* [87] revealed that the amount of MBC was directly related to the C concentration in the 1 - 2 mm aggregates and, as a consequence, to the C concentration in the stable aggregates. Thus, MBC appeared as efficient stabilizing agents, but it was not selectively preserved in stable aggregates. Microbial biomass nitrogen (MBN) was not related to any C and N pools in 1-2 mm aggregates. Das TK., *et al.* [88] found that crop residue

application at 3 t ha⁻¹ resulted in 41.0% and 39.8% higher MBC and MBN, respectively, over no residue application. Enhanced SOC with C input in crop residues at 3 t ha⁻¹ increased the amount of microbial biomass and enzymatic activities in the soil. Furthermore, combined application of pigeon-pea + wheat residue at 3 t ha⁻¹ resulted in higher MBC and MBN over no residue, which could be due to simultaneous C and N supply from the residues. The high C: N ratio of wheat residue temporally blocks N supply, this effect is probably masked by pigeon-pea residue that has low C: N ratio. Mikha MM., *et al.* [89] reported that SOC is physically protected from microbial decomposition within soil aggregates. Both, SOC and the coarse particulate organic carbon (CPOM-C) serve as energy source for soil microbial biomass and hence, their availability significantly influences soil microbial activities.

Govaerts B., *et al.* [31] concluded that under ZT the additional C improves the soil structure, especially in terms of macro-aggregates, which is active site for holding labile C. Hence, the increased OC content and better soil structure may have occurred under ZT. Mina BL., *et al.* [62] reported that there was respectively 15.0 and 18.3% higher MBC and MBN under ZT than CT after 4 years of cropping. Although the microbial biomass comprises only a small portion of the total SOC, it has a greater importance as it acts as a repository of nutrients for plants as it is more labile than the total SOC. So, any agronomic manipulation in the OC pools will have corresponding changes in microbial pool. Sa JCM and Lal R [63] found that the continuous replacement of organic manure on the soil creates a favorable environment for the C cycling and formation of macro-aggregates. Furthermore, POC acts as a cementing agent to stabilize macro-aggregates and protect intra-aggregate C in the form of POC. Verhulst N., *et al.* [64] reported that crop residue application of 3 t ha⁻¹ resulted in 41.0 and 39.8% higher MBC and MBN, respectively than with no residue application. Enhanced SOC with C input from crop residues at 3 t ha⁻¹ increased the amount of microbial biomass and enzymatic activities in the soil. Frequent tillage operations under CT can easily exacerbate breaking down of C-rich macro-aggregates in soils, then forming a large number of microaggregates with relatively low OC content and free organic matter particles. The latter have poor stability and are prone to degradation, thereby causing the loss of SOC [65,66].

Wuest S [90] also reported the slight differences in the SOC and TN concentrations between the two years of study could be attributed to the difference in the activities of soil microorganisms and the rate of residue decomposition due to the seasonal variation in soil temperature and moisture regime. Sepat S., *et al.* [91] observed that ZT increased the MBC and MBN by 15.0 and 18.3%, respectively, over CT. Plots under ZT - raised bed (ZT-B) recorded highest soil MBC, while f MBN under ZT-B remained comparable with ZT flatbed (ZT-F) and CT raised bed (CT-B). Crop residue application resulted in 41.0 and 39.8% higher MBC and MBN, respectively, over no residue. Furthermore, among the crop residues, combined application of pigeon-pea + wheat residues resulted in highest MBC and MBN followed by sole application of either pigeon-pea or wheat residue. Naresh RK. *et al.* [92] reported that ZT with residue retention resulted in 24-191% more ρ POM-C, averaging about 105% than no residue application. For ρ POM, the increase was 48 - 187% more, with an average of 74%. For both ρ POM and ρ POM fractions, the decreasing pattern in SOC concentration with depth was more prominent under conservation tillage, especially under ZT, in such a way that the average concentrations in the 0 - 40 cm profile were not significantly different from those under CT. Crop residue management influences microbial biomass as they are one of the primary forms of OC and nutrients used by the microbial biomass. Retaining crop residues rather than burning results in increased microbial biomass as the amount of OC available to the soil increases.

Soil carbon sequestration

World's soil holds around twice the amount of C (~1500 Pg C to 1 m depth (1 Pg = 10¹⁵ g) that is found in the atmosphere (~750 Pg C) and almost three times that is found in the biotic pool (~610 Pg C) [7]. Organic material is manufactured by plants using carbon dioxide from the air and water. Plants (and animals, as part of the food chain) die and return to the soil where they are decomposed and recycled. Minerals are released into the soil and carbon dioxide is released into the atmosphere. SOC sequestration is thus a part of the natural carbon cycle. Table 2 summarizes various strategies for sequestration of SOC. Dobermann A and Witt C [93] reported that rice straw contains 5 - 8 kg N, 0.7 - 1.2 kg P, 12 - 17 kg K, 0.5 - 1 kg S, 3 - 4 kg Ca and 1 - 3 kg Mg per ton straw on dry weight basis. These nutrients are released upon the decomposition of the straw and support SOC accumulation as well as crop production. Aoyama M and Kumakura N [94] reported an increase in SOM with animal manure application, and consequently, the formation of macro-aggregates (250 - 1,000 μ m). They further

pointed out that manure application increased the accumulation of macro-aggregate-protected C and thus sequestered more organic C in soils. concluded that on average, a change from CT to NT can sequester $57 \pm 14 \text{ g C/m}^2/\text{yr}$, with an average of $20 \pm 12 \text{ g C/m}^2/\text{yr}$. SOC sequestration rates can be expected to peak in 5-10 years with SOC reaching a new equilibrium in 15-20 years. Liu XB., *et al.* [95] showed that soil cultivation can reduce SOC content and lead to soil deterioration, and finally reduce soil productivity. They also suggested that by changing land use and tillage systems or by the adoption of sustainable crop rotations and the inclusion of perennial vegetation, SOC sequestration rates can be increased to $20 - 75 \text{ g C/m}^2/\text{yr}$; and it may reach a new equilibrium within several decades.

Campbell CA., *et al.* [96] reported an increase in SOC mostly by annual cropping with application of adequate fertilizer N and P in semiarid southwestern Saskatchewan, Canada. They concluded that SOC and total N, microbial biomass LOC and N, mineralizable N and wet aggregate stability all had generally positive response to fertilization. From a long-term pastures and cropping study in Georgia, USA, Schnabel RR., *et al.* [97] concluded greater SOC accumulation in pastures than annual crops due to longer growing periods, more extensive root system, and less soil disturbance. The study revealed that the SOC near the soil surface was greater under pasture than under conservation-tilled cropland, the latter with greater SOC than under conventional-tilled cropland (Figure 1). The SOC sequestration during 16 years of pasture was estimated at $1.03 + 0.90 \text{ Mg C/ha/y}$.

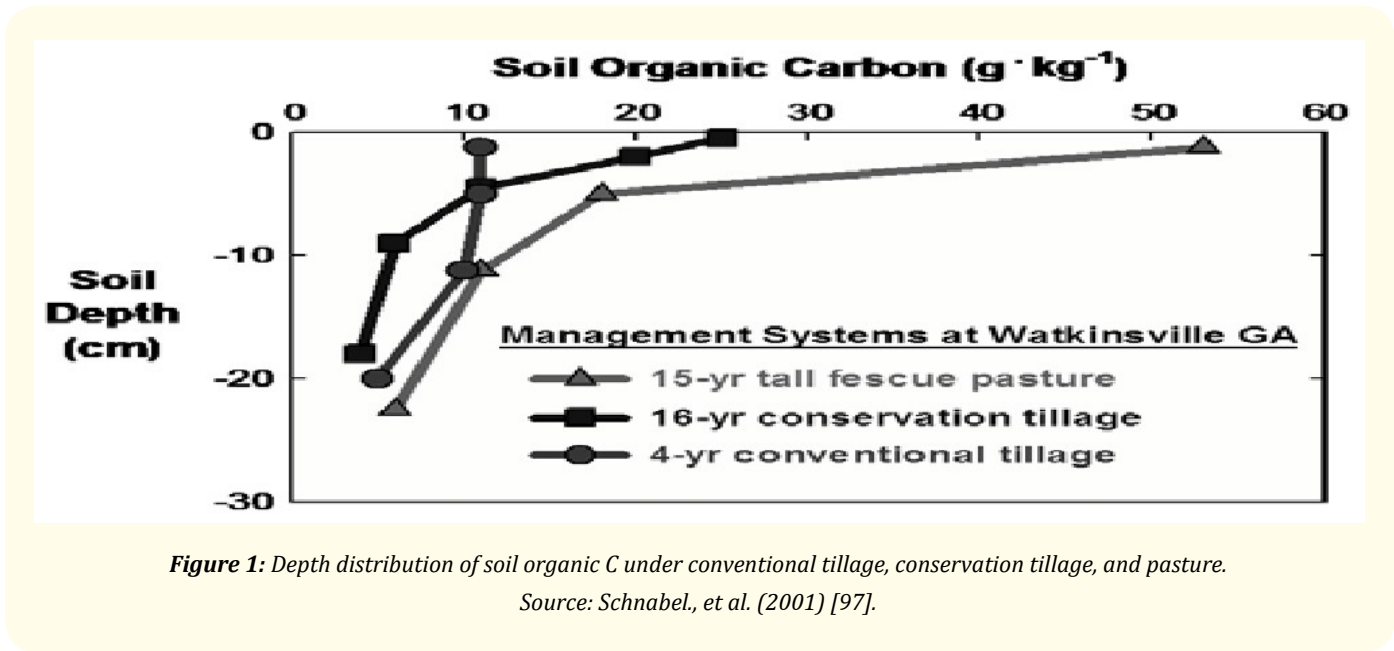


Figure 1: Depth distribution of soil organic C under conventional tillage, conservation tillage, and pasture. Source: Schnabel., *et al.* (2001) [97].

Witt C., *et al.* [98] found that the replacement of dry season rice by maize caused a reduction in soil C and N due to a 33 - 41% increase in the estimated amount of mineralized C and N during the dry season. As a result, there was 11 - 12% more C sequestration and 5 - 12% more N accumulation in soil continuously cropped with rice over maize-rice rotation with greater amounts sequestered in N-fertilized treatments. Francioso O., *et al.* [99] also reported that SOC and N differed significantly after 22 years for all treatments where the amendments with cattle manure markedly increased the SOC and N contents, while cow slurries and crop residues reduced SOC and N contents in rice.

(1) Maximizing C input	(2) Minimizing C loss from soil
Plant selection Species, cultivar, variety Growth habit (perennial/annual) Rotation sequence Biomass energy crops	Reducing soil disturbance Less intensive tillage Controlling soil erosion
Tillage Type Frequency	Utilizing available soil water Promotes optimum plant growth Reduces soil microbial activity
Fertilization Rate, timing, placement Organic amendments	Maintaining surface residue cover Increases plant water use and production More fungal dominance in soil

Table 2: Strategies to sequester soil organic C.

Source: Franzluebbbers, (2005) [100]

Franzluebbbers AJ [100] reported that the impact of conservation tillage on SOC sequestration may be greater in degraded soils than in fertile soils. The ratio of SOC under conservation to conventional tillage as related to initial SOC under CT was logarithmically greater in soils with inherently lower organic C than in soils with inherently higher organic C content (Figure 2). Therefore on a relative basis, the improvement in SOC was proportionately higher in degraded soils.

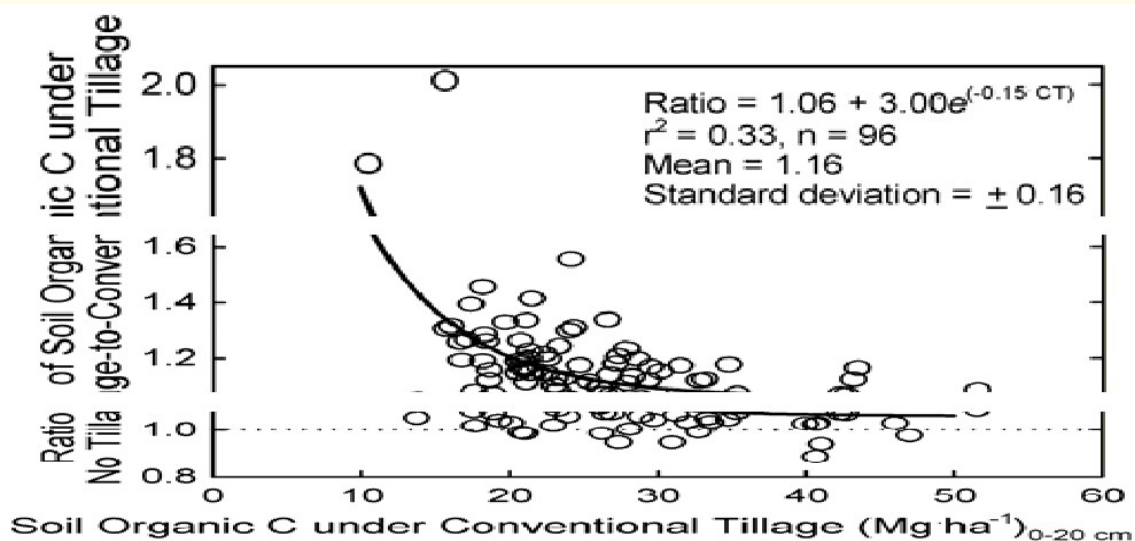


Figure 2: The ratio of soil organic C under conservation tillage-to-conventional tillage as related to the initial soil organic C content under conventional tillage (Franzluebbbers, 2005) [100].

Fertilization of crops is needed to overcome deficiency of nutrients especially in those soils exhausted by years of soil erosion, intensive disturbance with tillage, and continuous harvest of products [161]. Excessive fertilization can also occur when agronomic prescriptions exist without considering economic and environmental consequences [161]. Review of data from southeastern USA indicates that

SOC generally accumulates with increasing rate of N fertilizer application (Figure 3). The average N fertilizer rate to achieve maximum SOC sequestration (0.28 Mg C/ha/yr) was 171 kg N/ha/yr [100], well within the range of values often reported to maximize cereal crop yields. However, when considering the C costs of N fertilizer (i.e. manufacturing, distribution and application), the optimum N fertilizer rate was 107-120 kg /ha/yr based on C costs of 0.98 [0.86 + 0.08 + 0.04] to 1.23 kg C/kg for production, application, and liming components, respectively.

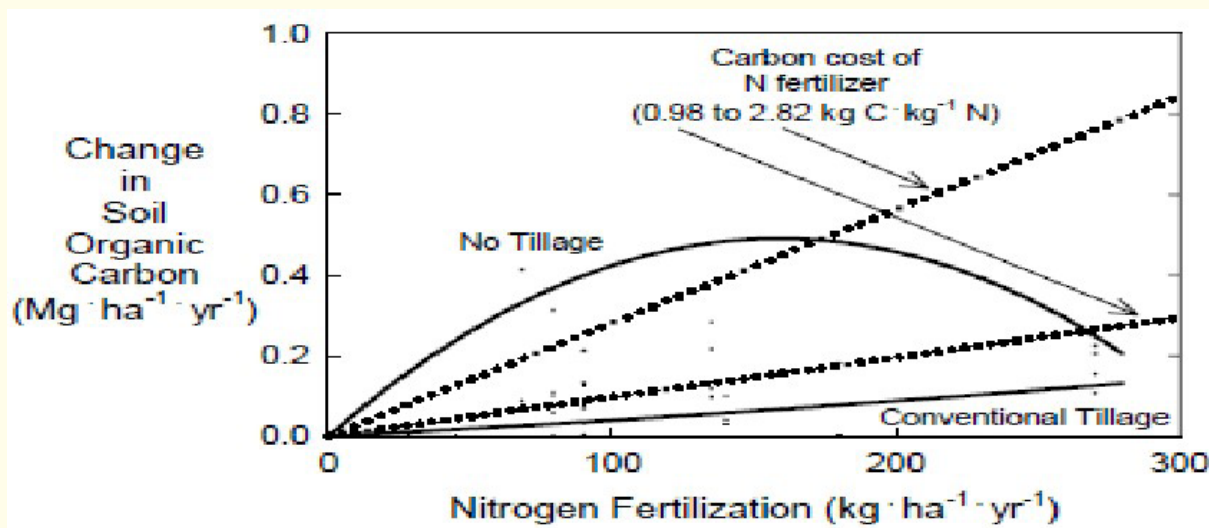


Figure 3: Average change in soil organic C as affected by N fertilizer rate in the southeastern USA (Franzluebbers 2005) [100]. Dotted lines represent the lower and upper limits of C cost of N fertilizer manufacture, distribution, and application.

Tillage increases the effect of drying-rewetting and freezing-thawing on soil, which increases macro-aggregate susceptibility to disruption [101,161] and accelerates the labile organic C mineralization and SOM degradation, thus increasing the loss of SOC in sub-tropical to warm temperate rice-wheat cropping systems in China [102]. Al-Kaisi MM., *et al.* [103] found that SOC content in 0 - 5 cm soil layer was highest under NT (8.6 g kg⁻¹), while it was lowest under CT (6.5 g kg⁻¹) and intermediate under RT. However, in 5 - 15 cm layer, the concentration was higher in MB over RT or CT. In 15 - 30 cm layer also, the concentration was higher in MB than in CT but was at par with NT or RT. The increase in SOC under NT in the surface soil was attributed to a combination of crop residue retention, reduced litter decomposition and reduced soil disturbance. Besides this, the SOM and the previous rice root residues below the surface were left undisturbed and thus were not subjected to accelerated decay under NT and RT.

Denef K and Six J [104] found that the ratio of POC and SOC improved from 31.4% in control to 38.5% in integrated use of chemical fertilizers and FYM, 36.0% in farmer's practice, and 35.5% in 50% RDN (FYM) treatments indicating that the regular addition of soil amendments can improve and stabilize C in the fine-textured soil particles. Rudrappa L., *et al.* [4] reported that the application of super-optimal dose of NPK (150% NPK) showed higher TOC (12.9 g C kg⁻¹) over either 50% NPK (9.3 g C kg⁻¹) or 100% NPK (10.0 g C kg⁻¹) in 0 - 15 cm soil layer. There was an improvement in TOC in 100% NPK or 100% NP (9.3 g C kg⁻¹) over 100% N (8.7 g C kg⁻¹) in the same depth. The application of FYM with 100% NPK showed 15.2, 9.9 and 5.2 g C kg⁻¹ in 0 - 15, 15-30 and 30-45 cm depth, respectively. Abid M and Lal R [105] reported that conservation tillage, particularly NT leads to a concentration of SOC in the top soil layer (0 - 5 cm) due to plant residues accumulating on the soil surface and alters its distribution within the soil profile.

Generally, NT, RT and ST system, where soil cultivation is reduced, and residues are generally present in surface or near surface, can result in higher SOM than in CT where the residues are incorporated into the soil. He JN, *et al.* [106] reported that the mean SOM in the 0 - 5 cm soil layer was 18.8 g kg⁻¹ under NT with straw cover which was significantly greater than 14.3 g kg⁻¹ under CT, but this difference declined in lower layer (from 14.1 g kg⁻¹ in 5 - 10 cm to 9.6 g kg⁻¹ in 10 - 20 cm depth), with no significance in 20 - 30 cm depth. Thierfelder C and Wall PC [107] also reported that the conventional ploughing resulted in an increase of C by only 6% in 0-20 cm depth (from the initial site mean of 6.5 Mg ha⁻¹ in 2004 to 6.9 Mg ha⁻¹ in 2008), whereas direct seeding increased SOC by 104% (to 13.3 Mg ha⁻¹) over the same period [108]. After 9 years of experimentation, significantly higher SOC was observed under NT in top layer (0 - 4 and 4 - 8 cm depths), where SOC was 57.8% and 15.1% greater than that in plow layer. In the 8 - 30 cm depth, the SOC concentration was not different among tillage systems. Similarly, after four years of experimentation, Tabaglio V, *et al.* [109] recorded significantly higher SOC in the top layer (0 - 5 cm depth) in favor of NT (13.9 g kg⁻¹) over CT (10.3 g kg⁻¹), however the difference in lower depth was not significant. In another study in Texas, USA, after 11 years of experiment, Dao TH [110] observed an increase of SOC by 65, 17, and 7% in NT compared to plow-till soil in the 0 - 5, 5 - 10 and 10 - 20 cm depths. In the 0 - 5 cm depth, difference in SOM between the NT and plow treatments were highly significant as NT resulted in 33% higher SOM than under plow (23.9 g kg⁻¹) [111]. NT also resulted in significantly higher (9%) SOC in 5 - 15 cm depth (26.6 g kg⁻¹). Further, increased sampling depth had lower SOC under NT system. After 43 years of continuous experiment on corn, SOM content in the top 30 cm layer was found to be significantly greater under NT (80.0 Mg ha⁻¹) than under chisel tillage (45.3 Mg ha⁻¹) or mold board plough tillage (44.8 Mg ha⁻¹) [112].

Guo LB and Gifford RM [113] revealed that the magnitude of SOC depletion was reduced by application of either chemical fertilizers alone or in combination with organic amendments. In comparison with control, the magnitude of SOC depletion was lower in treatments involving 50% RDN (F) + 50% RDN (FYM) (13%), 50% RDN (FYM) (29%), 100% RDN (F) (45%), and 50% RDN (F) (52%). The effect of tillage on SOC concentration was significant in the surface layer (0 - 10 cm) (NT = 13.0 g kg⁻¹; and CT = 10.1 g kg⁻¹). The concentration was initially higher in NT than in CT, and the difference increased further after 10 years (NT = 15.5 g kg⁻¹ vs CT = 10.8 g kg⁻¹). Within the 10 years of experiment, SOC content had increased by 21% in NT (gain of 0.61 Mg SOC ha⁻¹ yr⁻¹) whereas decreased by 2% in CT (loss of 0.06 Mg SOC ha⁻¹ yr⁻¹) [114]. At the end of 15 years of study, the SOM content in NT with straw cover was 0.3 g kg⁻¹ higher than the initial concentration, but was decreased by 0.2 g kg⁻¹ in CT with straw removal. Under NT with straw cover, SOM was increased by 40.3% from 13.9 g kg⁻¹ in the upper layer (0 - 5 cm) and by 14.3% from 14.7 g kg⁻¹ in 5-10 cm layer while it was decreased by 20.1% from 13.9 g kg⁻¹ in 10 - 20 cm and 35.1% from 9.7 g kg⁻¹ in 20-30 cm layer, while under CT with straw removal there were no significant changes were observed (Wang, 2008). The rates for SOC sequestration reported by [115] and [116] ranged from 0.34 to 0.81 Mg C ha⁻¹ yr⁻¹ for Brazilian Cerrado region, and the potential of SOC sequestration can be around 7.72 to 18.39 Tg yr⁻¹, if 100% of the Cerrado crop area was under NT.

Lal R, *et al.* [117] also estimated that the global potential of SOC sequestration and restoration of degraded/desertified soils of 0.6 to 1.2 Pg C yr⁻¹ for about 50yr with a cumulative sink capacity of 30 to 60 Pg, comprising 0.4 to 0.8 Pg C yr⁻¹ through adoption of recommended management practices (RMP) on cropland (1350 Mha), and 0.01 to 0.03 Pg C yr⁻¹ on irrigated soils (275 Mha), and 0.01 to 0.3 Pg C yr⁻¹ through improvements of rangelands and grasslands (3700 Mha). Causarano HJ, *et al.* [118] revealed that SOC sequestration under pasture compared with CT cropland averaged 0.53 Mg C/ha/yr at 0 - 5 cm ($p < 0.01$), 0.17 Mg C/ha/yr at 5 - 12.5 cm ($p < 0.01$), and 0.05 Mg C/ha/yr at 12.5-20 cm ($p > 0.05$) for a total of 0.74 Mg C/ha/yr to a cumulative depth of 0 - 20 cm (Figure 4).

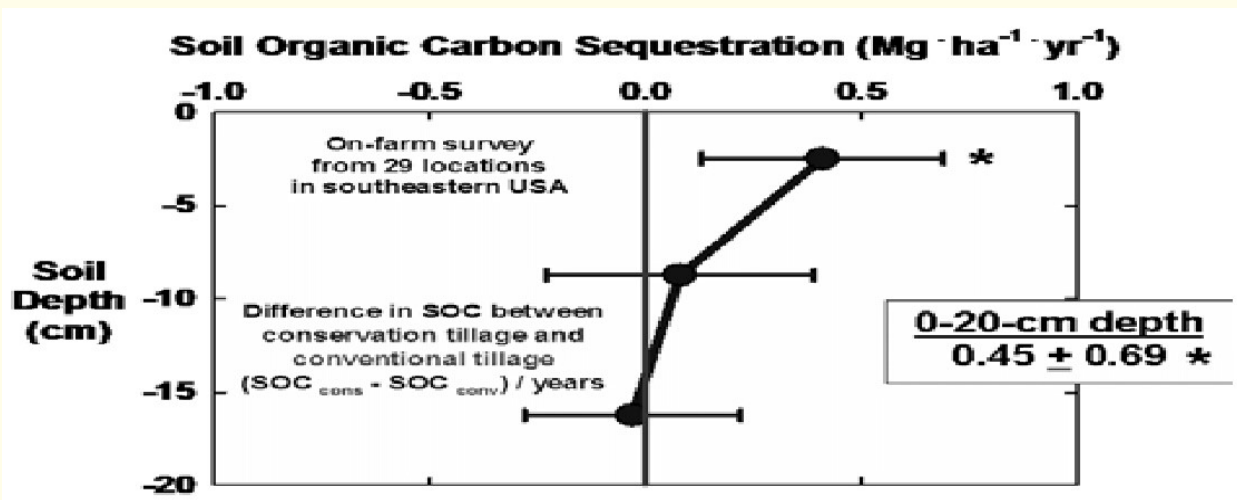


Figure 4: Difference in SOC sequestration between conservation-tillage and conventional-tillage cropland (adapted from Causarano, et al. 2008) [118].

Baker JM., et al. [6] argued that if the SOC content in the entire rooting profile were accounted (i.e., 0 - 2 m), the only reasonable conclusion would be that conservation tillage systems only change the depth distribution of SOC and not the total amount of C stored in soil. Liu SP., et al. [15] have found that SOM content for both plowing and rotary tillage at deeper soil was higher than that of the upper soil. The reason might be that rotary tillage and plowing tillage result in mixing of crop straw into the deeper layer of soil, making SOM well distributed at different depths [30]. Kukul SS., et al. [119] also observed that SOC concentration in the 0 - 60 cm soil profile was higher under FYM application (1.8 to 6.2 g kg⁻¹) followed by NPK application (1.7 to 5.3 g kg⁻¹) when compared to control plots. Tian SZ., et al. [120] found that rotary tillage with straw return had higher SOC than plowing tillage with straw return at 0 - 10 cm soil depth in wheat field.

Srinivasarao C., et al. [122] reported that in comparison with control, the 100% organic (FYM) treatment had significantly higher SOC (27.5 Mg ha⁻¹), and a higher C sequestration rate (6.6 Mg C ha⁻¹) at 1-m depth as compared to similar studies reported earlier. These parameters were also higher under 100% FYM at a rate providing equivalent amount of the recommended dose of N applied through chemical fertilizers followed by conjunctive use of FYM and chemical fertilizers. The SOC stock and SOC sequestration rates were both positively correlated with cumulative C input. Briedis C., et al. [123] reported that Ca²⁺ from the surface liming was positively correlated with the TOC content and acted as a cationic bridge between the clay particles' surfaces and the SOC, contributing to higher SOC sequestration. Chen HYH and Shrestha BM [124] observed that the SOC increased with time (year) and resulted in increased percentage of water-stable aggregates. Higher C accumulation in macro-aggregates could be due to the lower decomposable SOM associated with these aggregates and also the direct contribution of SOM to the stability of macro-aggregates. Srinivasarao C., et al. [125] observed that the application of FYM alone or in a combination with chemical fertilizers contributed to higher amounts of C inputs and subsequently in buildup of higher SOC pool. Application of 10 Mg ha⁻¹ of FYM and recommended dose of chemical fertilizer (25:21.8:20.7 and 50:21.8:20.7 kg N, P, K ha⁻¹ respectively for groundnut and finger-millet) increased SOC pool by 41.2% after 13 years (i.e., with an increase of 9.3 Mg ha⁻¹). In a hypothetical example, Causarano HJ, et al. [118] reported that in relative comparison with a conventional system, the SOC sequestration rate could have been realistically increased to 0.25 Mg C/ha/yr (Scenario A in Figure 5), because SOC declined by 0.10 Mg C/ha/yr under conventional agricultural practices following degradation from the previously elevated SOC amount. In Scenario B (the most often presumed

condition), SOC sequestration under conservation agriculture would have been effectively the same as that observed without comparison with conventional agriculture, because SOC under conventional agriculture was at a steady-state condition. In Scenario C, SOC sequestration under conservation agriculture would have to be adjusted to 0.05 Mg C/ha/yr, because the conventional system was improved by other practices similar to that under conservation agriculture, which sequestered SOC at 0.10 Mg C/ha/yr [118].

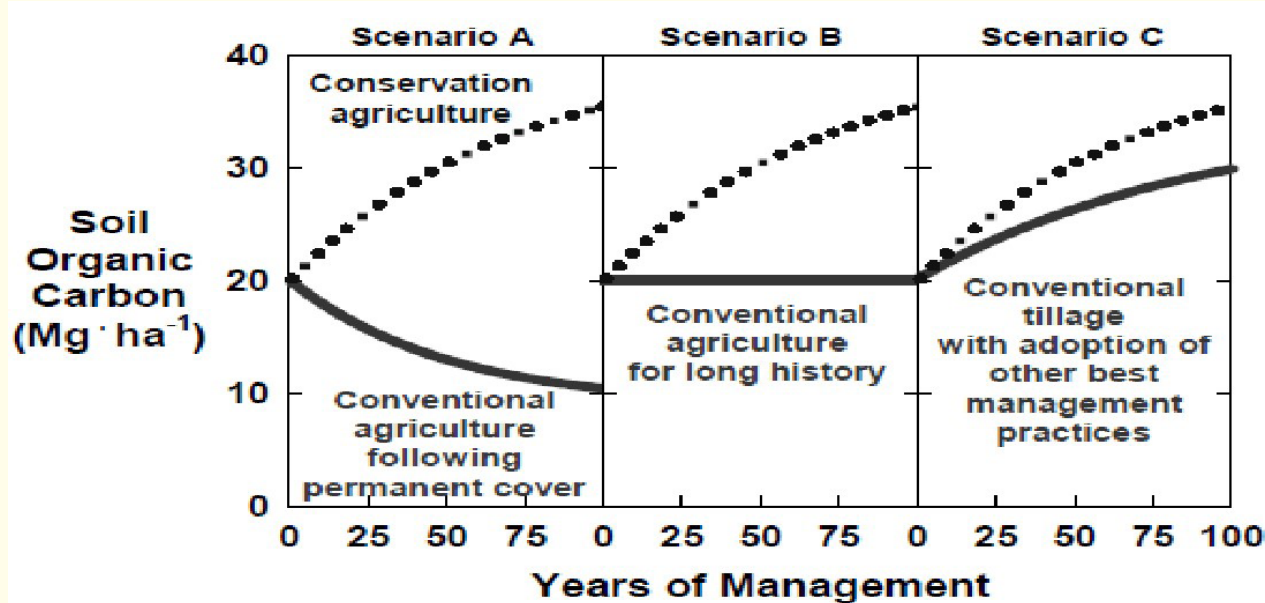


Figure 5: Hypothetical example of soil organic C content under conservation agriculture and three different baseline conditions of conventional agriculture. [Source Causarano, et al. 2008] [118].

Ghimire R., et al. [126] did not find any significant effect of crop residues incorporation on SOC in a conventionally tilled with no residue rice-wheat cropping system but SOC was significantly greater by 11% under NT with residue retention. Zhu Liqun., et al. [127] reported that all the four improved management practices (IMPs) such as organic manure application (OM), organic manure combined with chemical fertilizer application (MF), straw return (SR) and reduced RT or NT had significant effects on SOC sequestration. On an average, OM, MF, SR and NT enhanced SOC concentration by 260, 328, 278 and 134 kg ha⁻¹ yr⁻¹, respectively. The effective duration for OM, MF, SR and NT for SOC sequestration was about 48, 26, 22 and 18 years, respectively. Accumulation enhancements of SOC concentration for OM, MF, SR and NT over the SOC sequestration periods were about 34.7%, 36.1%, 22.0% and 12.7%, respectively.

Bhattacharyya R., et al. [128] reported that the ZT plots had nearly 17 and 14% higher total SOC and POC contents as compared with CT (~9.8 and 3.6 g kg⁻¹ soil) in the 0- to 5-cm soil layer after 9 yr of cropping. Jha M., et al. [129] revealed that the application of bio-nutrients containing *Pseudomonas mycostraw*, *Cyanobacteria*, and *Azospirillum* increased the SOC from 14 to 18% in a rice field in Bihar, India. Follett RF., et al. [130] reported that under NT, SOC pools and residual C₃-C were maintained and C₄-C pools increased (0.76 Mg C₄-C ha⁻¹ yr⁻¹), with 83% of the C₄-C accruing in the 0- to 30-cm soil depth. Increases in SOC were the result of increased C₄-C accumulation at depth while retaining residual C₃-C throughout the soil profile. Kahlon MS., et al. [131] reported higher SOC concentrations under conservation tillage than CT due to the disruption of soil aggregates and increased soil respiration because of release of protected SOC in the latter.

Zhu Liqun, *et al.* [132] also observed that soil TOC and LOC fractions in both rice and wheat straw return treatments were higher than with either wheat or rice straw return alone, indicating that increased straw return plays a very important role in increasing soil TOC and LOC fractions. Thakuria D., *et al.* [45] showed that the SOC content up to 15 cm soil depth was significantly higher in NT, RT and MB where wheat residues were left after harvest, than that in CT. The SOC in MB was significantly higher than CT in 15-30 cm soil layer. Ladha JK, *et al.* [133] and Alam MK, *et al.* [134] found that RT along with crop residues addition also benefit agro-ecosystems due to their effects on nutrient accumulation, crop yield, and improved agro-ecosystem resilience. Pandey D., *et al.* [135] compared four tillage treatments consisting of tillage time and intensity in a rice-wheat system in Varanasi, India, and reported that NT before sowing of rice and wheat could increase SOC by 0.59 Mg C ha⁻¹ yr⁻¹. Ghimire R, *et al.* [136] also observed that soil management practices, such as intensive tillage and crop residue burning or removal, contribute to decline in SOC. Weller S., *et al.* [137] reported that SOC is lost as CO₂ and CH₄ emissions from anaerobic soils *via* sequential oxidation-reduction reactions mediated by diverse microbial groups as follows: Organic matter+O₂→CO₂+H₂O (mediated by obligate aerobes), Organic matter+NO₃⁻→N₂+CO₂+H₂O (facultative anaerobes), Organic matter + MnO₂→Mn²⁺+ CO₂+H₂O (facultative anaerobes), Organic matter + Fe (OH)₃→Fe²⁺ +CO₂+H₂O (facultative anaerobes), Organic matter+SO₄²⁻→S²⁻+CO₂+H₂O (obligate anaerobes) and Organic matter+CO₂→CH₄+H₂O (obligate anaerobes).

Highly eroded soils like flooded rice soils, contribute to methane (CH₄) emission, which has adverse effects on the environment. Total anthropogenic CH₄ emission in 2010 has reached nearly 8 Gt CO₂-C eq. Yr⁻¹[138]. Of the major agriculture-related greenhouse gas emissions, rice fields contribute 11% of total annual CH₄ emissions. Mid-season drainage, intermittent flooding, or rotation of flooded rice with upland cropping can mitigate CH₄ emissions from rice-based cropping systems. Brar BS., *et al.* [139] reported that the SOC pool was lowest in unfertilized control (7.3 Mg ha⁻¹) and increased to 11.6 Mg ha⁻¹ with 100% NPK+FYM. Organic manures contain most of carbon in recalcitrant forms resulting in more C sequestration as it had already decomposed before its application to agricultural fields.

Ghimire R, *et al.* [121] discussed the influence of tillage, residue and nutrient management practices on SOC in rice-based cropping systems. A conceptual framework for such influences is presented in figure 6.

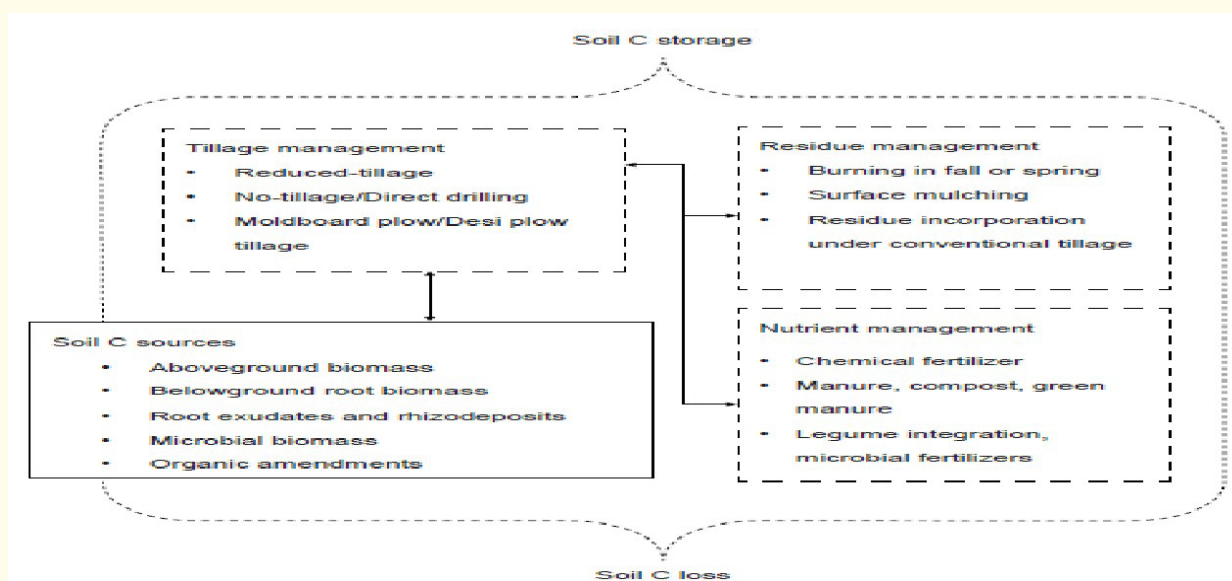


Figure 6: Conceptual framework to describe the influence of tillage, residue, and nutrient management practices on soil organic carbon in rice-based cropping systems. Carbon sources are present in a box marked with solid lines, and management practices are shown in boxes with dotted lines.

Source: Rajan, *et al.* (2017) [121].

Kushwa V., *et al.* [140] reported highest (8.8 g kg⁻¹) and lowest (5.9 g kg⁻¹) SOC concentrations in NT and CT, respectively in 0 - 5 cm depth whereas highest SOC was observed in MB in 5 - 15 cm depth. The stratification ratio of SOC was higher in NT (2.20) followed by RT (1.93), MB (1.68) and CT (1.51). Hossain M S., *et al.* [141] found greater SOC under poultry litter and cattle manure application in a rice-wheat-legume rotation over farmers' practice of no manure and fertilizer application in a rice-wheat fallow system in Bangladesh. Similarly, manure or straw addition when combined with N and P fertilizers increased SOC content by 0.30 Mg ha⁻¹ yr⁻¹ in a rice-wheat rotation in China [142]. Naresh RK., *et al.* [56] reported higher SOC (10.34 g kg⁻¹ soil) in permanently wide raised bed with residue retained plots followed by that in RT residue retained plots (8.14 g kg⁻¹ of soil) while lower SOC (5.49 g kg⁻¹ of soil) was found in puddled transplanted rice followed by wheat planted in conventionally tilled plots.

The above discussed information will be useful for developing appropriate technological and management solutions to increase agricultural sustainability and combat environmental degradation.

Effect of integrated nutrient management on soil properties and SOC

SOM is the central indicator of soil quality and health, which is strongly affected by crop and soil management. The importance of increased SOM or SOC lies in its positive effect on improving soil physical properties, conserving water, and increasing available nutrients. These improvements should ultimately lead to greater biomass and crop yield. There is considerable concern that if SOM or SOC concentrations in soils are decreased adversely, the productive capacity of agriculture will then be compromised by deterioration in soil physical properties and by impairment of soil nutrient cycling. Chaudhary J., *et al.* [143] reported that the NPK + FYM was superior to NPK alone in all soils in improving the SOC and soil physical properties, i.e., size of soil aggregates, soil microbial biomass and dehydrogenase activity. Table 3 shows that organic carbon, bacterial and fungal counts and activity of soil enzymes during wheat growth increased just after two years of soybean-wheat rotation and all these were higher in integrated nutrient management (INM) systems than with fertilizers alone. Kang GS., *et al.* [144] concluded that the rice-wheat cropping systems were sustainable only when fertilizers were supplemented with organic manures. After 17 years of continuous rice-wheat systems, there were significant improvements in SOC and total N, potentially mineralizable N and mycorrhizal infection, soil enzymes, soil microbial biomass, soil respiration, where 50% NPK for rice was complemented with 6 t/ha of either FYM or wheat straw or green manure after wheat grown with 100% NPK through fertilizers (Table 4).

Treatment	Organic C (%)	Bacteria (10 ⁶ /g)	Fungi (10 ⁴ /g)	Cellulase ¹	Urease ²	Acid Phosphatase ³	Alkaline Phosphatase ⁴	Aryl Sulphatase ⁵
FP	0.44	8.6	2.9	1.00	10.0	33.8	108.2	34.9
Chemical fertilizers	0.47	9.3	1.6	1.15	7.0	23.0	105.9	29.2
Organic manure	0.50	8.4	1.5	1.37	8.6	35.1	116.6	35.0
INM	0.54	13.0	2.1	1.27	9.0	27.1	115.8	31.4
LSD p = 0.05	-	2.3	0.9	0.15	2.5	10.9	41.4	11.1

Table 3: Microbial populations and soil enzymes in a vertisol in various nutrient management options in soybean- wheat rotation in India.

Cellulase = μM glucose/g soil/24h; Urease = μM NH₄-N g⁻¹ soil h⁻¹; acid and alkaline phosphatase and aryl sulphatase = μg p-nitrophenol g⁻¹ soil h⁻¹; FP: Farmer's Practice; INM: Integrated Nutrient Management
(Sources Rao, 2007) [145].

Treatment	OC%	TN kg/ha	Microbial infection (%)	DHA	Phosphatase	SMBC (mg/kg)	SMBN (mg/kg)	CO ₂ -C	PMN
Control	0.47	1292	28.6	105.6	15.1	141.1	48.3	4.4	5.9
100% NPK	0.50	1299	34.4	82.2	18.3	157.0	50.7	2.7	7.3
IPNS (FYM)	0.63	1508	51.0	123.9	23.2	163.0	55.6	7.4	13.6
IPNS (WS)	0.52	1236	49.6	105.6	22.9	153.3	52.1	4.5	7.1
IPNS (GM)	0.68	1442	52.0	119.0	27.6	172.8	63.1	5.5	15.9
LSD (p = 0.05)	0.05	NS	12.7	34.4	6.6	31.8	7.1	2.0	3.6

Table 4: Effect of continuous application of fertilizers and organic manures on soil health indicators of a sandy loam soil under rice-wheat system for 17 years in a semi-arid subtropical environment in India.

* DHA (dehydrogenase activity) = μg TPF g⁻¹ soil 24 h⁻¹; Phosphatase = μg PNP g⁻¹ soil h⁻¹; SMBC (soil microbial biomass carbon) and SMBN (soil microbial biomass nitrogen); CO₂-C respiration = mg CO₂-C evolved kg⁻¹ soil 10 d⁻¹; Potentially Mineralizable Nitrogen = mg kg⁻¹ soil 7d⁻¹. IPNS= Integrated Plant Nutrient System

Source: Kang., *et al.* (2005) [144]

Ghosh PK., *et al.* [146] and Sharma P., *et al.* [147] also observed that conservation tillage significantly increased soil respiration (+81.1%), SMBC (+104%) and soil dehydrogenase activity (+59.2%) compared to CT. Basak N [148] concluded that the soil enzyme activity, acid and alkaline phosphatase, and aryl sulphatase activity besides dehydrogenase activity were better under IPNS with GM as compared to IPNS with FYM. These results show a clear beneficial effect of continued green manuring on soil biological quality. Nath DJ., *et al.* [149] found that the building up of POM and SOM would demand addition of crop residues and chemical fertilizers in a balanced form and also to achieve intermediate C: N ratios since what is being built up through biological mechanisms is after all a reservoir of chemical nutrients in slow and intermediate pools of organic matter.

Tong X., *et al.* [150] showed that straw incorporation can replenish the SOM by enhancing carbon inputs, which has a positive effect on the accumulation of nutrients, improving the nutrient utilization efficiency. Zhu Liqun., *et al.* [132] revealed that soil LOC fractions were significantly and positively correlated with TOC concentrations at 0 - 30 cm soil depth. Such correlations suggested that TOC was a major determinant of soil LOC fractions. Lewis DB., *et al.* [83] found that combined application of pigeon pea+ wheat residue at 3 t ha⁻¹ resulted in higher dehydrogenase (20.9 µg-triphenyl formazan/g/h), β-glucosidase (145 µg p-nitrophenol/g/h), and acid phosphatase activities (24.5 µg p-nitrophenol/g/h) than the single application of wheat or pigeon pea residue in either season, or no residue control. Naresh RK., *et al.* [59] reported that the soil C content in the 400 - 800 and 800 - 1200 kg of soil m⁻² intervals performed similar change after 16 years. Changes over the length of the study averaged over tillage and crop residue practices were -0.07 ± 0.09 and -0.05 ± 0.02 kg C m⁻² in the 400 - 800 and 800 - 1200 kg of soil m⁻² intervals. This is equivalent to an average yearly change rate of -5.5 and -3.9 g C m⁻² yr⁻¹ for each mentioned soil mass interval.

Awale R., *et al.* [86] reported that the magnitude of changes in SOC fractions between conservation tillage practices (ST and NT) and CT was in the order of CPOM-C (17.2 - 41.8%) > cumulative C_{min} (6.6 - 22.5%) > KMnO₄-C (2.6 - 4.8%). These results suggest that tillage induced changes were sensitively reflected by the changes in physical (CPOM-C), chemical (KMnO₄-C), and biological (cumulative C_{min}) SOC fractions, and therefore can be used to estimate early changes in SOC dynamics. In terms of tillage effects, CPOM-C was the most sensitive fraction of organic C than total SOC which showed 2.7 - 6.6% enrichment. Thus, SOM is not only an important source of C for soil processes but also a sink for SOC sequestration. Cultivation can reduce SOC content and lead to soil deterioration, and can finally reduce soil productivity. By changing land use and tillage systems or by the adoption of sustainable crop rotations and the inclusion of pulses, SOC sequestration rates can be increased to a range of 20 - 75 g/m²/yr, and SOC may reach a new equilibrium within several decades.

Carbon input levels, and crop productivity

One of the current challenges in SOC studies is to quantify the mechanisms, capacity, and longevity of C stabilization in agricultural lands. The actual amount of soil C that can be stored is dependent on the farming systems and their management practices, soil type and climatic conditions, as well as the initial soil C level of the site. Restoration of depleted soils for sustaining crop production is the greatest challenge for sustaining agriculture and improving food security. Lowland rice-based cropping systems are considered to be the most stable systems and are also the largest SOC conserving systems.

Several studies reveal the positive effects of RT or NT, crop residue addition, and improved nutrient management to improve SOC and crop yields. Ghuman BS and Sur HS [151] reported that the RT in conjunction with crop residue improves soil properties and wheat yield on rice-wheat cropping systems on sandy loam soils in the subtropical climate of northwestern Punjab, India. Aulakh MS., *et al.* [152] reported that the incorporation of wheat residues in flooded rice could increase C storage and maintain high grain yields, also in rice-wheat systems. In that study, RT resulted in significantly higher wheat yield (5.1 Mg ha⁻¹) compared to CT (4.6 Mg ha⁻¹) and ZT (4.8 Mg ha⁻¹). Highest wheat yield (6.1 Mg ha⁻¹) was obtained in RT followed by CT (5.8 Mg ha⁻¹) under residue incorporation in the third year. Basak N [148] reported that total system productivity was 130% higher in a groundnut (*Arachis hypogaea* L.)-based systems (rainy season groundnut followed by other post rainy season crops namely, groundnut, chickpea [*Cicer arietinum* L.], wheat [*Triticum aestivum* L.], mustard [*Brassica* spp.], sunflower [*Helianthus annuus* L.]) than in a fallow-based (rainy season fallow followed by above post rainy season crops) system and was in the order: groundnut- groundnut > groundnut-chickpea > groundnut-wheat > groundnut-mustard > groundnut-sunflower, though sustainability yield index (SYI) was highest in the groundnut-groundnut system in Vertisols (*Typic Haplustert*). The gross C input was relatively higher but the C loss rate was greater for the groundnut-based system. The amount of crop residues needed ha⁻¹ yr⁻¹

to compensate the loss of SOC was estimated to be 4.3 Mg in the fallow-based and 7.6 Mg in the groundnut-based cropping system. Rasool R., *et al.* [154] established the quantitative relationship between relative soil quality index (SQI) and functional goal such as long-term average yields and SYI of sorghum and mungbean system (Table 5). Hossain M S., *et al.* [141] and Rasool R., *et al.* [154] also observed that the combinations of organic and inorganic fertilizers can augment SOC accumulation and improve crop production.

Location	Soil classification /textural type	Cropping system	Indicators identified	Indicator's contribution to SQI		
				> 25%	15 - 25%	< 15%
Varanasi	Typic Haplustept/ Sandy loam	Rice - Lentil	Available P and organic C	-	Available P	Organic C
Barrack-pore	Eutrochrept/ Sandy loam	Jute - Rice - Wheat	Mean weight diameter Available P, Microbial biomass C, and organic C	Mean weight diameter, Available P	Microbial biomass C	Organic C
Mohanpur	Aeric Haplaquept/ Sandy loam	Rice - Wheat	Alkaline phosphatase, organic C, mineralizable N	Alkaline phosphatase	Organic C	

Table 5: Soil quality indicators identified for different soil types and cropping systems and their contribution to soil quality index in three locations in India.

Source: Kusuma (2008) [153]

Koga N and Tsuji H [155] reported that the carbon input management practices (i.e. residue incorporation and manure application) significantly influenced the harvestable yield biomass production in wheat, potato, soybean and sugar beet in a temperate climate in Japan. Yield reduction resulting from residue removal was more pronounced in wheat than in the other three crops. The effects of tillage on crop yields were significant for wheat and potato as their yields were improved under RT than under CT. Srinivasarao C., *et al.* [125] reported that the conjunctive use of chemical fertilizers along with FYM produced higher agronomic yields and reduced the rate of SOC depletion. The higher average seed yields of pearl millet (809 kg ha⁻¹), cluster bean (576 kg ha⁻¹), and castor (827 kg ha⁻¹) over six cropping seasons were obtained through integrated use of fertilizers and FYM. For every increase in the profile SOC stock, there was an overall increase of 0.46 Mg of crop yield, comprising of individual yield increase of pearl millet (0.17 Mg ha⁻¹ y⁻¹), cluster bean (0.14) and castor (0.15) Mg⁻¹ SOC. Lewis DB., *et al.* [83] reported that comparatively lower SOC with CT than ST and NT could also be attributed to higher soil temperature favoring rapid C mineralization as a result of increased soil microbial activities under CT. Presence of high levels of microbial biomass and activity, due to increased substrate availability resulted in high quality soil and improved crop productivity. Lopes AAC., *et al.* [156] and Karami A., *et al.* [157] reported positive effects on the crop yield and soil productivity after straw application, which were attributed mainly to the improved soil quality. Salahin N., *et al.* [158] suggested that increased residue retention with minimum tillage practices improved soil properties and yields of upland crops but deeper tillage practices consistently maintained wetland rice production.

Need of predictive simulation models

The review suggests that various crop and soil management practices such as tillage, residue or nutrient management as well as various climates can influence SOM/SOC dynamics and SOC sequestration. Hence, experimental approaches alone will not provide enough information on the SOC components and SOC sequestration. Appropriate simulation models [159,162] will be necessary to predict SOC dynamics, including soil microbial biomass [159], and SOC sequestration in response to varying pedoclimate and agriculture systems so as to adapt to relevant management practices.

Conclusion

The dynamic processes that influence soil quality are complex, and they operate through time at different locations and situations. Soil organic matter is both a source of C release and a sink for SOC sequestration. Cultivation and intensive tillage practices can reduce and

change the distribution of SOC while appropriate crop rotations can increase or at least maintain the quantity and quality of SOM, and also improve soil chemical and physical properties. The return of crop residues and the application of manure and fertilizers can all contribute to an increase in soil nutrients and SOC content, but would need to be combined into an integrated nutrient management (INM) system for improvement. Thus, returning crop residue to the soil or adding FYM on the soil surface is crucial for improving the SOC levels. The large-scale implementation of the straw or manure plus inorganic fertilizer amendments will help enhance the SOC sequestration and promote food security but responses and impacts would differ across climates and regions.

Conservation agriculture based management systems such as reduced or no tillage, crop residue addition, FYM incorporation, and INM can increase SOC accumulation and improve sustainability of agricultural systems. No tillage can increase soil aggregations, improve soil properties, and favorably influence SOC accretion. Effects of crop residue addition are often observed when they are integrated with reduced tillage systems or with improved nutrient management. This study reviewed a large number of studies and identified several research opportunities in relation to the impacts of alternative tillage, crop residue, and nutrient management practices to increase SOC sequestration and enhance agricultural sustainability. Evaluating SOC dynamics of predominant crops and cropping systems of any region or country with alternative management practices, and evaluating their potential impacts on agricultural system sustainability would substantially benefit producers, researchers, and policy makers. More research evaluating impacts of alternative crop and soil (tillage, residues and nutrient) management practices on SOC dynamics and SOC sequestration is required. Specifically, understanding of SOC sequestration and nutrient dynamics during transition from conventional to conservation tillage for varying cropping systems are required. More research on the influence of alternative tillage, crop residue, and nutrient management systems on SOC dynamics and its sequestration, and development of SOC monitoring system through carefully-designed long-term experiments combined with C and N simulation models will advance our understanding of the SOC dynamics in major crops and cropping systems across representative climates and locations which will help improve agricultural system sustainability globally. This review has mostly focused on the impact of tillage and residue management systems on the short-term, which are yet to reach equilibrium. Although results may vary in the long-run, the short-term changes can provide an indication of the direction of changes, and a useful notion on the advantages and limitations in adopting specific agronomic management practices.

Bibliography

1. Haynes RJ. "Labile organic matter fractions as central components of the quality of agricultural soils: an overview". *Advances in Agronomy* 85 (2005): 221-268.
2. Rajan G., et al. "Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice-wheat rotation system". *Paddy and Water Environment* 10.2 (2012): 95-102.
3. Blair GJ., et al. "Soil carbon fractions based on their degree of oxidation and the development of a carbon management index for agricultural system". *Australia Journal of Agricultural Research* 46.7 (1995): 1459-1466.
4. Rudrappa L., et al. "Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustept of semi-arid subtropical India". *Soil and Tillage Research* 88.1-2 (2006): 180-192.
5. Yang CM., et al. "Organic carbon and its fractions in paddy soil as affected by different nutrient and water regimes". *Geoderma* 124.1-2 (2005): 133-142.
6. Baker JM., et al. "Tillage and soil carbon sequestration-what do we really know:?" *Agriculture Ecosystems and Environment* 118.1-4 (2007): 1-5.
7. Lal R. "Climate-resilient agriculture and soil organic carbon". *Indian Journal of Agronomy* 58.4 (2013): 440-450.
8. Six J., et al. "Soil structure and organic matter: I. Distribution of aggregate-size fractions and aggregate-associated carbon". *Soil Science Society of America Journal* 64 (2000): 681-689.

9. Angers DA, "Changes in soil aggregation and organic carbon under corn and alfalfa". *Soil Science Society of America Journal* 56.4 (1992): 1244-1249.
10. Christensen BT. "Physical fractionation of soil and structural and functional complexity in organic matter turnover". *European Journal of Soil Science* 52.3 (2001): 345-353.
11. Beare MH., et al. "Aggregate protected and unprotected organic matter pools in conventional and no-tillage soils". *Soil Science Society of American Journal* 58.3 (1994): 787-795.
12. Six J., et al. "Stabilization mechanisms of soil organic matter: implication for C-saturation of soils". *Plant and Soil* 241.2 (2002): 155-176.
13. Xia Xu., et al. "Soil properties control decomposition of soil organic carbon: Results from data-assimilation analysis". *Geoderma* 262 (2016): 235-142.
14. Hernanz JL., et al. "Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain". *Soil and Tillage Research* 66.2 (2002): 129-141.
15. Liu SP., et al. "Effects of tillage and straw returning on soil fertility and grain yield in a wheat-rice double cropping system". *Transactions of the CSAE* 22.7 (2006): 48-51.
16. Sun X., et al. "Effect of long-term application of straw on soil fertility". *Chinese Journal of Ecology and Agriculture* 16.3 (2007): 587-592.
17. West TO and Post WM. "Soil organic carbon sequestration rates by tillage and crop rotation". *Soil Science Society of America Journal* 66 (2002): 1930-1946.
18. Chen HQ., et al. "Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau of China". *Soil and Tillage Research* 106 (2009): 85-94.
19. Wang DD., et al. "Short-term Effects of Tillage Practices and Wheat-straw Returned to the Field on Topsoil Labile Organic Carbon Fractions and Yields in Central China". *Journal of Agronomy and Environmental Science* 32.4 (2013): 735-740.
20. Miller AJ., et al. "The effect of climate and cultivation on soil organic C and N". *Biogeochemistry* 67.1 (2004): 57-72.
21. Yamashita T., et al. "Organic matter in density fractions of water-stable aggregates in silty soils: effect of land use". *Soil Biology and Biochemistry* 38.11 (2006): 3222-3234.
22. Seiter Katherina., et al. "Organic carbon content in surface sediments—defining regional provinces". *Deep-Sea Research Part I: Oceanographic Research Papers* 51.12 (2004): 2001-2026.
23. Dillon Edward C., et al. "Large surface area activated charcoal and the inhibition of aspirin absorption". *Annals of Emergency Medicine* 18.5 (1989): 547-552.
24. Chen S., et al. "Improving soil protein extraction for metaproteome analysis and glomalin-related soil protein detection". *Proteomics* 9.21 (2009): 49-70.
25. Cambardella CA and Elliott ET. "Particulate soil organic-matter changes across a grassland cultivation sequence". *Soil Science Society of America Journal* 56.3 (1991): 777-783.

26. Murphy DV, *et al.* "Stratification of microbial biomass C and N and gross N mineralization with soil depth in two contrasting Western Australian Agricultural soils". *Australian Journal of Soil Research* 36 (1998): 45-56.
27. Arshad MA, *et al.* "Physical Tests for Monitoring Soil Quality". In: Doran JW, Jones AJ, editors. *Methods for assessing soil quality*. Madison, WI. (1996): 123-124.
28. Kemper WD and Rosenau RC. "Aggregate Stability and Size Distribution". In: Klute A, editor. *Methods of soil analysis. Part 1. Physical and mineralogical methods*. Madison, WI. (1986): 425-442.
29. Oades JM and Waters AG. "Aggregate hierarchy in soils". *Australian Journal of Soil Research* 29 (1991): 815-828.
30. Gao YJ, *et al.* "Long-term impact of different soil management on organic matter and total nitrogen in rice-based cropping system". *Soil and Environmental Science* 9.1 (2000): 27-30.
31. Govaerts B, *et al.* "Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems". *Plant and Soil* 291 (2007): 39-54.
32. Koushwaha CP. *et al.* "Soil organic matter and water-stable aggregates under different tillage and residue conditions in a tropical dryland agro-ecosystem". *Applied Soil Ecology* 16 (2001): 229-241.
33. Hao XY and Chang C. "Effect of 25 annual cattle manure applications on soluble and exchangeable cations in soil". *Soil Science* 167 (2002): 126-134.
34. Munkholm LJ, *et al.* "Aggregate strength and mechanical behaviour of a sandy loam soil under long term fertilization treatments". *European Journal of Soil Science* 53 (2002): 129-137.
35. Hao XY, *et al.* "Soil carbon and nitrogen response to 25 annual cattle manure applications". *Journal of Plant Nutrient and Soil Science* 166 (2003): 239-245.
36. Madari Beata, *et al.* "No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil". *Soil and Tillage Research* 80 (2005): 185-200.
37. Zotarelli I, *et al.* "Impact of tillage and crop rotation on aggregate-associated carbon in two Oxisols". *Soil Science Society of America Journal* 69 (2005): 482-491.
38. Blair N, *et al.* "Decomposition of ¹³C and ¹⁵N labelled plant residue materials in two different soil types and its impact on soil carbon, nitrogen and aggregate stability, and aggregate formation". *Australian Journal of Soil Research* 43 (2005): 873-886.
39. De Gryze S, *et al.* "A quantification of short-term macro-aggregate dynamics: influences of wheat residue input and texture". *Soil Biology and Biochemistry* 37.1 (2005): 55-66.
40. Helfrich M, *et al.* "Effect of litter quality and soil fungi on macroaggregate dynamics and associated partitioning of litter carbon and nitrogen". *Soil Biology and Biochemistry* 40 (2008): 1823-1835.
41. Hati KM, *et al.* "Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an alfisol". *Geoderma* 148.2 (2008): 173-179.
42. Song MW, *et al.* "Effects of different tillage methods on soil organic carbon pool". *Journal of Agro-Environment Science* 27.2 (2008): 622-626.

43. Simansky V, *et al.* "Soil tillage and fertilization of Orthic Luvisol and their influence on chemical properties, soil structure stability and carbon distribution in water-stable macro-aggregates". *Soil and Tillage Research* 100.1-2 (2008): 125-132.
44. Chung H, *et al.* "Evidence for carbon saturation in a highly structured and organic-matter-rich soil". *Soil Science Society of America Journal* 74.1 (2009): 130-138.
45. Thakuria D, *et al.* "Evaluation of rice-legume-rice cropping system on grain yield, nutrient uptake, nitrogen fixation, and chemical, physical, and biological properties of soil". *Biology and Fertility of Soils* 45.3 (2009): 237-251.
46. Lahmar R. "Adoption of conservation agriculture in Europe". *Land Use Policy* 21.1 (2010): 4-10.
47. Bandyopadhyay KK, *et al.* "Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean". *Soil and Tillage Research* 110.1 (2010):115-125.
48. Huang S, *et al.* "Soil aggregation and organic carbon fractions affected by long-term fertilization in a red soil of subtropical China". *Geoderma* 154.3-4 (2010): 364-369.
49. Li CF, *et al.* "Short-term effects of conservation management practices on soil labile organic carbon fractions under a rape-rice rotation in central China". *Soil and Tillage Research* 119 (2012): 31-37.
50. Mandal S, *et al.* "Tillage and residue management effect on soil hydro-physical environment under pigeon pea (*Cajanus cajan*)-wheat (*Triticum aestivum*) rotation". *Indian Journal of Agricultural Sciences* 83 (2013): 502-507.
51. Zhou H, *et al.* "Effects of organic and inorganic fertilization on soil aggregation in an ultisol as characterized by synchrotron based X-ray micro-computed tomography". *Geoderma* 196 (2013): 23-30.
52. Zhang-liuDU, *et al.* "Soil Aggregate Stability and Aggregate-Associated Carbon under Different Tillage Systems in the North China Plain". *Journal of Integrative Agriculture* 12.11 (2013): 2114-2123.
53. Hati KM, *et al.* "Conservation Tillage Effects on Soil Physical Properties, Organic Carbon Concentration and Productivity of Soybean-Wheat Cropping System". *Journal of Agricultural Physics* 14.2 (2014): 121-129.
54. Liqun Zhu, *et al.* "Effects of Different Tillage and Straw Return on Soil Organic Carbon in a Rice-Wheat Rotation System". *PLOS ONE* 9.2 (2014): 1-7.
55. Paul BK, *et al.* "Medium-Term Impact of Tillage and Residue Management on Soil Aggregate Stability, Soil Carbon and Crop Productivity". *Agriculture Ecosystems and Environment* 164 (2013):14-22.
56. Naresh RK, *et al.* "Tillage crop establishment strategies and soil fertility management: resource use efficiencies and soil carbon sequestration in a rice-wheat cropping system". *Ecology Environment and Conservation* 21 (2015): S121-S128.
57. Milad Mirzaei Aminiyan, *et al.* "Aggregation stability and organic carbon fraction in a soil amended with some plant residues, nano-zeolite, and natural zeolite". *International Journal of Recycling of Organic Waste in Agriculture* 4.1 (2015): 11-22.
58. Sandeep S, *et al.* "Soil carbon fractions under maize-wheat system: effect of tillage and nutrient management". *Environmental Monitoring and Assessment* 188.1 (2016): 14-27.
59. Naresh RK, *et al.* "Long term effects of tillage and residue management on soil aggregation and soil carbon sequestration under rice-wheat cropping system in Typic Ustochrept soil of Uttar Pradesh". *International Journal of Current Microbiology and Applied Sciences* 6.10 (2017): 1-36.

60. Franzluebbers AJ., *et al.* "Sorghum, wheat and soybean production as affected by long-term tillage, crop sequence, and N fertilization". *Plant and Soil* 173.1 (1995a): 55-65.
61. Manjaiah K and Singh D. "Soil organic matter and biological properties after 26 years of maize-wheat-cowpea cropping as affected by manure and fertilization in cambisol in semiarid region of India". *Agriculture Ecosystems and Environment* 86.2 (2001): 155-162.
62. Mina BL., *et al.* "Changes in soil nutrient content and enzymatic activity under conventional and zero tillage practices in an Indians and clayloam soil". *Nutrient Cycling in Agroecosystems* 82.3 (2008): 273-281.
63. Sa JCM and Lal R. "Stratification ratio of soil organic matter pools as an indicator of carbon sequestration in a tillage chronosequence on a Brazilian Oxisol". *Soil and Tillage Research* 103.1 (2009): 46-56.
64. Verhulst N., *et al.* "Conservation agriculture, improving soil quality for sustainable production systems?" In: Lal R, Stewart BA (eds) *Advances in soil science: food security and soil quality*. CRC Press, Boca Raton (2010): 137-208.
65. Six J., *et al.* "Aggregate and soil organic matter dynamics under conventional and no-tillage systems". *Soil Science Society of America Journal* 63.5 (1999): 1350-1358.
66. Yang JC., *et al.* "The dynamics of soil organic matter in cropland responding to agricultural practices". *Acta Ecologica Sinica* 23.4 (2003): 787-796.
67. Bhattacharyya R., *et al.* "Tillage and Irrigation Effects on Soil Aggregation and Carbon Pools in the Indian Sub-Himalayas". *Agronomy Journal* 105.1 (2013): 101-112.
68. Duval ME., *et al.* "Analysis of organic fractions as indicators of soil quality under natural and cultivated systems". *Soil and Tillage Research* 131 (2013): 11-19.
69. Liu E., *et al.* "Long-Term Effect of Manure and Fertilizer on Soil Organic Carbon Pools in Dryland Farming in Northwest China". *PLoS ONE* 8.2 (2013): 1-9.
70. Kumari M., *et al.* "Soil aggregation and associated organic carbon fractions as affected by tillage in a rice-wheat rotation in North India". *Soil Science Society of America Journal* 75.2 (2011): 562-567.
71. Xue J., *et al.* "Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in Southern China". *Soil and Tillage Research* 153 (2015): 161-168.
72. Hopkins DW and Shiel RS. "Size and activity of soil microbial communities in long term experimental grassland plots treated with manure and inorganic fertilizers". *Biology and Fertility of Soils* 22.1-2 (1996): 66-70.
73. Omay AB. "Soil microbial and chemical property under long crop rotation and fertilization". *Soil Science Society of America Journal* 61.6 (1997): 1672-1678.
74. Wani SP., *et al.* "Improved management of Vertisols in semiarid tropics for increased productivity and soil carbon sequestration". *Soil Use and Management* 19 (2003): 217-222.
75. Ghani A., *et al.* "Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilization, grazing and cultivation". *Soil Biology and Biochemistry* 35.9 (2003): 1231-1243.
76. Spedding TA., *et al.* "Soil microbial dynamics in maize-growing soil under different tillage and residue management systems". *Soil Biology and Biochemistry* 36 (2004): 499-512.

77. Tresder KK., *et al.* "The contribution of root exudates, symbionts, and detritus to carbon sequestration in the soil. Roots and soil management: interactions between roots and the soil". *Soil Science Society of America Journal* (2005): 145-16234.
78. Bowman RA., *et al.* "Soil organic matter changes in intensively cropped dryland systems". *Soil Science Society of America Journal* 63.1 (1999): 186-191.
79. Six J., *et al.* "Bacterial and fungal contributions to carbon sequestration in agro-systems". *Soil Science Society of America Journal* 70 (2008): 555-569.
80. Mandal A., *et al.* "Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages". *Bioresource Technology* 98.18 (2007): 3585-3592.
81. Hao XH., *et al.* "Effect of long-term application of inorganic fertilizer and organic amendments on soil organic matter and microbial biomass in three subtropical paddy soils". *Nutrient Cycling of Agro-ecosystems* 81.1 (2008): 17-24.
82. Yang Y., *et al.* "Effects of forest conversion on soil labile organic carbon fractions and aggregate stability in subtropical China". *Plant and Soil* 323.1-2 (2009): 153-162.
83. Lewis DB., *et al.* "Labile carbon and other soil quality indicators in two tillage systems during transition to organic agriculture". *Renewable Agriculture and Food Systems* 26.4 (2011): 342-353.
84. Wang J., *et al.* "Effects of tillage and residue management on soil microbial communities in North China". *Plant, Soil and Environment* 58 (2012): 28-33.
85. Moharana PC., *et al.* "Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet-wheat cropping system in an Inceptisol of subtropical India". *Field Crops Research* 136 (2012): 32-41.
86. Awale R., *et al.* "Tillage and N-fertilizer influences on selected organic carbon fractions in a North Dakota silt clay soil". *Soil and Tillage Research* 134 (2013): 213-222.
87. Hurisso TT., *et al.* "Rapid changes in microbial biomass and aggregate size distribution in response to changes in organic matter management in grass pasture". *Geoderma* 193 (2013): 68-75.
88. Das TK., *et al.* "Impacts of conservation agriculture on total soil organic carbon retention potential under an irrigated agro-ecosystem of the western Indo-Gangetic Plains". *European Journal of Agronomy* 51 (2013): 34-42.
89. Mikha MM., *et al.* "Long-term tillage impacts on soil aggregation and carbon dynamics under wheat-fallow in the Central Great Plains". *Soil Science Society of America Journal* 77 (2013): 594-605.
90. Wuest S. "Seasonal variation in soil organic carbon". *Soil Science Society of America Journal* 78.4 (2014): 1442-1447.
91. Sepat S., *et al.* "Productivity, Organic Carbon and Residual Soil Fertility of Pigeon pea-Wheat Cropping System under Varying Tillage and Residue Management". *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* 84.3 (2014): 561-571.
92. Naresh RK., *et al.* "Carbon, Nitrogen Dynamics and Soil Organic Carbon Retention Potential after 16 years by different land uses and Nitrogen Management in Typic Ustochrept Soil". *Paddy and Water Environment* (2017a).
93. Dobermann A and Witt C. "The potential impact of crop intensification on carbon and nitrogen cycling in intensive rice systems". In: Carbon and nitrogen dynamics in flooded soils (Kirk G J D, Olk D C eds) International Rice Research Institute, Los Baños, Philippines (2000): 1-25.

94. Aoyama M and Kumakura N. "Quantitative and qualitative changes of organic matter in an ando soil induced by mineral fertilizer and cattle manure application for 20 years". *Soil Science and Plant Nutrition* 47 (2001): 241-252.
95. Liu XB, *et al.* "Dynamics of soil organic carbon under different agricultural management systems in the black soil of China". *Communication Soil Science and Plant Analysis* 34 (2003): 973-984.
96. Campbell CA, *et al.* "Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan - Effect of crop rotations and fertilizers". *Canadian Journal of Soil Science* 80.1 (2000): 179-192.
97. Schnabel RR, *et al.* "The effects of pasture management practices". In: Follett, R.F., Kimble, J.M., Lal, R. (Editors) *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, Lewis Publishers, Boca Raton, FL (2001): 291-322.
98. Witt C, *et al.* "Crop rotation and residue management effects on carbon sequestration, nitrogen cycling and productivity of irrigated rice system". *Plant and Soil* 225.1-2 (2000): 263-278.
99. Francioso O, *et al.* "Spectroscopic characterization of soil organic matter in long-term amendments trials". *Soil Science* 165 (2000): 495-504.
100. Franzluebbers AJ. "Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA". *Soil and Tillage Research* 83.1 (2005):120-147.
101. Mikha MM and Rice CW. "Tillage and manure effects on soil and aggregate associated carbon and nitrogen". *Soil Science Society of America Journal* 68 (2004): 809-816.
102. Wang Q, *et al.* "Soil chemical properties and microbial biomass after 16 years of no-tillage farming on the Loess Plateau, China". *Soil and Tillage Research* 144 (2008): 502-508.
103. Al-Kaisi MM. *et al.* "Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils". *Agriculture Ecosystems and Environment* 105 (2005): 635-647.
104. Deneff K and Six J". Clay mineralogy determines the importance of biological versus abiotic processes for macro aggregate formation and stabilization". *European Journal of Soil Science* 56 (2005): 469-479.
105. Abid M and Lal R. "Tillage and drainage impact on soil quality. I. Aggregate stability, carbon and nitrogen pools". *Soil and Tillage Research* 100.1-2 (2008): 89-98.
106. He JN, *et al.* "Effects of 10 years of conservation tillage on soil properties and productivity in the farming -pastoral ecotone of Inner Mongolia, China". *Soil Use and Management* 25 (2009): 201-209.
107. Thierfelder C and Wall PC. "Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe". *Soil Use and Management* 28 (2012): 209- 220.
108. Zibilske LM, *et al.* "Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil". *Soil and Tillage Research* 66.2 (2002): 153-163.
109. Tabaglio V, *et al.* "Physico-chemical indicators and micro-arthropod communities as influenced by no-till, conventional tillage and nitrogen fertilization after four years of continuous maize". *Soil and Tillage Research* 105.1 (2009): 135-142.
110. Dao TH. "Tillage and crop residue effects on carbon dioxide evolution and carbon storage in a Paleustoll". *Soil Science Society of America Journal* 62.1 (1998): 250 - 256.

111. Gal A., *et al.* "Soil carbon and nitrogen accumulation with long-term no-till versus moldboard plowing overestimated with tilled-zone sampling depths". *Soil and Tillage Research* 96.1-2 (2007): 42-51.
112. Ussiri DA and Lal R. "Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio". *Soil and Tillage Research* 104.1 (2009): 39-47.
113. Guo LB and Gifford RM. "Soil carbon stocks and land use change: A meta analysis". *Global Change Biology* 8 (2002): 345-360.
114. Mazzoncini M., *et al.* "Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content". *Soil and Tillage Research* 114.2 (2011): 165-174.
115. Bayer C., *et al.* "Carbon sequestration in two Brazilian Cerrado soils under no-till". *Soil and Tillage Research* 86.2 (2006): 237-245.
116. Cerri CEP, *et al.* "Tropical agriculture and global warming: impacts and mitigations options". *Scientific Agriculture* 64.1 (2007): 83-99.
117. Lal R., *et al.* "Soil carbon sequestration to mitigate climate change and advance food security". *Soil Science* 172 (2007): 943-956.
118. Causarano HJ., *et al.* "Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain". *Soil Science Society of America Journal* 72 (2008): 221-230.
119. Kukul SS., *et al.* "Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice-wheat and maize-wheat systems". *Soil and Tillage Research* 102 (2009): 87-92.
120. Tian SZ., *et al.* "Effects of different tillage methods and straw-returning on soil organic carbon content in a winter wheat field". *Chinese Journal of Applied Ecology* 21.2 (2010): 373-378.
121. Ghimire R., *et al.* "Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems: A review". *Journal of Integrative Agriculture* 16.1 (2017): 1-15.
122. Srinivasarao C., *et al.* "Long-Term Effects of Soil Fertility Management on Carbon Sequestration in a Rice-Lentil Cropping System of the Indo-Gangetic Plains". *Soil Science Society of America Journal* 76 (2011):168-178.
123. Briedis C., *et al.* "Soil organic matter pools and carbon-protection mechanisms in aggregate fractions influenced by surface liming in a no-till system". *Geoderma* 170 (2012): 80-88.
124. Chen HYH and Shrestha BM. "Stand age, fire and clear cutting affect soil organic carbon and aggregation of mineral soils in boreal forests". *Soil Biology and Biochemistry* 50 (2012): 149-157.
125. Srinivasarao C., *et al.* "Long-Term Manuring and Fertilizer Effects on Depletion of Soil Organic Carbon Stocks under Millet-Cluster bean -Castor Rotation in Western India". *Land Degraded Development* (2011a).
126. Ghimire R., *et al.* "Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice-wheat rotation system". *Paddy and Water Environment* 10.2 (2012): 95-102.
127. Zhu Liqun., *et al.* "Effect of Improved Management Practices on Soil Organic Carbon Sequestration in Wheat-maize Double Cropping System in North China". *Journal of Agricultural Sciences* 4.9 (2012):114-125.
128. Bhattacharyya R., *et al.* "Tillage and Irrigation Effects on Soil Aggregation and Carbon Pools in the Indian Sub-Himalayas". *Agronomy Journal* 105.1 (2013): 101-112.
129. Jha M., *et al.* "Microbial consortium for sustainable rice production". *Agroecology and Sustainable Food Systems* 37 (2013): 340-362.

130. Follett RF, *et al.* "Soil carbon dynamics for irrigated corn under two tillage systems". *Soil Science Society of America Journal* 77 (2013): 951-963.
131. Kahlon MS, *et al.* "Twenty years of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio". *Soil and Tillage Research* 126 (2013): 151-158.
132. Zhu Liquan, *et al.* "Short-term responses of soil organic carbon and carbon pool management index to different annual straw return rates in a rice-wheat cropping system". *Catena* 135 (2015): 283-289.
133. Ladha JK, *et al.* "Role of nitrogen fertilization in sustaining organic matter in cultivated soils". *Journal of Environmental Quality* 40 (2011): 1756-1766.
134. Alam MK, *et al.* "Effect of tillage practices on soil properties and crop productivity in wheat-mungbean-rice cropping system under Subtropical climatic conditions". *The Scientific World Journal* 14 (2014): 1-15.
135. Pandey D, *et al.* "Recalcitrant and labile carbon pools in a sub-humid tropical soil under different tillage combinations: A case study of rice-wheat system". *Soil and Tillage Research* 143 (2014): 116-122.
136. Ghimire R, *et al.* "Long-term crop residue and nitrogen management effects on soil profile carbon and nitrogen in wheat-fallow systems". *Agronomy Journal* 107.6 (2015): 2230-2240.
137. Weller S, *et al.* "Greenhouse gas emissions and global warming potential of traditional and diversified tropical rice rotation systems". *Global Change Biology* 22.1 (2016): 432-448.
138. Climate Change: The Physical Science Basis" presents clear and robust conclusions. Working Group I contribution to the IPCC's Fifth Assessment (2013).
139. Brar BS, *et al.* "Effects of Long Term Application of Inorganic and Organic Fertilizers on Soil Organic Carbon and Physical Properties in Maize-Wheat Rotation". *Agronomy Journal* 5 (2015): 220-238.
140. Kushwa V, *et al.* "Long-term Conservation Tillage Effect on Soil Organic Carbon and Available Phosphorous Content in Vertisols of Central India". *Agricultural Research* 5.4 (2016): 353-361.
141. Hossain M S, *et al.* "Productivity and soil fertility of the rice-wheat system in the High Ganges River Floodplain of Bangladesh is influenced by the inclusion of legumes and manure". *Agriculture Ecosystems and Environment* 218 (2016): 40-52.
142. Fang C, *et al.* "Similar response of labile and resistant soil organic matter pools to changes in temperature". *Nature* 433 (2005): 57-59.
143. Chaudhary J, *et al.* "Assessing Soil Quality under Long-Term Rice-Based Cropping System". *Communication in Soil Science and Plant Analysis* 36.9-10 (2005): 1141-1161.
144. Kang GS, *et al.* "A new index to assess soil quality and sustainability of wheat based cropping systems". *Biology and Fertility of Soils* 41.6 (2005): 389-398.
145. Rao DLN. "Microbial Diversity, Soil Health and Sustainability". *Journal of the Indian Society of Soil Science* 55.4 (2007): 392-403.
146. Ghosh PK, *et al.* "Conservation agriculture towards achieving food security in North East India". *Current Science* 99.7 (2010): 915-921.
147. Sharma P, *et al.* "Conservation tillage, optimal water and organic nutrient supply enhance soil microbial activities during wheat (*Triticum aestivum* L.) cultivation". *Brazilian Journal of Microbiology* 42.2 (2011): 531-542.

148. Basak N. "Assessment of soil health under rice-based cropping systems". Ph.D. Thesis, BCKVV, West Bengal, India (2011): 221.
149. Nath DJ, *et al.* "Soil enzymes and microbial biomass carbon under rice-toria sequence as influenced by nutrient management". *Journal of the Indian Society of Soil Science* 60.1 (2012): 20-24.
150. Tong X., *et al.* "Long-term fertilization effects on organic carbon fractions in a red soil of China". *Catena* 113 (2014): 251-259.
151. Ghuman BS and Sur HS. "Tillage and residue management effects on soil properties and yields of rain-fed maize and wheat in a sub-humid subtropical climate". *Soil and Tillage Research* 58.1-2 (2001): 1-10.
152. Aulakh MS., *et al.* "Managing crop residue with green manure, urea, and tillage in a rice-wheat rotation". *Soil Science Society of America Journal* 65 (2001): 820-827.
153. Kusuma GJ. "Assessment of soil quality under different land use treatments in rainfed Alfisol". Ph.D Thesis, Jawaharlal Nehru Technological University, Hyderabad, Andhra Pradesh, India (2008): 250.
154. Rasool R., *et al.* "Soil physical fertility and crop performance as affected by long term application of FYM and inorganic fertilizers in rice-wheat system". *Soil and Tillage Research* 96 (2007): 64-72.
155. Koga N and Tsuji H. "Effects of reduced tillage, crop residue management and manure application practices on crop yields and soil carbon sequestration on an Andisol in northern Japan". *Soil Science and Plant Nutrition* 55.4 (2009): 546-557.
156. Lopes A A C. *et al.* "Interpretation of microbial soil indicators as a function of crop yield and organic carbon". *Soil Science Society of America Journal* 77 (2012): 461-472.
157. Karami A., *et al.* "Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties". *Agriculture Ecosystems and Environment* 148 (2012): 22-28.
158. Salahin N., *et al.* "Effect of Tillage and Residue Retention on Soil Properties and Crop Yields in Wheat-Mungbean- Rice Crop Rotation under Subtropical Humid Climate". *Journal of Soil Science* 7 (2017): 1-17.
159. Louise BP, *et al.* "soil C and N models that integrate microbial diversity". *Environmental Chemistry Letters* 14.3 (2016): 331-344.
160. Yadvinder-Singh., *et al.* "Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics". *Advances in Agronomy* 85 (2005): 269-407.
161. Timsina J and Connor, DJ. "The productivity and management of rice-wheat cropping systems: issues and challenges". *Field Crops Research* 69 (2001): 93-132.
162. Gaydon D S., *et al.* "Modelling the role of algae in rice crop nutrition and soil organic carbon maintenance". *European Journal of Agronomy* 39 (2012): 35-43.

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