

## Review Article

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## Effects of Conservation Agriculture and Temperature Sensitivity on Soil Organic Carbon Dynamics; its Fractions, and Soil Aggregate Stability in RWCS of Sub-tropical India: A Review

S. P. Singh<sup>1\*</sup>, R. K. Naresh<sup>2</sup>, Yogesh Kumar<sup>1</sup> and Robin Kumer<sup>3</sup>

<sup>1</sup>Department of Soil Science & Agricultural Chemistry, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, (UP), India

<sup>2</sup>Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, (UP), India

<sup>3</sup>Department of Soil Science & Agricultural Chemistry, Acharya Narendra Dev University of Agriculture & Technology, Kumar Gang, Ayodhya, (UP), India

\*Corresponding author

### ABSTRACT

Soil tillage can affect the stability and formation of soil aggregates by disrupting soil structure. Frequent tillage deteriorates soil structure and weakens soil aggregates, causing them to be susceptible to decay. Different types of tillage systems affect soil physical properties and organic matter content, in turn influencing the formation of aggregates. Retention of carbon (C) in arable soils has been considered as a potential mechanism to mitigate soil degradation and to sustain crop productivity. Soil organic carbon plays the crucial role in maintaining soil quality. The impact and rate of SOC sequestration in CA and conventional agriculture is still in investigation in this environment. Soil organic carbon buildup was affected significantly by tillage and residue level in upper depth of 0-20 cm but not in lower depth of 20-40 cm. Higher SOC content of 19.44 g kg<sup>-1</sup> of soil was found in zero tilled residue retained plots followed by 18.53 g kg<sup>-1</sup> in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg<sup>-1</sup> of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots. Zero tilled residue retained plots sequestered 0.91 g kg<sup>-1</sup> yr<sup>-1</sup> SOC which was 22.63% higher over the conventionally tilled residue removed plots. Therefore, CA in rice-wheat system can help directly in building-up of soil organic carbon and improve the fertility status of soil.

#### Keywords

Soil organic carbon, SOC storage, Labile SOM dynamics, Aggregate stability

#### Article Info

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### Introduction

Rice and wheat cropping system is very intensive and more exhaustive (Sharma and Behera 2011). Production and productivity of the system is very low (Regmi *et al.*, 2003).

Declining or stagnant yield and impact on environment are major well known problems of cropping system (Khanal *et al.*, 2012). Soil organic carbon is the fraction of organic matter; the decomposed plant and animal materials including microbial population. It is

directly associated with nutrient availability, soil physical properties, and biological soil health and buffer actions over various toxic substances. Soil carbon level determined to the abundance of nutrient and equilibrium of various nutrient elements (Bot and Benites, 2005). With the increase in the concentration of soil organic carbon, yield of the crop is increased directly especially in sandy loam soil (Rattan and Datta, 2011). The major cause of yield decline in this system is nutrient imbalance, which is associated with soil organic matter, declining over time where intensive cropping has been experienced (Ladha *et al.*, 2000). The equilibrium level of SOC in the soil is the function of climate, soil and nature of vegetation (Rattan and Datta, 2011). The carbon content was decreased up to by 15% per unit increase in pH, increase by 1% per percent increase in clay content and decreased up to by 0.3% per percent increase in slope (Bronson *et al.*, 1997).

Physical fractionation is widely used to study the storage and turnover of soil organic matter (SOM), because it incorporates three levels of analysis: SOM structural and functional complexity, and the linkage to functioning (Christensen, 2001; Wang *et al.*, 2015). Soil aggregates, which are the secondary organomineral complexes of soil, are important for the physical protection of SOM. Thus, changes in soil aggregates may be used to characterize the impacts of management strategies on soil quality, including soil porosity, aeration, water retention, and erodibility (Christensen, 2001). Organic carbon (OC) stored in macro-aggregates has a stronger response to land-use change than that of SOC, and may be used as an important diagnostic indicator for the potential changes (Denef *et al.*, 2007). To some extent, the protection of macro-aggregates is considered to be fundamental for sustaining high SOC storage, and has been used in many ecological models (Wiesmeier *et al.*, 2012; Gardenas *et al.*, 2011).

Adoption of CA in rice-wheat system can be a logical and environment-friendly option to sustain or improve the productivity and economic viability of rice-wheat cropping system (Hobbs *et al.*, 2008). Moreover, it can substantially improve soil properties through non-disturbance for a sufficiently longer period, and with retention of crop residue, physically protect the surface soil resulting in lesser run-off and higher water intake into the soil profile. In agro-ecosystems, soil aggregation formation is considered an important process in soil organic carbon (SOC) stabilization by hindering decomposition of SOC and its interactions with mineral particles (Gunina and Kuzyakov, 2014). Generally, a more rapid loss of SOC may occur from macro-aggregates than from micro-aggregates (Eynard *et al.*, 2005). The SOC change under agricultural management may owe to the aggregate stability index (Nascente *et al.*, 2015). Thus, soil aggregated fractionation has been widely applied to evaluate the SOC stability under contrasting tillage systems. The review study assessed that the adoption of CA in rice-wheat system for a few uninterrupted years can substantially improves the organic carbon carbon status, and reduce the sub-surface compaction and the modified soil environment may promote rice-wheat system productivity in direct-seeded/ unpuddled transplanted rice and no-till wheat system, in comparison to a conventional system, where rice was puddle-transplanted followed by conventionally tilled wheat.

#### **Annual Change in Soil Organic Carbon ( $\text{g kg}^{-1} \text{ yr}^{-1}$ Soil)**

Paudel *et al.*, (2014) reported that ZTR-ZTW+RR had higher increase in soil carbon ( $0.91 \text{ g kg}^{-1} \text{ yr}^{-1}$  soil) followed by BPR-BPW+RR ( $0.73 \text{ g kg}^{-1} \text{ yr}^{-1}$  soil) on upper depth 0-20cm. Carbon content was decreased in TPR-CTW for both depths. However, the

mean soil organic carbon content at the upper 0-20 cm depth was 17.25 g kg<sup>-1</sup> soil before rice season and 17.58 g kg<sup>-1</sup> soil after wheat season. The soil organic carbon at upper 0-20 cm depth was significantly influenced by conventional and conservation agricultural practices. Highest soil organic carbon change (122.63%) was found in ZTR-ZTW + RR plots followed by BPR-BPW + RR plots (111.61%). The use of ZTR-ZTW + RR and BPR-BPW+RR for five crop cycle increased soil organic carbon by 22.63% and 11.61% more than that of TPR-ZTW respectively. The percentage increment was smaller (22% more than CT) than findings (64.6% more than CT) of Calegari *et al.*, (2008). Higher soil organic carbon content in residue retention could be attributed to more annual nutrient recycling in respective treatments and decreased intensity of mineralization (Kaisi and Yin, 2005).

Chen *et al.*, (2016) reported that the SOC concentration decreased with soil depth. In both 0–10 and 10–20 cm, the SOC concentration in the RP treatment was significantly greater than that in the other four treatments, yet no significant differences were found among the other four. In 20–30 cm, there were in general no significant differences among all the rotation systems.

Zhao *et al.*, (2018) reported that the SOC content of each aggregate class in the 0–20 cm layer was significantly higher than that in the 20–40 cm layer. Increases in the SOC content of aggregate fractions were highest in MRWR, followed by MR, and finally WR. Crop-derived organic particles or colloids can combine with mineral matter, binding micro-aggregates into macro-aggregates. Zhang *et al.*, (2020) also found that the silt + clay (SC) fractions (<0.053 mm) were predominant, accounting for 32–56% of the mass at the 0–20 cm depth, and accounting for 41–55% of the mass at the 20–40cm depth (Fig.1a). Additionally, long-term no-tillage

management and straw-returning at different application rates increased the mass of large soil macro-aggregates (LMA), the LMA- and macro-aggregate- associated OC content, but decreased the SC-associated OC content. Mineral N and P fertilizers had a minor effect on the stabilization of soil aggregates. Moreover, SC fractions (<0.053 mm) were predominant, accounting for 32–56% of the mass of the 0–20 cm layer (Fig.1b). LMAs were the smallest fractions, accounting for 4–12% of the mass of the bulk soil at 0-20-cm depth. The mass of LMAs was not significantly affected by the tillage method, mineral fertilizer, and straw (Fig. 1b). However, no-tillage increased LMA mass by 55% at 0–20 cm depth, compared with conventional tillage, (Fig.1b).

#### **Distribution of soil aggregates with different sizes**

Jiang *et al.*, (2011) reported that the aggregate-associated SOC concentration in different soil layers was influenced by tillage systems. In the 0.00-0.05 m layer, SOC concentration in macro-aggregates showed the order of NT+S>MP+S= NT-S>MP-S, whereas the NT system was superior to the MP system. However, the NT system significantly reduced the SOC concentration in the 2.00-0.25 mm fraction in the 0.05-0.20 m layer. A similar trend was observed in the 0.25-0.053 mm fraction in the 0.20-0.30 m layer. Across all the soil layers, there was no difference in the <0.053 mm fraction between NT-S and MP-S, as well as between NT+S and MP+S, indicating that the NT system did not affect the SOC concentration in the silt + clay fraction. In average across the soil layers, the SOC concentration in the macro-aggregate was increased by 13.5% in MP+S, 4.4% in NT-S and 19.3% in NT+S, and those in the micro-aggregate <0.25 mm were increased by 6.1% in MP + S and 7.0% in NT + S compared to MP-S. For all the soil layers, the

SOC concentration in all the aggregate size classes was increased with straw incorporation, by 20.0, 3.8 and 5.7% under the MP system, and 20.2, 6.3 and 8.8% under the NT system.

Dou *et al.*, (2016) also found that an application of organic and inorganic fertilizers increased the weight distribution of <53 $\mu$ m size fraction compared with CK. In general, the aggregate distribution was dominated by macro-aggregates (2000–250 $\mu$ m; 48.31–64.10%) across all the fertilizer treatments. Long-term MNPk fertilizer strongly increased the SOC storage by an average of 466.0 g C m<sup>2</sup> in all aggregates. The SNPK fertilizer increased SOC by an average of 191.1 g C m<sup>2</sup> in macro-aggregates (> 250  $\mu$  m) but decreased it by an average of 131.4 g C m<sup>2</sup> in micro-aggregates (250–53  $\mu$  m) compared with CK. Besides, the SOC storage showed a decrease in 250–53  $\mu$  m aggregates compared with other aggregate sizes in the fertilized soils except for MNPk treatment. Generally, the SOC storage in macro-aggregates (> 250  $\mu$  m) was greater than in micro-aggregates (< 250  $\mu$  m) across the fertilizer treatments.

Ou *et al.*, (2016) revealed that tillage systems obviously affected the distribution of soil aggregates with different sizes. The proportion of the > 2 mm aggregate fraction in NT+S was 7.1 % higher than that in NT-S in the 0.00-0.05 m layer. There was no significant difference in the total amount of all the aggregate fractions between NT+S and NT-S in both the 0.05-0.20 and 0.20-0.30 m layers. NT+S and NT-S showed higher proportions of > 2 mm aggregate and lower proportions of <0.053 mm aggregate compared to the MP system for the 0.00-0.20 m layer. The proportion of > 0.25 mm macro-aggregate was significantly higher in MP+S than in MP-S in most cases, but the proportion of < 0.053 mm aggregate was

11.5-20.5 % lower in MP+S than in MP-S for all the soil layers. Souza Nunes *et al.*, (2011) also reported that the NT system resulted in stratification of SOC, while the MP system resulted in a more homogeneous distribution in the 0.00-0.20 m layer.

Dhaliwal *et al.*, (2018) revealed that the mean SOC concentration decreased with the size of the dry stable aggregates (DSA) and water stable aggregates (WSA). In DSA, the mean SOC concentration was 58.06 and 24.2% higher in large and small macro-aggregates than in micro-aggregates, respectively; in WSA it was 295.6 and 226.08% higher in large and small macro-aggregates than in micro-aggregates respectively in surface soil layer. The mean SOC concentration in surface soil was higher in DSA (0.79%) and WSA (0.63%) as compared to bulk soil (0.52%). Prasad *et al.*, (2019) also found that tillage significantly reduced the proportion of macro-aggregate fractions (> 2.00 mm) and thus aggregate stability was reduced by 35% compared with (ridge with no tillage) RNT, indicating that tillage practices led to soil structural change for this subtropical soil. The highest SOC was in the 1.00 – 0.25 mm fraction (35.7 and 30.4 mgkg<sup>-1</sup> for RNT and CT), while the lowest SOC was in micro-aggregate (<0.025 mm) and silt + clay (<0.053mm) fractions (19.5 and 15.7 mg kg<sup>-1</sup> for RNT and CT, respectively).

Zheng *et al.*, (2013) revealed that NT and RT treatments significantly increased the proportion of macro-aggregate fractions (>2000  $\mu$ m and 250-2000  $\mu$ m) compared with the MP-R and MP + R treatments. For the 0-5cm depth, the total amount of macro-aggregate fractions (>250 $\mu$ m) was increased by 65% in NT and 32% in RT relative to the MP+R. Averaged across all depths, the macro-aggregate fraction followed the order of NT (0.39) > RT(0.30) > MP+R (0.25)=MP-R (0.24). Accordingly, the

proportion of micro-aggregate fraction (53-250  $\mu\text{m}$ ) was increased with the intensity of soil disturbance. In the 0-5 and 5-10cm depths, NT and RT had significantly higher total soil C concentration than that of MP-R and MP+R in all aggregate size fractions. However, in the 10-20cm depth, conservation tillage system reduced total C concentration in the macro-aggregate fraction ( $>250\mu\text{m}$ ) but not in the micro-aggregate and silt plus clay fractions. The greatest change in aggregate C appeared in the large macro-aggregate fractions where aggregate-associated C concentration decreased with depth. In the 0-5cm depth, the  $>2000\mu\text{m}$  fraction had the largest C concentration under NT, whereas the  $<53\mu\text{m}$  fraction had the lowest C concentration under the MP-R treatment. Similar trend was also observed in the  $>2000\mu\text{m}$  and 25-2000 $\mu\text{m}$  fractions (23 vs. 24  $\text{g C kg}^{-1}$  aggregates) in the 5-10cm depth. The large macro-aggregate ( $>2000\mu\text{m}$ ) had relatively lower C concentration than that in the  $>250-2000\mu\text{m}$  fraction in the 10-20cm depth. Averaged across soil depths, all aggregate size fractions had 6-9% higher total soil C concentration in NT and RT than in MP-R and MP+R, except for the 53-250  $\mu\text{m}$  fraction. Again mould-board plough showed slightly higher soil C concentration than the conservation tillage systems in the 53-250 $\mu\text{m}$  fraction.

### Fractions of soil organic carbon

Parihar *et al.*, (2018) reported that plots under ZT and PB had larger C pools and a larger proportion of labile C to total SOC than for the CT plots at 0–5-, 5–15- and 15–30-cm soil depths. Among the maize-based crop rotations, the plots with MWMb and MCS systems resulted in greater accumulation of labile-C pools and proportion of labile-C to total SOC at 0–5-, 5–15- and 15–30-cm soil depths. However, the proportion of non-labile-C to total SOC was larger in the

MMS and MMuMb system plots at 0–5-, 5–15- and 15–30-cm soil depths. Mondal *et al.*, (2019) revealed that TOC of soil differed significantly among the treatments in the 0-5 cm layer. The highest value of TOC was recorded in NT-NT<sub>3</sub> (9.58 g/kg), which was significantly higher (38-46%, than NT-NT<sub>1</sub> (6.54 g/kg) and CT-CT (6.92 g/kg), but was comparable to NT-NT<sub>2</sub> (8.78 g/kg) and CT-NT (8.70 g/kg). In the below layer (5-15 cm), variation in TOC content reduced (5.23-5.86 g/kg), and both NT-NT<sub>1</sub> and NT-NT<sub>3</sub> had significantly higher (11-12%, TOC content than the CT-CT. Mean values of TOC was higher by 34% in NT. This highlights the favorable condition of soil organic carbon accumulation through no-tillage practice. Addition of crop residue and incorporation of legume in crop rotation in NT-NT<sub>3</sub> treatment could be the possible cause of higher TOC content in the soil. Residues get slowly decomposed and the resultant organic matter is added to the soil which helps in aggregate formation, water retention and improves overall soil physical health. In subsurface layers, TOC content was almost comparable between CT and NT, which implies that the role of tillage and crop residue is restricted to the surface layer (Meurer *et al.*, 2017).

Johnson *et al.*, (2013) also found that the intensive tillage at the Chisel field showed  $<20\%$  of the soil covered for all stover treatments, including full return, where all residues were returned; whereas, NT<sub>2005</sub> and NT<sub>1995</sub> had at least 45% of the soil covered even in low return. In NT<sub>2005</sub>, significant increases in aggregates  $<1$  mm and significant decreases in aggregates 5–9 mm were measured in low return compared to full return [Fig. 2]. Low Return had 15% and 60% more aggregates in the 0–0.5 and 0.5–1mm classes, respectively, compared to full return, but full return had 14% more 5–9 mm aggregates compared to low return, with moderate return intermediate. In Chisel and

NT<sub>1995</sub>, although means of aggregate distribution displayed a similar trend to the NT<sub>2005</sub>, no statistically significant increase in the frequency of aggregates <1 mm was detected [Fig. 2].

Ratnayake *et al.*, (2019) reported that AHG showed the highest TOC, although it was not significantly different from that of A–OF in both soil layers (Fig. 3a). On the other hand, the lowest TOC was recorded in A–OFS in both layers. However, it was not significantly different from that in USR. The highest MBC was observed in A–OF at both depths, although it was not significantly different from that of HG (Fig. 3b). The lowest MBC, at both depths, was found in A–OFS, and the difference was significant. Water–soluble C (WSC) content was relatively high in home gardens (HG, AHG) and A–O/IF, while it had lowest mean values in A–OFS and USR (Fig. 3c). Permanganate oxidizable C (POC) was the highest in A–O/IF at both depth interval and the difference was statistically significant when compared with other land uses types (Fig. 3d).

In the 0.00-0.05 m layer, SOC concentration in macro-aggregates showed the order of NT+S>MP+S = NT-S>MP-S, whereas the NT system was superior to the MP system. However, the NT system significantly reduced the SOC concentration in the 2.00-0.25 mm fraction in the 0.05-0.20 m layer. A similar trend was observed in the 0.25-0.053 mm fraction in the 0.20-0.30 m layer. Across all the soil layers, there was no difference in the <0.053 mm fraction between NT-S and MP-S, as well as between NT + S and MP + S, indicating that the NT system did not affect the SOC concentration in the silt + clay fraction. In average across the soil layers, the SOC concentration in the macro-aggregate was increased by 13.5 % in MP + S, 4.4 % in NT-S and 19.3 % in NT + S, and those in the micro-aggregate (<0.25 mm) were increased

by 6.1% in MP + S and 7.0 % in NT + S compared to MP-S. For all the soil layers, the SOC concentration in all the aggregate size classes was increased with straw incorporation, by 20.0, 3.8 and 5.7 % under the MP system, and 20.2, 6.3 and 8.8 % under the NT system. The higher proportion of >2 mm aggregates and lower proportion of <0.053 mm aggregates under NT systems might be the result of the higher soil hydrophobicity, low intensity of wetting and drying cycles, higher soil C concentration or the physical and chemical characteristics of large macro-aggregates making them more resistant to breaking up (Vogelmann *et al.*, 2013). Six *et al.*, (1998) concluded that the concentration of free LF C was not affected by tillage, but was on average 45% less in the cultivated systems than NV. Proportions of crop-derived C in macro-aggregates were similar in NT and CT, but were three times greater in micro-aggregates from NT than micro-aggregates from CT. Moreover, the rate of macro-aggregates in CT compared with NT leads to a slower rate of micro-aggregate formation within macro-aggregates and less stabilization of new SOM in free micro-aggregates under CT [Fig. 4].

Zheng *et al.*, (2018) also found that The SOC content for different treatments decreased with soil depth with significantly higher content in the topsoil than in the sub-layer. At the 0–10cm depth, the mean SOC varied with treatment, with the conservation tillage (ST and NT) significantly higher than conventional tillage (CT). At 10-30cm, especially, the ST treatment was significantly higher. At 20–30cm, the mean SOC from greatest to smallest was ordered ST> MP> CT> NT, with ST significantly higher than other treatments. Zhang *et al.*, (2020) observed that the treatment of CT<sub>1</sub>-N<sub>1</sub>-P<sub>1</sub>-Straw<sub>1</sub> significantly increased the OC content of the bulk soil compared CT<sub>1</sub>-N<sub>2</sub>-P<sub>2</sub>-Straw<sub>2</sub> and other treatments at the

0–20 cm depth. When the treatment without straw (CT<sub>1</sub>-N<sub>0</sub>-P<sub>0</sub>-Straw<sub>0</sub>, CT<sub>2</sub>-N<sub>1</sub>-P<sub>2</sub>-Straw<sub>0</sub>, and NT-N<sub>2</sub>-P<sub>1</sub>-Straw<sub>0</sub>), soil aggregate-associated OC was highest in the SC fractions than other three aggregate fractions, ranging from 30–50% of bulk soil OC at 0–20 cm depth. Whether conventional tillage or no-tillage method, the treatment with straw returning increased the aggregate-associated OC content of LMAs, MAs, and MIs. This result showed that straw changed the distribution of OC in the different size aggregates.

Gu *et al.*, (2016) reported that the adoption of GT and ST increased LOC contents in the 0-100 cm soil profile by 0.102 g kg<sup>-1</sup> and 0.136 g kg<sup>-1</sup> respectively, compared to CK, and there was a 70-80% increase in the 0-40 cm layer (Fig.5). The higher values of LOC in ST and GT can possibly be attributed to the inputs from organic materials and root residues, as well as decreased losses with surface runoff as a result of mulching (Gale *et al.*, 2000; Wander and Yang, 2000). The DOC concentration is considerably lower than those of other labile C fractions, generally not more than 200 mg kg<sup>-1</sup>, but it is the most mobile fraction of SOC. It controls the turnover of nutrient and organic matter by affecting the development of microbial populations. In this experiment, ST and GT treatments significantly increased soil DOC concentrations at depths of 0-40 cm, by 28.56% and 23.33% respectively, (Fig.5) compared to CK, but there was no difference between ST and GT treatments at each layer of the soil profile. The increase in DOC with ST may be due to the soluble decomposed organic materials of the straw, while the increase in DOC with GT could possibly be attributed to an increase in organic acids and water-soluble carbohydrates from rhizodeposition and root exudates. In addition, a decrease in surface runoff under GT and ST was an important reason for the

increased DOC, as DOC may be lost with runoff. Compared with CK, the DOC in GT and ST was favorably leached, deposited and absorbed into the subsoil layer, resulting in higher concentrations of DOC at depths of 20-40 cm (Fig.5). This was probably because of low soil bulk density in ST, and in GT lower pH would have increased DOC adsorption by soil (Jardine *et al.*, 1989).

### **SOC storage in different aggregate size fractions**

Ou *et al.*, (2016) reported that as compared to MP-S, the SOC stock in the >2 mm aggregate fraction increased and that in the <0.053 mm fraction declined in MP+S, NT-S and NT+S in the 0.00-0.05 and 0.05-0.20 m layers. Within the 0.00-0.20 m layer, the SOC stock in the >2 mm aggregate fraction was increased by 28.1, 56.1 and 88.4 %, and that in the <0.053 mm aggregate fraction decreased by 17.7, 30.3 and 34.2 % in MP+S, NT-S and NT+S than in MP-S. The SOC stock in the 2.00-0.25 mm aggregate fraction did not differ among the MP+S, NT-S and NT+S treatments, but was significantly increased compared to the 0.00-0.05 m layer for MP-S treatment. There was a significant increase in SOC stock of macro-aggregate in MP+S than in MP-S as well as in NT+S than in NT-S in the 0.05-0.20 and 0.20-0.30 m layers. Maximum increase in TOC stock under S<sub>3</sub> might be due to the highest addition of crop residues coupled with conservation tillage (Das *et al.*, 2013). Ploughing of soil causes breakage of macro-aggregates into micro-aggregate and silt and clay size particles inside soil (Bronick and Lal, 2005) exposing protected organic carbon inside macro-aggregate for oxidation. The principal cause of higher enrichment of SOC on top depth was more crop residue addition on top soil in comparison to soil of lower depth. Along with this, the root growth is limited by lesser nutrient and microbial activity in lower depth resulting in lower total

addition of crop residues in lower depth (Tiwari *et al.*, 1995).

Xu *et al.*, (2013) observed that the SOC stocks in the 0–80 cm layer under NT was as high as 129.32 Mg C ha<sup>-1</sup>, significantly higher than those under PT and RT. The order of SOC stocks in the 0–80 cm soil layer was NT > PT > RT, and the same order was observed for SCB; however, in the 0–20 cm soil layer, the RT treatment had a higher SOC stock than the PT treatment. Mangalassery *et al.*, (2014) also found that zero tilled soils contained significantly more soil organic matter (SOM) than tilled soils. Soil from the 0–10 cm layer contained more SOM than soils from the 10–20 cm layers in both zero tilled (7.8 and 7.4% at 0–10 cm and 10–20 cm, respectively) and tilled soils (6.6% at 0–10cm and 6.2% at 10–20 cm).

Meenakshi, (2016) revealed that under conventional tillage, the organic carbon content in the surface 0-15 cm soil depth was 0.44, 0.51 and 0.60% which was increased to 0.60, 0.62 and 0.70% under zero tillage practice in sandy loam, loam and clay loam soil. In all the three soils, the organic carbon decreased significantly with depth under both the tillage practices. Under conventional tillage, the amount of organic carbon observed in 0-15 cm found to decrease abruptly in 15-30cm soil depth as compared to the decrease under zero tillage practice in all the soils. Long term ZT practice in wheat increased the organic carbon content significantly as compared to CT in different depths of all the soils. As expected, the higher amount of organic carbon was observed in relatively heavier textured soil viz., clay loam > loam > sandy loam at both the depths. Moreover, under conventional tillage, the light fraction carbon, in the surface 0-15 cm soil depth was 0.29, 0.49 and 0.58 g kg<sup>-1</sup> which increased to 0.43, 0.62 and 1.01 g kg<sup>-1</sup> under zero tillage practice in sandy loam,

loam and clay loam soil. The heavy fraction carbon in the surface 0-15 cm soil layer was 3.8, 4.2 and 4.9 g kg<sup>-1</sup> which decreased to 2.0, 2.2 and 2.6 g kg<sup>-1</sup> in 15-30 cm soil layer in sandy loam, loam and clay loam, respectively. The heavy fraction carbon was highest in the surface layer in all the three soils and decreased with depth under both tillage treatments. The zero tillage resulted in an increase in heavy fraction carbon at both the depth. In the surface 0-15 cm, it increased the heavy fraction carbon significantly from 3.8 to 4.9, 4.2 to 4.9 and 4.9 to 5.1 g kg<sup>-1</sup> and in 15-30 cm soil depth from 2.0 to 2.9, 2.2 to 3.4 and 2.6 to 3.9 g kg<sup>-1</sup> in sandy loam, loam and clay loam. Relatively higher amount of heavy fraction carbon was observed in heavier textured soil at both the depth.

Wang *et al.*, (2018) reported that tillage system change influenced SOC content, NT, ST, and BT showed higher values of SOC content and increased 8.34, 7.83, and 1.64MgCha<sup>-1</sup>, respectively, compared with CT. Among the 3 changed tillage systems, NT and ST showed a 12.5% and 11.6% increase in SOC content then BT, respectively. Tillage system change influenced SOC stratification ratio values, with higher value observed in BT and NT compared CT but ST. Therefore, in loess soil, changing tillage system can significantly improve SOC storage and change profile distribution. Kumar *et al.*, (2019) revealed that the soil organic carbon (SOC) stock in bulk soil was 40.2-51.1% higher in the 0.00-0.05 m layer and 11.3-17.0% lower in the 0.05-0.20 m layer in NT system no-tillage without straw (NT-S) and with straw (NT+S), compared to the MP system moldboard plow without straw (MP-S) and with straw (MP+S), respectively. Residue incorporation caused a significant increment of 15.65% in total water stable aggregates in surface soil (0-15 cm) and 7.53% in sub-surface soil (15-30 cm). In surface soil, the maximum (19.2%) and minimum (8.9%)

proportion of total aggregated carbon was retained with >2 mm and 0.1-0.05 mm size fractions, respectively. At 0-7 cm depth, soil MBC was significantly higher under plowing tillage than rotary tillage, but EOC was just opposite. Rotary tillage had significantly higher soil TOC than plowing tillage at 7-14 cm depth. However, at 14-21 cm depth, TOC, DOC and MBC were significantly higher under plowing tillage than rotary tillage except for EOC. A considerable proportion of the total SOC was found to be captured by the macro-aggregates (>2-0.25 mm) under both surface (67.1%) and sub-surface layers (66.7%) leaving rest amount in micro-aggregates and "silt + clay" sized particles. Gu *et al.*, (2016) observed that mulching practices did not alter the seasonal dynamic changes of LOC, but could increase its content, e.g., in March, ST and GT increased LOC by 167% and 122% respectively (Fig. 6).

### **Soil aggregate stability**

Tillage system and crop rotation are essential factors in agricultural systems that influence soil fertility and the formation of soil aggregates (Saljnikov *et al.*, 2013). The stability of soil aggregates defines soil structure and influences crop development. A good soil structure has a stable aggregate fraction that tolerates different wetting conditions in particular and provides continuity of pores in the soil matrix, which improves soil air and moisture exchange between the roots and soil environment. Soils under no-till can have greater soil strength due to stable soil aggregates and soil biodiversity that contribute to the enhancement of water and nutrients available to plants for growth and development (Stirzaker *et al.*, 1996). Chen *et al.*, (2009) also found that the portion of 0.25–2 mm aggregates, mean weight diameter (MWD) and geometric mean diameter (GMD) of

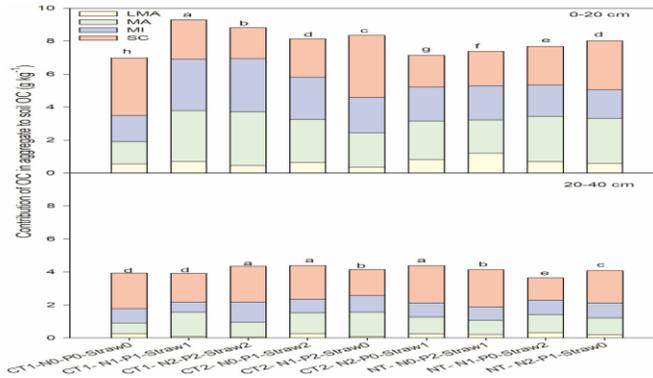
aggregates from ST and NT treatments were larger than from CT at both 0–15- and 15–30-cm soil depths.

Mondal *et al.*, (2019) reported that in 0-7.5 cm layer under fast-wetting pre-treatment condition, soil macro-aggregate content was significantly higher in NT-NT<sub>3</sub> (56- 287% while CT-CT recorded the lowest content (22.7%). Similar trend could be found in the following 7.5-15 cm layer, where the highest and the lowest amount of macro-aggregates were recorded in NT-NT<sub>3</sub> (48.2%) and CT-NT (19.9%), respectively. In 15-30 cm soil layer, macro-aggregates content was higher in NT-NT<sub>3</sub> compared to CT-NT and CT-CT (50-68%, but was at par with NT-NT<sub>1</sub> and NT-NT<sub>2</sub>. Amount of soil micro-aggregates followed the reverse; both CT-NT and CT-CT recorded 24- 115% higher in micro-aggregates content compared to NT-NT<sub>2</sub> and NT-NT<sub>3</sub>, but similar to NT-NT<sub>1</sub>. Amount of stable macro-aggregates were nearly doubled with slow-wetting pre-treatment. NT-NT<sub>2</sub> recorded significantly higher content than CT-CT and CT-NT (42 and 22%, respectively, but it was at par with other treatments. Similar results were obtained in 7.5-15 cm layer. No significant difference was found at 15-30 cm layer. In slow-wetting, micro-aggregate contents were comparable among the treatments at all the layers. Greater macro-aggregates ensured larger mean weight diameter (MWD) in NT-NT<sub>3</sub> (0.59 mm), followed by NT-NT<sub>2</sub> (0.47 mm), NT-NT<sub>1</sub> (0.41 mm), CT-NT (0.36 mm) and CT-CT (0.29 mm) in 0-7.5 cm soil layer, when the fast-wetting pre-treatment was followed. In 7.5-15 cm layer, MWD was lower compared to the layer above, and NT-NT<sub>3</sub> could only have a significantly different (56-77% higher, MWD compared to the rest of the treatments. In 15-30 cm layer, treatments were at par. When aggregates were slow-wetted, MWD improved and was 2-3 times higher than the corresponding fast-wetting MWD. Here,

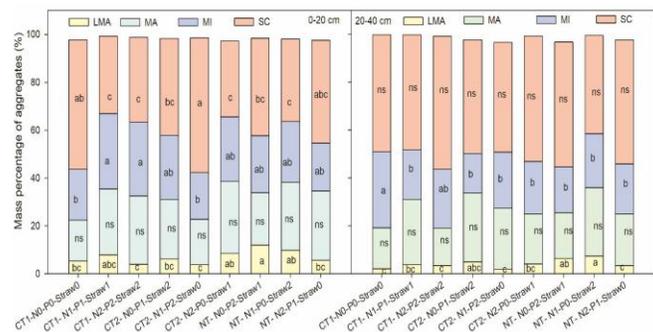
MWD of aggregates significantly higher in NT-NT<sub>3</sub> (44-195% than all other treatments except NT-NT<sub>2</sub>. Similar results were obtained

in other layers, and MWD in NT-NT<sub>3</sub> was higher compared to CT-NT and CT-CT treatments.

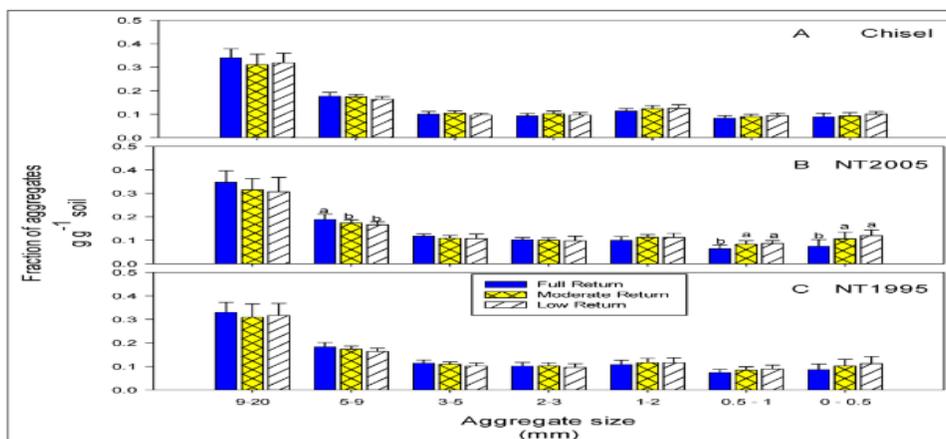
**Fig.1a** Soil organic carbon (OC) content (g kg<sup>-1</sup> soil) in four aggregate size fractions (>2, 0.25–2, 0.053–0.25, and <0.053 mm) in 0–20 and 20–40 cm



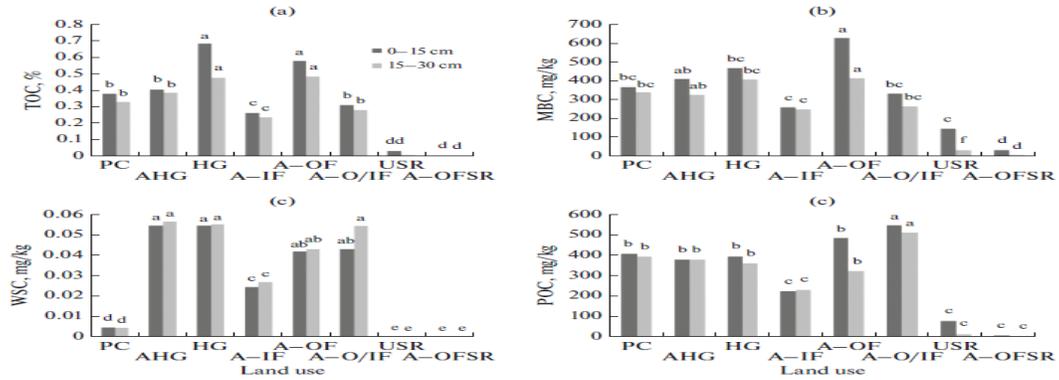
**Fig.1b** Mass distribution of four different size aggregates (>2, 0.25–2, 0.053–0.25, and <0.053 mm) under tillage and fertilization treatments from 0–20 and 20–40 cm



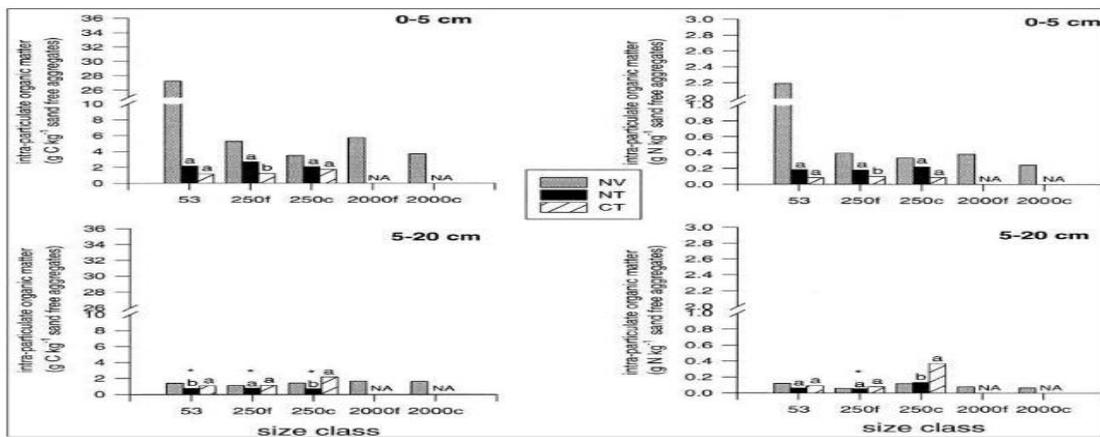
**Fig.2** Dry aggregate size distribution as affected by Stover return rates



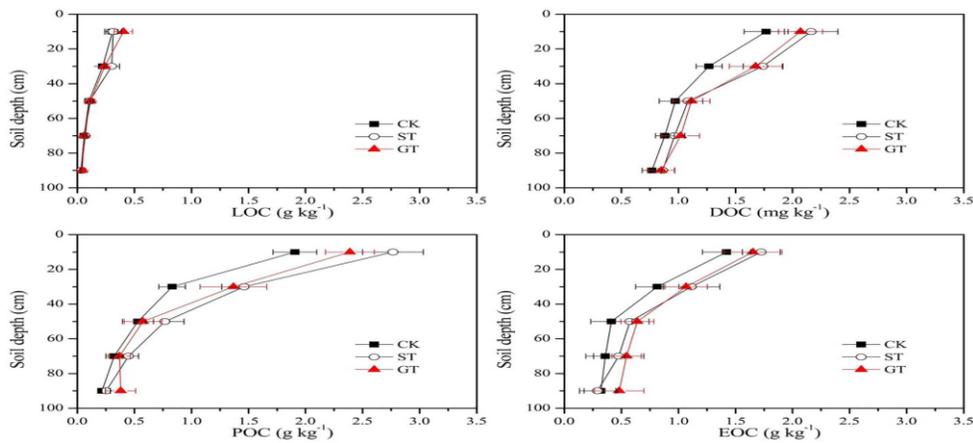
**Fig.3** C fractions levels at selected land uses: total organic C (TOC) variation in different land uses (a), microbial biomass carbon (MBC) variation in different land uses (b), water soluble C (WSC) variation in different land uses (c), KMnO<sub>4</sub> oxidizable carbon (POC) variation in different land uses.



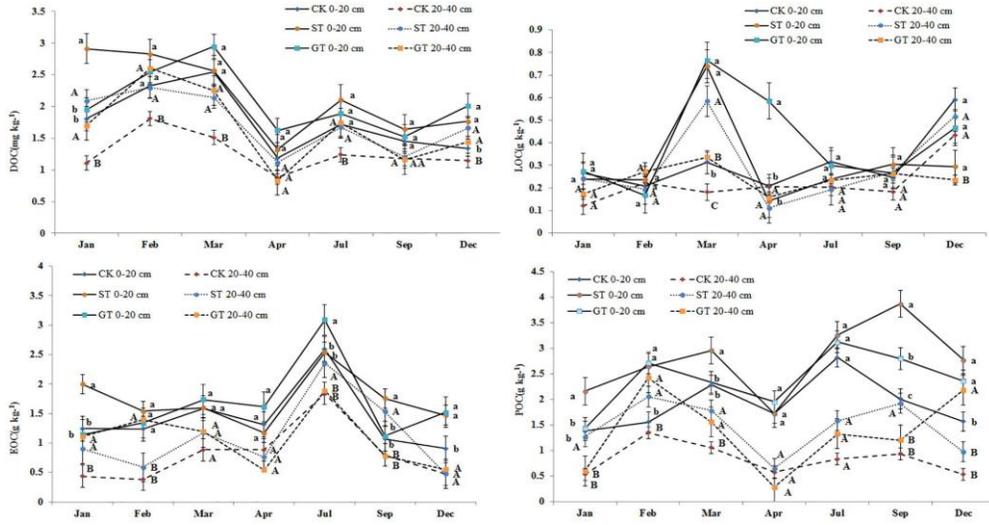
**Fig.4** Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems



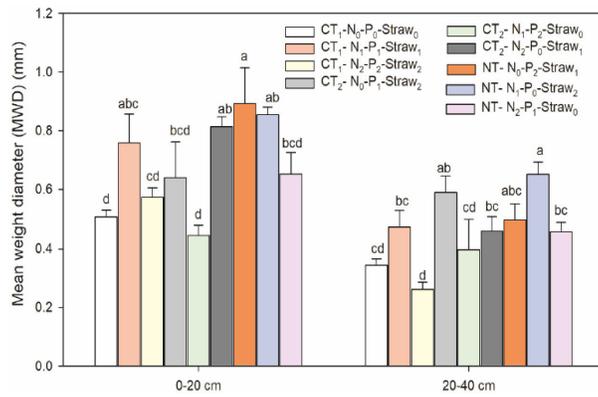
**Fig.5** Content of Carbon fractions at different depths.



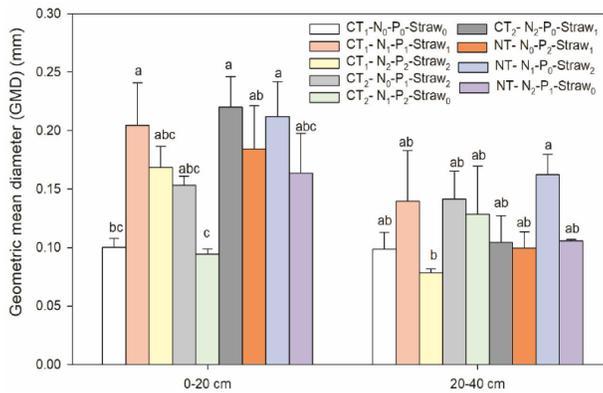
**Fig.6** Dynamic changes of carbon fractions



**Fig.7a** The mean weight diameter (MWD) of different tillage management and fertilization at 0–20 and 20–40 cm



**Fig.7b** The geometric mean diameter (GMD) of different tillage management and fertilization at 0–20 and 20–40 cm



The effect of tillage and residue management on size distribution and stability of soil aggregates was clearly distinguishable. Irrespective of pre-treatment to the soil, NT-NT provided a better soil aggregation. Crop residues on the surface protects the soil for the diurnal and seasonal changes in temperature, water content and aeration, and this maintains a good soil structural condition (Salem *et al.*, 2015, Mondal *et al.*, 2018).

The organic matter through decomposition of crop residues further promoted the stable aggregates formation in NT-NT, while physical disturbance and absence of crop residue in CT limits the formation and stabilization of soil aggregates (Jat *et al.*, 2013; Naresh *et al.*, 2017). Zhang *et al.*, (2020) reported that aggregate stability decreased with the depth, as indicated by the mean weight diameter (MWD) and the geometric mean diameter (GWD) (Figures 7a & 7b). In the surface layer, the treatment with straw-returning increased the MWD and GWD of soil aggregates by 16–50% and 14.67–70.88%, respectively, compared with the treatment without straw (CT<sub>1</sub>-N<sub>0</sub>-P<sub>0</sub>-Straw<sub>0</sub>, CT<sub>2</sub>-N<sub>1</sub>-P<sub>2</sub>- Straw<sub>0</sub>, and NT-N<sub>2</sub>-P<sub>1</sub>-Straw<sub>0</sub>).

Long-term applications of N and P fertilizer without straw did not significantly affect soil aggregate stability, as indicated by the similar MWD values in both surface and subsurface layers. However, the GWD of CT<sub>1</sub>-N<sub>0</sub>-P<sub>0</sub>-Straw<sub>0</sub> and CT<sub>2</sub>- N<sub>1</sub>-P<sub>2</sub>-Straw<sub>0</sub> treatments did not decrease at 20–40 cm depth soil (Fig.7b).

This may be attributed to the fact that no tillage decreased soil disturbance, facilitating the protection of soil organic matter from microbial degradation, which in turn favored the generation of physically stable LMAs and Mas, and increase the soil stability (Sarker *et al.*, 2018)..

## Soil temperature

Soil temperatures in surface layers can be significantly lower (often between 2 and 8°C) during daytime (in summer) in zero tilled soils with residue retention compared to conventional tillage (Oliveira *et al.*, 2001). Dahiya *et al.*, (2007) compared the thermal regime of a loess soil during two weeks after wheat harvest between a treatment with wheat straw mulching, one with rotary hoeing and a control with no mulching and no rotary hoeing. Compared to the control, mulching reduced average soil temperatures by 0.74, 0.66, 0.58°C at 5, 15, and 30 cm depth respectively, during the study period. The rotary hoeing tillage slightly increased the average soil temperature by 0.21°C at 5 cm depth compared to the control. The tillage effect did not transmit to deeper depths. Gupta *et al.*, (1983) also found that the difference between zero tillage with and without residue cover was larger than the difference between conventional tillage (mouldboard ploughing) and zero tillage with residue retention. Both mouldboard ploughing and zero tillage without residue cover had a higher soil temperature than zero tillage with residue cover, but the difference between mouldboard ploughing and zero tillage with residue cover was approximately one-third the difference between zero tillage with and without residue.

Naresh *et al.*, (2015) reported that soil temperature at transplanting zone depth (5 cm) during rice crop establishment was lower in 2009 than in 2010 and did not differ in the years 2010 to 2011. Treatments T<sub>1</sub> and T<sub>2</sub> reduced the mean maximum soil temperature at transplanting zone depth by 3.6 and 2.7°C compared to the treatment T<sub>3</sub>, respectively. Zero tillage reduced the impact of solar radiation by acting as a physical barrier resulting in lower soil temperature than the plough soil. The increased value of soil temperature for narrow raised beds was

probably due to exposure of more surface area to the incident solar radiation in narrow raised beds than in flat conventional treatments. T<sub>3</sub> and T<sub>4</sub> recorded higher soil temperature (mean of 38.4 V/S 37.7°C) compared to the flat treatments T<sub>1</sub>, T<sub>2</sub> and T<sub>5</sub> at 15 DAT.

In conclusion the review study indicated that conservation tillage, especially no-tillage with straw-returning, improves soil structure, and change the size distribution of the aggregates. Soil aggregates are important agents of SOC retention and protection against decomposition. Quantity and quality of SOC fractions have an impact on soil aggregation that in turn physically protect the carbon from degradation by increasing the mean residence time of carbon. Soil management through the use of different tillage systems affects soil aggregation directly by physical disruption of the macro-aggregates, and indirectly through alteration of biological and chemical factors. Crop residue plays an important role in SOC sequestration, improving soil organic matter. Tillage reduction and residue retention both increased the proportion of soil organic matter as microbial biomass.

The findings also demonstrate the negative effect of conventional tillage not only on SOC decline, but also the weakening of soil aggregate formation and strength under continuous wet conditions, which can lead to other negative effects such as sediment loss and water quality concerns. The logical consequence is that the micro-aggregate-within-macro-aggregate fraction shows promising potential for early detection of changes in soil C arising from changes in management. A greater percentage of carbon was found in all aggregate size classes with the conservation tillage treatments than CT at the 0- to 5-cm depth. At the 10– 15-cm depth, however, the highest carbon percentages were found in aggregates from the CT and RT treatments, again reflecting a probable lower

deposition of carbon due to the NT treatment at the lower depth.

The organic carbon content under no-tillage and reduced tillage system increased compared to conventional tillage due to retention of residues and minimum disturbance in the former system. The no-tillage system showed a trend to accumulate organic carbon near the soil surface layer. Conventional tillage reduced soil organic C stocks and that of its labile fractions both in top and subsoil (20-100 cm). Reduced LOC fraction stocks in subsoil could partially be explained by the decrease in fine root biomass in subsoil, with consequences for SOC stock. However, not all labile fractions could be useful early indicators of SOC alterations due to tillage and residue management options. There were good relationships between cumulative levels of C input and macro-aggregate-associated carbon and between cumulative levels of carbon input and associated fraction of silt and clay (53-um). Soil sequestration with organic carbon in (0.25-0.1 mm) fraction is the optimal long-term sequestration measure for both carbon and nitrogen.

The no-tillage method revealed a tendency towards accumulation of organic carbon below the base of the soil surface. Conventional tillage decreased the stocks of carbon organic soil and its labile fractions in both the top and the subsoil (20-100 cm). The reduction of POC in topsoil was mainly motivated by a decrease in fine POC, while DOC was mainly reduced in the subsoil. The LOC fractions also decreased to SOC ratios, suggesting a decline in carbon efficiency as a result of tillage and residue management. Reduced LOC fractional stocks in the subsoil may be partly explained by the decline in subsoil fine root biomass, with implications for SOC stocks.

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