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REVIEW PAPER

Effect of tillage and straw return on carbon footprints, soil organic carbon fractions and soil microbial community in different textured soils under rice–wheat rotation: a review

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Abstract Measuring the influence of long-term agricultural tillage practices on soil organic carbon (SOC) is of great importance to farmers and policy-makers. Different management practices affected SOC mainly at the soil surface level. The different fractions of SOC viz. total SOC, particulate organic carbon, soil microbial biomass carbon, and potentially mineralizable carbon, were reported to be strongly correlated over a diversity of soils and management systems. Frequent tillage deteriorates soil structure and weakens soil aggregates, causing them to be susceptible to decay. The mixing of residues/surface retention into the soil increases SOM mineralization due to greater exposure to microbial decomposers and optimal moisture and temperature. Increased efficiency of N fertilizers use can result in reduced carbon footprints of field crops, because the contribution of N fertilizers is 36–52% of total emissions while increased soil C sequestration reduces the carbon footprint, because the input carbon as CO_2 from atmospheric is converted into the plant biomass and eventually deposited to the soil. Decreasing soil tillage integrated with crop residues retention can increases SOC and decreases carbon footprint, and the mixing of key agricultural practices could increase the crop yields, reduce the emissions and carbon footprint respectively.

Keywords Tillage · Soil quality · Straw return · Microbial community · Carbon footprint · Soil aggregates

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1 Introduction

Soil organic carbon (SOC) is affected by a number of factors like tillage practices, residue management (Sun et al. 2015), soil aggregate sizes (Zhang et al. 2013) and microbial functional diversity (Guo et al. 2016). Augmenting agricultural management can lessen the SOC loss, or even rise its content. Intensive and continuous soil tilling is in agricultural practices from thousands of years in India (Larkin 2015). Intensive conventional tillage results in frequent soil disturbance which reduces the soil aggregate sizes, thus accelerate the SOC oxidation and decreasing its content. For soil microorganisms major source of energy is soil organic carbon (SOC) (Mathew et al. 2012; Guo et al. 2016) and its content deeply affects the properties of soil that comprise the cycling of nutrients and aggregate stability (Varvel and Wilhelm 2010). SOC is also very important in preserving long-term sustainability of agricultural-ecosystems and worldwide biogeo-chemical cycles (Larkin 2015; FAO 2017).

Combustion of crop residues, a common practice in agriculture, also decreases the amount of organic substances and the storage capacity of water through the soil and reduces the microbial biomass and the functional diversity of the soil (Guo et al. 2016). Biota of soil microbial communities and their interactions with environmental factors greatly influence the dynamics of SOC (Zhang et al. 2013; Mau et al. 2015; Yue et al. 2015). Microorganisms, such as bacteria and fungi, are the main factors of soil processes in agricultural ecosystems, including the nutrient cycle and the decomposition of MOS (Acosta-Martínez et al. 2010; Figuerola et al. 2012). Different practices, such as soil working and the return of the straw, have influenced the activity and the structure of the population of soil microorganisms. These techniques change the characteristics of the habitat for soil microorganisms. For example porosity and soil moisture and substrates for soil microorganisms, as a result, influence SOC dynamics in the soil ecosystem. Although many studies have shown that soil fungi are the main factor influencing the carbon content of the soil in general, these studies have focused only on mountain ecosystems as forest ecosystems (Ekblad et al. 2013). Several researchers have reported that the bacteria were dominant in the rice and wheat system (Guo et al. 2015), which could be due to its ability to break up more labile carbon sources than other microorganisms such as fungi (Govaerts et al. 2007) thus contributing to the higher concentration of SOC through fresh and labile organic matter binding groups with microaggregates to form macroaggregates (Grosbellet et al. 2011). The flooded field for long-term spelled fields were mainly in anaerobic conditions during the rice growing period (Witt et al. 2000), inhibiting the growth of fungi and reducing the contribution of fungi to SOC. Therefore, bacteria can have a greater contribution to the concentration of SOC than mushrooms in the rice and wheat system.

Most of earlier studies revealed that both non-tillage and straw returning practices can increased soil bacterial abundance (Guo et al. 2015; Zhang et al. 2014) which can be due to the more favorable environmental conditions for soil micro-organisms provided by these practices (Zhu et al. 2014). Zhang et al. (2014) also reported a significantly increase in bacterial biomass under non-tillage as compared with conventional tillage practice. On the other hand, these studies overlooked the relations between SOC and soil bacterial communities. Zhang et al. (2013) stated that microbial communities both directly and indirectly controls C storage through microbial biomass carbon. Soil bacteria are known to facilitate the C sesquiteration soil aggregates which could be the reason for increased SOC levels in upper layer of the soil due to increased metabolic actions of microbes (Guo et al. 2016). But the mechanism with which these microbial population are related to sequestration under different practices and systems is still unknown. Thus more study is required to understand the relation of soil microbial communities including bacteria with SOC under different tillage practices. The review comprised some key agronomical strategies that can increase the relative contributions of different C fractions and microbial communities of soil to SOC and in which way these interactions may change under different practices of different textured soils while at the same time.

2 Review of literature

Rice–wheat (RW) cropping system retains an important purpose in food security in the world. This system occupies around 10.0 million ha of cropping area in India only (Kumari et al. 2011). The RW cropping system substainability is inversely affected with problems like soil degradation, air pollution (Guo et al. 2010) and conventional management practices used for long-term, i.e. burning or removing crop residue, intensive soil tillage etc. (Guo et al. 2015). Many researches had already elucidated how the tillage practices or straw-returning methods effects the physical–chemical properties, nutrient index of soil and yield of crops under RW cropping system (Zhu et al. 2014; Ding et al. 2013). But little work had been reported about the relationships of SOC with its fractions and microbial communities of soil under various tillage and straw-returning practices. The adoption of alternative farming methods had also been reported to increase the yield of crops while decreasing the C emissions (Gan et al. 2014). Further it was computed that carbon footprint of alternative wheat production systems suited to semiarid environments. The integrating improved farming practices i.e. fertilizing crops based on soil tests, reducing summer fallow frequencies and rotating cereals with grain legumes, lowers wheat carbon footprint effectively, averaging -256 kg CO_2 eq ha^{-1}year^{-1}. About 27–377 g CO_2 equivalent is sequestered into the soil for each kg production of wheat grain. With the view of better farming practices, wheat takes up more CO_2 from the atmosphere than it actually emits (mainly from the reduction of carbon in the soil, respiration of crop residues, tractor fuel, and perhaps burning of the stubble) during its production.

2.1 Effect of tillage and straw return on carbon footprints

Carbon footprint is a term for global warming potential and refers to the total greenhouse gas (GHG) emissions associated with a product or service. The carbon footprint for agriculture products depends on the agricultural farming. Emissions of Greenhouse gases is from fossil fuels used in the production of crops, from the use of fertilizers in the production. Al-Mansour and Jejcic (2014) showed that in addition to tillage or cropping methods carbon footprints are also influenced by farm size. Larger farms show less carbon footprints than smaller farm. This might be because large farms were able to use more efficiently the direct energy inputs and reduce their carbon footprint per unit production. Carbon footprints per unit area of large-scale farms were declined in the wheat as compared to small farms, than in maize in wheat–maize cropping system than in wheat-rice cropping system (Fig. 1a). Greenhouse gas emission (GHG) emissions were higher from wheat-rice rotation system than from wheat–maize rotation system (Fig. 1a) and were mainly due to paddy production which caused in high emissions of methane. In wheat–maize rotation system, CO_2 produced while manufacturing the N fertilizer chiefly contributes to total GHG emission, followed by N_2O, produced due to application of N fertilizer to soils whereas contribution of other factors like irrigation, farm mechanized operations, crop residue incorporation, farm machinery, organic fertilizer and pesticide application is small (Fig. 1a). Moreover, Large-scale farming operations reduced emissions of GHG and enhanced SOC stocks, in comparison to small household farming operations (Fig. 1b). SOC stock changes measured in the soils of large farms were higher under wheat–maize than under RW cropping system and these changes were 9 and 6% in wheat–maize and RW systems respectively (Herrero et al. 2016). The increase in SOC stocks has largely been attributed to the crop residue incorporation in soils, followed by the use of chemical fertilizer and combined application of chemical and organic fertilizer. The rate of SOC increase yearly in large scale operations in farm were attributed to the use of organic fertilizer and incorporation of crop residues. The maximum organic carbon build-up was recorded when green manure @ 15 t ha^{-1} which was applied and increase was up to 5.7 g kg^{-1} of soil (Dhaliwal et al. 2019).

Liu et al. (2016a, b) observed that GHG emissions due to N fertilizer application was 16 times more than different farming methods in durum wheat production. Additionally the emissions and carbon footprint were also influenced by the rates at which N fertilizer were applied (Fig. 1c). Greater GHG emissions from the barley crop occurred as more N fertilizer was applied to the oilseed crops grown the previous year. In other words, the total emission during the barley crop was a function of the rate of fertilizer N applied to the previous oilseeds (Higgins et al. 2015). Further the yield of wheat was reported highest in continuous wheat system and SOC gain over the years was also maximum, resulting in minimum footprint value which was quite lower than the footprint for the other three systems (Fig. 1d). Li et al. (2018) reported that the contents of DOC (Dissolved organic carbon),

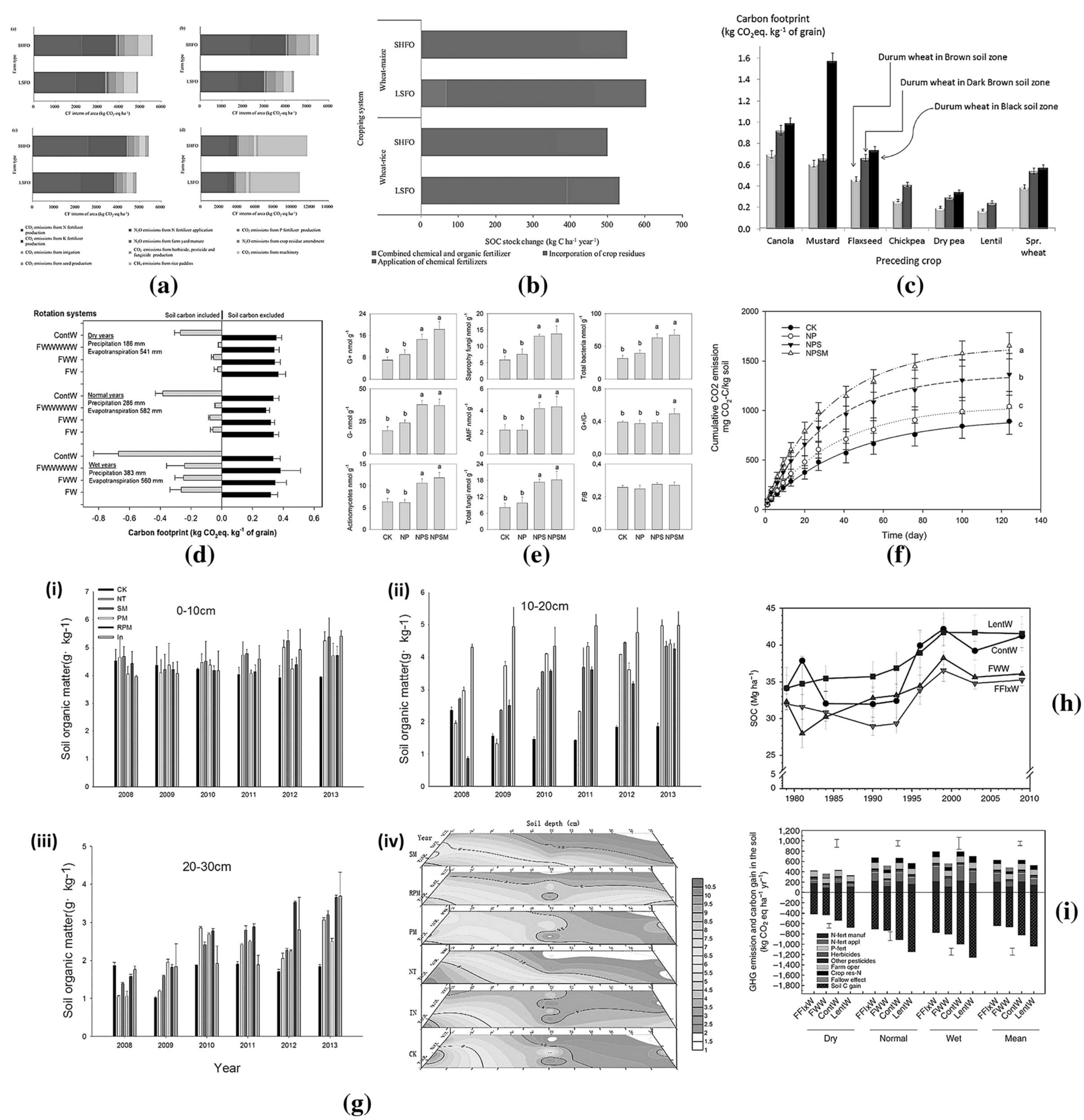


Fig. 1 **a** GHG emissions from wheat–maize and wheat-rice rotation systems. Note: (a) CF_{area} of wheat in wheat–maize rotation systems (b) CF_{area} of maize in wheat–maize rotation systems (c) CF_{area} of wheat in wheat-rice rotation systems (d) CF_{area} of rice in wheat-rice rotation systems. (*Source*: Zhu et al. 2018). **b** Impact of farm scales on soil organic carbon storage in maize-wheat and rice–wheat rotation systems (*Source*: Zhu et al. 2018). **c** The carbon footprint of durum wheat (*Source*: Liu et al. 2016a, b). **d** The carbon footprint of spring wheat (*Source*: Liu et al. 2016a, b). **e** Organic C contents and C:N ratios of bulk soil and labile fractions under different fertilization regimes (*Source*: Li et al. 2018). **f** Cumulative CO_2 emission over time under different fertilization regimes (*Source*: Li et al. 2018). **g** Soil organic matter as affected by tillage treatments, 0–30 cm (1) soil organic matter over 0–10 cm depth (2) soil organic matter over 10–20 cm depth (3) soil organic matter over 20–30 cm depth (4) dynamic changes of soil organic matter on six treatments at 0–30 cm soil depth (*Source*: Tan et al. 2015). **h** Soil organic carbon in 0–15 cm depth under four cropping systems (*Source*: Gan et al. 2014). **i** Carbon emission (top) and sequestration (bottom) for alternative wheat cropping systems (*Source*: Gan et al. 2014)

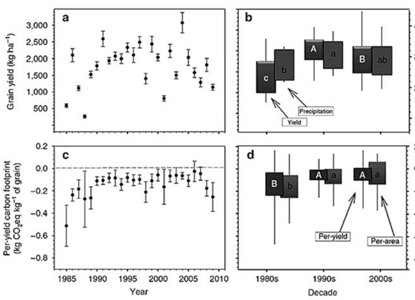
LFOC (Labile fraction of organic carbon) and MBC were increased multiple folds higher after manure plus straw and NP fertilizers (NPSM) and maize straw plus NP fertilizers (NPS) treatment in comparison to those of control (CK). Amongst all fertilization treatments, C: N ratio of bulk soil was constant, but that of LOC fractions were to the different treatments (Fig. 1e). The soils treated with exogenous organic amendment and chemical fertilizers showed lower DOC: DON (dissolved organic nitrogen) and LFOC/LFN (Light fraction nitrogen) ratios as compared to control. In contrast, the MBC: MBN (Microbial biomass nitrogen) ratio was 19% higher under NPSM application than control. Moreover, cumulative CO_2–C emission over time were higher in NPSM and NPS than in control and NP (nitrogen phosphorus fertilizer) treatments during the incubation period (Fig. 1f). After incubation, the NPSM treatment exhibit highest increase i.e. 85% in cumulative mineralization of C (C_{min}), whereas the increase was 53% in NPS treatment as compared to control.

Tan et al. (2015) reported that the SOM content in the upper (0–10 cm) soil layer increased to variable degrees under various tillage systems except in the CK treatment. However, in the soil layer 10–30 cm deep, the SOM content for different tillage systems increased and were higher than CK treatment. Amongst them, straw mulching has the highest SOM content (Fig. 1g). This result could be in associated with crop straw, a rich in source of organic carbon compounds viz. cellulose and lignin, which further are major sources of SOM. Decomposition of straw releases CO_2, which either promotes soil microbial immobilization or release or mineralize inorganic nitrogen, eventually forming SOM (Devêvre and Horwáth 2000).

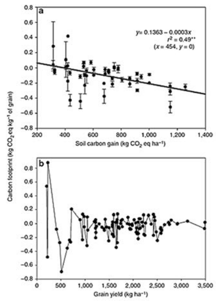
The SOC had a base value of 33 Mg ha^{-1} in 1979 when lentil-wheat system was introduced (Gan et al. 2014). Meanwhile, the levels of SOC with wheat cropping systems increased gradually (Fig. 1h). The larger addition of SOC during the later period was due to greater crop productivity resulting in greater biomass C reverted back to soil. This was achieved mainly by higher application rates of N fertilizer coupled with more favorable cultivation season. Higher sequestration of C was achieved by well managed cropping systems (Dhaliwal 2008). Guo et al. (2019) reported that SOC content increases with use of 34-year continuous fertilization. Results revealed that C input in the combined straw or manure treatments with inorganic fertilization (3.24–7.45 Mg C ha^{-1} year^{-1}) was much greater than that in the NPK (2.16 Mg C ha^{-1} year^{-1}) and control (0.23 Mg C ha^{-1} year^{-1}) treatments. The C input in the form of stubble and root for wheat (0.13–1.76 Mg C ha^{-1} year^{-1}) was greater than that of soybean (0.04–0.88 Mg C ha^{-1} year^{-1}) for a given fertilization practice. The crop residue retention serves as an important factor in increasing the quantity of SOC. Additionally, GHG emissions over a year had mean value of 357 kg CO_2 eq ha^{-1} in dry years, lower than that in normal and wet years (Fig. 1i). However, conversion of C by wheat plants from atmospheric CO_2 into plant biomass, was more than counterbalance and sequestered into the soil (Fig. 1i). Weather played a significant role in affecting both emissions and sequestration of C. Annual gain of soil C was 877 ± 15 kg CO_2 eq. ha^{-1} in normal years. Gan et al. (2014) also calculated the yearly mean value of per unit area carbon footprint by decade, in the 1980 was − 181 ± 12 kg CO_2 eq ha^{-1}, quite lower than that in the 1990 and 2000 (Fig. 2a). Furthermore, wheat carbon footprint was found to be a linear function of the levels of SOC increased, with each kg of soil C gain resulting in lower level of carbon footprint values by 0.0003U. The sensitivity test reveals that a gain of SOC at more than 454 equivalent of CO_2 ha^{-1} year^{-1} rate could lead to negative carbon footprints (Fig. 2b).

2.2 Effect of tillage and straw return on soil organic carbon fractions

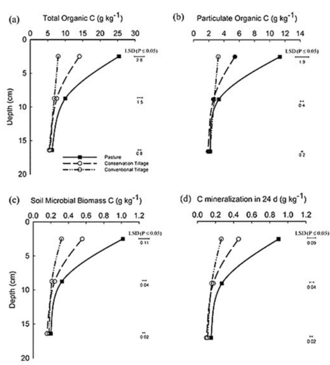
SOC levels were found to be higher in paddy field under different fertilizer treatments viz. mineral fertilizer (MF), rice straw residues and mineral fertilizer (RF), organic matter: mineral fertilizer (3:7) (LOM), and organic matter: mineral fertilizer (6:4) (HOM) than under the treatment without fertilizer (CK) (Fig. 2c). SOC levels were also higher at late growth stages than at early growth stages of late rice and highest content was noted at the heading stage of late rice, which declined at the maturity stage. Similar trend was observed in case of soil microbial biomass carbon (SMBC) also. Furthermore, SMBC contents under the LOM and HOM treatments were higher than under the MF, RF, and control treatments (Fig. 2c). The value of the SMBC: SMBN (soil microbial


Grain yield (kg ha⁻¹)
Precipitation (mm)
Precipitation
Yield
Per-yield carbon footprint (kg CO2eq kg⁻¹ of grain)
Per-area carbon footprint (kg CO2eq ha⁻¹)
Per-yield
Per-area
Year
Decade
1980s
1990s
2000s

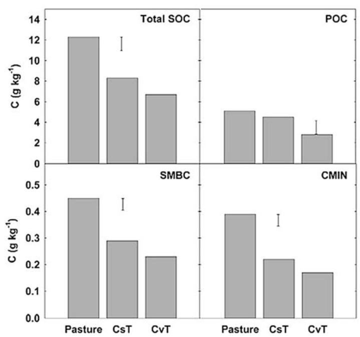
(a)


Soil carbon gain (kg CO2 eq ha⁻¹)
Grain yield (kg ha⁻¹)

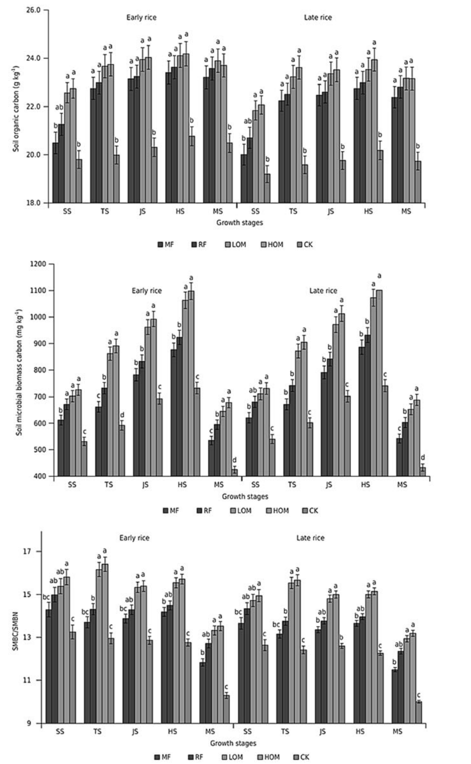
(b)


Total Organic C (g kg⁻¹)
Particulate Organic C (g kg⁻¹)
Soil Microbial Biomass C (g kg⁻¹)
C mineralization in 24 d (g kg⁻¹)
Depth (cm)
Pasture
Conservation Tillage
Conventional Tillage

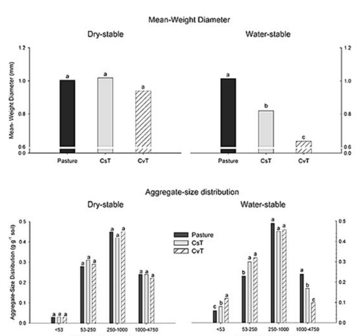
(d)


Total SOC
POC
SMBC
CMIN
C (g kg⁻¹)
Pasture
CsT
CvT

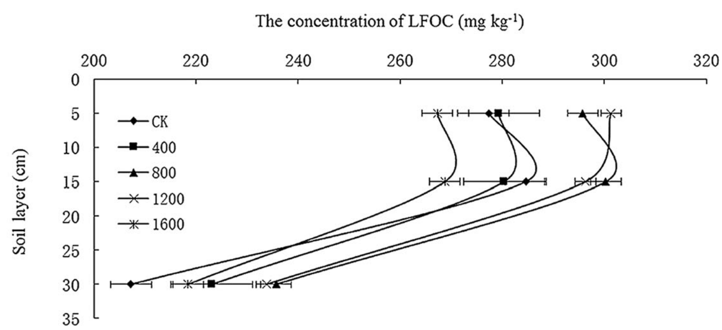
(e)


Early rice
Late rice
Soil organic carbon (g kg⁻¹)
Soil microbial biomass carbon (mg kg⁻¹)
SMBC/SMBN
Growth stages
SS
TS
JS
HS
MS
MF
RF
LOM
HOM
CK

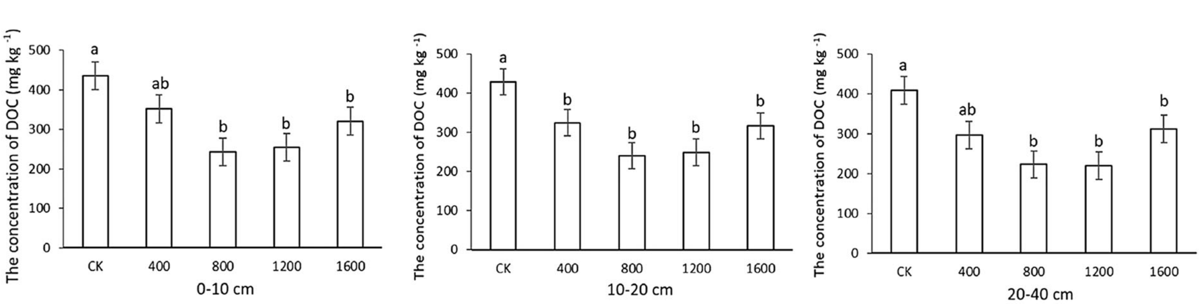
(c)


Mean-Weight Diameter
Dry-stable
Water-stable
Aggregate-size distribution
Pasture
CsT
CvT
Aggregate size class (μm)

(f)


The concentration of LFOC (mg kg⁻¹)
Soil layer (cm)
CK
400
800
1200
1600

(g)


The concentration of DOC (mg kg⁻¹)
CK
400
800
1200
1600
0-10 cm
10-20 cm
20-40 cm

(h)

◀**Fig. 2** **a** Grain yield and carbon footprints of spring wheat in different years or decades (*Source*: Gan et al. 2014). **b** The relationship between carbon footprint and soil carbon gain and crop yield in wheat (*Source*: Gan et al. 2014). **c** Effects of different long-term fertilization treatments on soil organic carbon content in a paddy field at main rice growth stages, soil microbial biomass carbon, soil microbial biomass carbon and nitrogen ratio in a paddy field at main rice growth stages (*Source*: Xu et al. 2018). **d** Depth distribution of (a) total SOC (b) POC (c) SMBC (d) C_{min} (*Source*: Causarano et al. 2008). **e** Effect of pasture, CsT, and CvT on total SOC, POC, SMBC, and C_{min} in 24 d at 20-cm depth (*Source*: Causarano et al. 2008). **f** Dry-stable and water-stable mean-weight diameter and aggregate-size distribution (0–5 cm) under pasture, CsT, and CvT systems (*Source*: Causarano et al. 2008). **g** Effects of straw return to deep soil on the easily oxidized organic carbon (EOC) and soil light fraction organic carbon (LFOC) at three soil depths (*Source*: Zou et al. 2016). **h** Effects of returning straw to the deep soil on soil dissolved organic carbon (DOC) at the three soil depths (*Source*: Zou et al. 2016)

biomass nitrogen) ratio under fertilizer treatments was higher than CK. (Figure 2c). (Xu et al. 2018).

Kaur et al. (2005) reported that SOC content increases with applications of organic matter and on the basis of type of fertilizer used, decreasing order of soil microbial biomass was found to be: organic fertilizer > mineral fertilizer > no fertilizer. The reason behind order could be the large amounts of labile organic C confined in decomposed organic matter and rice straw residues, which not only readily decomposed, but might had promoted microbial activity and eventually improved the mineralization of inherent SOC. Application of rice straw residues or organic matter were beneficial because they contain substantial organic carbon (Elzobair et al. 2016), and conversion rate of carbon was increased under collective uses of organic matter or rice straw residues.

Causarano et al. (2008) stated that despite of greater SOC level at upper layer of soil of pastures, no changes amongst management systems at lower depths (5–20 cm) was observed and similar relationship of management systems were observed in case of particulate organic carbon (POC), SMBC, and C_{min} also (Fig. 2d). The average concentrations of total SOC, POC, SMBC, and C_{min} within the surface 20 cm followed the order: pasture > conservation tillage row cropping (CsT) > conventional tillage row cropping (CvT) while potential C_{min} decreased with depth and was different among management systems in the order: pasture > CST > CvT (Fig. 2e). Moreover, the impact of management on water-stable mean-weight diameter and aggregate-size distribution, however, following the order: pasture > CsT > CvT (Fig. 2f).

Zou et al. (2016) observed appreciable differences between the straw return in the different treatments, which decreased in the order (in kg ha^{-1} straw) 800 > 400 > 1200 > 1600 > control (Fig. 2g). The soil DOC contents were not significantly different between the soil layers in each treatment. About the vertical distribution, the soil DOC decreased with increasing soil depth in all treatments (Fig. 2h). This result potentially occurred because the crops absorbed DOC during their growth and development or because the DOC was temporarily accumulated in or transformed to other substances. Otherwise, the decrease in DOC could be associated with microbial use (Moore et al. 1992). In addition, the environmental changes in soil chemistry should also be considered (Ji et al. 2014). The ranges of soil LFOC in all treatments decreased as follows (in kg ha^{-1} straw): 1200 > 800 > 400, Control > 1600 at 0–10 cm depth, (in kg ha^{-1} straw) 800, 1200 > Control, 400 > 1600 at 10–20 cm, and 800, 1200 > 400 > 1600 > control at 20–40 cm (Fig. 2g).

Johnson et al. (2013) observed that in newly established no tillage fields, significant increases in aggregates < 1 mm and significant decreases in aggregates 5–9 mm were observed in low return compared to full return (Fig. 3a). In Chisel and newly established no tillage fields, means of aggregate distribution followed a similar trend to the newly established no tillage fields, but statistically no increase in the frequency of aggregates < 1 mm was detected (Fig. 3a).

Singh (2018) reported that there may be more processes that control the SOC's response to fertilization with N, but the increase in C inputs and, finally, SOC mineralization, depends on the sufficiency level of N (Fig. 3b). He suggested that the inorganic N of the residual soil produced when N fertilizers were applied beyond the optimal level, which could resulted in increase in SOC mineralization either by eliminating N limitations on growth of microbes or by negatively affecting the soil aggregation, which makes SOM more susceptible to decay. Decrease in C:N ratio of crop residues and increase the rate of decomposition were observed with excessive N. Naresh et al. (2017) indicated that SOC usually accumulated with increased rates of N fertilizer application (Fig. 3c).

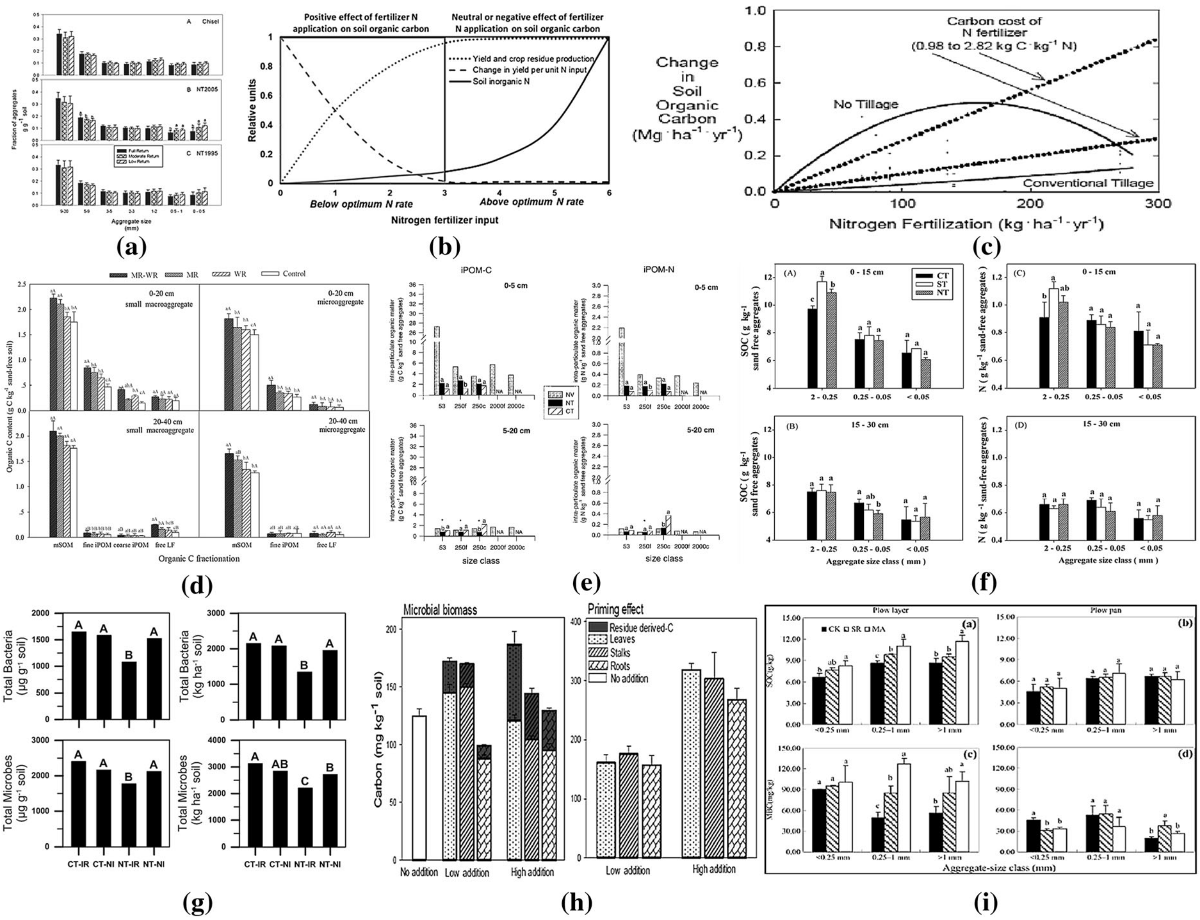


Fig. 3 **a** Dry aggregate size distribution as affected by Stover return rates (*Source*: Johnson et al. 2013). **b** Effects of fertilizer application to crops on SOC as defined by relationships between increasing fertilizer N application levels and (1) yield and crop residue production, (2) change in yield per unit N input, and (3) residual soil inorganic N (*Source*: Singh 2018). **c** Effect of Nitrogen fertilizers on change in SOC under no tillage and conventional tillage treatments (Naresh et al. 2017). **d** Organic C content (g kg^{-1} soil) of the SOC fractions: coarse intra-aggregate POM, fine intra-aggregate POM, mineral-associated matter, and free light fraction of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under maize and wheat straw, maize straw and wheat straw (*Source*: Zhao et al. 2018). **e** Aggregate and SOM dynamics under conventional and no-tillage systems (*Source*: Six et al. 1998). **f** SOC and nitrogen content (g kg^{-1}) of sand-free aggregates from two depths under conventional tillage with residue removal, shallow tillage with residue cover, and no-tillage with residue cover (*Source*: Naresh et al. 2017). **g** Tillage [conventional tillage (CT) and no-tillage (NT)] treatment effects on total bacterial and total microbial biomass concentrations (*Source*: Desrochers 2017). **h** The contribution of residue derived and soil organic matter (SOM) derived C to microbial biomass (left) and the amount of primed C due to low and high level of crop residue addition (right) (*Source*: Sainju et al. 2012). **i** Effects of different annual straw return rates on soil TOC (A), DOC (B), EOC (C) and MBC (D) contents at the three soil depths (*Source*: Zhu et al. 2015)

The average rate of N fertilizer to achieve maximum SOC sequestration was reported to be 171 kg N ha^{-1} $year^{-1}$ (Franzluebbers 2005). Though, when C costs of N fertilizer were considered the optimum N fertilizer rate was 107–120 kg ha^{-1} $year^{-1}$ for production, application, and liming components, respectively.

Zhao et al. (2018) also found that the straw return methods, specifically through maize and wheat straw systems, enlarged the proportions of mineral-associated matter and fine intra-aggregate POM within small macro- and micro-aggregates. The carbon content of intra-aggregate POM was very low at 20–40 cm than at 0–20 cm (Fig. 3d). Six et al. (1998) stated that the free light fraction C concentration was not influenced by the tillage of the soil, but that in cultivated systems it was about 45% lower than the non-processing. The percentage of C derived from macro-aggregate crops were similar in unconventional and conventional tillage, but were three times higher in micro-aggregates than in no tillage than in micro-aggregates of conventional tillage treatment (Fig. 3e). Naresh et al. (2017) found that macro-aggregates are less stable than micro-aggregates and, therefore, more sensitive to ground breaking interruption forces. The influence of the processing on the aggregate C and the contents without processing are shown in (Fig. 3f). Chen et al. (2009) reported that reduced processing (RT) contained 7.3% more SOC and 7.9% more N reserves than plough (PT) processing at depth of 0 to 20 cm, respectively, and it is estimated that RT accumulates an average of 0.32 Mg C ha^{-1} $year^{-1}$ and 0.033 Mg N ha^{-1} $year^{-1}$ more than PT over an average period of 11 years, respectively.

Zhu et al. (2015) revealed that the total content of organic C (TOC) and labile organic fraction C was higher in the straw return treatments than straw treatment without return (0% S) at 0–21 soil depth. The annual straw yield rate of 50% (50% S) had a significantly higher content than that of TOC, DOC, EOC and MBC compared to treatment with 0% S at a depth of 0–21 cm. All the straw return treatments had a significantly higher DOC content than the treatment with 0% S at a depth of 0–21 cm, with the exception of 100% rice straw (100% RS) return treatment (Fig. 3i). A plausible explanation could be that changes in DOC are generally insensitive to recent management practices, since these changes occur slowly and are relatively small compared to the vast SOC background (Gong et al. 2009). Although it is below 50% of the treatment with S, the conditions for the growth of the microorganisms are more favorable for an efficient decomposition of the straw, thus stimulating the increase in DOC.

2.3 Effect of tillage and straw return on soil microbial community

Desrochers (2017) also found that the greater aggregated soil fraction and total microbial and bacterial biomass observed under the conventional tillage-irrigated compared to no tillage-irrigated treatment combination supports the notion that a greater microbial biomass increases aggregation through the production of microbial exudates. However, the No tillage-irrigated combination has a greater fine light fraction C content compared to the three remaining tillage-irrigation combinations, suggesting the combined effects of tillage and irrigation may alter the near-surface soil microclimate to benefit fine light fraction C accumulation (Fig. 3g). Bacterial biomass content, averaged across burn and residue level treatments, total microbial biomass content was 15 and 42% greater (Fig. 3g), in the conventional tillage-irrigated (3134 kg ha^{-1}) than in the no tillage-non-irrigated (2720 kg ha^{-1}) and no tillage-irrigated combinations (2212 kg ha^{-1}), respectively (Fig. 3g). Total microbial biomass was also 23% greater in the no tillage-non-irrigated (2752 kg ha^{-1}) than in the no tillage-irrigated combinations (2212 kg ha^{-1}), while total microbial biomass in the conventional tillage—non-irrigated (2851 kg ha^{-1}) did not differ from the conventional tillage—irrigated or no tillage-non-irrigated combinations, but was 29% greater than in the no tillage—irrigated combination (Fig. 3g). The greater microbial and bacterial biomass content associated with the conventional tillage—compared to the no tillage—irrigated and non-irrigated combination in addition to the greater conventional tillage compared to no tillage -residue-level combinations partially supports the positive association between microbial biomass and the macro-aggregate fraction.

The levels of SOC were reported to decrease with soil depth under different cropping systems of winter viz. rice-fallow (RF), rice–wheat (RW), rice-potato + rice straw mulch (RP), rice-green manure (RG), and rice-oilseed (RO). It was found that in upper layer significant greater SOC was observed in case of RP system only whereas no noticeable alterations were observed amongst the other systems. While at deeper depth i.e. 20–30 cm, there was no observable differences amongst all tested cropping systems. On other hand level of POC were higher in RW system and DOC was higher in PR treatments than other tested systems. DOC levels were lower in case of RF system. The levels of hot water carbon (HWC) in the RG and RP rotation systems were significantly more whereas quantity of MBC in RW and RO decreased significantly as compared to other tested systems in upper layers. The contents of DOC, $KMnO_4$–C, HWC and MBC in the treatment of RP were relatively higher compared to the other treatments. The improved SOC fractions may partly explain the improvement in soil properties. (Chen et al. 2016).

Application of manure amplified the levels of total microbial, fungal, bacterial, and arbuscular mycorrhizal fungi (AMF) phospholipid fatty acids (PLFA) in bulk soil and all macro-aggregate but not in micro-aggregates. Under the control treatment i.e. untreated conditions, the macro-aggregates had same contents of total microbial and bacterial PLFAs and fungi to bacteria PLFAs ratios whereas amongst manuring groups these contents were higher in macro-aggregates. Although the fungal and AMF PLFAs were higher than control treatment than in micro-aggregates. Application of manure and size of aggregate significantly effects the microbial PLFAs (Wang et al. 2017). The major reasons behind same levels of bacterial PLFAs in micro- and macro-aggregates could that the bacteria have same access to water, nutrients and oxygen, in both micro- and macro-aggregates, bacteria mainly lives in small pores inside micro-aggregates (Ding and Han 2014) and the TN content of both micro- and macro-aggregates is same. Amongst manuring groups, macro-aggregates contains the higher levels of bacterial PLFAs than micro-aggregates. This alteration might be originated due to higher availability of C in macro-aggregates (Chen et al. 2015).

A constructive relationship amongst water soluble C (WSC) and C_{min} was reported by Sainju et al. (2012). The techniques of application and the quantity of added residue also affect the WSC and C_{min} values. Overall, the soils containing higher C exhibited more C_{min} (Fig. 3h). Triple increase in SOC reserves under minimal tillage than the conventional tillage was reported by Sapkota et al. (2017). SOC accumulation in the Indo-Gangetic plains was reported to increase at a rate of 0.16–0.49 t C ha^{-1} per year with minimum soil tillage than conventional tillage (Powlson et al. 2016).

Zhang et al. (2014) revealed that in the ploughing layer the application of organic amendments enlarged the macro-aggregates percentage and mean diameter by weight. The dispersal patterns of SOC and MBC inside aggregate were affected by organic treatments. In the plough layer, the SOC increased by 35.5% in macro-aggregates than control treatment and differences found in the MBCs in macro-aggregates amongst organic amendments were also significant. Mean diameter by weight positively correlated with SOC and MBC. The organic modification, through crop residues or the application of manure, had improved the stability of the soil aggregate with positive effects on soil binding agents, including SOC, MBC. In a field study of different land use systems, Dhaliwal et al. (2008) reported a higher MBC in the forest land use system compared to normal processing and undisturbed land.

3 Conclusions

The review of literature showed that studying the influence of tillage and straw return on carbon footprints, soil organic carbon fractions and soil microbial community is prominence to farmers and policymakers. In comparison to traditional tillage treatments, conservative tillage results in increase of SOM. All SOC fractions were found to be strongly correlated between all soils and managements. Manure modification has favored soil structure, increased C sequestration, microbial activity and increased soil fertility. The soil cannot increase soil aggregation, improve soil properties and favorably influence the accumulation of SOC. The effects of the addition of crop residues are often observed when integrated with reduced tillage systems or better nutrient management. The amount of new SOCs took about 30 years to reach the same level as the old SOC in upper layer of land after the conversion of cultivated lands. This suggests that organic matter in soils under wheat-rice systems could easily be lost by decomposition if the present land use is altered. SOC was also found to be related with size of farm, type of manure and use of mineral fertilizers integrated with organic residues incorporated in soil. The tillage can alter the flow of water and oxygen, the structure of the soil, the temperature and the formation of aggregates that directly or indirectly affect soil microbes. Microbial communities are involved in various biogeochemical cycles and soil formation. Alterations in this habitat can compromise the productivity of the land. A better understanding of the interactions of soil properties will help to improve the management of the land and will protect our soil from further deterioration.

Adoption of conservative tillage in combination with the retention of crop residues, the systematic integration of key farming practices and the integration of these best agricultural practices help reduce the use of inorganic fertilizers, increase system productivity and reduce the carbon footprint. With the relevant agro-environmental policies implemented, along with the adoption of better agronomic tactics, the increase of the microbial community population protects the environment in an effective, efficient and economical way. The lack of awareness about the latest techniques lead to a lesser implementation of these technologies in agricultural fields. Since the major portion of GHG emission comes from agriculture sector. It is important to study the various parameters to understand and develop the better techniques to increase the efficiency of the energy inputs, fertility of soil, yield of produce, farmer's income and decrease the fertilizer demand and GHG emissions.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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