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Organic matter fractions and soil carbon sequestration after 15- years of integrated nutrient management and tillage systems in an annual double cropping system in northern India

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Abstract

Labile soil organic carbon pools are valuable indicators of soil quality, early changes in soil total organic carbon (TOC) stocks, and (hence) changes in soil carbon sequestration pools and dynamics induced by changes in soil tillage and nutrient management practices. To improve the soil carbon sequestration in northern India, we have examined effects of tillage, crop residues and nutrient management treatments applied in a 15-year experiment on TOC and the following fractions: soil organic carbon (SOC), particulate organic carbon (POC), total nitrogen (TN), water soluble carbon (WSC), light fraction organic carbon (LFOC), dissolved organic carbon (DOC) microbial biomass carbon and (MBC). The tillage crop residue practices were ZT without residue (T_1), ZT with 4 tha^{-1} residue retained (T_2), ZT with 6 tha^{-1} residue retained (T_3), PRB without residue (T_4), PRB with 4 tha^{-1} residue retained (T_5), PRB with 6 tha^{-1} residue retained (T_6), and conventional tillage (T_7) was combined with the following nutrient management treatments: control (no manure and fertilizer) (F_1), 100% RDN as CF (F_2), 75% RDN as CF+25% RDN as FYM (F_3), 75% RDN as CF+25% RDN as GM/SPM (F_4), 50% RDN as CF+50% RDN as FYM (F_5), 50% RDN as CF+50% RDN as GM/SPM (F_6) and1/3rd N as CF+1/3rd N as FYM+1/3rd N as GM/SPM (F_7). After 15 years, T_3 treatment resulted in significantly increased 66.1%, 63.9%, 57.9%, 50.9%, 39.4%, 38.3%, 37.3% and 32% LFOC, TOC, SOC, PON, TN, LFON, DOC and POC, over T_7 treatment and WSC 39.6% in surface soil and 37.4% in subsurface soil.

Out of the four C fractions, LFOC and $KMnO_4$ C were the most sensitive indicators of changes in TOC induced by the soil tillage and nutrient management practices. Under RWCS, TOC contents were similar in F_6, F_7 and F_3 plots, and significantly higher than those in F_1 plots (by 50.4% 48.3%, and 43.3% respectively). Manure addition further enhanced TOC contents, which were highest following the F_5 treatment (21.37 gkg^{-1}). LFOC were also significantly higher following the treatments including organic amendment than following applications solely of chemical fertilizers, except that the F_5, F_6 and F_7 treatments resulted in similar LFOC contents. Application solely of chemical fertilizers had no significant effects on LFOC and $KMnO_4$C fractions compared with unfertilized control plots. Nevertheless, application of F_5 or F_6 significantly increased contents of POC and MBC relative to F_1 (by 49.6%and 40.9% or70.2% and 63.4%, respectively). These results demonstrated that conservation agriculture that integrates application of nutrient management, tillage and crop residue is crucial for improving soil health and sustainability of farming systems in northern India.

Keywords: Organic matter fractions; Soil organic carbon; Microbial biomass carbon, Soil health

1. Introduction

In Indian IGP, Rice (*Oryza sativa* L.)–Wheat (*Triticum aestivum* L.) (RW) is the dominant annual double- cropping system, occupying about 10.3 million ha and accounts for 23% and 40% of India's rice and wheat area, respectively (Gathala *et al*. 2013) [16-32]. Rice is grown during the summer season (June to October) and wheat during the winter season (November to April), leaving the land fallow for about 60–65 days after wheat harvest until rice planting. However, sustainability of conventional RW system has recently been questioned due to the high labour, water and energy requirements (Kumar *et al*. 2013) [16] which are gradually becoming scarce and expensive. Frequent tillage may destroy soil organic matter (SOM) Tian *et al*., 2010 [56] and speed up the movement of SOM to deep soil layers Zhu *et al*., (2011) [61]. As a consequence, agricultural practices that reduce soil degradation are essential to improve soil quality and agricultural sustainability. Crop residue plays an important role in SOC sequestration, increasing crop yield, improving soil organic matter, and reducing the greenhouse gas (Li *et al*., 2012 and Guo *et al*., 2015) [33]. As an important agricultural practice, straw return is often implemented with tillage in the production process.

Although numerous studies have indicated that tillage methods combined with straw return had a significant effect on labile SOC fractions, the results varied under different soil/climate conditions.

Application of manure could increase SOC, and the nutrient input could improve soil fertility and soil structure (Mikha and Rice, 2004) [38]. Jiao *et al*., (2006) [25] found that aggregate stability(>2 mm) and nutrient retention were improved when manure and mineral fertilizer were applied in combination at a rate of 30 $Mgha^{-1}$,as compared to mineral fertilization alone. Many studies have shown that balanced application of inorganic fertilizers or organic manure plus inorganic fertilizers can increase SOC and maintain soil productivity Powlson *et al*., 2012 [42]. However, SOM is not sensitive to short-term changes of soil quality with different soil or crop management practices due to high background levels and natural soil variability Haynes, 2005 [20]. Labile soil organic carbon pools like dissolved organic C (DOC), microbial biomass C (MBC), and particulate organic matter C (POC) are the fine indicators of soil quality which influence soil function in specific ways and are much more sensitive to change in soil management practices (Xu *et al*., 2011) [60]. Recently, many studies have reported responses of labile SOC pools to management practices (Liang *et al*., 2011 and Nayak *et al*., 2012) [34], though limited to tillage practices Dou *et al*., 2008 [13]. Challenges for irrigated farming in western Uttar Pradesh, India are low SOC and nutrient retention Naresh *et al*., 2015 [40]. However, little is known about the long-term application of inorganic fertilizers either alone or with organic manure on SOC and the distribution of labile organic C fractions at different profile depths. Thus, it is crucial to collect SOC data from long-term experiments in order to understand and estimate the contribution of manure and fertilizer to soil C dynamics. This study provided a unique opportunity to examine the effects of manure and fertilizer on soil organic carbon pools for subtropical climatic conditions in western Uttar Pradesh, India. We hypothesized that fertilizer and manure application would influence the SOC and labile carbon. Moreover, we considered labile organic C fractions would be responsive indicators to SOC change with long histories of fertilizer managements. Our objective was to study the nutrient, crop residue and tillage management on SOC and SOC fractions under a 15-year field experiment in the western U. P., India, and to explain the relationship between different SOC fractions and SOC concentrations. Improved understanding of labile organic matter fractions will provide valuable information for establishing sustainable fertilizer management systems to maintain and enhance soil quality.

2. Materials and Methods

2.1. Experimental site

The long-term field experiments was initiated in 2000 at Sardar Vallabhbhai Patel University of Agriculture &Technology, Meerut research farm (29^0 04', N latitude and77^0 42' 'E longitude a height of 237m above mean sea level) U.P., India. During the 15 -year period of field experiment, mean weekly maximum and minimum air temperature for the crop seasons were recorded ranged from 16.3 to 36.4°C and 5.2 to 19.6°C, respectively. The area receives an average annual rainfall of 695 mm (constituting 44% of pan evaporation) of which about 80% is received during the monsoon period.

2.2 Soil of the experimental site

A composite soil sample was collected from the experimental field to study the contents of available N, P and K, pH, electric conductivity, organic carbon content and some physical properties of the soil. The soil analysis revealed that the soil was sandy-loam with 55, 18, and 27% sand, silt, and clay, respectively, Typic Ustochrept; non-saline (EC 0.42 dS m^{-1}) but mild alkaline in reaction (pH 7.98). The soil (0-15 cm depth) initially had 4.1 g kg^{-1} of SOC and 16.4, 96, and 14.5 kg ha^{-1} of available P, K, and S, respectively.

2.3 Experimental details

The experiment was laid out in a split plot design keeping seven tillage crop establishment methods T_1- ZT without residue, T_2-, ZT with 4 t residue retained, T_3- ZT with 6 t residue retained, T_4- PRB without residue, T_5- PRB with 4 t residue retained, T_6- PRB with 6 t residue retained, T_7- Conventional tillage in main plots and seven nutrient management practices were F_1-Control (no manure and fertilizer); F_2-100% RDN as CF; F_3-75% RDN as CF+25% RDN as FYM; F_4-75% RDN as CF+25% RDN as GM/SPM*;* F_5-50% RDN as CF+50% RDN as FYM; F_6-50% RDN as CF+50% RDN as GM/SPM*;* F_7-1/3 rd N as CF+1/3 rd N as FYM+1/3 rd N as GM/SPM allotted to sub-plots in a split-plot design and replicated thrice. The gross and net plot sizes were 8 m×3.2 m and 6.0 m×2.0 m, respectively and treatments were superimposed in the same plot every year to study the cumulative effect of treatments.Farmyard manures (FYM) was applied on the basis of N equivalent basis in 100% RDN. The N, P_2O5, and K_2O in FYM, rice straw, wheat straw, sulphitation press mud (SPM), and dhaincha (GM) residue were 0.5, 0.25, 0.3; 0.5, 0.23, 1.14; 0.5, 0.25, 1.21; 0.45, 0.33, 0.5; and 0.72, 0.18,0.53%, respectively.

The tillage and crop establishment methods comprised of (i) conventional tillage (CT): In conventional tillage there were four tillage operations. The first tillage was performed in the pre-monsoon season (April/May) and the second one was performed in May/June, some 20–25 days after the first tillage. The third tillage was conducted during June and the fourth rice harvest (October/November) at deeper depth (>15 cm) using a tractor drawn cultivator. Similar tillage operations were followed for the wheat crop.; (ii) Permanent Raised Beds (FIRB): seeds were drilled, 5 cm deep, over rice harvested bed tops, in six rows, after superficial reshaping using plots using inclined plate zero-till cum raised bed planter (FIRB); and (iii) zero tillage (ZT): seeds were drilled, 5cm deep, on untilled rice harvested plots using inclined plate zero-till seed drill. The residue management consisted of (i) residue retention (RR): The 40 cm stubbles of preceding crop were left at harvest and chopped rice straw of size 15–20 cm was applied in 4 tha^{-1} and 6 t ha^{-1} as mulch manually on the same day after sowing of wheat in each year. (ii) Residue removal (RO): preceding crop was harvested from ground level leaving about 5 cm stubbles. The nutrient management practices one-third of N and entire P, K were applied at the time of transplanting/sowing and remaining N was top dressed in 2 equal splits at maximum tillering and panicle/ear emergence. The FYM was incorporated in the soil one week while GM/SPM was incorporated 15-20 days before transplanting/sowing of the crops. In the treatments involving GM was sown immediately after wheat harvest, and the above ground biomass was incorporated by dry tillage before puddling. Both crops were grown under assured irrigated conditions with recommended agronomic practices.

2.4. Soil sampling and processing

After wheat harvest (May 2015), two sets of triplicate undisturbed soil cores were collected from 0 to 5 and 5 to 15 cm soil depths using a core sampler (7.5 cm diameter) from all treatments to determine the cumulative effect of application of 15 years of treatments on SOC dynamics. Bulk density was determined using one sample set. Samples from individual plots (the second set) were thoroughly mixed, air-dried, and passed through a 5 mm sieve. We found no aggregates >5 mm diameter. Air-dried samples were placed in plastic bags and stored at ambient laboratory temperature. A soil sub-sample was taken from both depths and analyzed for soil aggregation, total SOC and labile and recalcitrant SOC pools, as reported below.

2.4.1. Separation of soil aggregates and fractionation of SOC

Aggregate-size separation was performed using a wet sieving method (Elliott, 1986) [15]. Soil samples (100-g air-dried <5 mm) were placed on top of a 2.0 mm sieve and submerged for 5 min in deionized water, to allow slaking (Kemper and Rosenau, 1986) [30]. Sieving was performed mechanically moving the sieve up and down 3 cm, 50 times in 2 min using a modified Yoder's apparatus. A series of five sieves (2, 1, 0.5, 0.25 and 0.11 mm) was used to obtain six aggregate fractions (i) >2 (Very large macro-aggregates), (ii) 2-1 (large macro-aggregates), (iii) 1-0.5 (medium macro-aggregates), (iv) 0.5-0.25 (small macro-aggregates), (v) 0.25-0.0.106 (micro-aggregates), and (vi) <0.106 (silt- and clay-sized particles).

A subsample was taken from the collected soil suspension. The subsample was passed through the < 0.25 sieve ('silt clay'-sized fraction). This subsample, along with soil aggregate fractions retained on different sieves, was oven-dried at 50°C, weighed and stored in glass jars for total SOC analysis. Different particle-size fractions obtained from the aggregate analysis were measured and converted into fractions. The fraction of aggregates <0.25 mm was calculated by summing up the total mass of the material retained on the >2 mm sieves and this was subtracted from the total weight of the soil taken for wet-sieving analysis. Small and large macro-aggregates together constitute the macro-aggregates. The total SOC concentrations of bulk soil and in each aggregate fraction were determined following the dry combustion method (Nelson and Sommers, 1982) [41] using a CHN analyzer. Since the measured inorganic C (carbonates) contents of the samples were nil, the total soil C was equal to total SOC.

2.4.2. Carbon management index and carbon pool calculations

The carbon management index (CMI) provides a sensitive measure of the rate of change in soil C dynamics of a given system relative to a more stable reference soil (Blair *et al*., 1995) [4]. This index was calculated for each of the treatments using a reference sample value, obtained from the control plot under the cropping system without any fertilizers, as follows:

(1) Firstly, a C pool index (CPI) was calculated from:

$$CPI = \frac{\text{sample total organic C (g/kg)}}{\text{reference sample total C (g/kg)}}$$

(2) Then, a lability index (LI) from:

$$LI = \frac{\text{lability of C in each sampled soil}}{\text{lability of C in the reference soil}}$$

Where

$$\text{lability of C} = \frac{KMnO_4\ C}{TOC - KMnO_4\ C}$$

(3) The CMI was then estimated from: CMI = CPI x LI x100

2.4.3. Total organic carbon

The TOC content was determined by using Walkley and Black's (1934) [59] rapid titration method and computed using Eq. (1):

TOC stock (Mg C ha^{-1}) = TOC content (g C kg^{-1}) × Db (Mg m^{-3}) × Soil layer (m) × 10 (1)

Where,

Db is bulk density of the particular soil layer (Db values for 0-5 cm and 5-15 cm soil layer were 1.32 and 1.34 Mg m^{-3}, respectively).

2.4.4. Particulate organic carbon

For the POM fraction, 50 g of air-dried soil sample was submerged in deionized water for 30 min to promote slaking of aggregates. Then, the mixture was poured onto a 250-µm sieve inside a cylinder and reciprocally shaken at 120rpm with 50glass beads of 10-mm diameter. The micro-aggregates that passed through the 250-µm sieve were collected in a bottom sieve of 25-µm. The fraction retained on the 250-µm sieve consisted of coarse material (POM and sand from 250to 2,000-µm) and was labeled as coarse POM. The aggregates retained on the 25-µm sieve (having size from 25 to 250-lm) were dispersed by shaking for 18 h with 25 ml of 0.5g ml^{-1} sodium hexametaphosphate and 12 glass beads of 4-mm diameter in a 50-ml centrifuge tube to isolate the fine POM (Cambardella and Elliott 1992) [7].

2.4.5 Light Fraction Organic C and N

PMN in soil was determined by the method described by Keeney (1982) [29], where 10 g air-dry soil was taken in a test tube with distilled water (1:2) and incubated for 7 days under waterlogged conditions at 40°C. The mineralized NH_4^+ N was determined by the Kjeldahl's distillation method. The amount of PMN (mg NH_4^+ N kg^{-1} d^{-1}) was determined by subtracting the concentration of NH_4^+ N at the beginning of incubation.

2.4.6. Labile carbon pools

$KMnO_4$ oxidizable carbon (KOC) in soil was determined by following the procedure of Blair *et al*. (1995) [4]. Moist sample of soil (2.0 g) was taken in centrifuge tube and oxidized with 25 ml of 333 mM $KMnO_4$ by shaking on a mechanical shaker for 1 h. The tubes were then centrifuged for 5 min at 4000 rpm and 1.0 ml of supernatant solution was diluted to 250 ml with double distilled water. The concentration of $KMnO_4$ was measured at 565 nm wavelength using a spectrophotometer. The change in concentration of $KMnO_4$ is used to estimate the amount of carbon oxidized assuming that 1.0 mM of MnO_4^- was consumed ($Mn^{7+} \rightarrow Mn^{2+}$) in the oxidation of 0.75 mM (9.0 mg) of carbon.

2.4.7. Dissolved organic carbon

Dissolved organic C (DOC) was extracted from 10 g of moist soil with 1:2.5 ratio of soil to water at 25.8°C Jiang *et al*., (2006) [24]. After shaking for 1 h and centrifuging for 10 min at 4500 r min^{-1}, the supernatant was filtered with a 0.45 mm membrane filter. The filtrate was measured by oxidation with potassium dichromate and titration with ferrous ammonium sulphate.

2.4.8. Microbial biomass carbon

For the estimation of soil microbial biomass C and N by the chloroform fumigation and incubation method Horwath and Paul, (1994) soil moisture was adjusted to 55% field water

capacity, pre-incubated at 25°C for 7 days in the dark, and each soil sample was subdivided into two subsamples for fumigated and non-fumigated treatments. For MBC, soil samples, equivalent to 30 g dry weight, were fumigated with $CHCl_3$ for 24h at 25°C.After removing the $CHCl_3$, each soil sample was incubated at 25°C for a period of 10 days in closed tight Mason jar along with vials containing 1.0 ml 2 M NaOH. The flush of CO_2-C released upon fumigation was determined from titration with HCl.
The MBC was computed using Eq. (2):

$$\text{MBC (mg kg}^{-1}\text{)} = (\text{Fc}-\text{UFc})/\text{Kc} \quad (2)$$

Where, Fc is CO_2 evolved from the fumigated soil,
UFc is CO_2 evolved from the unfumigated soil, and
Kc is a factor with value of 0.41 Anderson and Domsch, (1978) [1].
For MBN, fumigated and non-fumigated soil samples after 10-day incubation were extracted with 2 M KCl (5:1 ratio of extractant: soil) for 1 h and inorganic N was determined by the Kjeldahl distillation as described by Keeney and Nelson (1982) [29]. The MBN was computed using Eq. (3):

$$\text{MBN (mg kg}^{-1}\text{)} = (\text{Fn}-\text{UFn})/\text{Kn} \quad (3)$$

Where,
Fn is mineral N from fumigated soil,
UFn is mineral N from unfumigated soil, and
Kn is a factor with value of 0.57 Jekinson, (1988) [23].

2.5. Statistical Analysis
Statistical analysis of data of various soil health parameters was carried out by ANOVA in split-split plot design Cochran and Cox, (1950) [10]. The effects of different treatments were evaluated using the least significant difference (LSD) test at the 0.05 level of probability. The data presented in figures are means ± standard deviation (SD) of three replications.

3. Results

Table 1: Biochemical composition (%, on oven-dry basis) of the organic amendments used (According to Bandyopadhyay *et al*., 2011) [3].

Composition	Farmyard manure	Paddy straw	Green manure	Wheat straw
C (%)	33.3±5.1	42.0±3.0	41.5±3.6	44.8±2.8
C:N	66.6±0.4	97.7 ±0.3	24.3±0.2	79±0.2
Cellulose	23.1±0.4	35.0±0.3	10.0±0.2	32.3±0.3
Lignin	17.5±0.2	11.0±0.1	8.9±0.1	8.0±0.2
Polyphenol	1.1±0.03	0.6±0.03	0.3±0.02	1.10±0.03

3.1. Aggregate-size distribution
Aggregate size distribution in different soil depths were significantly impacted by management practices (Table 2). Macro aggregates accounted for >51% of total aggregates. In topsoil (0–10 cm soil layer), these were the dominant water-stable aggregates (WSA). Significantly higher (60%) water-stable macro-aggregates were recorded in PRB plots compared with CT in the topsoil, with a concurrent decrease in micro aggregates in the ZT plots. A similar trend also was recorded in sub-surface soil (Table 2). Small macro-aggregates were the greatest proportion of the whole soil, followed by aggregates <0.106 mm in topsoil. Plots under PRB had significantly more large and small micro-aggregates than ZT plots in 0-10 and 10-20 cm soil layers. The PRB plots had significantly more large macro-aggregates, with a concomitant decrease in 'silt + clay' sized aggregates (<0.106 mm) compared with ZT plots in the topsoil.
In the sub-surface soil, size distributions of aggregates were also significantly influenced by tillage, practices. Small macro-aggregates comprised the greatest proportion of the whole soil, followed by aggregates <0.106 mm in the 10–20 cm soil layer. Subsurface soil (10–20 cm depth) had 34% higher macro-aggregates than micro-aggregates (Table 2). The percentage of water-stable aggregates of the largest size class (>2 mm) in PRB plots at depth of 0 to 10, 10 to 20, and 20 to 30 cm was approximately twice the percentage under CT but significant only below the 10-cm soil layer. The comparison between ZT and CT did not produce significant results until a depth of 20 cm. In contrast, the soil in all layers of the CT treatment had the highest percentage of water-stable aggregates of the smallest size class (<0.106 mm) compared with both the PRB and ZT treatments. Aggregate data revealed that the macro-aggregates increased by 39% and micro-aggregates decreased by 9% in PRB plots compared with CT plots. Decrease in micro-aggregates and increase in macro-aggregates with application of conservation tillage might have enhanced soil aggregation processes.

Table 2: Soil stable aggregate size classes for zero-till (ZT), permanent raised bed (PRB) and conventional tillage (CT), treatments in the 0- to 30-cm soil depth in 2015.

Depth (cm)	Treatment	Aggregate size distribution						Macro-aggregates (>0.25 mm)	Micro-aggregates (<0.25 mm)
		>2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.106 mm	<0.106 mm		
		%							
0–10	ZT	5.31 b	6.06 a	5.67 a	17.60 a	35.45 b	53.73a	28.89 a	67.11 a
	PRB	6.45 b	9.73 b	8.09 a	8.95 a	12.83 a	31.66 b	33.44 a	66.57 a
	CT	2.13 a	4.26a	5.59 a	5.33 a	13.08 a	66.91 a	19.01 a	79.99 a
10-20	ZT	4.36 ab	5.62 a	5.22 a	20.23 b	36.90 b	57.47a	31.46b	68.54b
	PRB	6.68 b	5.69 a	4.05 a	14.98 ab	11.07 a	27.55 b	35.56 b	64.44 b
	CT	2.90 a	3.57 a	4.17 a	5.53 a	12.34 a	72.08 a	15.59 a	84.42 a
20-30	ZT	4.70 a	4.14 a	3.52 a	8.70 a	21.06 b	61.84 ab	17.10 a	82.90 a
	PRB	7.82 a	8.55 b	8.43 b	13.96 b	16.36 ab	41.55 b	38.89 b	61.11 b
	CT	3.55 a	4.10 a	3.14 a	4.10 a	11.90 a	76.76 a	13.81 a	88.76 a
0–30	ZT	4.46ab	4.72 a	4.86 a	14.17 b	31.47 b	52.92 b	28.18 b	71.82 b
	PRB	6.41 b	7.96 b	7.53 b	9.30 ab	13.82 a	40.35b	31.26 b	68.74 b
	CT	3.20 a	4.24 a	4.25 a	4.79 a	12.44 a	71.85 a	16.47 a	84.39 a

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

3.2. Soil organic carbon (SOC)

Results of resource conservation practices after 15 years significantly influenced the total organic carbon (TOC), total nitrogen (TN) and soil organic carbon (SOC) content of the surface soil is depicted in (Table 3). Data indicate that residue removal have a resulted in highly significant losses of SOC ranging from 9.45 to 16.48% for both the 0–5 and 5–15cm depths. In surface soil (0-5 cm layer) highest soil organic carbon change (35.40%) was found in ZT with 6 tha^{-1} residue retention plots followed by PRB with 6 tha^{-1} residue retention plots (33.52%). The use of ZT with residue retention and PRB with residue retention for fifteen crop cycle increased soil organic carbon by 54.68% and 54.22% more than that of conventional tillage (CT), respectively. These treatments were statistically similar and significantly higher from all other treatments. Irrespective of residue retention in 0– 5 cm soil layer ZT with 6tha^{-1} residue retention enhanced 63.9%, 39.4% and 57.9% followed by PRB with 6tha^{-1} residue retention 61.1%,50.1% and 55.5% TOC, TN and SOC, respectively, in surface soil as compared to CT in RWCS. Simultaneously, residue retention caused an increment of 34.3%, 27.5% and 41.9% in TOC, TN and SOC, respectively over the treatments with no residue management. Similar increasing trends were observed in 5 -15 cm soil layer, however, the magnitude was relatively lower (Table 3).

The distribution of SOC with depth was dependent on the use of various fertilizers (Table 3). The highest SOC concentration was obtained for 0–5 cm depth and decreased with sub surface depth for all treatments. The SOC concentration in 0–5 and 5– 15 cm depths increased significantly by farmyard manure or GM/SPM application. At the 0–5 and 5–15 cm soil depths, SOC was highest in 50% RDN as CF+50% RDN as FYM (F_5) followed by 50% RDN as CF+50% RDN as GM/SPM (F_6) treatments and the least in Control (no manure and fertilizer) F_1 treatment. However, the soil organic C pools directly affect soil physical, chemical and biological properties. After 15 years, there was an increase in total SOC content in all INM plots. Soils under 50% RDN as CF+50% RDN as FYM treated plots contained higher SOC by ~12.5 and 11.4% in the 0–5 and 5–15 cm soil layers, respectively, over 100% RDN as CF-treated plots (Table 3). The total SOC stocks in the 0-15 cm layer was ~35.17 Mgha^{-1} for 50% RDN as CF+50% RDN as FYM-treated soils compared with ~28.43 Mgha^{-1} for 100% RDN as CF-treated plots and 26.45 Mg ha^{-1} for unfertilized control plots. Soil organic C content in the 0–15 cm soil layer in the plots under 50% RDN as CF+50% RDN as FYM treatment was ~ 16% higher than that under 75% RDN as CF+25% RDN as FYM-treated plots.

The TOC in surface soil were in the order of 50% RDN as CF+50% RDN as FYM (23.65 g kg^{-1}) > 50% RDN as CF+50% RDN as GM/SPM (21.47 g kg^{-1}) > 1/3 rd N as CF+1/3 rd N as FYM+1/3 rd N as GM/SPM (21.40 gkg^{-1}) >75% RDN as CF+25% RDN as FYM (19.64 gkg^{-1}) > unfertilized control (10.99 gkg^{-1}). However, increase in TOC was more in surface as compared to sub-surface soil, which indicate that higher accumulation of organic carbon due to application of organic fertilizer was confined to surface soil. The increase in TOC in organic + inorganic fertilizer as FYM and GM/SPM treatments in surface layer was 53.5 and 48.8% over unfertilized control, while they were 24.8 and 17.2% greater over 100% RDN as CF treatment, respectively. No significant difference in TOC in 50% RDN as CF+50% RDN as FYM and 50% RDN as CF+50% RDN as GM/SPM treatments during the study period. This might be due to more turn-over of root biomass in 50% RDN as CF+50% RDN as FYM treatment because of better growth and higher average yields obtained during the study period of both the crops in 50% RDN as CF+50% RDN as FYM treatment as compared to 50% RDN as CF+50% RDN as GM/SPM treatment.

Table 3: Effect of 15 years of application of treatments on total organic C (TOC), total N (TN), and soil organic carbon (SOC)

Treatments	0-5 cm layer				5-15 cm layer			
	TOC (g kg^{-1})	TN (mg kg^{-1})	SOC (g kg^{-1})	SOC stock (Mg ha^{-1})	TOC (g kg^{-1})	TN (mg kg^{-1})	SOC (g kg^{-1})	SOC stock (Mg ha^{-1})
Tillage crop residue practices								
T_1	19.30^{c}	539^{c}	5.9^{c}	19.79^{e}	14.37 ^{d}	489^{c}	4.5d	14.91^{c}
T_2	23.00^{b}	590^{b}	6.5^{b}	30.05^{c}	17.98^{c}	561^{bc}	5.8^{bc}	27.70^{b}
T_3	25.68^{a}	696^{ab}	7.2^{a}	35.40^{a}	21.63 ^{a}	643^{ab}	6.6^{a}	30.97^{a}
T_4	18.50^{c}	516^{c}	4.5^{d}	22.18^{d}	14.32 ^{d}	483^{c}	4.6^{d}	16.79^{c}
T_5	23.01^{b}	584^{bc}	6.1^{bc}	31.63^{bc}	18.89^{bc}	546^{bc}	5.4^{c}	25.99^{b}
T_6	23.87^{ab}	845^{a}	6.8^{ab}	33.52^{ab}	19.98 ^{ab}	765^{a}	6.1^{ab}	29.26^{ab}
T_7	9.28^{d}	422^{c}	3.6^{e}	14.91^{f}	7.36^{e}	328^{d}	3.2^{e}	9.46^{d}
Nutrient Management Practices								
F_1	10.99^{d}	406^{cd}	7.9^{c}	29.16^{c}	9.01^{d}	349^{d}	6.8^{c}	23.74^{c}
F_2	17.78^{b}	577^{c}	8.4^{bc}	30.70^{c}	15.13^{c}	554^{bc}	7.3^{bc}	26.15^{c}
F_3	19.64^{b}	621^{bc}	8.5^{b}	31.97^{bc}	15.64^{bc}	568^{bc}	7.5^{bc}	27.75^{bc}
F_4	13.56^{c}	544^{cd}	8.1^{c}	29.67^{c}	13.37^{c}	514^{c}	7.0^{bc}	29.55^{c}
F_5	23.65^{a}	896^{a}	9.6^{a}	36.14^{a}	19.08^{a}	783^{a}	8.3^{a}	34.19^{a}
F_6	21.47^{a}	737^{ab}	9.0^{ab}	34.59^{a}	18.80^{a}	694^{ab}	8.1^{a}	31.17^{ab}
F_7	21.40^{ab}	645^{bc}	8.6^{b}	32.62^{b}	17.30^{ab}	608^{b}	7.6^{ab}	29.86^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

3.3. Water Soluble Carbon

The distribution of soil mass among the size classes of water stable carbon (WSC) was strongly influenced by tillage and residue management practices in both the soil depths (0–5 cm and 5-15 cm). WSC was found to be 3.74% higher in surface soil than in sub-surface soil (Table 4). In both the depths, T_6 treatment had the highest WSC as compared to the other treatments studied. Compared to conventional tillage, PRB and ZT coupled with 6tha^{-1} CR increased 39.6% WSC in surface soil and 37.4% in sub surface soil. Among all the treatments, T_6 had significantly higher (20.15%) proportion of WSC than the other treatments compared. Irrespective of tillage practices, residue retention resulted in 26.39% and 22.17% higher WSC as compared to the non-residue treatments in surface and sub-surface soil, respectively. The WSC content in surface soil (0–5 cm) was significantly higher in 50% RDN as CF+50% RDN as FYM (F_5) treatment (32.5 mg kg^{-1}) followed by 50% RDN as CF+50% RDN as GM/SPM (F_6) (31.6 $mgkg^{-1}$) and least in unfertilized control plot [(F_1) (21.9 $mgkg^{-1}$) (Table 4)]. However, similar significant effect was observed in sub-surface soil (5-15 cm) and the magnitude was relatively lower.The increase in WSC in 0–15 cm soil depth was 37.2 and 32.9% in 50% RDN as CF+50% RDN as FYM (F_5) and 50% RDN as CF+50% RDN as GM/SPM (F_6) treated plots over control. This increase is attributed to the accretion of sulphur through FYM/GM/SPM application.

3.4. Soil Particulate Organic Carbon

After 15 years of the experiment, tillage-induced changes in POC were distinguishable in the surface (0- to 5-cm) and subsurface (5-15 cm) soil layer (Table 4). Plots under ZT had about 32% higher POC than CT plots (620 $mgkg^{-1}$ bulk soil) in the surface soil layer (Table 4). In 0 - 5 cm soil layer of tillage system, T_1, and T_4 treatments increased POC content from 620 $mgkg^{-1}$ in CT (T_7) to 638 and 779 $mgkg^{-1}$ without residue retention and to 898, 1105, 1033 and 1357 $mgkg^{-1}$ in ZT and PRB with residue retention (T_2, T_3, T_5, and T_6), respectively (Table 4). In subsurface layer (5-15 cm), similar increasing trends were observed, however, the magnitude was relatively lower (Table 4). It is evident that the POC contents in both surface and sub-surface soil were significantly higher in plots receiving 50% RDN as CF+50% RDN as FYM (F_5) treated plots compared to 50% RDN as CF+50% RDN as GM/SPM (F_6) fertilizer and unfertilized control (F_1) plots (Table 4). The values of POC in surface soil varied from 631 $mgkg^{-1}$ in unfertilized control plot to 1381 mg kg^{-1} in integrated nutrient use of 50% RDN as CF+50% RDN as FYM (F_5) plots, respectively; while it varied from 585 $mgkg^{-1}$ (control) to 1032 $mgkg^{-1}$ (50% RDN as CF+50% RDN as FYM, F_5) in sub-surface soil. The values of POC increased by 45.4 and 54.3% under 50% RDN as CF+50% RDN as GM/SPM (F_6) and 50% RDN as CF+50% RDN as FYM (F_5) treatments in surface soil over control. While, there were 24.8 and 37.1% increase of POC over 100% RDN as CF (F_2) i.e. NPK fertilizer, respectively. The highest value of POC due to integrated use of FYM and NPK fertilizer might be due to higher turn-over of root biomass produced under INM treatment.

Particulate organic nitrogen (PON) content over CT (T_7) of the field after 15 -year crop cycle is presented on Table 4. Upper and lower depth (0-5 cm & 5-15 cm) had significantly different PON change. Highest PON change (66.1%) was found in PRB with 6 tha^{-1} residue retention (T_6) plots followed by ZT with 6 tha^{-1} residue retention (T_3) plots (50.9%). The use of PRB with residue retention (T_5 & T_6) plots and ZT with residue retention (T_2 & T_3) plots for fifteen crop cycle increased PON by 48.1% and 43.4% more than that of T_1,T_4 and T_7, respectively. In lower depth (5-15 cm), similar increasing trends were observed, however, the magnitude was relatively lower **(Table 4).** Significant contrast was observed in conventional versus zero tillage and residue retention versus residue harvested practices while there was no significant difference in between zero tillage versus bed planting. Similar to SOC trend, continuous application of organic and inorganic fertilizers in rice–wheat system resulted significantly higher PON over control at 0–15 cm soil depth in all the treatments. Application of 50% RDN as CF+50% RDN as FYM (F_5) resulted in a significant positive built up of PON over 100% RDN as CF (F_2) at both soil depths (Table 4). Similarly, substitution of 50% N through GM or SPM to rice and wheat crop also recorded significantly higher PON concentration over 100% RDN as CF (F_2) in 0–5 and 5–15 cm soil depths. The additional amounts of organic C input from organics in the treatments received 100% RDN as CF along with organics further enhanced the PON contents in these treatments. The main source of PON in this study was mainly the left over root biomass and increased microbial biomass debris. It is suggested that the greater biochemical recalcitrance of root litter might have also increased the PON contents in soil depending upon the root biomass produced. The sequestration rate of PON in all the treatments followed the order 50% RDN as CF+50% RDN as FYM (F_5) > 50% RDN as CF+50% RDN as GM/SPM (F_6) > 1/3rd N as CF+1/3rd N as FYM+1/3rd N as GM/SPM (F_7) >75% RDN as CF+25% RDN as FYM (F_3) > 100% RDN as CF (F_2).

Table 4: Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil

Treatments	0-5 cm layer					5-15 cm layer				
	WSC ($mgkg^{-1}$)	POC ($mgkg^{-1}$)	PON ($mgkg^{-1}$)	LFOC ($mgkg^{-1}$)	LFON ($mgkg^{-1}$)	WSC ($mgkg^{-1}$)	POC ($mgkg^{-1}$)	PON ($mgkg^{-1}$)	LFOC ($mgkg^{-1}$)	LFON ($mgkg^{-1}$)
Tillage crop residue practices										
T_1	23.9^{d}	638^{d}	67.2^{d}	81.3^{d}	9.1^{d}	15.7^{d}	535^{e}	54.7^{e}	65.1^{d}	7.8^{d}
T_2	25.9^{c}	898^{bc}	88.6^{cd}	107.8^{bc}	11.8^{c}	17.8^{cd}	674^{cd}	74.5^{cd}	94.1^{bc}	9.1^{c}
T_3	27.8^{ab}	1105^{ab}	106.7^{ab}	155.2^{a}	13.3^{ab}	19.6^{bc}	785^{bc}	91.8^{ab}	132.6^{a}	10.9^{ab}
T_4	22.7^{d}	779^{cd}	77.9^{d}	95.7^{c}	9.8^{d}	17.6^{cd}	609de	69.1^{de}	87.6^{c}	8.3^{cd}
T_5	26.4^{bc}	1033^{b}	97.4^{bc}	128.8^{b}	12.6^{bc}	20.3^{ab}	842^{ab}	87.3^{bc}	102.9^{b}	10.4^{b}
T_6	29.2^{a}	1357^{a}	117.5^{a}	177.8^{a}	14.2^{a}	22.6^{a}	974^{a}	106.1^{a}	141.2^{a}	11.8^{a}
T_7	17.2^{e}	620^{d}	22.5^{e}	52.7^{e}	8.2^{d}	13.2^{e}	485^{e}	18.8^{f}	49.8^{e}	6.8^{e}
Nutrient Management Practices										
F_1	21.9^{e}	631^{d}	24.7^{e}	89.2^{c}	6.8^{d}	15.1^{e}	585	17.3^{e}	47.9^{f}	5.9^{e}
F_2	29.2^{cd}	869^{c}	92.5^{c}	96.4^{c}	9.5^{c}	20.2^{cd}	789	73.5^{cd}	85.9^{d}	8.9^{c}
F_3	29.8^{c}	956^{bc}	96.8^{c}	108.1^{bc}	10.5^{bc}	21.9^{bc}	813	79.4^{c}	96.9^{cd}	9.6^{bc}
F_4	28.4^{d}	788^{cd}	72.9^{d}	91.3^{c}	7.9^{d}	18.8^{d}	728	59.4^{d}	66.7^{e}	7.2^{d}
F_5	32.5^{a}	1381^{a}	130.8^{a}	183.9^{a}	13.8^{a}	26.4^{a}	1032a	112.1^{a}	152.9^{a}	12.4^{a}
F_6	31.6^{ab}	1156^{ab}	114.2^{ab}	160.5^{a}	12.6^{ab}	23.6^{ab}	905ab	96.7^{ab}	139.7^{a}	11.9^{a}
F_7	30.9^{b}	1102^{b}	103.9^{bc}	123.5^{b}	11.5^{b}	22.7^{b}	826b	88.3^{bc}	103.2^{bc}	10.1^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

WSC = water soluble C, POC = particulate organic C, PON = particulate organic N, LFOC = light fraction organic C, and LFON = light fraction organic N.

3.5. Soil light fraction organic carbon

The labile fraction organic carbon (LFOC) is considered as a useful approach for the characterization of SOC resulting from different soil management practices including cropping systems and application of organic and inorganic sources of nutrients. The values of LFOC in surface soil were 81.3, 95.7, 107.8, 155.2, 128.8, 177.8 and 52.7 mgkg^{-1} in ZT and PRB without residue retention, ZT and PRB with 4 & 6 tha^{-1} residue retention and conventional tillage (CT) treatments, respectively (Table 4). In 5- 15 cm layer, the increasing trends in LFOC content due to use of tillage practices and residue retention were similar to those observed in 0-5cm layer, however, the magnitude was relatively lower (Table 4).Significant increase in LFOC in surface soil (0–5 cm) was maintained in plots receiving 50% RDN as CF+50% RDN as FYM (F_5) and integrated use of 50% RDN as CF+50% RDN as GM/SPM (F_6) fertilizer over 1/3rd N as CF+1/3rd N as FYM+1/3rd N as GM/SPM (F_7) over unfertilized control plots (F_1) (Table 4). However, increases in LFOC in sub-surface soil (5–15 cm) were observed only under plots receiving 50% RDN as CF+50% RDN as FYM (F_5), 50% RDN as CF+50% RDN as GM/SPM (F_6), integrated use of 1/3rd N as CF+1/3rd N as FYM+1/3rd N as GM/SPM (F_7), 75% RDN as CF+25% RDN as FYM (F_3) and 100% RDN as CF (F_2) fertilizer over unfertilized control. Increase in LFOC in surface soil was 44.4 and 51.5% in 50% RDN as CF+50% RDN as GM/SPM (F_6) and 50% RDN as CF+50% RDN as FYM (F_5) fertilizer treated plots over control, respectively.

Results on LFON content in 15-year experiment showed that in 0 - 5 cm soil layer of tillage system, T_2, T_3, T_5 and T_6 treatments increased LFON content from 8.2 mg·kg^{-1} in CT (T_1) to 11.8,12.6,13.3 and 14.2 mgkg^{-1} with 4 & 6 tha^{-1} residue retention under ZT and PRB, respectively (Table 4) In 5 - 15 cm layer, the increasing trends in LFON content due to the use of tillage crop residue practices were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (Table 4). Significantly greater amount of LFON content in surface soil was maintained in all the treatments receiving manure and fertilizer applied either alone or in combination over unfertilized control plot (Table 4). The build-up of LFON in surface soil (0–5 cm depth) were 13.8, 12.6 and 10.5 mgkg^{-1} in plots receiving 50% RDN as CF+50% RDN as FYM (F_5), 50% RDN as CF+50% RDN as GM/SPM (F_6), and 75% RDN as CF+25% RDN as FYM (F_3), respectively as against 6.8 mg kg^{-1} in unfertilized control plot. The LFON increased by 51.5, 48.2 and 36.8% in plots receiving 50% RDN as CF+50% RDN as FYM (F_5), 50% RDN as CF+50% RDN as GM/SPM (F_6), and 75% RDN as CF+25% RDN as FYM (F_3), respectively over unfertilized plot in 0-15 cm soil depth.In general, the impact of applied fertilizer, organic sources and residue retention in improving WSC, POC, PON, LFOC and LFON content was significant in 0 - 5 cm soil layer and was substantially higher than in 5 - 15 cm soil layer under both ZT& PRB and CT system. Response of the LFOC and LFON contents to fertilization treatments was similar to those observed for the POC and PON contents.

3.6. Potentially Mineralizable N

After 15 years of the experiment, potentially mineralizable nitrogen (PMN) content showed that in 0-5 cm soil layer T_1 and T_4 treatments increased from 3.3 mgkg^{-1} in conventional tillage (T_7) to 5.7 and 6.6 mgkg^{-1} in ZT and PRB without residue retention and 7.5, 10.66 mg kg^{-1} in ZT and 9.3, 12.46 mgkg^{-1} in PRB with 4 & 6 tha^{-1} residue retention (T_2, T_3, T_5, T_6), respectively (Table 5). While POC accounted for 17.5% to 22.4 & 40.7% and 27.3% to 39.3 & 47.9%, the proportion of LFOC ranged from 15.8% to 33.3 & 54.3% and 23.8% to 38.5 & 57.9% of TOC, respectively in ZT and PRB system. In 5 -15 cm layer, the increasing trends due to the use of tillage crop residue practices were similar to those observed in 0 -5 cm layer however, the magnitude was relatively lower (Table 5).Continuous application of FYM either alone or in combination with RDN resulted in considerable accumulation of PMN in 0–5 cm soil layer than unfertilized control plots (Table 5). Soils under the 50% RDN as CF+50% RDN as FYM (F_5), treated plots resulted in higher PMN in the 0–5 cm soil layer over those under the 100% RDN as CF treated plots. The PMN in surface soil were in the order of 50% RDN as CF+50% RDN as FYM (F_5) 14.6 mgkg^{-1} > 50% RDN as CF+50% RDN as GM/SPM (F_6) 12.5 mgkg^{-1} > 75% RDN as CF+25% RDN as FYM (F_3) 11.4 mgkg^{-1} > 75% RDN as CF+25% RDN as FYM (F_3) 9.8 mgkg^{-1} > unfertilized control (3.6 mgkg^{-1}). However, increase in PMN was more in surface as compared to sub-surface soil, which indicate that higher accumulation of organic carbon due to application of FYM was confined to surface soil. The increase in PMN in 1/3rd N as CF +1/3rd N as FYM+1/3rd N as GM/SPM (F_7) and 75% RDN as CF+25% RDN as FYM (F_3) treatments in surface layer was 68.4 and 63.3% over unfertilized control, while they were 21.9 and 9.2% greater over 100% RDN as CF (F_2) treatment, respectively. No significant difference in PMN in F_7 and F_3 treatments although the amount of FYM applied during the study period in F_5 treated plot was double of the amount applied in F_3 treated plot. This might be due to more turn-over of root biomass in F_5 treatment because of better growth during the study period of both the crops in F_5 treatment as compared to F_3 treatment. It is evident that irrespective of depths, greater accumulation of PMN was observed with F_5 treatment while control plot showed the lowest value.

3.7. Soil microbial biomass carbon

The level of MBC was indistinguishable between the CT and ZT without residue retention regimes and was markedly lower under these regimes than under ZT with residue retention and PRB with residue retention (Table 5). Changes in MBC can indicate the effects of management practices on soil biological and biochemical properties. The higher MBC we observed in the ZT and PRB with residue retention plots than the CT plot under the RWCS suggests that abandonment of the cropland had substantial beneficial effects on the activity of microbial organisms probably caused by the accumulation of organic C compounds at the soil surface. A possible reason for this difference is that in the absence of growing plants other labile C fractions may provide food for microbes, and thus maintain MBC. Another possible reason could be related to the soil moisture status. Under the CT treatment, in which biomass production would inevitably deplete much more soil moisture, the microbes in the plot would be stressed at the time of sampling (wheat maturity).

The microbial biomass carbon (MBC) is an important component of the SOM that regulates the transformation and storage of nutrients. The soil MBC regulates all SOM transformations and is considered to be the chief component of the active SOM pool. It is evident that the MBC contents in both surface and sub-surface soil were significantly higher in plots receiving 50% RDN as CF+50% RDN as FYM (F_5) and 50% RDN as CF+50% RDN as GM/SPM (F_6) treated plots compared to 100% RDN as CF (F_2) fertilizer and unfertilized control plots (Table 5). The values of MBC in surface soil varied from 116.8 mgkg^{-1} in unfertilized control plot to 424.1 mgkg^{-1} in integrated nutrient use of 50% RDN as CF+50% RDN as FYM (F_5) plots, respectively; while it varied from 106.6 mgkg^{-1} (control) to 324.9 mgkg^{-1} (50% RDN as CF+50% RDN as FYM F_5) in sub-surface (5-15 cm) soil layer. The values of MBC increased by 58.4 and 72.5% under 75% RDN as CF+25% RDN as FYM (F_3) and 50% RDN as CF+50% RDN as FYM (F_5) treatments in surface soil over control. While, there were 14.5 and 43.4% increase of MBC over 100% RDF as CF (F_2) fertilizer, respectively. The highest value of MBC due to integrated use of FYM and RDN fertilizer might be due to higher turn-over of root biomass produced under 50% RDN as CF+ 50% FYM treatment. Application of 100% RDN as CF fertilizer is not only required for better growth of the crop but also required for synthesis of cellular components of microorganisms. Therefore, higher root biomass under 50% RDN as CF+50% FYM fertilizer treatment helped in increasing MBC over other treatments. Although MBC content in soil represent a small fraction i.e. about 2-4% of TOC, however, variation in this pool due to management and cropping systems indicate about the quality of soil, because the turn-over of SOM is controlled by this pool of SOC which can provide an effective early warning of the improvement or deterioration of soil quality as a result of different management practices. In our study, MBC was highest in the 50%inorganic fertilizer+50% FYM treatment. The increase of MBC under FYM amended soils could be attributed to several factors, such as higher moisture content, greater soil aggregation and higher SOC content. The FYM amended plots provided a steady source of organic C to support the microbial community compared to inorganic fertilizer treated plots. Generally, FYM applied to soil has long been employed to enhance favourable soil conditions.

Table 5: Effect of 15 years of application of treatments on contents of various biological fractions of carbon in soil

Treatments	0-5 cm layer				5-15 cm layer			
	PMN (mgkg^{-1})	MBC (mgkg^{-1})	MBN (mgkg^{-1})	DOC (mgkg^{-1})	PMN (mgkg^{-1})	MBC (mgkg^{-1})	MBN (mgkg^{-1})	DOC (mgkg^{-1})
Tillage crop residue practices								
T_1	5.7^{c}	311.4^{c}	12.1^{cd}	153.5^{bc}	4.6^{cd}	193.9^{cd}	11.7^{de}	146.7^{cd}
T_2	7.5b^{c}	345.2^{bc}	17.9^{b}	176.9^{ab}	6.6^{bc}	219.8^{c}	16.3^{bc}	162.9^{bc}
T_3	10.6^{ab}	481.7^{a}	25.7^{a}	206.4^{a}	8.9^{ab}	294.8^{ab}	24.9^{a}	198.6^{a}
T_4	6.6^{c}	306.5^{c}	9.8^{de}	142.5^{cd}	5.6^{c}	187.5^{cd}	9.5^{ef}	137.6^{d}
T_5	9.3^{b}	398.6^{b}	14.9^{c}	164.1^{b}	7.5^{b}	240.9^{bc}	14.1^{cd}	151.2^{c}
T_6	12.4^{a}	535.8^{a}	20.3^{b}	197.6^{a}	11.2^{a}	361.8^{a}	19.6^{b}	178.6^{ab}
T_7	3.3^{e}	266.7^{c}	7.1^{e}	114.9^{d}	2.4^{d}	145.9^{d}	6.5^{f}	102.8^{e}
Nutrient Management Practices								
F_1	3.6^{e}	116.8^{c}	7.7^{d}	103.7^{d}	2.8^{d}	106.6^{d}	7.1^{d}	92.3^{d}
F_2	8.9^{cd}	239.9^{bc}	14.7^{cd}	136.^{4c}	7.4^{c}	196.8^{bc}	13.8^{bc}	119.6^{c}
F_3	9.8^{c}	280.7b	16.1^{bc}	155.7^{bc}	8.2^{bc}	219.9^{bc}	15.9^{b}	126.4^{bc}
F_4	7.3^{d}	189.2^{c}	10.9^{de}	128.3^{c}	5.9^{c}	166.8^{cd}	10.3^{cd}	106.9^{cd}
F_5	14.6^{a}	424.1^{a}	26.2^{a}	189.8^{a}	12.8^{a}	324.9^{a}	25.6^{a}	161.9^{a}
F_6	12.5^{ab}	343.9^{ab}	22.4^{ab}	167.9^{ab}	10.4^{ab}	267.3^{a}	21.5^{ab}	142.3^{ab}
F_7	11.4^{bc}	341.7^{b}	19.1^{b}	160.6^{b}	8.9^{b}	260.3^{b}	17.9^{b}	131.1^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

PMN = potentially mineralizable N, MBC = microbial biomass C, MBN = microbial biomass N, DOC = dissolved organic carbon

3.8 Dissolved Organic Carbon

Dissolved organic carbon (DOC) content over CT (T_7) of the field after 15 -year crop cycle is presented on Table 5. Surface and subsurface soil layers (0-5 and 5-15 cm) had significantly different DOC change. Highest DOC change (37.3%) was found in ZT with 6 tha^{-1} residue retention (T_3) plots followed by PRB with 6 tha^{-1}residue retention (T_6) plots (31.4%). The use of ZT and PRB with residue retention (T_2, T_3, T_5 andT_6) plots for fifteen crop cycle increased DOC by 30.3 and 24.4% more than that of ZT and PRB without residue retention and conventional tillage (T_1, T_4 and T_7), respectively. In subsurface soil layer similar increasing trends were observed, however, the magnitude was relatively lower (Table 5). Irrespective of soil depths, 50% RDN as CF+ 50% FYM invariably showed higher content of DOC over all other treatments. The 100% RDN as CF and unfertilized treatments showed lower content of DOC. The DOC concentrations in 0–5 cm and 5–15 cm depths were observed highest for 50% RDN as CF+ 50% FYM (F_5) followed by 50% RDN as CF+50% RDN as GM/SPM (F_6) and 1/3rd N as CF +1/3rd N as FYM+1/3rd N as GM/SPM (F_7), and both of them were significant higher than 100% RDN as CF (Table 5).However, in the 5-15 cm layer, the difference in DOC between rests of the treatments was not significant.

3.9. Proportion of Labile Organic C and N Fractions in Total Organic C

After 15 years of the experiment, WSC accounted for 6.4% to 9.6 & 12.90% and 7.8% to 16.1 & 22.9% of TOC in different treatments of ZT and PRB system, respectively in 0 - 5 cm soil layer (Table 6). While POC accounted for 17.5% to 22.4 & 40.7% and 27.3% to 39.3 & 47.9%, the proportion of LFOC ranged from 15.8% to 33.3 & 54.3% and 23.8% to 38.5 & 57.9% of TOC, respectively in ZT and PRB system. In 5 - 15 cm layer, the trends of WSC, POC and LFOC in TOC due to the use of tillage crop residue practices were similar to those observed in 0 - 5 cm layer however, the magnitude was relatively lower (Table 6). The proportion of MBC ranged from 16.1% to 21.2% under ZT and PRB without residue retention and 27.8% to 31.6% of TOC under ZT and PRB system with residue retention, which showed gradual increase with the application of residue retention treatments and was maximum in 6 tha^{-1} residue retention treatment under both tillage systems (Table 6).

The proportions of WSC, POC, LFOC and MBC in TOC were highest in 50% RDN as CF+ 50% FYM (F_5) system (Tables 6). Significantly higher contents and proportions of these labile C pools obtained with fertilizer and organic (50%

RDN as CF+50% FYM F_5) than unfertilized plots were more pronounced in 0-5 cm soil layer. These results indicated that WSC, POC, LFOC and MBC, can be used as sensitive indicators of INM effects. Increased MBC in TOC also with the addition of fertilizer and organic sources could be attributed to the better crop growth resulting in greater root derived organic matter. The significant increase in MBC in treatments containing 50% RDN as CF+50% FYM or 50% RDN as CF+50% GM/SPM could be ascribed to the availability of more carbon as was evident from several other fractions of TOC such as WSC, POC and LFOC. MBC is an active component of SOM and constitutes an important soil health parameter as carbon contained within microbial biomass is a stored energy for microbial process.

Table 6: Effect of 15 years of application of treatments on proportion of carbons

Treatments	0-5 cm layer				5-15 cm layer			
	WSC (% of TOC)	POC (% of TOC)	LFOC (% of TOC)	MBC (% of TOC)	WSC (% of TOC)	POC (% of TOC)	LFOC (% of TOC)	MBC (% of TOC)
Tillage crop residue practices								
T_1	0.50^{cd}	15.5^{cd}	1.9^{de}	3.1^{c}	0.47^{c}	14.8^{e}	1.5^{cd}	2.6^{c}
T_2	0.52^{cd}	16.5^{c}	2.4^{bc}	3.4^{bc}	0.49^{bc}	16.1de	2.2^{b}	3.0^{b}
T_3	0.54^{bc}	21.6^{ab}	3.5^{a}	3.8^{a}	0.53^{a}	18.1^{bc}	3.3^{ab}	3.4^{a}
T_4	0.51^{cd}	17.6^{c}	2.1^{cd}	3.3^{bc}	0.44d	17.6^{cd}	2.1^{bc}	2.9^{bc}
T_5	0.56^{ab}	21.1^{b}	2.6^{b}	3.6^{ab}	0.50^{b}	19.7^{ab}	2.5^{b}	3.2^{ab}
T_6	0.61^{a}	24.6^{a}	3.8^{a}	3.9^{a}	0.55^{a}	21.4^{a}	3.4^{a}	3.5^{a}
T_7	$0. 47^{d}$	12.8^{d}	1.6^{e}	2.6^{d}	0.42^{d}	11.7^{f}	1.1^{d}	2.1^{d}
Nutrient Management Practices								
F_1	0.53^{c}	15.2^{c}	1.5^{d}	2.7^{d}	0.49^{d}	14.6^{d}	1.2^{e}	2.3^{e}
F_2	0.60^{bc}	17.6^{c}	2.1^{bc}	3.4^{c}	0.56^{c}	17.2^{bc}	2.0^{c}	3.2^{c}
F_3	0.62^{bc}	18.8^{bc}	2.3^{b}	3.6^{bc}	0.58^{bc}	17.9^{bc}	2.2^{bc}	3.3^{bc}
F_4	0.58^{bc}	16.9^{c}	1.8^{cd}	3.3^{c}	0.51^{d}	16.1^{cd}	1.6^{d}	2.9^{d}
F_5	0.75^{a}	26.5^{a}	3.8^{a}	4.2^{a}	0.66^{a}	22.9^{a}	3.6^{a}	3.9^{a}
F_6	0.66^{ab}	22.7^{ab}	3.4^{a}	3.9^{ab}	0.63^{ab}	20.8^{ab}	3.3^{a}	3.7^{ab}
F_7	0.63^{b}	21.9^{b}	2.5^{b}	3.8^{b}	0.61^{b}	19.3^{b}	2.4^{b}	3.5^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

WSC = water soluble C; POC = particulate organic C; LFOC = labile fraction organic C; MBC = microbial biomass C and TOC = total organic C

3.10. $KMnO_4$-oxidizable carbon and the carbon management index

The $KMnO_4C$ content was also significantly affected by the soil management regimes; highest under the cropping system, the plots receiving organic materials treatment F_5 followed by F_6 and lowest under F_1"control" plots (Table 7). The $KMnO_4C$ was probably significantly higher in the organic material-amended soil than in the chemical fertilizer-treated soil because of the higher labile carbon inputs associated with the straw and manure. The discrepancies in results from various studies might be related to differences in variables such as soil type, cropping system and climate in the investigated systems. They also indicate that measurement of the $KMnO_4C$ fraction alone is not sufficient to distinguish effects of different nutrient management treatments, at least in the experimental conditions of a study such as this.

The carbon management index (CMI) is derived from the total soil organic C pool and C lability index and is useful to evaluate the capacity of management systems to promote soil quality. This index compares the changes that occur in total and labile carbon as a result of agricultural practices, with an emphasis on the changes in labile carbon, as opposed to non-labile carbon in SOM. Therefore, the integration of both soil organic C pool and C lability into the carbon management index can provide a useful parameter to assess the capacity of management systems to promote soil quality. A management system is considered sustainable, if the value of CMI is greater than 100. In the present study, the highest CMI values of 109.7 at 0–5 cm soil depth and 101.4 at 5–15 cm soil depth were obtained in treatment receiving integrated use of GM/SPM and NPK fertilizer (Table 7). The addition of FYM also resulted in CMI values of 124.8 and 109.2 at 0–5 and 5–15 cm soil depth, respectively; while that of NPK fertilizer resulted in CMI values of 52.1 and 36.9 at 0–5 and 5–15 cm soil depth, respectively. Improvement in CMI value under integrated use of organic and inorganic fertilizer over their sole application could be attributed to addition of organic carbon and other nutrients through these sources. In general, the CMI values decreased from surface soil to sub-surface soil depth irrespective of nutrient management practices. The higher values of CMI indicate that the system have greater soil quality than the other management systems.

Table 7: Effect of 15 years of application of treatments on different carbon pool

Treatments	0-5 cm layer					5-15 cm layer				
	KOC ($g\ kg^{-1}$)	NKOC ($g\ kg^{-1}$)	LI	CPI	CMI	KOC ($g\ kg^{-1}$)	NKO C ($g\ kg^{-1}$)	LI	CPI	CMI
Tillage crop residue practices										
T_1	0.79^{c}	8.52^{c}	1.46^{d}	0.38^{d}	55.9^{d}	3.68^{cd}	7.4^{cd}	1.19^{c}	0.35^{d}	41.7^{c}
T_2	1.05^{bc}	9.07^{b}	1.52^{bc}	0.47^{c}	71.4^{cd}	3.79^{b}	8.2^{ab}	1.46^{b}	0.46^{c}	67.2^{b}
T_3	1.45^{a}	9.48^{a}	1.91^{a}	0.56^{b}	106.9^{a}	3.96^{a}	8.6^{a}	1.69^{ab}	0.53^{ab}	89.6^{a}
T_4	0.77^{c}	8.25^{c}	1.49^{cd}	0.43^{cd}	64.1^{d}	3.62^{d}	6.9^{d}	1.13^{c}	0.38^{d}	42.9^{c}
T_5	0.98^{b}	8.79^{bc}	1.54^{bc}	0.58^{ab}	89.3^{b}	3.76^{bc}	7.9^{bc}	1.31^{bc}	0.49^{bc}	64.2^{b}
T_6	1.15^{ab}	9.76^{a}	1.96^{a}	0.63^{a}	123.5^{a}	3.88^{a}	8.9^{a}	1.81^{a}	0.58^{a}	104.9^{a}
T_7	0.51^{c}	6.63^{d}	0.99^{e}	0.31^{e}	30.7^{e}	1.42^{e}	5.9^{e}	0.82^{d}	0.28^{e}	23.1^{d}

Nutrient Management Practices										
F_1	1.08^{c}	7.62^{d}	1.00^{d}	1.00	100	0.34^{e}	6.3^{d}	1.00^{d}	1.00	100
F_2	1.28^{c}	9.06^{bc}	1.37^{c}	0.38^{c}	52.1^{c}	0.78^{cd}	7.4^{cd}	1.16^{c}	0.34^{cd}	36.9^{cd}
F_3	1.48^{bc}	9.09^{b}	1.48^{bc}	0.41^{bc}	60.7^{bc}	0.86^{bc}	7.9bc	1.36^{b}	0.37^{bc}	50.3^{bc}
F_4	1.15^{c}	8.49^{c}	1.22^{c}	0.36^{c}	43.9^{c}	0.53^{de}	6.4^{d}	1.07^{cd}	0.30^{d}	32.1^{d}
F_5	1.89^{a}	10.37^{a}	1.92^{a}	0.65^{a}	124.8^{a}	1.33^{a}	9.7^{a}	1.85^{a}	0.59^{a}	109.2^{a}
F_6	1.71^{a}	9.75^{a}	1.86^{ab}	0.59^{a}	109.7^{a}	1.08^{ab}	8.6^{ab}	1.81^{a}	0.56^{a}	101.4^{a}
F_7	1.68^{b}	9.11^{b}	1.62^{b}	0.46^{b}	74.5^{b}	0.94^{bc}	8.2^{bc}	1.48^{b}	0.42^{b}	62.3^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

KOC = $KMnO_4$-oxidizable carbon; NKOC= non- $KMnO_4$ oxidizable carbon; LI= lability index; CPI = Carbon pool index; CMI =Carbon management index

4. Discussion

As illustrated by this long-term experiment conducted from 2000 to 2015 in the Meerut District of Uttar Pradesh, India implementation of PRB and ZT and addition of organic matter in situ or ex situ enhanced soil aggregation processes and water stable aggregates in annual double-cropping areas of northern India. The carbon management index (CMI) proved very effective in assessing the best conservation management practice. The estimation of CMI values of any conservation measures can quantitatively indicate soil degradation status and thus provide valuable information for conservation planning and mitigating land degradation. This result agreed with that of He *et al*., (2012) [21] in north western China under a spring wheat monoculture system. Furthermore, Naresh *et al*., (2012) [39] showed significant effects of ZT and residue retention on soil aggregate stability in western Uttar Pradesh under an alternative wheat production system.

4.1. Soil Total C

Suitable soil tillage practice can increase the SOC content, and improve SOC density of the plough layer Duan *et al*., (2012) [14]. The effect size of tillage methods on SOC dynamics depends on the tillage intensity Zhu *et al*., (2011) [61]. Compared to conventional tillage (CT), zero-tillage and permanent raised beds (PRB) could significantly improve the SOC content in cropland. Frequent tillage under CT easily exacerbate C-rich macro-aggregates in soils broken down due to the increase of tillage intensity, then forming a large number of small aggregates with relatively low organic carbon content and free organic matter particles. Free organic matter particles have poor stability and are easy to degradation, thereby causing the loss of SOC Song *et al*., (2011). Results of this work show that the PRB and ZT system with residue retention conserved and increased SOC compared to the (CT), and that obtained values were similar to those found after 26 years of NT in a wheat-based trial in Mediterranean conditions Melero *et al*., (2009) [37]. Several works have demonstrated that organic matter increases under CA as a result of physical protection of soil organic matter within more stable aggregates, reduced aeration and reduced plant residue contact with the soil (Mikha and Rice, 2004) [38].
The residues in PRB protect the soil from raindrop impact whereas in CT the lack of a protective cover increases soil susceptibility to further disruption (Boulal *et al*., 2012; Wang *et al*., 2013) [5, 58]. Moreover, surface residues tend to decompose more slowly than soil-incorporated residues, because of greater fluctuations of temperature and moisture in surface and reduced availability of nutrients to microbes colonizing the residues (Schomberg *et al*., 1994) [46]. An accumulation of organic matter in soil confers important improvements in soil quality, soil fertility and carbon sequestration (Six *et al*., 2000) [50]. Furthermore, tillage reduces micro and macro fauna populations in comparison with systems without tillage (Kladivko, 2001) [31], thus decreasing their potentially positive effect on physical properties (Six *et al*., 2004) [52]. In our study, the tillage system had also an effect on soil biochemical properties and found higher microbial biomass in ZT and PRB compared to CT in a RWCS only ten years after the establishment of the trial. Otherwise biochemical properties seem to be more affected by the nature of the most abundant residue. Crop residue type plays an important role in organic matter cycling due to differences in C/N ratio or quality and quantity of residue (Potter *et al*., 1998) [43]. In our study, rice and wheat residues differed in their capacity to affect soil organic matter cycling and quality. Rice residues were the most effective in increasing soil microbiological status. Tillage, residue management and establishment method affects carbon pool of the soil in this cropping system. In this cropping system, more increase in carbon content of soil in ZT residue retained plots. The percentage increment was 64.8% more than CT and findings 64.6% more than CT of Calegari *et al.,* (2008) [8]. 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) [26]. Carbon input in the form of crop residue had primary factor for stabilization of soil carbon (Singh, 2011) [48]. Less carbon sequestration in bed planting than zero tillage in same level of residue retention in this cropping system might be due to earlier dryness, less microbial population and less decomposition in bed during wheat season. The variation of soil organic carbon sequestration also depends on difference in microbial populace, moisture and temperature fluctuation (Govaerts *et al*., 2009) [18]. Residue retention and tillage has key role in soil carbon conservation (Anyanzwa *et al*., 2010) [2].
From 2000 to 2015, SOC concentrations (0–15 cm) layer increased significantly for all treatments except the unfertilized control treatments, and the greatest increases occurred for the three plots of 50% RDN as CF+50% RDN as FYM (F_5), 50% RDN as CF+50%RDN as GM/SPM (F_6) and 1/3rd N as CF+1/3rd N as FYM+1/3rd N as GM/SPM (F_7) treatments that received organic materials (Table 3). Apparently, application of only N fertilizer did not increase SOC content over long-term cropping. This observation was consistent with that of Goyal *et al*., (1992) [17], who reported that no significant increase in SOC by the addition of only N fertilizer. In the present study, SOC in the unfertilized control and N soil were at par, presumably because of lower crop productivity that results in significantly lower accumulation of root biomass and has the capacity to sequester more C with the increase of C inputs through organic amendment as well as crop C inputs.

4.2. Soil C Fractions

The POC fraction has been defined as a labile SOC pool mainly consisting of plant residues partially decomposed and not associated with soil minerals Six *et al*., (2002) [51]. The decrease in the disruption of soil macro-aggregates under ZT plots permitted a greater accumulation of SOC between and within the aggregates. Thus, less soil disturbance is the major cause of higher POC in the ZT and PRB plots compared with the CT plots in the 0- to 5-cm soil layer. Thus, in this study, POC was also partly responsible for the greater SOC retention in the plots under ZT and PRB than CT. This phenomenon might lead to micro-aggregate formation within macro-aggregates formed around fine intra-aggregate POC and to a long-term stabilization of SOC occluded within these micro-aggregates. Because increased POC is regarded as a potential indicator of increased C accumulation (Six *et al*., 1999) [49], the results of this study indicate that ZT and PRB had a significant effect on the formation and stabilization of SOM within the 0- to 5-cm soil layer and the soil amended by FYM or GM/SPM contained significantly higher POC in the 0–15 cm than that in the inorganic fertilizer treatments after 15 yr of cropping in the Northern India. Rudrappa *et al*., (2006) [45] reported that the additional organic carbon input could enhance the POC accumulation. Rajan *et al*., (2012) [44] concluded that FYM can increase the root biomass and microbial biomass debris which is the main source of POC. It is suggested that the greater biochemical recalcitrance of root litter Puget and Drinkwater, (2001) might have also increased the POC contents in soil depending upon the root biomass produced. The continuous replacement of organic manure on the soil creates a favourable environment for the cycling of C and formation of macro-aggregates. Furthermore, POC acts as a cementing agent to stabilise macro-aggregates and protect intra-aggregate C in the form of POC Six *et al*., (2002) [51].

PMN, a measure of the soil capacity to supply mineral N, constitutes an important measure of the soil health due to its strong relationship with the capability of soil to supply N for crop growth. Likewise, in our study, the upper 5 cm soil layer under ZT with 6 tha^{-1} residue retention and 50% RDN as CF + 50% RDN as FYM had more PMN content than that of lower layer (Table 5). This observation was consistent with that of Walia and Kler *et al*., (2006) [57] revealed higher mineralizable N under organic farming treatments as compared to chemical fertilizers alone showing better availability of N under organic farming. Kang *et al*., (2005) [28] found that application of organic residues increased PMN, which was positively related to increase in TOC content of soil. DOC is believed to be derived from plant roots, litter and soil humus and is a labile substrate for microbial activity Kalbitz *et al*., (2000) [27]. The concentration of DOC varied widely among all the treatments and a significant increase was observed in surface soils under different fertilizer treatments compared with unfertilized control. In the long-term, the quantity of organic residues are the main factors influencing the amount and composition of DOC. Likewise, in our study, the upper 5 cm soil layer had more DOC concentration than that of lower layer. DOC in subsurface soils may be a result of decomposition of crop residues or translocation from surface soil Dou *et al*., (2008) [13]. Several field studies have shown that concentration and fluxes of DOM in soil solution decrease significantly with soil depth Kalbitz *et al*., (2000) [27].

In our study, MBC was highest in the farmyard manure plus inorganic fertilizer treatment in top soil, an increased MBC content after farmyard application was also reported by Chakraborty *et al*., (2011) [9]. This indicated the activation of micro-organisms through carbon source inputs consisting of organic residues. Increases in soil organic matter are usually associated with similar increases in microbial biomass because the SOM provides principal substrates for the microorganisms Melero *et al*., (2009) [37]. Among the investigated fertilizer treatments, FYM/GM/SPM plus inorganic fertilizer had impact on the microbial biomass. This effect is mainly due to the input of straw manure as an organic carbon source. Schjønning *et al*., 2002 [47] reported that the highest MBC content of 515.4 $\mu g\ g^{-1}$ at surface soil (0–15 cm) was observed in FYM+NPK plots. It is known that the microbial fraction of clay soils is often greater than it is in sandy soils due to the protective effect of clays on microbial biomass (Sparling, 1997) [55]. According to Table 5, the study showed that MBC was affected by the straw return factor with an affecting force of 66.39% at 0–5cm depth and 60.24% at 5–15 cm depth. The probable explanation maybe that crop residue might enter the labile C pool, provide substrate for the soil micro-organisms, and contribute to the accumulation of labile C Li *et al*., (2012) [33]. Although our results have demonstrated that incorporation of readily decomposable organic matter i.e. GM, SPM and FYM caused about 100, 66 and 33% increase in MBN over the control, probably because, these organics stimulate biological activity in soils causing both an increase in microbial biomass C and N there (Table 5). Dalal *et al*., (1991) [12] studied the effects of 20 years of tillage practice, CR management and fertilizer N application on microbial biomass and found that MBN was significantly affected by tillage, residue and fertilizer N individually as well as through their interaction. The soil layers under no-till contained higher amount of MBN than that under CT treatments. POC, MBC and DOC concentrations increased linearly with increasing soil SOC content (Table 3, 4&5), suggesting that total organic matter content was a major determinant of the amount of POC, MBC and DOC present Liu *et al*., (2013) [35].

5. Conclusion

Soil conservation management improved the quality of the soil by enhancing the labile and total organic carbon fractions and biological status, especially in 0-5cm upper layer. Results of this 15-year field study with rice- wheat cropping system indicate that the content of TOC, SOC, PON, TN, LFON, DOC and POC decreased with soil depth, and thin surface layer (0 – 5 cm) contained much higher concentration of these labile pools than 5 - 15 cm subsurface layer. The surface soil layer had substantially higher levels of all soil health parameters than subsurface layer, presumably due to higher retention of crop stubbles, fallen leaves and root biomass. The enhanced proportions of WSC, POC, LFOC, MBC in TOC with the supply of optimum and balanced N and organic manures and retention of crop residues indicate that the improvement in labile forms of both C and N was relatively rapid than control suggesting that active C and N pools reflect changes due to integrated nutrient management (INM).The macro-aggregates increased by 39% and micro-aggregates decreased by 9% in PRB plots compared with CT plots. Decrease in micro-aggregates and increase in macro-aggregates with application of conservation tillage might have enhanced soil aggregation processes and compared to conventional tillage (CT), zero-tillage and permanent raised beds (PRB) could significantly improve the SOC content in cropland and the POC, LFOC, LFON, PON and MBC concentrations were greatly influenced by ZT in the surface (0 - 5 cm) and subsurface (5 - 15 cm) soil layer after 15 cycles of the experiment.

In Northern India, the effects of manure and fertilizer application practices on soil C sequestration were studied so that irrigated farming soil could contribute to both sustainable food production and mitigation of greenhouse gas emissions through soil C sequestration. Our results have very significant implications for soil C sequestration potential in semiarid subtropical soils inherently low in organic matter and nutrients of Northern India. SOC concentration in surface soil (0– 15 cm) was not significantly or slightly increased by the 15 yr of fertilizer treatments (N), but they were sharply increased by the manure and straw amendment (FYM, and FYM+GM/SPM). Thus, returning crop residue to the soil or adding farmyard manure on the soil surface is crucial to improving the SOC level. The large scale implementation of the straw or manure plus inorganic fertilizer amendments will help to enhance the capacity of carbon sequestration and promote food security in the region. Therefore, local government should encourage farmers to manage the nutrients and soil fertility based on integrated nutrient management by combining organic matter with inorganic fertilizer to improve soil carbon pools and increase crop productivity for long-term.

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