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Impact of Integrated Nutrient, Crop Residue and Tillage Management on Soil Aggregates and Organic Matter Fractions in Semiarid Subtropical Soil under Soybean-Wheat Rotation

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ABSTRACT

Various physical, chemical and biological soil properties in surface (0 - 5 cm) and subsurface (5 - 15 cm) soil were determined in a 4-year field experiment conducted at Punjab Agricultural University Ludhiana, India with sixteen treatments consisted of different combinations of fertilizer N (0, 20 and 25 kg N ha^{-1}), P (0, 60 and 75 kg P_2O_5 ha^{-1}), FYM (0 and 10 t·ha^{-1}) and wheat (*Triticum aestivum* L.) residue (WR) (0 and 6 t·ha^{-1}) applied to summer-grown soybean (*Glycine max* L.) and fertilizer N (0, 120 and 150 kg N ha^{-1}), P (0, 60 and 75 kg P_2O_5 ha^{-1}), and soybean residue (SR) (0 and 3 t·ha^{-1}) applied to winter-grown wheat crop continuously in both conventional tillage (CT) and conservation agriculture (CA), arranged in a split-split plot design with tillage system in main blocks, under irrigated subtropical conditions. Application of fertilizer N, P, FYM and crop residue (CR) significantly increased water stable aggregates and had profound effects in increasing the mean weight diameter as well as the formation of macro-aggregates, which were the highest in both surface (85%) and subsurface (81%) soil layers with application of 20 kg N + 60 kg P_2O_5 + 10 t FYM + 6 t WR ha^{-1} applied to soybean and 120 kg N + 60 kg P_2O_5 + 3 t SR ha^{-1} applied to wheat crop in CA, respectively, and were 83% and 77% in CT treatments after 2 years. Hence, better aggregation was found with 100% NP + FYM + CR, where macro-aggregates were greater than 50% of total soil mass. The same treatment also enhanced total organic C (TOC) from 3.8 g·kg^{-1} in no-NP-FYM-CR control to 5.8 g·kg^{-1} in surface layer and from 2.7 to 3.6 g·kg^{-1} in subsurface layer after 2 years leading to the 41% and 39% higher TOC stocks over CT-Control in 0 - 15 cm soil layers of CT and CA, respectively. The changes in TOC stocks after 4 years were 52% and 59%. Likewise, the labile C and N fractions such as water soluble C, particulate and light fraction organic matter, potentially mineralizable N and microbial biomass were also highest under this integrated inorganic and organic treatment. These results demonstrated that conservation agriculture that integrates application of inorganic fertilizer, organic manure and crop residue, is crucial for improving soil health and sustainability of farming systems in semiarid subtropical soils.

Keywords: Soybean; Conservation Agriculture; Water Stable Aggregates; Organic Matter Fractions

1. Introduction

Sustainable soil management is desirable to promote profitable agricultural practices that respect the environment, such as conservation agriculture (CA). It attaches great importance to maintenance of soil structure, productivity and biodiversity. It also reduces the negative impacts of tillage, preserves soil resources and can lead to accrual of much of the soil carbon lost during tillage [1]. Intensive land cultivation to meet the food and fiber needs of fast growing population, and removal or burning of crop residues after crop harvest cause losses of organic matter and nutrients from agricultural soils. Burning of crop residues not only results in losses of organic matter and nutrients but also causes atmospheric pollution due

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to the emission of toxic and greenhouse gases like CO, CO_2 and CH_4 that pose a serious threat to human and environmental health. Soil organic matter (SOM) is important for the supply of N, P and S through mineralization, the retention of some micronutrient elements, enhanced cation exchange capacity, favourable water relations and aggregate stability. Water stable aggregates (WSA) play an important role in nutrient cycling and in supplying substrate for microbial processes that lead to structural stability. However, labile organic matter fractions are readily accessible sources to microorganisms, turnover rapidly (weeks or months), and have direct impact on plant nutrient supply [2]. Labile organic matter fractions generally include water soluble C (WSC), particulate organic matter (POM), light-fraction organic matter (LFOM), soil microbial biomass (SMB), and potentially mineralizable N (PMN). Microbial biomass C (MBC) and N (MBN) generally have higher mineralization rates than SOM. In contrast to temperate climate where decomposition is slow, harsh hot and dry climate in semiarid, arid, subtropical and tropical environments causes fast decomposition. While the soils in these regions are inherently poor in SOM, the use of inadequate and imbalanced chemical fertilizers over a long period adversely affects soil health and productivity [3]. In contrast to CT, CA maintains a continuous soil cover through surface retention of crop residue, with no or reduced tillage, and the use of cover or green manure crops in rotations. However, comparative effects of inorganic fertilizer N and P, organic manures and crop residue incorporation to crops in CT and CA in semiarid subtropical soils have seldom been investigated. Such information is needed to identify crop nutrient management practices for sustaining or improving soil heath leading to the environmental safety, conservation of resources and the success of sustaining farming systems. Therefore, a 4-year field experiment was conducted to study the changes in soil quality/health parameters like WSA and various organic matter fractions under CA and CT systems.

2. Materials and Methods

2.1. Experimental Site and Climate

A 4-year field experiment on soybean-wheat rotation was established in 2005 at Punjab Agricultural University Research Farm, Ludhiana (30˚54'N, 75˚48'E, 247 m above mean sea level), India on a *Fatehpur* loamy sand soil (*Typic Haplustept*). During the 4-year period of field experiment, while the mean monthly minimum air temperature ranged from 4˚C in January to 28˚C in July, maximum temperature ranged from 17˚C in January to 40˚C in June. The annual rainfall ranged from 563 to 995 mm of which 71% to 88% was received during monsoon period (June-September).

2.2. Treatments and Field Operations

A total of 16 treatment combinations in triplicate with respect to CT and CA system, crop residue and fertilizer N and P (as listed in **Table 1**) were arranged in a split-split plot design with tillage system in main blocks, CR treatments in sub plots and fertilizer treatments in sub-sub plots of 3.15 × 8.30 m size. The recommended rates of fertilizer nutrients for optimum yields of soybean are 20 kg N and 60 kg P_2O_5 ha^{-1} [4] and wheat are 120 kg N and 60 kg P_2O_5 ha^{-1}. Experimental details and results on crop yields, nutrients uptake etc. from this experiment have been reported earlier [5]. In brief, the treatments consisted of control (T_1), 100% of recommended NP without CR (T_2), 125% of recommended NP without CR (T_3), 100% NP + 10 t FYM ha^{-1} without CR (T_4) and each of these treatments with CR (T_5, T_6, T_7 and T_8) in CT. The corresponding treatments were given in CA as well (T_9 to T_{16}, respectively). In CR treatments, 6 t wheat residue ha^{-1} and 3 t soybean residue ha^{-1} were incorporated in CT and spread on the soil surface in CA system. While the soil was tilled in CT treatments, crops were seeded by using manually-operated plough minimizing the soil disturbance in CA. At harvesting of each crop, the residue was either removed or incorporated in respective treatments in CT. In respective treatments of CA, crop residue was either removed or retained on the soil surface. In crop residue treatments, wheat residue was incorporated in CT and spread on the soil surface in CA system before seeding soybean. Similarly, soybean residue was applied before sowing wheat. The crops were irrigated (7.5 cm) as and when required by taking into consideration the moisture received through rainfall.

2.3. Soil Sampling and Analyses

After the completion of two and four cycles of soybean-wheat rotations, representative soil samples were collected from four random spots within each plot and mixed thoroughly to prepare a composite sample for 0 - 5 and 5 - 15 cm layer and air dried under shade. A portion of each sample was passed through 2 mm sieve and analyzed for TOC, water soluble C (WSC), particulate organic C and N (POC and PON), light fraction organic C and N (LFOC and LFON), potentially mineralizable N (PMN), and microbial biomass C and N (MBC and MBN). Rest of the clods was broken by hand in such a manner that the size of the clods remained between 5 - 8 mm, later were used for the estimation of water stable aggregates (WSA). The aggregate size distribution was determined by wet sieving method as described by Yoder

Table 1. Effect of fertilizer, FYM and crop residue treatments on soil aggregate size distribution (%) and mean weight diameter (MWD) in 0 - 5 cm soil layer after 2-year of the experiment.

Treatment No.	Treatments: Soybean	Treatments: Wheat	Distribution of WSA in different sizes (%): 0.11 - 0.25 mm	0.25 - 0.50 mm	0.5 - 1.0 mm	1.0 - 2.0 mm	>2.0 mm	Total WSA (%)	MWD (mm)
	Conventional tillage								
T_1	N_0 P_0 WR_0†	N_0 P_0 SR_0‡	23.2	22.7	14.9	7.1	3.1	70.9	0.41
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	25.2	25.4	14.3	9.6	4.5	79.0	0.44
T_3§	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	-	-	-	-	-	-	-
T_4	N_{20} P_{60} WR_0 + FYM_{10}^	N_{120} P_{60} SR_0	24.7	25.5	14.7	10.2	5.6	80.6	0.47
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	25.9	20.9	15.5	7.6	3.8	73.7	0.42
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	25.5	22.6	16.5	11.9	5.2	81.7	0.48
T_7§	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	-	-	-	-	-	-	-
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	25.0	22.8	17.3	12.8	5.3	83.3	0.49
	CT Mean		**24.9**	**23.3**	**15.5**	**9.9**	**4.6**	**78.2**	**0.45**
	***LSD* (0.05)**		**ns**	**ns**	**0.78**	**0.87**	**0.69**	**1.7**	**0.01**
	Conservation agriculture								
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	22.1	23.9	14.1	10.1	4.9	75.1	0.47
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	24.8	25.1	15.3	10.6	5.3	81.1	0.47
T_{11}§	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	-	-	-	-	-	-	-
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	23.6	27.5	15.3	10.5	5.0	81.9	0.46
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	24.0	20.9	15.2	10.6	5.1	75.8	0.48
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	26.7	23.4	15.6	11.2	5.5	82.6	0.47
T_{15}§	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	-	-	-	-	-	-	-
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	24.6	27.7	15.6	11.4	5.4	84.7	0.47
	CA Mean		**24.3**	**24.8**	**15.2**	**10.7**	**5.2**	**80.2**	**0.47**
	***LSD* (0.05)**		**ns**	**3.7**	**0.8**	**ns**	**ns**	**2.8**	**ns**

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue (t·ha^{-1}); ‡SR = Soybean crop residue (t·ha^{-1}); §WSA and MWD were not measured in Treatments (T_3, T_7, T_{11}, and T_{15}); ^FYM = farmyard manure (t·ha^{-1}); ns = non-significant.

[6] by uniformly spreading soil clods on the top most sieve of a nest of sieves having pore diameter 2, 1, 0.5, 0.25 and 0.11 mm. The nest of sieves was oscillated up and down by a pulley arrangement for 30 minutes at a frequency of 30 cycles per minute in salt-free water. WSA of different sizes were collected from the respective sieves separately after oven-drying the sieves at 50˚C.

% WSA in each size group = (Weight of aggregates in each size group / Total weight of soil) × 100

Total N content of soil samples was determined by digestion in concentrated H_2SO_4 followed by Kjeldahl's steam distillation. WSC was determined by following the method described by McGill *et al.* [7] and POC and PON were determined by the method of Cambardella and Elliott [8]. LFOC and LMON were determined by the method of Compton and Boone [9], and PMN in soil was determined by following the incubation method [10]. The chloroform fumigation and incubation method was used for the determination of biomass in the soil [11]. For this, the soil samples were pre-incubated for 7 days at 40% WHC at 25˚C to avoid the exaggerated values as there is spurt of microbial activity in soil after wetting of dry soil [12]. The moisture content of the soil samples was adjusted to 55% WHC by adding sterile distilled water. The increases in CO_2 evolution and extractable NH_4^+ from fumigated samples were determined to estimate the MBC and MBN, respectively. In the representative soil samples collected from 0 - 5 and 5 - 15 cm layers after 4 years of experimentation, soil pH was determined in soil:water suspension (1:2 ratio) using glass electrode.

2.4. Statistical Analysis

Statistical analysis of data of WSA and various soil health parameters was carried out by ANOVA in split-split plot design [13]. 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

3.1. Soil Physical Properties

3.1.1. Water Stable Aggregates

Results on total WSA after 2 years of the experiment showed that in 0 - 5 cm soil layer of CT system, T_2 and T_4 treatments increased total WSA from 71% in control (T_1) to 79 and 81% without CR, and to 82 (T_6) and 83% (T_8) with CR, respectively (**Figure 1**). The corresponding increase of total WSA under CA system was 75% in control (T_9) to 81 (T_{10}) and 82% (T_{12}) without CR and 83 (T_{14}) and 85% (T_{16}) in with CR, respectively. In 5 - 15 cm layer, the increasing trends due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (**Figure 2**). The impact of applied fertilizer, FYM and CR in improving total WSA was significant in 0 - 5 cm soil layer, and higher than in 5 - 15 cm soil layer under both CA and CT system. The trends were similar after 4 cycles of the experiment with small increase in WSA.

3.2.2. Distribution of Aggregates in Different Size

Distribution of aggregates in different size classes (0.11 - 0.25, 0.25 - 0.5, 0.5 - 1.0, 1 - 2 and >2 mm diameter) in two soil layers under CT and CA system is presented in **Tables 1** and **2**. In all the treatments, the proportion of macro-aggregates in the size class of 0.25 to >2 mm was higher as compared to micro-aggregate in the size class 0.11 - 0.25 mm. Among the macro-aggregates, 0.25 - 0.50 mm fraction constituted the greatest proportion followed by 0.5 - 1.0, 1.0 - 2.0, and >2 mm fraction constituted the least proportion in both 0 - 5 cm and 5 - 15 cm

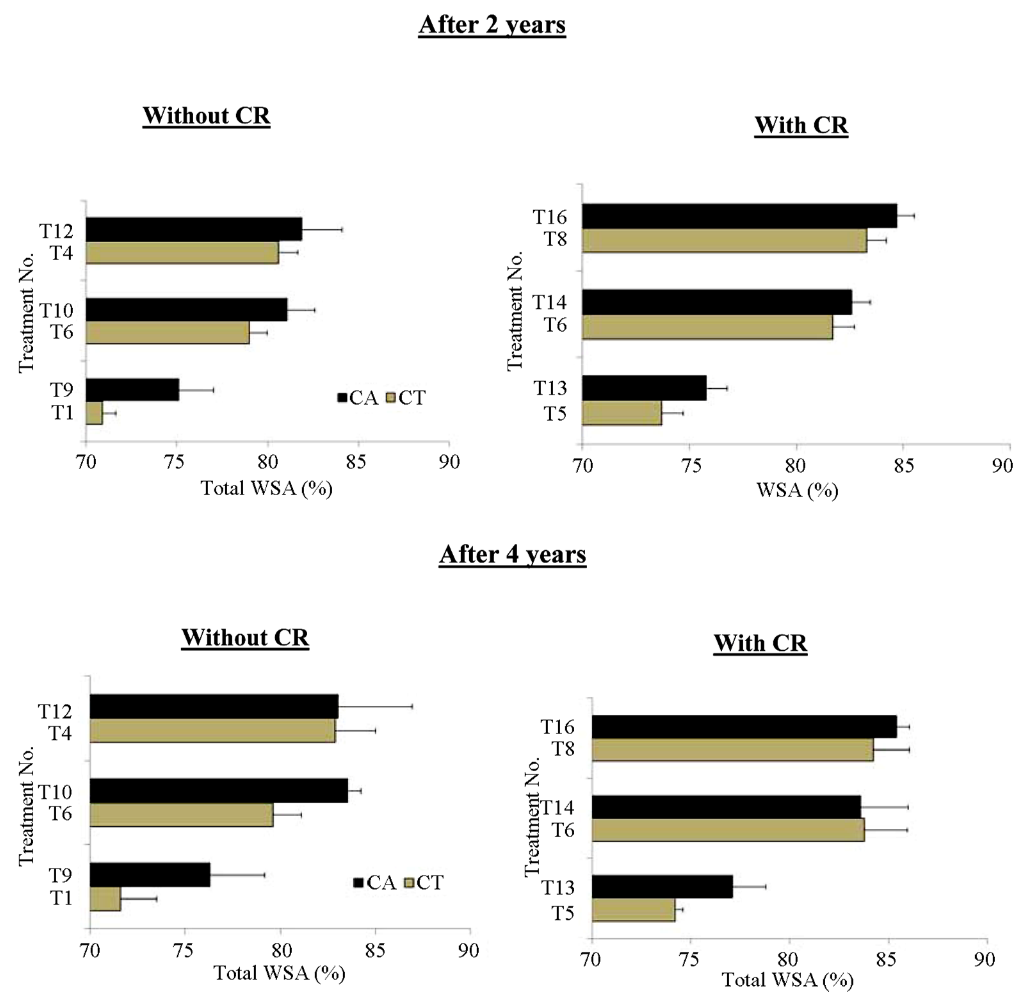

Figure 1. Effect of fertilizer, tillage and crop residue treatments on total water stable aggregate (WSA) in 0 - 5 cm soil layer after 2-year and 4-year of soybean-wheat experiment under CT (Grey color bars) and CA systems (Black color bars). For treatment abbreviations, see Table 1.

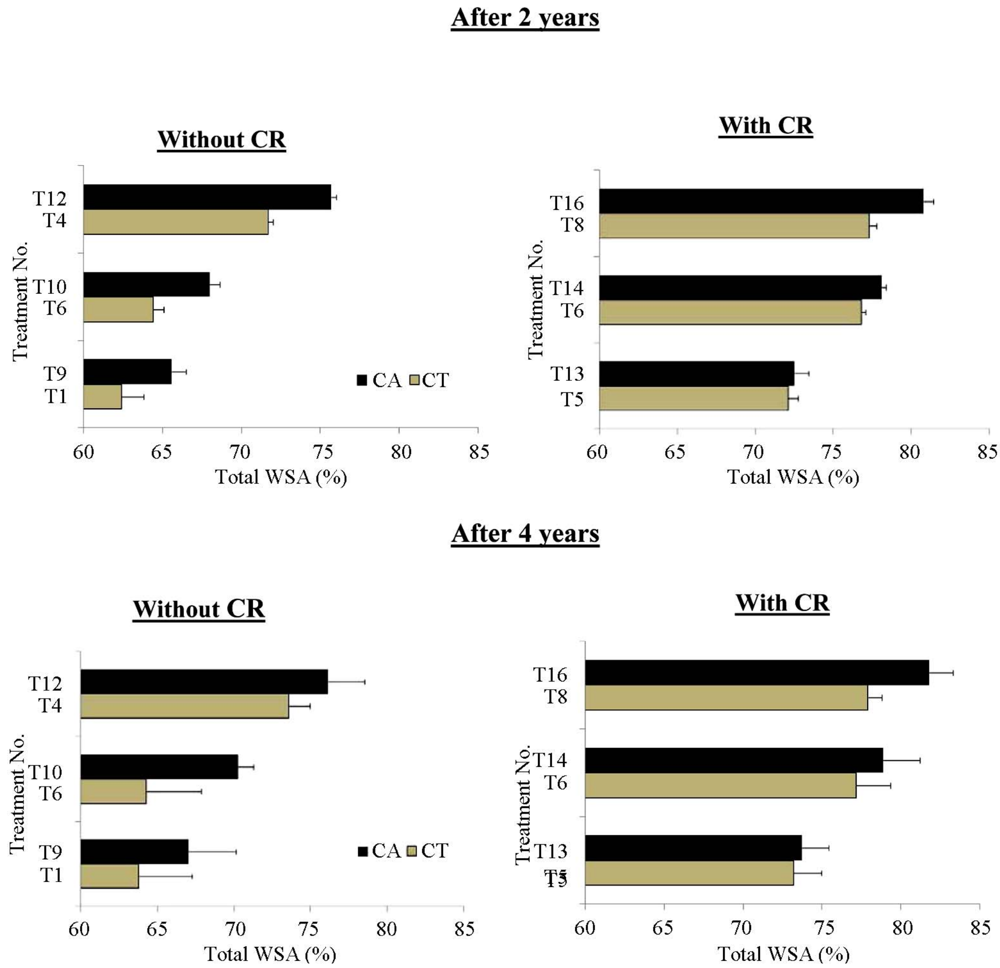

Figure 2. Effect of fertilizer, tillage and crop residue treatments on total water stable aggregate (WSA) in 5 - 15 cm soil layer after 2-year and 4-year of soybean-wheat experiment under CT and CA systems (For treatment abbreviations, see Table 1).

soil layers under both CT and CA system. Integrated use of organic and inorganic fertilizers significantly increased total WSA which was highest in all the macro-aggregate size fractions in 0 - 5 cm (**Table 1**) and 5 - 15 cm soil layer (**Table 2**). In 0 - 5 cm soil layer of CA system without CR, macro-aggregates in the 0.25 - 0.5, 0.5 - 1.0, 1 - 2, and >2 mm were 23.9, 14.1, 10.1 and 4.9%, respectively in control plots (T_9), which increased to 27.5, 15.3, 10.5 and 5.0%, respectively in T_{12} plots. Whereas with CR, macro-aggregate in the respective classes were 20.9, 15.2, 10.6 and 5.1%, in control (T_{13}), which increased to 27.7, 15.6, 11.4 and 5.4% in T_{16} treatment. In 5 - 15 cm soil layer, the increasing trends of macro-aggregates in these classes under CT and CA system due to the application of N and P fertilizers, FYM and CR were quite similar to those in 0 - 5 cm layer, however, the magnitude was relatively lower (**Table 2**).

Micro-aggregate (0.11 - 0.25 mm) ranged from 23% - 26% in the 0 - 5 cm (**Table 1**) and 21 - 24% in 5 - 15 cm soil layer in CT (**Table 2**). Whereas under CA system, micro-aggregate ranged from 22% - 27% in 0 - 5 cm layer (**Table 1**) and 21% - 25% in the 5 - 15 cm soil layer (**Table 2**).

MWD in the 0 - 5 cm layer ranged from 0.41 to 0.49 mm in CT and 0.46 to 0.48 mm in CA system (**Table 1**). The corresponding values for 5 - 15 cm soil layer varied from 0.41 to 0.51 and 0.43 to 0.48 mm (**Table 2**). The MWD was significantly higher in FYM and CR treatments as compared to control in CT system in both the soil layers.

3.2. Soil Chemical Properties

3.2.1. Total Organic C, Total N and C/N Ratio

Results on TOC content after 2 and 4 years showed that with N and P fertilizers, FYM and CR treatments, TOC content significantly differed under CT and CA systems in both 0 - 5 cm and 5 - 15 cm soil layers (**Tables 3** and **4**). In 0 - 5 cm layer of CT system, T_2, T_3 and T_4 treatments increased TOC content from 3.84 g·kg^{-1} in control (T_1) to 4.19, 4.33 and 4.45 g·kg^{-1} without CR, and to

Table 2. Effect of fertilizer, FYM and crop residue treatments on soil aggregate size distribution (%) and mean weight diameter (MWD) in 5 - 15 cm soil layer after 2-year of the experiment.

Treatment No.	Treatments Soybean	Wheat	Distribution of WSA in different sizes (%) 0.11 - 0.25 mm	0.25 - 0.50 mm	0.5 - 1.0 mm	1.0 - 2.0 mm	>2.0 Mm	Total WSA (%)	MWD (mm)
	Conventional tillage								
T_1	N_0 P_0 WR_0†	N_0 P_0 SR_0‡	23.4	19.2	9.0	7.9	3.0	62.4	0.41
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	21.7	20.4	10.5	8.6	3.2	64.4	0.43
T_3§	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	-	-	-	-	-	-	-
T_4	N_{20} P_{60} WR_0 + FYM_{10}^	N_{120} P_{60} SR_0	20.6	21.9	14.9	9.7	4.6	71.7	0.48
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	22.2	21.0	15.7	9.2	4.1	72.1	0.46
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	23.6	22.3	15.3	11.1	4.5	76.8	0.47
T_7§	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	-	-	-	-	-	-	-
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	20.7	23.2	15.8	12.1	5.5	77.3	0.51
	CT Mean		**22.0**	**21.3**	**13.5**	**9.8**	**4.2**	**70.8**	**0.46**
	***LSD* (0.05)**		**ns**	**ns**	**2.2**	**1.4**	**0.57**	**1.6**	**0.01**
	Conservation agriculture								
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	22.0	21.3	10.7	8.2	3.4	65.6	0.43
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	21.0	24.0	10.6	8.2	4.1	68.0	0.44
T_{11}§	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	-	-	-	-	-	-	-
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	22.6	22.3	15.4	10.3	5.1	75.7	0.48
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	22.5	21.4	14.5	9.8	4.3	72.5	0.46
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	23.8	23.9	14.5	10.9	5.1	78.1	0.47
T_{15}§	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	-	-	-	-	-	-	-
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	24.6	24.4	15.5	11.0	5.3	80.8	0.47
	CA Mean		**22.8**	**22.9**	**13.5**	**9.7**	**4.6**	**73.5**	**0.46**
	***LSD* (0.05)**		**ns**	**2.2**	**1.0**	**0.83**	**0.62**	**1.2**	**0.01**

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); §WSA and MWD were not measured in Treatments (T_3, T_7, T_{11}, and T_{15}); ^FYM = farmyard manure ($t \cdot ha^{-1}$); ns = non-significant.

4.40, 4.83 and 5.79 $g \cdot kg^{-1}$ with CR (T_6, T_7 and T_8) after 2 years. The corresponding values of TOC content under CA system were 4.55 $g \cdot kg^{-1}$ in control to 4.73, 4.79 and 5.02 $g \cdot kg^{-1}$ without CR and to 4.95, 5.07 and 5.30 $g \cdot kg^{-1}$ with CR. After 4 years of these treatments, there was further improvement in TOC content from 1% to 26% in CT and none to 19% in CA treatments. In 5 - 15 cm layer, the increasing trends due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (**Table 4**). The impact of applied fertilizer, FYM and CR in improving TOC content was more in 0 - 5 cm soil layer than in 5 - 15 cm soil layer under both CA and CT system. With the application of inorganic and organic fertilizer treatments, TOC stock significantly differed under CT and CA system with different treatments in both 0 - 5 cm and 5 - 15 cm soil layers (**Tables 3** and **4**). In 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased TOC stock from 2.92 $t \cdot C \cdot ha^{-1}$ in control (T_1) to 3.19, 3.29 and 3.38 $t \cdot C \cdot ha^{-1}$ without CR, and to 3.35, 3.67 and 4.40 $t \cdot C \cdot ha^{-1}$ with CR (T_6, T_7 and T_8) after 2 years (**Table 3**). The corresponding increase of TOC stock under CA system was from 3.46 $t \cdot C \cdot ha^{-1}$ in control to 3.59, 3.64 and 3.82 $t \cdot C \cdot ha^{-1}$ without CR and to 3.76, 3.85 and 4.03 $t \cdot C \cdot ha^{-1}$ with CR. In 5 - 15 cm layer, the increasing trends in TOC stocks due to the application of N and P fertilizers, FYM and CR were similar to those in 0 - 5 cm layer, however, the magnitude was relatively higher in 5 - 15 cm soil layer, obviously due to high soil mass (**Table 4**). After 2 years, the TN content ranged

Table 3. Total organic C (TOC), total N (TN) and C/N ratio in 0 - 5 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment	Treatments		TOC ($g \cdot kg^{-1}$)		TOC ($t \cdot ha^{-1}$)		TN ($mg \cdot kg^{-1}$)		C/N ratio	
No.	Soybean	Wheat	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr
	Conventional tillage									
T_1	$N_0 P_0 WR_0$†	$N_0 P_0 SR_0$‡	3.84	3.89	2.92	2.95	437	439	8.8	8.9
T_2	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	4.19	4.31	3.19	3.28	514	518	8.2	8.3
T_3	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	4.33	4.38	3.29	3.33	548	550	7.9	8.0
T_4	$N_{20} P_{60} WR_0 + FYM_{10}$^	$N_{120} P_{60} SR_0$	4.45	5.60	3.38	4.26	583	585	7.6	9.6
T_5	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	4.02	4.46	3.05	3.39	464	470	8.7	9.5
T_6	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	4.40	4.95	3.35	3.76	587	592	7.5	8.4
T_7	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	4.83	5.35	3.67	4.07	655	658	7.4	8.1
T_8	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	5.79	5.89	4.40	4.48	844	847	6.9	7.0
	CT Mean		**4.48**	**4.86**	**3.41**	**3.69**	**579**	**582**	**7.9**	**8.5**
	Conservation agriculture									
T_9	$N_0 P_0 WR_0$	$N_0 P_0 SR_0$	4.55	4.50	3.46	3.42	476	483	9.6	9.3
T_{10}	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	4.73	4.75	3.59	3.61	542	547	8.7	8.7
T_{11}	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	4.79	5.03	3.64	3.82	575	579	8.3	8.7
T_{12}	$N_{20} P_{60} WR_0 + FYM_{10}$	$N_{120} P_{60} SR_0$	5.02	5.98	3.82	4.54	618	624	8.1	9.6
T_{13}	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	4.90	4.92	3.73	3.74	522	541	9.4	9.1
T_{14}	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	4.95	5.07	3.76	3.85	642	648	7.7	7.8
T_{15}	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	5.07	5.65	3.85	4.29	683	692	7.4	8.2
T_{16}	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	5.30	5.99	4.03	4.56	887	906	6.0	6.6
	CA Mean		**4.91**	**5.24**	**3.73**	**3.98**	**618**	**628**	**8.2**	**8.5**
	Overall mean		**4.70**	**5.05**	**3.57**	**3.83**	**599**	**605**	**8.0**	**8.5**
	***LSD* (0.05)**									
	Treatment		0.23	0.52	0.16	0.39	13	15	-	-
	Tillage		0.02	ns	0.02	ns	25	20	-	-
	Crop residue		0.15	0.26	0.11	0.20	13	16	-	-

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$); ns = non-significant.

from 437 to 844 $mg \cdot kg^{-1}$ and 476 to 887 $mg \cdot kg^{-1}$ in 0 - 5 cm soil layer under CT and CA system, respectively (**Table 3**). The further increase in TN after 4 years was negligible. In 0 - 5 cm soil layer, the C/N ratio was 8.8 in control, which became narrower with application of N and P, FYM and CR treatments and narrowest C/N ratio of 6.9 was found in T_8 treatment under CT system after 2 cycles. Similarly, in CA system, the C/N ratio was 9.6 in control that reduced to 6.0 in T_{16} treatment. The overall TOC stock increased over control by 10%, 16% and 23% without CR, and by 19%, 28% and 41% with CR in 0 - 15 cm soil layer of CT system. The corresponding increase in TOC stock under CA system over control was by 4.7%, 8.4% and 12.2% without CR and by 12.7%, 15.3% and 19.4% with CR. Of the TOC stocks found in different treatments in 0 - 15 cm surface layer of both CT and CA, 39% to 44% were present in surface 5 cm and only 56% to 61% in next 10 cm depth suggesting decrease in TOC stocks with soil depth. The treatments T_8 and T_{16} in subsurface layer after 2 cycles leads to 41%

Table 4. Total organic C (TOC), total N (TN) and C/N ratio in 5 - 15 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment	Treatments		TOC ($g \cdot kg^{-1}$)		TOC ($t \cdot ha^{-1}$)		TN ($mg \cdot kg^{-1}$)		C/N ratio	
No.	Soybean	Wheat	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr
	Conventional tillage									
T_1	N_0 P_0 WR_0†	N_0 P_0 SR_0‡	2.69	2.75	4.12	4.21	421	426	6.4	6.5
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	2.99	2.99	4.57	4.58	478	487	6.3	6.1
T_3	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	3.18	3.53	4.86	5.41	533	545	6.0	6.5
T_4	N_{20} P_{60} WR_0 + FYM_{10}^	N_{120} P_{60} SR_0	3.47	3.70	5.30	5.66	583	601	5.9	6.2
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	2.98	3.43	4.55	5.24	477	484	6.2	7.1
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	3.29	3.55	5.03	5.43	579	580	5.7	6.1
T_7	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	3.48	4.08	5.32	6.23	639	647	5.4	6.3
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	3.61	4.18	5.53	6.39	822	834	4.4	5.0
	CT Mean		**3.21**	**3.53**	**4.91**	**5.39**	**567**	**576**	**5.8**	**6.2**
	Conservation agriculture									
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	3.10	3.21	4.75	4.91	423	430	7.3	7.5
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	3.27	3.40	5.00	5.20	481	487	6.8	7.0
T_{11}	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	3.44	3.48	5.26	5.32	547	561	6.3	6.2
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	3.53	3.73	5.40	5.70	566	570	6.2	6.5
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	3.31	3.50	5.06	5.36	469	472	7.1	7.4
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	3.59	3.83	5.49	5.85	606	610	5.9	6.3
T_{15}	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	3.67	4.00	5.62	6.12	634	653	5.8	6.1
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	3.77	4.44	5.77	6.79	678	687	5.6	6.5
	CA Mean		**3.46**	**3.70**	**5.29**	**5.66**	**551**	**559**	**6.4**	**6.7**
	Overall mean		**3.34**	**3.61**	**5.10**	**5.52**	**559**	**567**	**6.1**	**6.5**
	***LSD* (0.05)**									
	Treatment		0.20	0.37	0.29	0.56	11.7	14	-	-
	Tillage		ns	ns	ns	ns	12.5	ns	-	-
	Crop residue		0.15	ns	0.23	ns	15.2	12	-	-

†N = fertilizer N ($kg\ N\ ha^{-1}$); P = fertilizer P ($kg\ P_2O_5\ ha^{-1}$); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$); ns = non-significant.

and 39% higher TOC stocks over CT-control in CT and CA, respectively. The corresponding changes after 4 cycles of the experiment in TOC stocks were 52% and 59%.

3.2.2. Water Soluble C

After 2 years, in 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased WSC content from 11 $mg \cdot kg^{-1}$ in control (T_1) to 16, 19 and 23 $mg\ kg^{-1}$ without CR, and to 20, 21 and 28 $mg \cdot kg^{-1}$ with CR (T_6, T_7 and T_8), respectively (**Table 5**). The corresponding increase of WSC content under CA system was from 20 $mg \cdot kg^{-1}$ in control to 25, 26 and 27 $mg \cdot kg^{-1}$ without CR and to 26, 27 and 29 $mg \cdot kg^{-1}$ with CR. The trends were similar after 4 years indicating a small improvement in WSC content of different treatments. Similar increasing trends were observed in 5 - 15 cm soil layer, however, the magnitude was relatively lower (**Table 6**).

3.2.3. Particulate Organic C and N

After 2 years of the experiment, in 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased POC content from 390 $mg \cdot kg^{-1}$ in control (T_1) to 550, 646 and 780 $mg \cdot kg^{-1}$ without CR, and to 920, 1040 and 1310 $mg \cdot kg^{-1}$ with CR (T_6, T_7 and T_8), respectively (**Table 5**). The corresponding increase of POC content under CA system was from 500 $mg \cdot kg^{-1}$ in control to 690, 730 and 910 $mg \cdot kg^{-1}$ without CR and 1050, 1110 and 1440 $mg \cdot kg^{-1}$ with CR. The trends were similar after 4 cycles of soybean-wheat rotation indicating a small improvement in POC content of different treatments. In subsur-

Table 5. Water soluble C (WSC), particulate organic C (POC), particulate organic N (PON), light fraction organic C (LFOC), and light fraction organic N (LFON) in 0 - 5 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment No.	Treatments		WSC ($mg \cdot kg^{-1}$)		POC ($mg \cdot kg^{-1}$)		PON ($mg \cdot kg^{-1}$)		LFOC ($mg \cdot kg^{-1}$)		LFON ($mg \cdot kg^{-1}$)	
	Soybean	Wheat	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year
	Conventional tillage											
T_1	$N_0 P_0 WR_0$†	$N_0 P_0 SR_0$‡	11.0	12.4	390	409	17.4	17.6	40.0	41.1	5.6	5.8
T_2	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	16.2	16.6	550	643	59.5	61.6	76.7	79.7	8.6	9.2
T_3	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	19.0	20.6	646	690	79.9	80.3	94.2	94.9	10.0	11.1
T_4	$N_{20} P_{60} WR_0 + FYM_{10}$^	$N_{120} P_{60} SR_0$	22.9	24.0	780	839	96.6	99.1	149.1	149.9	13.0	14.0
T_5	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	12.6	13.7	500	613	19.6	20.3	62.9	64.2	8.3	8.8
T_6	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	20.4	22.1	920	964	69.0	69.2	93.2	95.5	9.9	10.3
T_7	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	20.9	22.6	1040	1045	89.1	90.8	130.4	134.0	12.6	13.2
T_8	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	28.4	25.8	1310	1332	101.9	104.2	171.0	171.7	14.1	14.6
	CT Mean		**18.9**	**19.7**	**767**	**817**	**66.6**	**67.9**	**102.2**	**103.9**	**10.3**	**10.9**
	Conservation agriculture											
T_9	$N_0 P_0 WR_0$	$N_0 P_0 SR_0$	20.1	20.9	500	511	23.5	23.7	45.9	48.2	6.2	6.6
T_{10}	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	24.7	24.8	690	715	70.4	70.7	87.1	88.5	9.4	9.6
T_{11}	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	26.1	26.4	730	807	89.3	91.3	121.3	122.7	12.2	12.7
T_{12}	$N_{20} P_{60} WR_0 + FYM_{10}$	$N_{120} P_{60} SR_0$	27.0	28.2	910	942	112.2	116.1	174.0	176.4	13.7	14.0
T_{13}	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	23.5	25.2	630	699	26.9	27.1	69.4	70.7	8.7	9.1
T_{14}	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	26.2	28.1	1050	1164	80.7	82.5	105.1	106.5	10.8	11.5
T_{15}	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	27.2	27.7	1110	1262	102.9	103.9	141.0	142.1	13.3	13.7
T_{16}	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	29.2	29.7	1440	1452	122.2	129.4	193.5	194.6	14.6	14.9
	CA Mean		**25.5**	**26.4**	**882**	**944**	**78.5**	**80.6**	**117.2**	**118.7**	**11.1**	**11.5**
	Overall mean		**22.2**	**23.1**	**825**	**880**	**72.6**	**74.2**	**109.7**	**111.3**	**10.7**	**11.2**
	***LSD* (0.05)**											
	Treatment		0.4	2.4	38	66	1.4	3.9	5.3	4.1	0.5	1.0
	Tillage		0.8	ns	108	ns	4.8	7.0	12.4	6.7	ns	ns
	Crop residue		0.4	1.7	55	49	2.3	4.3	2.7	3.8	0.5	0.9

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$); ns = non-significant.

face layer, similar increasing trends were observed, however, the magnitude was relatively lower (**Table 6**). Results on PON content after 2-year showed that in 0-5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased PON content from 17 $mg \cdot kg^{-1}$ in control (T_1) to 60, 80 and 97 $mg \cdot kg^{-1}$ without CR, and to 69, 89 and 102 $mg \cdot kg^{-1}$ with CR (T_6, T_7 and T_8) (**Table 5**). The corresponding increase of PON content under CA system was from 23.5 $mg \cdot kg^{-1}$ in control to 70, 89 and 112 $mg \cdot kg^{-1}$ without CR and 81, 103 and 122 $mg \cdot kg^{-1}$ with CR. Small improvement in PON content was observed after 4 years of the experiment. The increasing trends in PON content were observed in subsurface layer, however, the magnitude was relatively lower (**Table 6**).

3.2.4. Light Fraction Organic C and N

Results on LFOC content in 2-year experiment showed that in 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased LFOC content from 40 $mg \cdot kg^{-1}$ in control (T_1) to 77, 94 and 149 $mg \cdot kg^{-1}$ without CR, and to 93, 130 and 171 $mg \cdot kg^{-1}$ with CR (T_6, T_7 and T_8), respectively (**Table 5**). The corresponding increase of

Table 6. Water soluble C (WSC), particulate organic C (POC), particulate organic N (PON), light fraction organic C (LFOC), and light fraction organic N (LFON) in 5 - 15 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment No.	Treatments		WSC ($mg \cdot kg^{-1}$)		POC ($mg \cdot kg^{-1}$)		PON ($mg \cdot kg^{-1}$)		LFOC ($mg \cdot kg^{-1}$)		LFON ($mg \cdot kg^{-1}$)	
	Soybean	Wheat	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year
	Conventional tillage											
T_1	$N_0 P_0 WR_0$†	$N_0 P_0 SR_0$‡	8.7	10.2	260	313	15.8	16.1	32.3	32.4	5.1	5.6
T_2	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	10.6	11.8	410	473	47.3	50.7	58.2	59.0	7.9	8.1
T_3	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	12.3	13.8	520	537	67.7	71.5	79.3	81.0	10.0	11.5
T_4	$N_{20} P_{60} WR_0 + FYM_{10}$^	$N_{120} P_{60} SR_0$	14.1	16.8	600	687	85.3	86.4	128.8	130.0	11.0	11.4
T_5	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	10.3	12.2	340	380	16.9	17.6	50.8	52.4	7.4	8.1
T_6	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	12.9	13.9	590	680	61.3	67.8	65.8	66.8	7.1	8.2
T_7	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	14.8	17.1	650	709	86.1	87.8	89.7	90.5	9.6	10.8
T_8	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	16.4	19.2	710	838	99.6	100.5	125.2	125.8	10.5	11.2
	CT Mean		**12.5**	**14.4**	**510**	**577**	**60.0**	**62.3**	**78.8**	**79.7**	**8.6**	**9.4**
	Conservation agriculture											
T_9	$N_0 P_0 WR_0$	$N_0 P_0 SR_0$	10.6	11.2	320	367	20.6	21.3	37.8	40.1	5.6	5.9
T_{10}	$N_{20} P_{60} WR_0$	$N_{120} P_{60} SR_0$	13.4	15.7	460	531	61.7	62.3	69.8	71.0	8.1	8.7
T_{11}	$N_{25} P_{75} WR_0$	$N_{150} P_{75} SR_0$	13.7	19.1	580	617	81.0	82.0	104.0	105.8	11.9	13.7
T_{12}	$N_{20} P_{60} WR_0 + FYM_{10}$	$N_{120} P_{60} SR_0$	20.2	21.9	630	700	108.0	109.2	157.9	159.4	13.0	13.4
T_{13}	$N_0 P_0 WR_6$	$N_0 P_0 SR_3$	12.6	13.3	400	440	22.6	23.2	57.3	59.2	8.0	8.5
T_{14}	$N_{20} P_{60} WR_6$	$N_{120} P_{60} SR_3$	15.1	16.5	660	683	74.3	74.7	84.9	86.1	9.3	9.8
T_{15}	$N_{25} P_{75} WR_6$	$N_{150} P_{75} SR_3$	18.5	20.7	710	810	98.7	99.5	109.2	111.9	11.4	12.2
T_{16}	$N_{20} P_{60} WR_6 + FYM_{10}$	$N_{120} P_{60} SR_3$	26.0	26.4	780	827	115.3	124.1	153.6	154.4	12.3	13.0
	CA Mean		**16.3**	**18.1**	**567**	**622**	**72.8**	**74.6**	**96.8**	**98.5**	**10.0**	**10.7**
	Overall mean		**14.4**	**16.2**	**539**	**600**	**66.4**	**68.4**	**87.8**	**89.1**	**9.3**	**10.0**
	***LSD* (0.05)**											
	Treatment		0.4	2.4	34	65	1.8	3.2	4.8	3.5	0.5	0.9
	Tillage		Ns	2.5	ns	ns	3.1	3.1	1.3	3.4	0.8	ns
	Crop residue		0.4	ns	34	74	1.0	2.6	3.9	3.6	0.2	ns

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$); ns = non-significant.

LFOC content under CA system was from 45.9 $mg \cdot kg^{-1}$ in control to 87, 121 and 174 $mg \cdot kg^{-1}$ without CR and 105, 141 and 194 $mg \cdot kg^{-1}$ with CR. After 4 years, there was a further increase in LFOC in most of the treatments. The trends were similar after 4 years of soybean-wheat experiment indicating a negligible improvement in LFOC content of different treatments. In 5 - 15 cm layer, the increasing trends in LFOC content due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (**Table 6**).

Results on LFON content in 2-year experiment showed that in 0 - 5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased LFON content from 5.6 $mg \cdot kg^{-1}$ in control (T_1) to 8.6, 10.0 and 13.0 $mg \cdot kg^{-1}$ without CR, and to 9.9, 12.6 and 14.1 $mg \cdot kg^{-1}$ with CR (T_6, T_7 and T_8), respectively (**Table 5**). The corresponding increase of LFON content under CA system was from 6.2 $mg \cdot kg^{-1}$ in control to 9.4, 12.2 and 13.7 $mg \cdot kg^{-1}$ without CR and 10.8, 13.3 and 14.6 $mg \cdot kg^{-1}$ with CR. After 4 years, there was a small improvement in LFON in most of the treatments. In 5 - 15 cm layer, the increasing trends in LFON content due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (**Table 6**).

In general, the impact of applied fertilizer, FYM and CR 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 CA and CT system.

3.3. Soil Biological Properties

3.3.1. Potentially Mineralizable N

Results on PMN content after 2 years of the experiment showed that in 0-5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased PMN content from 2.7 mg·kg^{-1} 7d^{-1} in control (T_1) to 2.9, 3.9 and 5.1 mg·kg^{-1} 7d^{-1} without CR, and to 6.9, 8.4 and 9.7 mg·kg^{-1} 7d^{-1} with CR (T_6, T_7 and T_8), respectively (**Table 7**). The corresponding increase of PMN content under CA system was from 3.6 mg·kg^{-1} 7d^{-1} in control to 3.9, 5.1 and 6.5 mg·kg^{-1} 7d^{-1} without CR and to 8.9, 10.3 and 12.1 mg·kg^{-1} 7d^{-1} with CR. The trends were similar after 4 years of soybean-wheat experiment indicating a small improvement in PMN content of different treatments. In 5 - 15 cm layer, the increasing trends due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer, however, the magnitude was relatively lower (**Table 7**).

3.3.2. Microbial Biomass C and N

Results on MBC content after 2 years of the experiment showed that in CT system, T_2, T_3 and T_4 treatments in creased MBC content from 93 mg·kg^{-1} in control (T_1) to 126, 136 and 156 mg·kg^{-1} without CR, and to 147, 162

Table 7. Potentially mineralizable N (PMN), microbial biomass C (MBC) and microbial biomass N (MBN) in 0 - 5 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment	Treatments		PMN (mg·kg^{-1})				MBC (mg·kg^{-1})		MBN (mg·kg^{-1})	
No.	Soybean	Wheat	0 - 5 cm		5 - 15 cm		0 - 5 cm		0 - 5 cm	
			2-yr	4-yr	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr
	Conventional tillage									
T_1	N_0 P_0 WR_0†	N_0 P_0 SR_0‡	2.7	3.3	1.4	1.6	93	94	5.9	6.3
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	2.9	3.4	2.9	3.2	126	132	9.5	9.8
T_3	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	3.9	4.3	4.2	4.4	136	140	12.7	13.7
T_4	N_{20} P_{60} WR_0 + FYM_{10}^	N_{120} P_{60} SR_0	5.1	5.3	4.9	5.1	156	157	16.0	16.7
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	3.3	3.4	1.8	1.9	118	126	7.0	7.2
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	6.9	7.1	5.9	6.2	147	149	12.9	13.2
T_7	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	8.4	8.7	7.1	7.5	162	189	17.6	18.1
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	9.7	10.4	9.3	9.6	202	196	24.3	25.1
	CT Mean		**5.4**	**5.7**	**4.7**	**4.9**	**143**	**148**	**13.2**	**13.7**
	Conservation agriculture									
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	3.6	3.8	1.5	1.8	116	119	6.4	6.8
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	3.9	4.0	2.3	2.4	142	143	10.4	10.6
T_{11}	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	5.1	5.4	4.0	4.1	153	155	15.6	16.2
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	6.5	7.1	5.5	5.8	170	171	16.8	17.1
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	4.2	4.8	2.8	3.1	139	140	7.2	7.9
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	8.9	9.5	5.9	6.8	159	162	15.4	16.0
T_{15}	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	10.3	11.0	8.4	8.7	168	193	20.5	22.7
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	12.1	12.9	10.7	11.4	227	215	27.3	26.1
	CA Mean		**6.8**	**7.3**	**5.1**	**5.5**	**159**	**162**	**15.0**	**15.4**
	Overall mean		**6.1**	**6.5**	**4.9**	**5.2**	**151**	**155**	**14.1**	**14.6**
	***LSD* (0.05)**									
	Treatment		0.6	0.6	0.4	0.5	5.5	6.0	0.5	0.8
	Tillage		ns	ns	ns	ns	10.9	10.8	1.1	0.7
	Crop residue		0.4	0.6	0.7	0.7	5.7	6.8	0.6	0.3

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue (t·ha^{-1}); ‡SR = Soybean crop residue (t·ha^{-1}); ^FYM = farmyard manure (t·ha^{-1}); ns = non-significant.

and 202 mg·kg^{-1} with CR (T_6, T_7 and T_8), respectively (**Table 7**). The corresponding increase of MBC content under CA system was from 116 mg·kg^{-1} in control to 142, 153 and 170 mg·kg^{-1} without CR and to 159, 168 and 227 mg·kg^{-1} with CR. Similar trends were observed after 4 years indicating a small improvement in MBC content of different treatments. Results on MBN content after 2 years showed that in CT system, T_2, T_3 and T_4 treatments increased MBN content from 5.9 mg·kg^{-1} in control (T_1) to 9.5, 12.7 and 16.0 mg·kg^{-1} without CR, and to 12.9, 17.6 and 24.3 mg·kg^{-1} with CR (T_6, T_7 and T_8), respectively (**Table 7**). The corresponding increase of MBN content under CA system was from 6.4 mg·kg^{-1} in control to 10.4, 15.6 and 16.8 mg·kg^{-1} without CR and to 15.4, 20.5 and 27.3 mg·kg^{-1} with CR. Maximum MBN contents were found in T_8 and T_{16} treatments plots of both CT and CA systems.

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

After 2 years of the experiment, WSC accounted for 0.29% to 0.52% and 0.44% to 0.55% of TOC in different treatments of CT and CA system, respectively in 0 - 5 cm soil layer (**Table 8**). While POC accounted for 10.2% to 22.6% and 11.0% to 27.2%, the proportion of LFOC ranged from 1.0% to 3.3% and 1.0% to 3.6% of TOC, respectively in CT and CA system. In 5 - 15 cm layer, the trends of WSC, POC and LFOC in TOC due to the application of N and P fertilizers, FYM and CR were similar to those observed in 0 - 5 cm layer (**Table 9**). The proportion of MBC ranged from 2.4% to 3.5% under CT and 2.5% to 4.3% of TOC under CA system, which showed gradual increase with the application of N and P, FYM and CR treatments (**Table 10**) and was maximum in N_{20} P_{60} WR_6 + FYM_{10} treatment under both tillage systems. After 4 years, there were minor changes in the proportion of different labile C fractions in TOC.

PON accounted for 4.0% to 18.2% of TN content in 0 - 5 cm soil layer under both CT and CA system after 2 years of experimentation (**Table 8**). The MBN content ranged from 1.4% to 2.9% and 1.4% to 3.1% of TN in CT and CA system, respectively. The proportion of both PMN and MBN gradually increased with the application of N and P, FYM and CR treatments. While the proportion of PMN was highest in T_7 and T_{15} treatments, MBN was highest in T_8 and T_{16} treatment under CT and CA systems respectively after 2 years of the experiment (**Table 10**).

4. Discussion

Application of FYM enhances the soil organic C content (SOC) and has direct and indirect effects on soil properties and processes. There was a significant improvement in water stable aggregation and proportion of macro-aggregates, SOC content, labile C and N fractions such as water soluble C, particulate and light fraction organic matter, potentially mineralizable N and microbial biomass with the application of 10 t FYM ha^{-1} along with recommended rate of NP to soybean.

After 2 years of the experiment, total WSA in 0 - 5 cm soil layer increased from 71% in control (T_1) to a maximum of 83 (T_8) and 85% (T_{16}) treatments in CT and CA, respectively with the addition of FYM and incorporation of crop residues (**Figure 1**). Likewise, the increase in total WSA was from 62% in control to 77 and 81%, respectively in 5 - 15 cm layer (**Figure 2**), indicating the beneficial effect of integrated use of inorganic fertilizers and organic materials on the formation of aggregates over the unmanured treatments. The effects were similar after 4 years of experiment with further improvement in WSA, and the effect of tillage was statistically significant. The CA system causes less disturbance of soil and retains CR on soil surface than CT system, which could enhance and protect SOM content and improve soil structure.

TOC and TN contents of 0 - 5 cm surface soil layer significantly improved with N and P, FYM and CR under both CT and CA systems. After 4 years of study, maximum TOC content was recorded in T_8 and T_{16} treatments, which was 5.89 and 5.99 g·kg^{-1} in 0 - 5 cm and 4.18 and 4.44 g·kg^{-1} in 5 - 15 cm soil layer in CT and CA, respectively (**Tables 3** and **4**). Integrated use of inorganic fertilizers, FYM and CR significantly improved both TOC content and stock. The beneficial effects were more pronounced in 0 - 5 cm surface layer than 5 - 15 cm subsurface soil layer. Conservation tillage resulted in significantly higher TOC than CT. The narrowest C/N ratio of 6.9 and 6.0 was found in 0 - 5 cm in $N_{20}P_{60}WR_6$ + FYM_{10} – $N_{120}P_{60}SR_3$ treatment of CT and CA system, respectively indicating improvement in N supplying capability of soil as the plant materials and residues in the soil decompose rapidly at narrow C/N ratio and convert unavailable plant nutrients to available form [14]. These results are in conformity with Hao *et al.* [15] who observed that application of inorganic fertilizer alone did not significantly improve TOC content as compared to the control while the application of inorganic fertilizer along with manure or straw significantly increased TOC content. Kaur *et al.* [16] reported that continuous cropping with and without use of chemical fertilizers and FYM resulted in the improvement of TOC content in a long-term CT experiment. While intensive tillage practices enhance the decomposition of SOM, no-till practices generally enhance the TOC concentration in surface soil. No-till provides greater physical protection to TOC within macro-aggregate protected TOC than with CT but mostly at soil surface [17]. The higher TOC content and

Table 8. Proportion of water soluble C (WSC), particulate organic C (POC) and light fraction organic C (LFOC) in total organic C (TOC), and particulate organic N (PON) and light fraction organic N (LFON) in total N (TN) in 0 - 5 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment No.	Treatments		WSC (% of TOC)		POC (% of TOC)		LFOC (% of TOC)		PON (% of TN)		LFON (% of TN)	
	Soybean	Wheat	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year
	Conventional tillage											
T_1	$N_0\ P_0\ WR_0$†	$N_0\ P_0\ SR_0$‡	0.29	0.32	10.2	10.5	1.0	1.1	4.0	4.0	1.3	1.3
T_2	$N_{20}\ P_{60}\ WR_0$	$N_{120}\ P_{60}\ SR_0$	0.39	0.38	13.1	14.9	1.8	1.8	11.6	11.9	1.7	1.8
T_3	$N_{25}\ P_{75}\ WR_0$	$N_{150}\ P_{75}\ SR_0$	0.44	0.47	14.9	15.8	2.2	2.2	14.6	14.6	1.8	2.0
T_4	$N_{20}\ P_{60}\ WR_0 + FYM_{10}$^	$N_{120}\ P_{60}\ SR_0$	0.51	0.43	17.5	15.0	3.3	2.7	16.6	16.9	2.2	2.4
T_5	$N_0\ P_0\ WR_6$	$N_0\ P_0\ SR_3$	0.31	0.31	12.4	13.7	1.6	1.4	4.2	4.3	1.8	1.9
T_6	$N_{20}\ P_{60}\ WR_6$	$N_{120}\ P_{60}\ SR_3$	0.46	0.45	20.9	19.5	2.1	1.9	11.8	11.7	1.7	1.7
T_7	$N_{25}\ P_{75}\ WR_6$	$N_{150}\ P_{75}\ SR_3$	0.43	0.42	21.5	19.5	2.7	2.5	13.6	13.8	1.9	2.0
T_8	$N_{20}\ P_{60}\ WR_6 + FYM_{10}$	$N_{120}\ P_{60}\ SR_3$	0.49	0.44	22.6	22.6	3.0	2.9	12.1	12.3	1.7	1.7
	CT Mean		**0.42**	**0.40**	**16.7**	**16.4**	**2.2**	**2.1**	**11.0**	**11.2**	**1.8**	**1.9**
	Conservation agriculture											
T_9	$N_0\ P_0\ WR_0$	$N_0\ P_0\ SR_0$	0.44	0.46	11.0	11.4	1.0	1.1	4.9	4.9	1.3	1.4
T_{10}	$N_{20}\ P_{60}\ WR_0$	$N_{120}\ P_{60}\ SR_0$	0.52	0.52	14.6	15.0	1.8	1.9	13.0	12.9	1.7	1.8
T_{11}	$N_{25}\ P_{75}\ WR_0$	$N_{150}\ P_{75}\ SR_0$	0.55	0.53	15.2	16.1	2.5	2.4	15.5	15.8	2.1	2.2
T_{12}	$N_{20}\ P_{60}\ WR_0 + FYM_{10}$	$N_{120}\ P_{60}\ SR_0$	0.54	0.47	18.1	15.8	3.5	3.0	18.2	18.6	2.2	2.2
T_{13}	$N_0\ P_0\ WR_6$	$N_0\ P_0\ SR_3$	0.48	0.51	12.8	14.2	1.4	1.4	5.2	5.0	1.7	1.7
T_{14}	$N_{20}\ P_{60}\ WR_6$	$N_{120}\ P_{60}\ SR_3$	0.53	0.55	21.2	23.0	2.1	2.1	12.6	12.7	1.7	1.8
T_{15}	$N_{25}\ P_{75}\ WR_6$	$N_{150}\ P_{75}\ SR_3$	0.54	0.49	21.9	22.3	2.8	2.5	15.1	15.0	1.9	2.0
T_{16}	$N_{20}\ P_{60}\ WR_6 + FYM_{10}$	$N_{120}\ P_{60}\ SR_3$	0.55	0.49	27.2	24.2	3.6	3.2	13.8	14.3	1.6	1.6
	CA Mean		**0.52**	**0.50**	**17.8**	**17.7**	**2.4**	**2.2**	**12.3**	**12.4**	**1.8**	**1.8**
	Overall mean		**0.47**	**0.45**	**17.2**	**17.1**	**2.3**	**2.1**	**11.7**	**11.8**	**1.8**	**1.8**

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$).

stock found in CA were due to better preservation of the SOM originally present in the soil and/or less mineralization of surface retained organic residues [18].

After 4 years of study, maximum WSC contents of 25.8 and 29.7 $mg \cdot kg^{-1}$ were found in 0 - 5 cm and 19.2 and 26.4 $mg \cdot kg^{-1}$ in 5 - 15 cm soil layer in T_8 and T_{16} treatments in CT and CA, respectively (**Tables 5** and **6**). Same treatment resulted in the maximum contents of POC, PON, LFOC, LFON, PMN, MBC and MBN in CT and CA and the effect of tillage was statistically significant (**Tables 5-7**). Thus, integrated use of inorganic fertilizers, FYM and CR significantly improved these labile C and N pools of soil.

The proportions of WSC, POC, LFOC and MBC in TOC and of PON, PMN and MBN in TN were highest in CA system (**Tables 8-10**). Significantly higher contents and proportions of these labile C and N pools obtained with CA than CT were more pronounced in 0 - 5 cm soil layer. These results indicated that POC, LFOC MBC, PON, PMN, MBN and LFOC can be used as sensitive indicators of management effects. Increased MBC in TOC and MBN in TN 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 FYM + CR could be ascribed to the availability of more carbon as was evident from several other fractions of TOC such as WSC, POM, LFOC, and MBC. The rapid build-up of microbial biomass in subtropical conditions implies that MBN could serve as a potential source of mineralizable N for plant nutrition in such soils. MBC is an active component of SOM and constitutes an important soil

Table 9. Proportion of water soluble C (WSC), particulate organic C (POC) and light fraction organic C (LFOC) in total organic C (TOC), and particulate organic N (PON) and light fraction organic N (LFON) in total N (TN) in 5 - 15 cm soil layer after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment No.	Treatments		WSC (% of TOC)		POC (% of TOC)		LFOC (% of TOC)		PON (% of TN)		LFON (% of TN)	
	Soybean	Wheat	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year	2-year	4-year
	Conventional tillage											
T_1	N_0 P_0 WR_0†	N_0 P_0 SR_0‡	0.32	0.37	9.7	11.4	1.2	1.2	3.7	3.8	1.2	1.3
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	0.35	0.40	13.7	15.8	1.9	2.0	9.9	10.4	1.6	1.7
T_3	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	0.39	0.39	16.4	15.2	2.5	2.3	12.7	13.1	1.9	2.1
T_4	N_{20} P_{60} WR_0 + FYM_{10}^	N_{120} P_{60} SR_0	0.41	0.45	17.3	18.6	3.7	3.5	14.6	14.4	1.9	1.9
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	0.35	0.36	11.4	11.1	1.7	1.5	3.5	3.6	1.5	1.7
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	0.39	0.39	18.0	19.2	2.0	1.9	10.6	11.7	1.2	1.4
T_7	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	0.42	0.42	18.7	17.4	2.6	2.2	13.5	13.6	1.5	1.7
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	0.45	0.46	19.6	20.1	3.5	3.0	12.1	12.1	1.3	1.3
	CT Mean		**0.39**	**0.40**	**15.6**	**16.1**	**2.4**	**2.2**	**10.1**	**10.3**	**1.5**	**1.6**
	Conservation agriculture											
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	0.34	0.35	10.3	11.5	1.2	1.2	4.9	5.0	1.3	1.4
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	0.41	0.46	14.1	15.6	2.1	2.1	12.8	12.8	1.7	1.8
T_{11}	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	0.40	0.55	16.9	17.7	3.0	3.0	14.8	14.6	2.2	2.4
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	0.57	0.59	17.9	18.8	4.5	4.3	19.1	19.1	2.3	2.3
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	0.38	0.38	12.1	12.6	1.7	1.7	4.8	4.9	1.7	1.8
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	0.42	0.43	18.4	17.9	2.4	2.3	12.3	12.2	1.5	1.6
T_{15}	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	0.50	0.52	19.3	20.3	3.0	2.8	15.6	15.2	1.8	1.9
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	0.69	0.60	20.7	18.6	4.1	3.5	17.0	18.1	1.8	1.9
	CA Mean		**0.46**	**0.48**	**16.2**	**16.6**	**2.7**	**2.6**	**12.7**	**12.8**	**1.8**	**1.9**
	Overall mean		**0.43**	**0.44**	**15.9**	**16.4**	**2.6**	**2.4**	**11.4**	**11.5**	**1.7**	**1.8**

†N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); ‡SR = Soybean crop residue ($t \cdot ha^{-1}$); ^FYM = farmyard manure ($t \cdot ha^{-1}$).

health parameter as carbon contained within microbial biomass is a stored energy for microbial process. Thus MBC and MBN, the measure of potential microbial activity, are strongly related to soil aggregate stability. POM, dominated by undecomposed plant residues that retain recognizable cell structures including fungal hyphae, seeds, spores, and fungal skeletons, is an active fraction of SOM, which supplies nutrients to the growing plants [19]. POM-C and POM-N provide estimates of the intermediate pool of SOM between the active and passive pools [8] and provide substrate for microorganisms and influence soil aggregation [20,21]. LFOM, composed primarily of plant derived remains, and microbial and micro-faunal debris and other incompletely decomposed organic residues, is more sensitive to management practices than POM [22].

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. In an earlier study from Ludhiana, Tirol-Padre *et al*. [23] observed that PMN was highest with GM+NPK under anaerobic incubation. In another study from Ludhiana, Walia and Kler [24] 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*. [25] found that application of organic residues increased PMN, which was positively related to increase in TOC content of soil. Yan *et al*. [26] reported that response of the LFOC and LFON contents to fertilization

Table 10. Proportion of microbial biomass C (MBC) in total organic C (TOC), and potentially mineralizable N (PMN) and microbial biomass N (MBN) in total N (TN) in soil after 2 and 4 years of soybean-wheat rotation as influenced by fertilizers, FYM and crop residue management practices under conventional tillage (CT) and conservation agriculture (CA).

Treatment	Treatments		PMN (% of TN)				MBC (% of TOC)		MBN (% of TN)	
No.	Soybean	Wheat	0 - 5 cm layer		5 - 15 cm layer		0 - 5 cm layer		0 - 5 cm layer	
			2-yr	4-yr	2-yr	4-yr	2-yr	4-yr	2-yr	4-yr
	Conventional tillage									
T_1	N_0 P_0 WR_0[†]	N_0 P_0 SR_0[‡]	0.61	0.74	0.33	0.38	2.4	2.4	1.4	1.4
T_2	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	0.57	0.66	0.61	0.65	3.0	3.1	1.9	1.9
T_3	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	0.71	0.79	0.79	0.81	3.1	3.2	2.3	2.5
T_4	N_{20} P_{60} WR_0 + FYM_{10}[^]	N_{120} P_{60} SR_0	0.88	0.91	0.85	0.85	3.5	2.8	2.7	2.9
T_5	N_0 P_0 WR_6	N_0 P_0 SR_3	0.70	0.72	0.38	0.39	2.9	2.8	1.5	1.5
T_6	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	1.18	1.20	1.02	1.07	3.3	3.0	2.2	2.2
T_7	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	1.28	1.33	1.12	1.16	3.4	3.5	2.7	2.7
T_8	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	1.15	1.23	1.13	1.16	3.5	3.3	2.9	3.0
	CT Mean		**0.88**	**0.95**	**0.78**	**0.81**	**3.2**	**3.0**	**2.2**	**2.3**
	Conservation agriculture									
T_9	N_0 P_0 WR_0	N_0 P_0 SR_0	0.76	0.79	0.35	0.42	2.5	2.6	1.4	1.4
T_{10}	N_{20} P_{60} WR_0	N_{120} P_{60} SR_0	0.71	0.73	0.47	0.50	3.0	3.0	1.9	1.9
T_{11}	N_{25} P_{75} WR_0	N_{150} P_{75} SR_0	0.89	0.94	0.73	0.74	3.2	3.1	2.7	2.8
T_{12}	N_{20} P_{60} WR_0 + FYM_{10}	N_{120} P_{60} SR_0	1.06	1.13	0.98	1.01	3.4	2.9	2.7	2.7
T_{13}	N_0 P_0 WR_6	N_0 P_0 SR_3	0.80	0.89	0.60	0.66	2.8	2.9	1.4	1.5
T_{14}	N_{20} P_{60} WR_6	N_{120} P_{60} SR_3	1.38	1.46	0.97	1.11	3.2	3.2	2.4	2.5
T_{15}	N_{25} P_{75} WR_6	N_{150} P_{75} SR_3	1.50	1.59	1.33	1.33	3.3	3.4	3.0	3.3
T_{16}	N_{20} P_{60} WR_6 + FYM_{10}	N_{120} P_{60} SR_3	1.37	1.42	1.58	1.65	4.3	3.6	3.1	2.9
	CA Mean		**1.06**	**1.12**	**0.87**	**0.93**	**3.2**	**3.1**	**2.3**	**2.4**
	Overall mean		**0.97**	**1.03**	**0.83**	**0.87**	**3.2**	**3.1**	**2.3**	**2.3**

[†]N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); WR = Wheat crop residue ($t \cdot ha^{-1}$); [‡]SR = Soybean crop residue ($t \cdot ha^{-1}$); [^]FYM = farmyard manure ($t \cdot ha^{-1}$).

treatments was similar to those observed for the POC and PON contents. Manna *et al*. [27] also observed that LFOC and LFON did not show any significant changes with N, N + P and N + P + K treatments except N + P + K + FYM treatment because newly humified organic matter application through FYM sustained higher amounts of LFOC and LFON content. Dalal *et al*. [28] 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.

Thus, application of inorganic fertilizers like N and P in optimum amount along with organic manures and crop residue incorporation provides a better option in significantly improving the aggregate stability, MWD, storage of nutrients in labile pools, and C sequestration in semi-arid subtropical soils that are inherently low in organic matter and nutrients.

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 - 5 cm upper layer. Results of this 4-year field study with soybean-wheat cropping rotation indicate that the content of TOC, POM-C, POM-N, LFOM-C, LFOM-N and PMN 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, POM-C, LFOM-C, MBC in TOC and that of POM-N, LFOM-N, MBN in TN with the supply of optimum and balanced N, P and organic manures and incorporation 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). INM significantly increased water stable aggregates and had profound effects in increasing the mean weight diameter as well as the formation of macro-aggregates, which were highest in both surface (85%) and subsurface (81%) soil layers with application of 20 kg N + 60 kg P_2O_5 + 10 t FYM + 6 t WR ha^{-1} applied to soybean and 120 kg N + 60 kg P_2O_5 + 3 t SR ha^{-1} applied to wheat crops in CA (T_{16}) and respectively, 83% and 77% in CT (T_8) treatments after 2 cycles of the experiment. Similarly, the content and stock of TOC and contents of POM-C, LFOC-C, PMN, MBC and MBN were highest with the INM. Thus, application of fertilizer in optimum amounts and inclusion of manure in the fertilizer schedule could maintain the soil health under intensive agriculture. In conclusion, INM plays a significant role in building-up/restoring soil health and productivity with co-benefits of improved C sequestration in semiarid subtropical soils inherently low in organic matter and nutrients.

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