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Effect of conservation agriculture on soil organic carbon dynamics and mineral nitrogen under different fertilizer management practices in maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system

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ABSTRACT

Soil organic carbon (SOC) is the center of all physical, chemical and biological properties of soils, its maintenance and buildup in soils is necessary to sustain the intensive cereal-based cropping system of Indo Gangetic plains. Intensive tillage, residue removal and indiscriminate use of fertilizers led to a continuous deterioration of soil health in Indo Gangetic parts of the country. Under this context, a field experiment on conservation agriculture (CA) was conducted at Taroari, Karnal, comprising four combinations of tillage and residue management [*i.e.* conventional tillage (CT) with complete residue removal (CT-RR), CT with 20% residue incorporation of wheat, 50% residue incorporation of maize and incorporation of green gram residue (CT+RI+GI), permanent beds (PB) with 20% residue retention of wheat and 50% residue retention of maize (PB+RR), and PB with 20% residue retention of wheat, 50% residue retention of maize and retention of green gram residue (PB+RR+GR)] and three nutrient management options [*viz.* farmers fertilization practice (FFP), recommended fertilizer dose (RDF) and site-specific nutrient management (SSNM)]. The results showed that, there was an increase in SOC mainly the active SOC pools, permanganate oxidizable-C (1.70 g/kg), hot water extractable-C (0.32 g/kg) and soil microbial biomass C (310 mg/kg) under CA-based treatment (PB+RR+GR) compared to CT (0.58, 0.23 g/kg, 183 mg/kg, respectively). Also, the mineral N was invariably greater under residue treatments. Therefore, crops residue retention as well as balanced fertilization (RDF and SSNM) under CA helped in improving SOC; mineral N and soil aggregation stability which can lead to increased sustainability under cereal-based intensive cropping systems.

Key words: Conservation agriculture, Mineral nitrogen, Nutrient management, Soil organic carbon

Managing soil organic carbon (SOC) is a pre-requisite for restoring soil health and sustaining high productivity (Meena *et al.* 2012). Soil physical, chemical and biological properties are intrinsically linked to SOC (Thomas *et al.* 2018). The SOC levels of most of the Indian soils are extremely low, *i.e.* 0.3 to 0.4% resulting in poor soil health and low crop yields. Continuous intensive tillage, imbalanced fertilization and continuous cropping of rice-wheat system is practiced especially in the Indo-Gangetic plains (IGP) caused further degradation of SOC (Das *et al.* 2017, Dey *et al.* 2018).

Balanced fertilization as an agricultural management strategy is being used to promote soil C storage (Mandal *et al.* 2013) which could directly or indirectly increase the SOC inputs and thereby change the availability of nutrients and soil turnover. In fact, Vanlauwe *et al*. (2014) proposed nutrient management as the fourth principle of CA and argued that appropriate use of fertilizer is required to define CA to enhance both crop productivity and produce sufficient crop residues to ensure soil cover.

Soil organic C consists of multiple compounds, from simple to more complex molecules having varying lability (Mandal *et al*. 2013). Since changes induced by soil management practices are often difficult to detect by total SOC measurement, assessing rapidly changing SOC pools, *i.e.* labile pool, might be more informative to assess soil quality (Awale *et al*. 2017, Nath *et al.* 2017). Therefore, different methods used to assess mainly the labile fractions of SOC such as potassium permanganate oxidizable C ($KMnO_4$-C), microbial biomass carbon (MBC), and hot water-extractable C (HWEC) have recently received more attention due to their sensitivity to management practices.

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These labile fractions change rapidly with time and can provide an early assessment of SOC changes induced by management practices such as tillage, cropping system, and N fertilization (Chen *et al*. 2009). Bhattacharyya *et al*. (2019) advocated that short-term CA had positive effects on soil aggregation and nitrogen accumulation, which further had a role in increasing sustainability of cereal based cropping systems. This underlines the importance of such studies on CA and nutrient management under different cropping system and thereby, establishing specific fertilizer management for its successful adoption by farmers. Therefore, this study was conducted based on the hypothesis that retention of crop residues under CA would reflect early changes in various SOC pools and mineral N, with objectives to evaluate the impact of different tillage and residue management practice on SOC and N pools; and to outline the best fertilizer management option under CA.

MATERIALS AND METHODS

Study site characteristics

A field experiment on conservation agriculture (CA) was initiated in the year 2012 at a farmer's field located at village Taraori, Karnal to encourage the farmer's participation under Participatory Platform for Climate Smart Agriculture under the aegis of CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) of CIMMYT. The soil type is Typic Ustocrept. The climate of study area is semi-arid subtropical, characterized by very hot summers and cool winters. The average annual rainfall recorded is 700 mm of which 70-80% is received during July to September. The collected initial soil samples from uncultivated area (two depth, *i.e*. 0-5 and 5-15 cm soil depth) were analysed for their characteristics. The soil was non-saline (EC 0.39 dS/m), clay loam with mildly alkaline reaction (pH 8.02), and medium in Walkley-Black carbon (0.57%). The experimental soil was categorized low in $KMnO_4$-oxidizable N (157 kg/ha), medium in 0.5*M* $NaHCO_3$-extractable P (17.6 kg/ha) and also medium in 1*N* NH_4OA_C-extractable K (235 kg/ha). The initial soil was fairly permeable with a bulk density of 1.52 Mg/m^3.

Treatments and experimental design

The field experiment was established in split-plot design under maize (*Zea mays* L.) - wheat (*Triticum aestivum* L.) cropping system with 12 treatments combinations. The main plot comprised of 4 treatment combinations of tillage, residues and legume, *viz*. (i) conventional tillage with complete residue removal (CT-RR), (ii) conventional tillage with 20% residue incorporation of wheat, 50% residue incorporation of maize and incorporation of green gram residue (CT+RI+GI), (iii) permanent beds with 20% residue retention of wheat and 50% residue retention of maize (PB+RR), and (iv) permanent beds with 20% residue retention of wheat, 50% residue retention of maize and retention of greengram residue (PB+RR+GR). The actual amount of crop residue retained/incorporated is given in Table 1. The sub-plot consists of 3 treatments of different nutrient management options, *viz.* (i) Farmer's fertilizer practice (FFP), (ii) Recommended dose of fertilizers (RDF), and (iii) Site-specific nutrient management ((SSNM). Farmer's fertilizer practice (FFP) was based on a local survey conducted in that area for fertilizer application rates practiced by farmers in maize and wheat crops. Recommended dose of fertilizers (RDF) were fertilizers doses for maize and wheat as advocated by CCS Haryana Agricultural University, Hisar. The SSNM options were calculated based on a computer-based decision support system 'Nutrient Expert'. The amount of fertilizers applied to the crops as per treatments is given in Table 2.

Soil sampling and analysis

After completion of three cropping cycles, soil samples were collected from two depths, *i.e.* 0-5 cm and 5-15 cm of treated plots using core sampler at physiological maturity of wheat. Carbon fractions, *i.e.* (i) Very labile SOC (C_{VL}): SOC oxidizable with 12 *N* H_2SO_4; (ii) Labile SOC (C_L): Difference between SOC oxidizable with 18 *N* H_2SO_4 and 12 *N* H_2SO_4; (iii) Less labile SOC (C_{LL}): Difference between SOC oxidizable with 24 *N* H_2SO_4 and 18 *N* H_2SO_4; and (iv) Non-labile SOC (C_{NL}): Difference between TOC and 24 *N* H_2SO_4 were determined using Modified Walkley-Black method (Chan *et al*. 2001).

The permanganate oxidizable C ($KMnO_4$-C) was determined by oxidizing the samples with 33 *mM* $KMnO_4$ (Tirol-Padre and Ladha 2004), hot water extractable carbon (HWE-C) by Ghani *et al*. (2003) and soil microbial biomass carbon (MBC) by fumigation-extraction method described (Jenkinson and Ladd 1981). Microbial extraction efficiency (K_{EC} of 0.25) was used for MBC determination.

Table 1 Treatment-wise amount of crop residues (t/ha) retained/incorporated in the soil

Treatment*	FFP	RDF	SSNM
CT-RR	0	0	0
CT+RI+GI	4.14	4.31	4.63
PB+RR	3.39	3.56	3.74
PB+RR+GR	4.52	4.62	4.85

*CT: Conventional tillage; PB: Permanent beds; -RR: Residue retention; +RR: Residue removal; GI: Greengram residue incorporation; GR: Greengram residue retention

Table 2 Nutrient applied (kg/ha) in maize and wheat under different nutrient management practices

Treatment@	Maize			Wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
FFP	172.5	22.5	0	230	22.5	0
RDF	187.8	24.5	62.5	177-184	23.5	60
SSNM (NE)	172.5	18.0	60-75	150-164	15.3	81

@ FFP: Farmer's fertilizer practice; RDF: Recommended dose of fertilizer; SSNM: Site-specific nutrient management

For mineral-N (NH_4 + NO_3) determination, moist soil sample was extracted with 2*M* KCl solution (soil: solution:: 1:5) (Rowell 1994). Aggregate stability, *viz.* mean weight diameter (MWD) and geometric mean diameter (GMD) were calculated as the indices of aggregate stability (van Bavel 1950; Kemper and Roseneau 1986) using following formula:

$$MWD = \Sigma xiwi$$

$$\text{and, } GMD = \exp [\Sigma (wi \log xi)/(\Sigma wi)$$

where, wi is the weight of each aggregate class to the total soil weight; and xi the mean diameter (mm) of the class. The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for split-plot design using SAS 9.1 software. The least significant difference (LSD) test was used to interpret the effect of treatments at 5% level of significance (p=0.05).

RESULTS AND DISCUSSION

Soil organic C pools

The active SOC (C_{VL} and C_L) and recalcitrant pool (C_{LL} and C_{NL}), both declined in lower soil depth (5-15 cm) compared to surface 0-5 cm. These fractions followed the order as: $C_{VL}>C_{NL}>C_{LL}>C_L$. Tillage and residue management significantly influenced different SOC fractions in the surface soil depth (0-5cm), while in 5-15 cm depth no significant variation within treatments was observed, except C_L fraction. The highest C_{VL} was recorded under PB+RR+GR (2.84 g/kg) it was 25.7% higher than that under CT-RR and followed a trend as: PB+RR+GR>CT+RI+GI>PB+RR>CT-RR. Among the nutrient management options, the C_{VL} content was highest under RDF (2.81 g/kg). Unlike C_{VL}, C_L was not significantly affected by tillage, residue management or nutrient management options in surface depth. However, in 5-15 cm soil depth, the individual impact of tillage practices gave significantly higher C_L (0.66 g/kg) under PB+RR+GR. The PB+RR showed significantly higher C_{LL} (1.92 g/kg) compared with other tillage practices in surface soil depth. The results indicated that both PB as well as CT treatments was at par with each other. The effect of nutrient management options was significant with relatively higher C_{LL} under SSNM (1.87 g/kg). The C_{NL} content under different tillage practices varied from 2.34 to 2.53 g/kg and 1.15 to 2.97 g/kg in 0-5 and 5-15 cm depths, respectively. The effect of nutrient management options was significant only for surface soil with comparatively higher C_{NL} (2.52 g/kg) content under SSNM, showing its superiority over FFP.

On an average, the contribution of active SOC was higher in the surface soil, whereas there was a shift towards recalcitrant pools in the lower depth. Labile organic matter in soil mainly originates from the decomposition of plant and faunal biomass, root exudates, and deceased microbial biomass (Bolan *et al*. 2011). Addition of organic matter and reduced tillage in the surface soil layer may likely to increase labile organic carbon in the soils (Cooper *et al*. 2016). Other researcher reported greater lability of C under CA compared with CT (Bhattacharya *et al*. 2012; Dey *et al*. 2018). In addition, these practices have the potential to enhance C and N cycling, as well as soil aggregation, which is one of the primary mechanisms through which organic carbon is sequestered in soil (Panettieri *et al*. 2015; Mandal *et al.* 2019).

Potassium permanganate oxidizable, hot-water extractable and soil microbial biomass carbon

The influence of tillage and residue management practices on permanganate oxidizable C ($KMnO_4$-C) showed significant difference in both soil depths (Table 4). It was highest (1.70 and 0.77 g/kg) under PB+RR+GR and lowest (0.58 and 0.66 g/kg) under CT-RR in 0-5 and 5-15 cm depths, respectively. A similar trend for $KMnO_4$-C content was observed in both soil depths which was influenced by different tillage practices and followed the order

Table 3 Effect of tillage, residue and nutrient management practices on different SOC fractions (g/kg)

Treatment	Very labile C		Labile C		Less labile C		Non-labile C	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Tillage and residue management (T)								
CT-RR	2.26^{b}	2.41	1.28	0.43^{b}	1.62^{b}	1.47	1.15^{c}	2.34
CT+RI+GI	2.82^{a}	2.73	1.50	0.61^{a}	1.58^{b}	1.54	2.35^{b}	2.43
PB+RR	2.65^{a}	2.65	1.62	0.62^{a}	1.92^{a}	1.58	2.93^{a}	2.34
PB+RR+GR	2.84^{a}	2.43	1.74	0.66^{a}	1.87^{a}	1.69	2.97^{a}	2.53
LSD (P=0.05)	0.33	NS	NS	0.10	0.19	NS	0.54	NS
Nutrient management practices (N)								
FFP	2.61^{b}	2.49	1.52	0.57	1.74^{b}	1.57	2.04^{b}	2.31
RDF	2.81^{a}	2.67	1.53	0.59	1.63^{b}	1.56	2.49^{a}	2.39
SSNM	2.52^{b}	2.50	1.55	0.59	1.87^{a}	1.58	2.52^{a}	2.51
LSD (P=0.05)	0.13	NS	NS	NS	0.11	NS	0.34	NS
T × N								
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 4 Effect of tillage, residue and nutrient management practices on different forms of soil organic carbon

Treatment	$KMnO_4$-C (g/kg)		HWE-C (g/kg)		MBC (mg/kg)	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Tillage and residue management (T)						
CT-RR	0.58^{c}	0.66^{b}	0.23^{b}	0.18^{a}	183^{c}	136^{b}
CT+RI+GI	1.29^{b}	0.68^{b}	0.26^{b}	0.18^{a}	235^{b}	155^{b}
PB+RR	1.61^{a}	0.75^{a}	0.30^{a}	0.25^{a}	258^{b}	172^{ab}
PB+RR+GR	1.70^{a}	0.77^{a}	0.32^{a}	0.26^{a}	310^{a}	211^{a}
LSD (P=0.05)	0.12	0.05	0.03	0.03	36.9	39.3
Nutrient management practices (N)						
FFP	1.07^{b}	0.66^{b}	0.27	0.21	234^{b}	167
RDF	1.40^{a}	0.80^{a}	0.28	0.23	229^{b}	166
SSNM	1.41^{a}	0.69^{b}	0.28	0.23	276^{a}	172
LSD (P=0.05)	0.13	0.07	NS	NS	31.2	NS
T × N						
LSD (p=0.05)	0.24	NS	NS	NS	NS	NS

PB+RR+GR> PB+RR> CT+RI+GI> CT-RR. In surface soil, SSNM and RDF were statistically at par with each other whereas in second 5-15 cm depth, RDF performed better as compared to SSNM. The interaction effect of tillage and nutrient management option on $KMnO_4$-C was found significant only in surface (0-5 cm) soil. The PB+RR+GR in combination with RDF was recorded highest $KMnO_4$-C (1.86 g/kg) content among different treatment combinations (Fig 1). Also, the impact of different tillage practices on HWE-C was found similar to that of $KMnO_4$-C for both 0-5 and 5-15 cm depths (Table 4). Nutrient management options did not showed significant effect on HWE-C in soil depths. Labile pools of SOC ($KMnO_4$-C and HWE-C) were found sensitive to the alteration in tillage, residue retention as well as nutrient management options. Although the quantities of HWE-C and $KMnO_4$-C are similar and both fractions probably comprised of C derived from dissolved organic matter and microbial biomass, they are most likely derived from different organic matter fractions. HWE-C largely (45-60%) comprised carbohydrates and amides derived from soil microorganisms, enzymes, root exudates and lysates, while $KMnO_4$-C contains also compounds like lignin and complex polysaccharides (Ghani *et al.* 2003, Mandal *et al.* 2013). None the less, determination of such labile SOC fractions may help to elucidate changes in the SOC pool at early stages of changes under various land use or management system.

Soil MBC, a labile form of organic C, showed a significantly measurable response as a result of no-tillage, residue retention as well as nutrient management options in the present study. In the surface soil, the MBC content was 69.4% higher under PB+RR+GR (310 mg/kg) as compared to CT-RR (183 mg/kg). The individual impact of different nutrient options was found significant in 0-5 cm soil depth, while it showed non-significant results for soil depth of 5-15 cm (Table 4). Among all nutrient options, SSNM registered highest MBC (276 mg/kg), followed by FFP (234 mg/kg) and RDF (229 mg/kg) in surface soil. The interaction of tillage and nutrient options showed no effects in both 0-5 and 5-15 cm soil depths. A favorable moisture content and soil temperature of top soil layer during crop growing season encourages faster residue decomposition with microbial growth and more microbial biomass production (Miltner *et al.* 2012). Also, the decomposition of residues provides enough energy and C source to soil microorganisms, which might cause an increased microbial activity in soil under PB+ residue plots. Similar findings were reported by other researchers (Nath *et al.* 2017). Also, in the present study the MBC declined sharply in consecutive depths. Such variability in MBC across soil depths is possible due to lesser source of SOM inputs and consequently lowers microbial activity (Mandal *et al.* 2013).

Mineral N in soil

A significant increase in mineral-N contents (NH_4^+ and NO_3^-) was observed under PB as compared to CT in both soil depths; the values were invariably greater under residue recycling treatments. The NH_4-N under PB+RR+GR was 41.9% and 52.7% higher than CT-RR in 0-5 and 5-15 cm depths, respectively (Table 5). Under the fertilizer management treatments, SSNM and RDF contained comparable NH_4-N and NO_3-N in both depths. The PB+RR+GR in combination with RDF showed significantly highest NH_4-N (13.2 mg/kg) as well as NO_3-N (26.1 mg/kg) compared to other treatment combination, hence showed more favorable results (Fig 2). As the SOC and N are intrinsically linked with each other through various nutrient cycling processes, the increment in mineral-N may be attributed to higher SOC in soil. Similar results were reported under pigeonpea-wheat system with higher mineral-N contents under PB in sandy loam soils of the IGP (Singh *et al.* 2010). Another possible reason for higher mineral N in PB treatments may be associated with the preparation of raised beds owing to

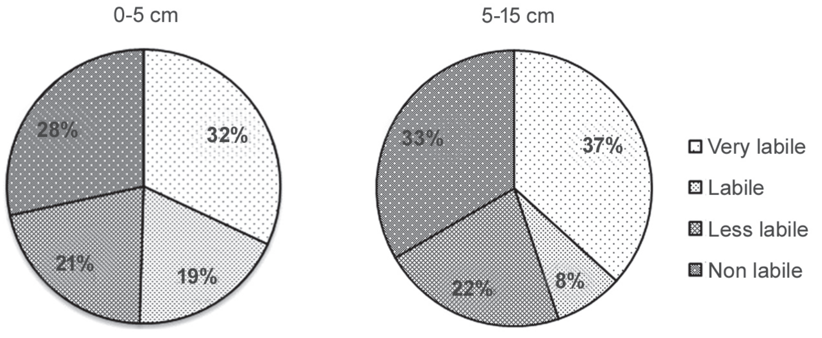

Fig 1 Percent distribution of different SOC fractions in 0-5 and 5-15 cm soil depth.

Table 5 Depth-wise distribution of mineral-N (mg/kg soil) as affected by different tillage, residue and nutrient management practices in soil

Treatment	NH_4-N		NO_3-N	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Tillage and residue management (T)				
CT-RR	7.40^{c}	9.09^{c}	16.5^{c}	13.5^{c}
CT+RI+GI	9.63^{b}	11.0^{b}	22.5^{ab}	20.2^{b}
PB+RR	9.92^{ab}	11.2^{b}	21.3^{b}	20.6^{b}
PB+RR+GR	11.3^{a}	12.9^{a}	24.8^{a}	25.7^{a}
LSD (P=0.05)	1.39	1.10	2.45	1.27
Nutrient management practices (N)				
FFP	8.54^{b}	9.51^{b}	19.9	19.5^{b}
RDF	10.2^{a}	11.9^{a}	20.4	21.5^{a}
SSNM	9.97^{a}	11.8^{a}	19.6	22.8^{a}
LSD (P=0.05)	1.04	1.06	NS	1.78
T × N				
LSD (P=0.05)	2.19	NS	3.79	NS

greater accumulation of fertile top soil compared with the conventional (flat beds) crop establishment.

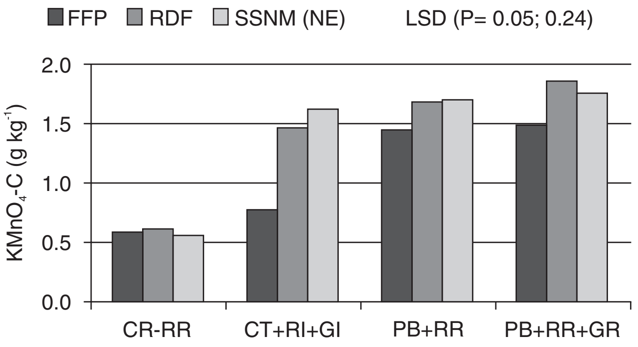

Fig 2 Interaction effect of tillage, residue and nutrient management options on permanganate oxidizable C ($KMnO_4$-C) in soil depth of 0-5 cm.

Soil aggregation indices

The impact of different tillage and residue management on soil aggregation stability can be distinguished through aggregation indices, *viz*. mean weight diameter (MWD) and geometric mean diameter (GMD). The MWD was 12.9, 22.8 and 27.3% higher in PB+RR+GR compared with PB+RR, CT+RI+GI and CT-RR, respectively in 0-5 cm soil depth (Fig 3a). Similarly, for 5-15 cm depth MWD was highest under PB + RR + GR (0.70 mm) and lowest in CT-RR (0.55 mm). The SSNM showed maximum MWD (0.63 mm) in 0-5 cm soil, followed by RDF (0.61 mm) and FFP (0.59 mm). The GMD was highest (0.58 mm) in surface soil under PB+RR+GR which was 5.45% greater than CT-RR. On the other hand, result was not significant in other 5-15 cm soil depth. The individual effect of nutrient management options as well as their interaction with tillage and residue

Table 6 Simple correlation (r) between yield, mineral N, SOC pools and microbial biomass C in 0-5 cm soil depth

	Yield	C_{VL}	C_L	C_{LL}	C_{NL}	$KMnO_4$-C	HWEC
NH_4-N	0.54**						
NO_3-N	0.51**						
C_{VL}	0.12^{NS}						
C_L	0.45**	0.50**					
C_{LL}	0.47**	0.44**	0.98**				
C_{NL}	0.49**	0.12^{NS}	0.52**	0.46**			
$KMnO_4$-C	0.61**	0.41*	0.77**	0.72**	0.80**		
HWEC	0.36*	0.12^{NS}	0.51**	0.48**	0.57**	0.62**	
MBC	0.43**	0.13^{NS}	0.67**	0.61**	0.55**	0.66**	0.54**

Where * and ** indicate the value of 'r' is significant at 5% and 1% probability levels, respectively.

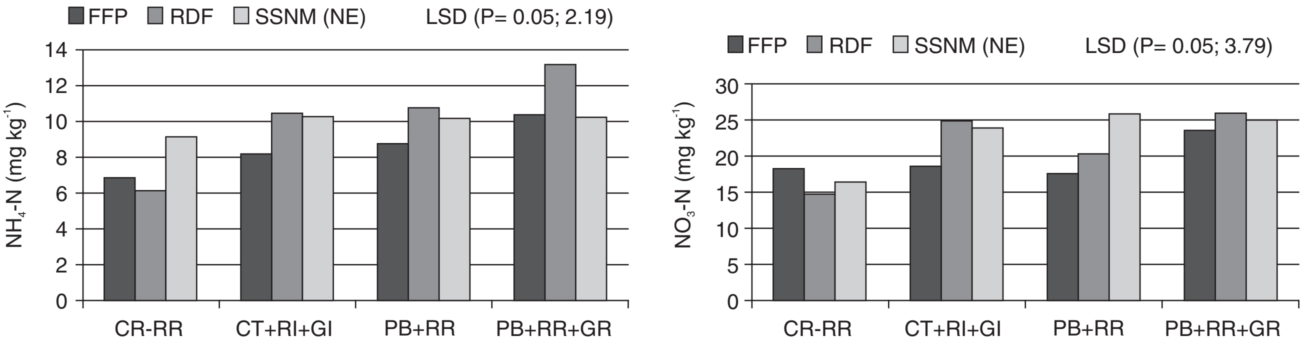

Fig 3 Interaction effect of tillage, residue and nutrient management options on NH_4-N and NO3-N (mg/kg) in 0-5 cm soil depth.

Table 7 Simple correlation (r) between yield, mineral N, SOC pools and microbial biomass C in 5-15 cm soil depth

	Yield	C_{VL}	C_L	C_{LL}	C_{NL}	$KMnO_4$-C	HWEC
NH_4-N	0.51^{**}						
NO_3-N	0.43^{**}						
C_{VL}	0.42^{*}						
C_L	0.43^{**}	0.50^{**}					
C_{LL}	0.43^{**}	0.29^{NS}	0.46^{**}				
C_{NL}	0.52^{**}	-0.03^{NS}	0.32^{NS}	0.11^{NS}			
$KMnO_4$-C	0.20^{NS}	0.34^{*}	0.11^{NS}	0.45^{**}	0.07^{NS}		
HWEC	0.40^{*}	0.26^{NS}	0.25^{NS}	0.69^{**}	0.18^{NS}	0.60^{**}	
MBC	0.40^{*}	0.31^{NS}	0.25^{NS}	0.57^{**}	0.18^{NS}	0.32^{NS}	0.35^{*}

Where * and ** indicate the value of 'r' is significant at 5% and 1% probability levels, respectively.

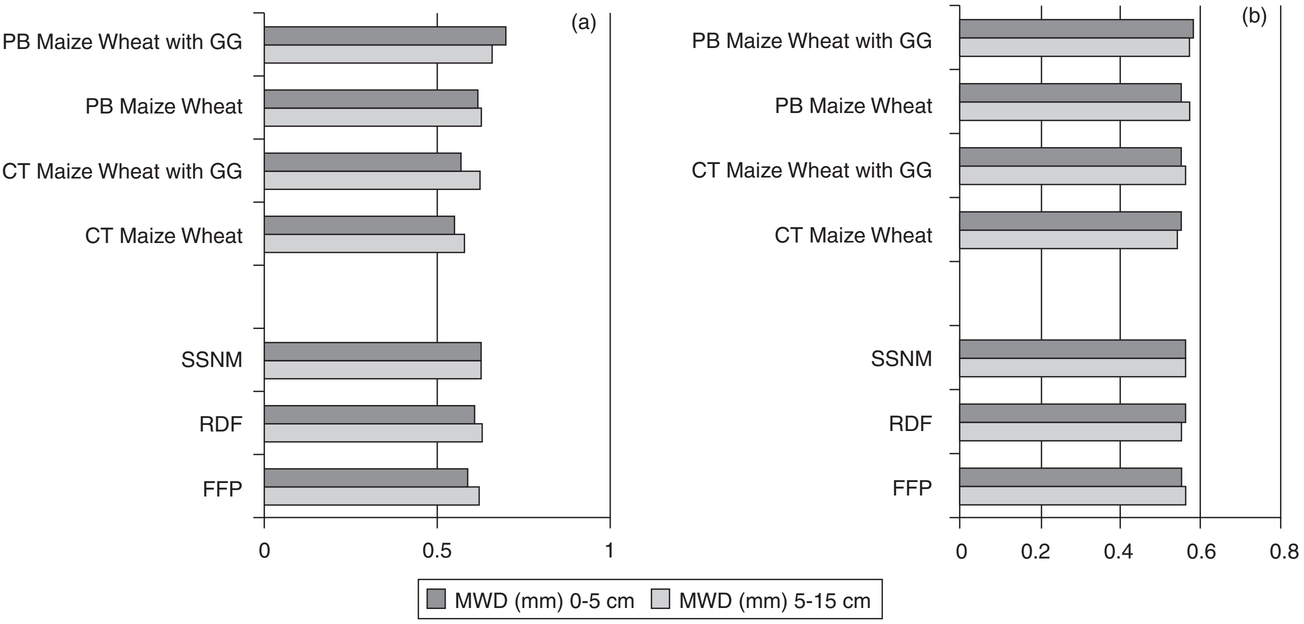

Fig 4 Effect of tillage and nutrient management options on soil aggregation indices viz. (a) mean weight diameter (MWD) and (b) geometric mean diameter (GMD).

management showed no significant effects on GMD in either soil depths (Fig 3b). Mandal *et al.* (2019) reported that, long-term application of organic residues improved SOC and soil aggregation such as mean weight diameter (MWD) and geometric mean diameter (GMD). Zhang *et al.* (2013) reported that, the average MWD across all depths of NT and CT were 47% and 20% higher than CT without residue under maize-wheat cropping system.

Relationship of wheat grain yield with mineral N and various SOC pools

Among various pools of SOC measured, $KMnO_4$-C showed apparently highest correlation with yield than others, in surface soil (Table 6). Different parameters such as $KMnO_4$-C ($r = 0.89; p=0.01$), HWEC ($r = 0.56; p=0.05$), C_L($r = 0.91; p=0.01$), MBC ($r = 0.64; p=0.01$) as well as mineral-N indicated positive correlation with wheat grain yield and similar relationship between different parameter was observed for 5-15 cm soil depth (Table 7).

Conclusion

From the present study, it may be concluded that permanent bed with crop residues retention as well as balanced fertilization (RDF and SSNM) under CA improved SOC, mineral N and soil aggregation stability which can lead to increased sustainability under cereal-based intensive cropping systems.

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