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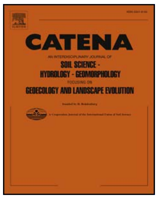

Effects of irrigation, crop residue mulch and nitrogen management in maize (*Zea mays* L.) on soil carbon pools in a sandy loam soil of Indo-gangetic plain region

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ABSTRACT

Different land use management practices e.g. native forest vegetation, pastures and the agricultural management practices (e.g. tillage, cropping system, crop residue mulching and fertilizer and manure application) influence the soil organic carbon pools, which has short term and long term implications on soil carbon dynamics. Field experiments were conducted in a sandy loam soil of the Indian Agricultural Research Institute, New Delhi research farm during the *kharif* season (July to October) of 2012 and 2013 with the objective to study the short term (2 years) impact of irrigation, crop residue mulch and nitrogen management in maize on soil organic carbon pools and to identify the best management practice in terms of Carbon Management Index (CMI). Maize (cv. HQPM 1) was grown in a split-split plot design with two levels of irrigation (irrigated and rainfed) as main factor, two levels of mulch (No mulch and wheat residue at a rate of 10 Mg/ha as mulch) as sub factor and three levels of nitrogen (0, 75 and 150 kg N/ha) as subsub factor. The results showed that total organic carbon (TOC) increased by 40.5% in irrigation treatment compared to the rainfed treatment for the 0–5 cm soil depth after 2nd year of cropping. Application of crop residue mulch significantly increased the TOC concentration by 14.9% at 0–5 cm soil depth compared to the no mulch treatment. Crop residue mulch also significantly increased carbon stratification ratio (SR) by 9.2% compared to no mulch treatment for the same depth. Nitrogen application at 150 kg/ha significantly increased TOC concentration at 0–5 cm soil depth by 22.2% and 7.8% over control and 75 kg/ha, respectively. Water stable aggregate associated carbon concentration in large macro-aggregates and micro-aggregates increased significantly by 16.7% and 11.8%, respectively due to crop residue mulching. Application of crop residue mulch resulted in significant increase in labile and non-labile pools of carbon at 0–5 cm soil depth compared to the no mulch treatment, and among the labile pools of carbon, the maximum increase was recorded in very labile (VL) pools. The Carbon Lability Index (CLI) decreased whereas Carbon Pool Index (CPI) and Carbon Management Index (CMI) increased due to irrigation and crop residue mulch application. Application of 75 kg N/ha resulted in significantly higher CMI than that of 150 kg N/ha at 0–5 and 5–15 cm soil depth. So maize may be grown under irrigated condition with wheat residue mulch at a rate of 10 Mg/ha and 75 kg N/ha to achieve higher total organic carbon pool and labile pools of carbon, better Carbon Management Index.

1. Introduction

Pedologic pool, representing the third largest Global carbon pool is estimated at 2500 Pg up to 1 m depth. It consists of two components: the soil organic carbon (SOC) pool estimated at 1550 Pg and the soil inorganic pool (SIC) estimated at 950 Pg (Batjes, 1996). Most of the cultivated soils have lost half to two thirds of the original SOC pool with a cumulative loss of 30–40 Mg C/ha. Depletion of SOC pool has contributed to 78 ± 12 Pg C to the atmosphere. The depletion of soil C is accentuated by soil degradation and mismanagement of soil. Adoption of recommended management practices on agricultural soils can enhance carbon sequestration and reduce the rate of enrichment of atmospheric CO_2. It will ultimately have positive impacts on food security, water quality and environment. Besides mitigation of climate

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change, carbon sequestration helps in building soil fertility, improving soil health, improving agronomic productivity and nurturing soil biodiversity. Soil aggregates enhance C sequestration by physically protecting it from the microbial activity (Gregorich et al., 1997). Different land use management practices e.g. native forest vegetation, pastures and the agricultural management practices (e.g. tillage, cropping system, crop residue mulching and fertilizer and manure application) influence the relative distribution of aggregate mass, their stability and the distribution of C and N in these aggregates (Elliott, 1986; Aoyama et al., 1999; Six et al., 1998; Six et al., 1999; Six et al., 2000; Denef et al., 2004; Abid and Lal, 2008). The position of SOC in the aggregates and its chemical nature affects the rate of its decomposition (Elliott et al., 1996; Christensen, 1996; Besnard et al., 1996) and hence GHG emissions, which differ in the micro and macro aggregates. Organic matter of recent plant origin is believed to be preferentially recovered in sand size fraction (particulate organic matter), whereas more microbially processed material can be found in the silt and clay-size fraction (mineral associated organic matter) (Chesire and Mundie, 1981). Cambardella and Elliott (1992, 1993) and Camberdella and Elliott (1995) suggested that the labile organic carbon pool within macro-aggregates of grassland soils is either particulate organic matter or relatively low density, mineral associated-organic matter, probably of microbial origin. On the other hand, the micro-aggregates are more resistant to microbial decomposition than the macro-aggregates (Elliott, 1986). Ghimire et al. (2008) reported that SOC sequestration could be increased with minimum tillage and surface application of crop residue and SOC sequestration was highest in top 0–5 cm soil depth irrespective of the tillage and crop residue management practices. Suman et al. (2009) reported that changes in residue management and incorporation of organic manures may help in carbon sequestration by restoring soil organic carbon (SOC). The impact of different management strategies on SOC pools rather than total organic carbon pools gives an insight on their potential in influencing soil quality. The SOC stock is comprised of labile or actively cycling pool and stable, resistant/recalcitrant pools with varying residence time. Labile C pool is the fraction of SOC with rapid turnover rates. It is important as an energy source for the soil food web and thus influences nutrient cycling for maintaining soil quality and its productivity (Chan et al., 2001). Highly recalcitrant or passive pool is only very slowly altered by microbial activities (Sherrod et al., 2005). Some C pools like microbial biomass C, mineralizable C, particulate organic C and oxidizable organic C are used as indicators of soil quality. They are the first to be depleted as a result of cultivation or other perturbations (Sherrod et al., 2005). Significant changes in all these pools of SOC due to different land management practices with different cropping systems, however, can only be observed after long periods of cultivation (Conant et al., 2003). Changes in labile pools of SOC due to different soil management practices have been studied mainly in cooler and temperate regions of the world (Wu et al., 2003; Sherrod et al., 2005), but such studies in tropical and subtropical regions of the world are very few (Majumder et al., 2007; Rudrappa et al., 2006). Soil C oxidized by neutral $KMnO_4$, or permanganate-oxidizable C (PMOC), has been used as an index of labile C by several workers. Blair et al. (1995) modified the procedure of Loginow et al. (1987) using a single concentration of $KMnO_4$ (333 mM) as the oxidizing agent. Lenka et al. (2014) reported that conversion from conventional to conservation tillage with the application of farmyard manure (FYM) at 2 Mg/ha every year showed highest impact on soil C sequestration and Carbon Management Index under soybean-wheat system in a Vertisol. Maharana et al. (2012) reported that labile organic carbon and microbial biomass carbon were significantly correlated with grain yield in a pearl millet – wheat cropping system in a sandy loam soil. The Carbon Management Index increased significantly wherever FYM was used alone or in conjunction with inorganic fertilizers. Das et al. (2016) also showed that labile fractions of soil organic carbon showed more consistent and positive relationship with crop yields than the stabilized fractions of soil organic carbon in a rice-wheat cropping system. Thus it was hypothesized that application of crop residue as mulch may influence the soil organic carbon pools and also different management interventions like application of irrigation and nitrogen promote root growth, which contributed towards soil carbon pools. To test this hypothesis, the present study was undertaken with the following objectives (i) to study the short term impact of irrigation, crop residue mulch and nitrogen management in maize on soil organic carbon pools and water stable aggregate associated carbon and (ii) to find out the best management practice in terms of Carbon Management Index (CMI).

2. Materials and methods

2.1. Soil and weather condition

A field experiment was conducted on maize (*Zea mays* L.), during *kharif* season (rainy season) of 2012 and 2013 on a Typic Haplustept soil of Indian Agricultural Research Institute (IARI), New Delhi research farm. The experimental site (28.63°N, 77.15°E, and 250 m above mean sea level) is located in the Upper-Indo Gangetic Plain zone representing an irrigated, mechanized and input-intensive cropping area. The climate of New Delhi is sub-tropical semi-arid, with dry hot summers (March to June) and brief severe winters (December to February). The average monthly minimum and maximum temperature in January (the coldest month) ranged between 5.9 °C and 19.9 °C, respectively. The corresponding temperature in May (the hottest month) ranged between 24.4 and 38.6 °C, respectively. The average annual rainfall is 651 mm, and nearly three-fourth of this is received through south-west monsoon during July to September.

The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (> 2 m), flat and well drained. Detailed soil characteristics were determined at the initiation of the experiment and the data are presented in Table 1. It was observed that the soil was mildly alkaline (pH = 7.1), non-saline (EC = 0.36 dS/m), low in organic C (SOC = 4.2 g/kg, Walkley and Black C) and total N (0.032%) and medium in available P (7.1 kg/ha) and K (281.0 kg/ha) content. Soil bulk density (BD) was determined by core method using a core sampler (Blake and Hartge, 1986) at flowering stage. Saturated hydraulic conductivity of undisturbed soil cores was determined using constant head method by permeameter (Klute, 1986). Particle size analysis was carried out by Hydrometer method (Day, 1965). The

Table 1
Soil properties of the experimental site.

Depth (cm)	Bulk density ($Mg\,m^{-3}$)	pH	EC (ds/m)	Saturated hydraulic conductivity (cm/h)	SOC (g/kg)	Particle size distribution			Soil texture	Soil moisture constants (cm^3/cm^3)	
						Sand (%)	Silt (%)	Clay (%)		0.033 MPa	1.5 MPa
0–15	1.58	7.1	0.46	1.01	4.2	64.00	16.80	19.20	SL	0.254	0.101
15–30	1.61	7.2	0.24	0.82	2.2	64.40	10.72	24.88	SCL	0.269	0.112
30–60	1.64	7.5	0.25	0.71	1.6	63.84	10.00	26.16	SCL	0.283	0.129
60–90	1.71	7.5	0.25	0.49	1.2	59.84	10.00	30.16	SCL	0.277	0.110
90–120	1.72	7.7	0.30	0.39	1.1	53.68	13.44	32.88	SCL	0.247	0.097

surface soil (0–15 cm) has bulk density 1.58 Mg/m^3; hydraulic conductivity (saturated) 1.01 cm/h, saturated water content (0.41 m^3/m^3), sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. Bulk density of the soil varied from 1.58 Mg m^{-3} in the 0–15 cm depth to 1.72 Mg m^{-3} in the 90–120 cm depth.

2.2. Treatment details

The treatments comprising of two levels of irrigation as main plot factor (Rainfed and 4 irrigations at critical growth stages i.e. seedling, knee height, flowering and grain filling stages in the absence of rainfall in these stages), two levels of mulching as sub plot factor (with and without wheat residue mulching at a rate of 10 Mg/ha) and three levels of nitrogen as sub sub plot factor (0, 75 and 150 kg N/ha) laid out in a split-split plot design with three replications. The sub sub plot-size was 4.5 m × 5 m. There were buffer zones between the treatments. Maize (*Zea mays* L. cv. HQPM-1) was sown every year (2012 and 2013) during third week of July at 45 cm × 15 cm spacing and harvested manually during last week of October. Nitrogen was supplied as urea in four splits i.e., 20% at sowing, 20% at four leaf stage, 30% at eight leaf stage and rest 30% at flowering stage. All the plots received a uniform dose of 75 kg P_2O_5/ha as Single super phosphate and 75 kg K_2O/ha as muriate of potash applied at sowing. The field was kept weed free by employing manual weeding 3–4 times during crop growth stages. Four irrigations were supposed to be applied in the irrigated treatment at critical growth stages of maize viz., seedling, knee height, flowering and grain filling stages as per the treatment envisaged in the absence of rainfall during these stages. However, rainfall occurred at two critical growth stages i.e. Knee height and Flowering stage in both the years. So only 2 irrigations instead of 4 irrigations were applied for both the years of study. Before the start of the experiment the experimental site was under maize-wheat system.

2.3. Estimation of soil organic carbon fractions

2.3.1. Soil sampling and processing scheme

Soil samples were collected from 0 to 5 and 5–15 cm soil depths using bucket type core samplers (Eikjelkamp, The Netherlands). Per replication three samples were collected. Then these samples were broken with gentle strokes and dried in shade. A portion these samples were passed through 8 mm size sieve and retained in 4 mm size sieve. This 4–8 mm size fraction was used for aggregate analysis. Another portion of the sample was processed and passed through 2 mm size sieve and stored for other analysis. A portion of the < 2 mm sample was further processed to pass through 0.2 mm size sieve. This < 0.2 mm size samples were used for TOC analysis.

2.3.2. Total organic carbon (TOC)

Soil sample was passed through 0.2 mm sieve for determination of TOC. Organic C was measured by adding one to two drops of 15% (v/v) HCl to 60 mg soil sample in a silver capsule to convert carbonates to CO_2. The sample in the silver capsule was then dried in an oven at 50 °C for about 2 h. The sample was sealed in the silver capsule and analysed for total organic carbon using the Vario EL, ElementarAnalysen systeme GmbH, Germany.

Total organic carbon stock or pool at a given depth is determined as (Lal et al., 1998):

$$\mathrm{Cpool}\left(\frac{\mathrm{Mg}}{\mathrm{ha}}\right) = \mathrm{A} \times \mathrm{D} \times \rho_\mathrm{b} \times \mathrm{C} \times 10^{-3} \tag{1}$$

where, A = area (ha, 10^4 m^2); D = depth of soil (m), ρ_b = bulk density (Mg m^{-3}); C = Concentration of C (g/kg bulk soil).

Soil bulk density (BD) was determined by core method using a core sampler (Blake and Hartge, 1986) with the core dimension of 5 cm internal diameter and 5 cm height.

2.3.3. Microbial biomass carbon

Microbial biomass carbon (MBC) was determined by fumigation-extraction method as outlined by Jenkinson and Ladd (1981). For this purpose, 5 g of moist soil sample was fumigated with chloroform ($CHCl_3$) in a vacuum desiccator and extracted with 0.5 M K_2SO_4 solution (soil:solution::1:5). A duplicate soil sample without fumigation (non-fumigated) was also extracted with 0.5 M K_2SO_4 solution in a similar fashion. The extracts of non-fumigated and fumigated soil samples were subjected to wet-oxidation separately with potassium persulphate and dilute H_2SO_4 by heating the contents on a digestion block for 2 h. Evolved CO_2 was trapped in 4 mL of 0.1 M NaOH solution. The amount of CO_2 absorbed was determined by back titration with 0.01 N HCl. Contents of MBC were computed by subtracting the amount of CO_2 evolved in case of fumigated soil from that of non-fumigated one. A subsample of the moist soil was drawn for determination of moisture content so as to express the data on dry weight basis. The amount of MBC in soil was calculated as follows:

$$\text{Microbial biomass carbon} = (\mathrm{OC_F} - \mathrm{OC_{UF}})/\mathrm{K_{EC}} \tag{2}$$

where, OC_F and OC_{UF} are organic carbon extracted from fumigated and unfumigated soil, respectively (expressed on oven dry basis), and K_{EC} is the efficiency of extraction. A K_{EC} value of 0.45 is considered as a general value for microbial extraction efficiency used for the calculation.

2.3.4. Permanganate-oxidizable organic carbon

The permanganate-oxidizable organic carbon (PmOC) was determined following the procedure of Tirol-Padre and Ladha (2004). In this method, 2.0 g of soil was taken in centrifuge tube and oxidized with 25 mL of 33 mM $KMnO_4$ by shaking on a mechanical shaker for 1 h. The contents were centrifuged for 5 min at 4000 rpm, and 2.0 mL of supernatant was diluted to 50 mL with double distilled water. The absorbance of the samples and blanks was then measured at 565 nm wavelength on a Double beam UV-VIS spectrophotometer (Electronics Corporation of India Ltd.). The concentration of $KMnO_4$ from the samples and blank was determined using the standard calibration curve. The amount of PmOC in the sample was computed as follows:

$$\mathrm{PmOC}\left(\frac{\mathrm{mg}}{\mathrm{g}}\right) = \frac{\left[(\text{mM Blank} - \text{mM Sample}) \times \left(\frac{50}{2}\right) \times 25 \times 9\right]}{[1000\ (\text{mL L} - 1) \times \text{Weight of sample (g)}]} \tag{3}$$

2.3.5. Oxidizable organic carbon and its fractions

The content of oxidizable organic carbon (OOC) and its different fractions in the soil were determined following the Walkley and Black (1934) method as modified by Chan et al. (2001) using 5, 10 and 20 mL of concentrated (18.0 mol L^{-1}) H_2SO_4 and $K_2Cr_2O_7$ solution. This resulted in three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 that corresponded to 6.0, 9.0 and 12.0 mol L^{-1} H_2SO_4, respectively, and produced different amounts of heat of reaction to bring about oxidation of SOC of varying oxidizability. The amounts of OOC thus determined allowed separation of TOC into the following four fractions of decreasing oxidizability as defined by Chan et al. (2001):

Fraction I (very labile, C_{VL}): Organic C oxidizable with 6.0 mol L^{-1} H_2SO_4

Fraction II (labile, C_L): Difference in OOC oxidizable with 9.0 mol L^{-1} and that with 6.0 mol L^{-1} of H_2SO_4

Fraction III (less labile, C_{LL}): Difference in OOC oxidizable with 12.0 mol L^{-1} and that with 9.0 mol L^{-1} of H_2SO_4 (12.0 mol L^{-1} H_2SO_4 is equivalent to the standard Walkley and Black method)

Fraction IV (non-labile, C_{NL}): Residual organic C after oxidation with 12.0 mol L^{-1} H_2SO_4 when compared with TOC.

2.3.6. Aggregate-associated carbon

Total organic carbon content in different aggregate size fractions

(8.0–4.0 mm, 4.0–2.0 mm, 2.0–1.0 mm, 1.0–0.5 mm, 0.5–0.25 mm, 0.25–0.1 mm and 0.1–0.053 mm), obtained by the process of wet sieving technique, was also determined. The soil samples, after oven drying at 60 °C at 48 h and passing through a 0.2 mm sieve, were used for determination of organic carbon concentration. The aggregate fractions were pooled to large macro-aggregates (> 2000 μm), small macro-aggregates (250–2000 μm) and micro-aggregates (53–250 μm) size fractions. The macroaggregates are easily disrupted by cultivation process compared to the microaggregates. The macroaggregate associated carbons are more labile and hence more likely to be lost whereas the microaggregate associated carbon is relatively stable and hence important from carbon sequestration point of view (Six et al., 1999). Each size fraction was taken in a mortar, mixed well with pestle and passed through a 0.2 mm sieve. The TOC content of these samples was determined by automatic elemental analyser (*Vario EL, Elementar Analysensysteme GmbH*, Hanau, Germany).

2.4. Computations of soil organic carbon indices

2.4.1. Lability index of SOC

The loss of labile C is of greater consequence than the loss of non-labile C. To account for this, since it is the turnover of labile carbon which releases nutrients and the labile carbon component of SOM appears to be of particular importance in affecting soil physical factors (Whitbread, 1995). A lability index for SOC was computed by first expressing the amounts of each of three labile pools namely (C_{VL}, C_L and C_{LL}) as a fraction of TOC, and then multiplying the fractions with their respective weightages of 3, 2 and 1, respectively given on the basis of ease of their oxidation, and finally adding them up for different depths and treatments (Majumder et al., 2007).

$$\text{Lability index (LI)} = (C_{VL}/\text{TOC}) \times 3 + (C_L/\text{TOC}) \times 2 + (C_{LL}/\text{TOC}) \times 1 \quad (4)$$

The values thus obtained are compared for assessing the relative performance of different treatments in maintaining labile soil organic carbon at different depths.

2.4.2. Carbon Pool Index of SOC

The loss of C from a soil with a large carbon pool is of less consequence than the loss of the same amount of C from a soil already depleted of C or which started with a smaller total C pool. Similarly, the more a soil has been depleted of carbon, the more difficult it is to rehabilitate (Blair et al., 1995). To account for this a Carbon Pool Index is calculated. It is the relative proportion of total organic carbon with respect to the reference value. It is computed as:

$$\text{CPI} = [\text{Sample total C (mg/g)}/\text{Reference total C (mg/g)}] \quad (5)$$

2.4.3. Carbon Management Index

Carbon Management Index (CMI) was computed as per procedure proposed by Blair et al. (1995) using the following formula:

$$\text{CMI} = \text{Carbon Pool Index (CPI)} \times \text{Lability index (LI)} \times 100 \quad (6)$$

where, CPI = Carbon Pool Index and LI = Lability index of C.

The index provides a sensitive measure of the rate of change in soil C dynamics of systems relative to a more stable reference soil. When monitored over time or when a new practice is introduced the CMI indicates if the system is in decline or being rehabilitated. There is no ‘ideal’ value of CMI. In experimental situations, CMI can be used to monitor differences in soil C dynamics between treatments and over time (Blair et al., 1995).

2.4.4. Carbon stratification ratio

The stratification index was computed as per Franzluebbers (2002) i.e. value of the parameter affected by plough zone (0–5 cm) and the value of the parameter not affected by plough zone (5–15 cm), which is an indicator of soil quality.

2.5. Statistical analysis

The analysis of variance (ANOVA) test was performed using the GLM procedure of SAS (SAS Institute, 2003) to determine the effect of irrigation, mulch and nitrogen on (put the appropriate parameters tested) as applicable to split-split plot design. The means were compared using least significant difference and Duncan's Multiple Range Test (DMRT). The coefficient of determination (R^2) of regression equations and correlation coefficient (r) were computed by following the least square method (Smith and Norman, 2005) with a computer MS Excel program (2007).

3. Results and discussion

3.1. Total organic carbon and its stratification in soil as influenced by irrigation, crop residue mulching and nitrogen management

Total organic carbon (TOC) as influenced by irrigation, crop residue mulching and nitrogen management and its stratification in soil and TOC pool at harvest of maize, 2013 for 0–5 and 5–15 cm soil depth have been presented in Table 2. The TOC content ranged between 3.2 ($I_0M_0N_0$) to 6.4 g/kg ($I_+M_+N_{150}$) with a mean value of 5.0 g/kg at 0–5 cm soil depth and from 3.5 ($I_+M_0N_0$) to 4.5 g/kg ($I_+M_+N_{75}$) with a mean value of 4.0 g/kg at 5–15 cm soil depth. Maharana et al. (2012) reported that TOC ranged between 7.53 and 11.08 g/kg in a sandy loam soil of Indogangetic plain region under different manure application. TOC increased by 40.5% due to irrigation over the rainfed treatment at 0–5 cm soil depth, whereas, at 5–15 cm soil depth the effect of irrigation was not significant on TOC concentration. There was decline in TOC with depth indicating stratification of TOC. This is mainly attributed to increased carbon input through root biomass under irrigation treatment. This result is in agreement with the findings of Liu et al. (2012). Application of crop residue mulch significantly increased the TOC concentration by 14.9% at 0–5 cm soil depth compared to the no mulch treatment, this was due to addition of carbon through crop residues. However, the effect of crop residue mulch was not significant on TOC concentration at 5–15 cm soil depth. Application of crop residue mulch significantly increased stratification ratio (SR) by 9.2% compared to no mulch treatment. Application of 150 kg N/ha significantly increased the TOC concentration by 22.2% and 7.8% over control and 75 kg N/ha, respectively at 0–5 cm soil depth. The effect of nitrogen was not significant on TOC concentration at 5–15 cm soil depth. The stratification ratio and TOC pools also increased significantly due to application of N. This is mainly attributed to higher carbon input through root biomass at higher N level. Application of 150 kg N/ha significantly increased the SR of TOC by 10.7% over 75 kg N/ha. It was observed that there was mild increase in TOC pool by 6.4% compared to the initial value after two years of imposition of irrigation, residue and nitrogen management practices in maize. The TOC stock at 0–15 cm soil depth ranged between 8.98 ($I_0M_0N_{75}$) to 11.71 Mg/ha ($I_+M_+N_{150}$) with a mean value of 10.24 Mg/ha. The analysis of variance for TOC stock has been presented in Table 3. Das et al. (2018) reported that in the IGP region the TOC stock in the 0–5 cm soil depth ranged from 5.82 (CT) to 6.87 Mg/ha (ZT+ Residue) and at 5–15 cm soil depth it ranged from 10.66 Mg/ha to 13.75 Mg/ha (Permanent Broadbed + Residue) in a maize-wheat system. The TOC stock presented in the present study is in the range of these observations. Application of irrigation, crop residue mulch and N significantly increased TOC stock at 0–15 cm soil depth but there was no significant difference between 75 and 150 kg N/ha with respect to the TOC stock at 0–15 cm soil depth. Lal (1997) reported that crop residue mulch resulted in increase in carbon accumulation on clayey Oxisol by 15% at 0–10 cm soil depth after 6 years, which represented 0.65 Mg of C/ha/yr and 14% of mulched carbon. In the present study, the increase in carbon stock due to crop residue mulch compared to no

Table 2
Total organic carbon (%), stratification ration and total organic carbon stock (Mg/ha) as influenced by irrigation, mulching and N management.

Treatments	Total organic carbon (g/kg)		Bulk density (Mg/m^3)		Stratification ratio	TOC stock (0–15 cm) Mg/ha
	0–5 cm	5–15 cm	0–5 cm	5–15 cm		
Irrigation effect						
Rainfed (I_0)	$4.2^{b,*}$	4.0^{a}	1.46b	1.71a	1.05^{b}	9.59^{b}
Irrigated (I_+)	5.9^{a}	4.1^{a}	1.54a	1.72a	1.44^{a}	10.88^{a}
Mulch effect						
Without mulch (M_0)	4.7^{b}	4.0^{a}	1.51a	1.73a	1.19^{b}	9.81^{b}
With wheat residue mulch @ 10 t/ha (M_+)	5.4^{a}	4.1^{a}	1.49b	1.70b	1.30^{a}	10.67^{a}
Nitrogen effect						
Control (N_0)	4.5^{b}	3.9^{a}	1.53a	1.72a	1.16^{c}	9.69^{b}
75 kg N/ha (N_{75})	5.1^{a}	4.1^{a}	1.46b	1.72a	1.22^{b}	10.28^{a}
150 kg N/ha (N_{150})	5.5^{a}	4.0^{a}	1.51a	1.70a	1.35^{a}	10.75^{a}
Irrigation × mulch × nitrogen interaction effect						
$I_0M_0N_0$	3.2^{f}	4.1^{abc}	1.37^{a}	1.80^{a}	0.79^{j}	9.06^{c}
$I_0M_0N_{75}$	3.7^{ef}	4.0^{abc}	1.56^{a}	1.70^{a}	0.92^{i}	8.98^{c}
$I_0M_0N_{150}$	4.0^{def}	3.8^{bc}	1.50^{a}	1.63^{a}	1.07^{h}	9.12^{c}
$I_0M_+N_0$	4.3^{def}	$4.0a^{bc}$	1.44^{a}	1.72^{a}	1.07^{h}	9.39^{c}
$I_0M_+N_{75}$	4.7^{cde}	$3.9a^{bc}$	1.47^{a}	1.74^{a}	1.19^{g}	9.88^{bc}
$I_0M_+N_{150}$	5.2^{abcd}	$4.1a^{bc}$	1.40^{a}	1.67^{a}	1.25^{f}	11.14^{a}
$I_+M_0N_0$	4.9^{bcde}	3.5^{c}	1.45^{a}	1.75^{a}	1.40^{d}	9.42^{c}
$I_+M_0N_{75}$	6.0^{ab}	4.1^{abc}	1.59^{a}	1.75^{a}	1.45^{c}	11.24^{a}
$I_+M_0N_{150}$	6.3^{a}	4.2^{ab}	1.59^{a}	1.77^{a}	1.49^{b}	11.01^{a}
$I_+M_+N_0$	5.8^{abc}	4.1^{abc}	1.56^{a}	1.61^{a}	1.40^{d}	10.89^{ab}
$I_+M_+N_{75}$	6.0^{ab}	4.5^{a}	1.49^{a}	1.69^{a}	1.32^{e}	11.02^{a}
$I_+M_+N_{150}$	6.4^{a}	4.0^{abc}	1.55^{a}	1.74^{a}	1.61^{a}	11.71^{a}

* Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT.

Table 3
Analysis of variance (ANOVA) for total organic carbon stock (Mg/ha) at 0–15 cm soil depth.

Source	DF	Sum of squares	Mean square	F-ratio	p-Value	Significant
REP	2	11.2067	5.6033	81.1947	0.0122	*
MP	1	25.0333	25.0333	362.7437	0.0027	*
Error(a)	2	0.1380	0.0690	–	–	
SP	1	2.8787	2.8787	13.1320	0.0223	*
MP * SP	1	0.3560	0.3560	1.6241	0.2715	NS
Error(b)	4	0.8768	0.2192	–	–	
SSP	2	6.7529	3.3765	13.2142	0.0004	*
MP * SSP	2	4.3459	2.1730	8.5042	0.0030	*
SP * SSP	2	0.4993	0.2496	0.9770	0.3978	NS
MP * SP * SSP	2	3.4814	1.7407	6.8124	0.0072	*
Error(c)	16	4.0883	0.2555	–	–	
Total	35	59.6573	–	–	–	

NS - Non-Significant, p-Value < 0.05 - Significant at 5%, p-Value < 0.01 - Significant at 1%.
MP = Main plot factor (Irrigation); SP = Subplot factor (Mulching): SSP = Subsub plot factor (Nitrogen levels).
* Significant at 5% (level of significance opted by user).

Table 4
Permanganate oxidizable carbon (mg/g) as influenced by irrigation, mulching and N management at 0–5 and 5–15 cm soil depth after harvest of maize, 2013.

Treatments	Permanganate oxidizable carbon (mg/g)		Stratification ratio
	0–5 cm	5–15 cm	
Irrigation effect			
Rainfed (I_0)	0.39a*	0.32b	1.23a
Irrigated (I_+)	0.31b	0.41a	0.75b
Mulch effect			
Without mulch (M_0)	0.38a	0.38a	1.02a
With wheat residue mulch @ 10 t/ha (M_+)	0.32b	0.36a	0.96b
Nitrogen effect			
Control (N_0)	0.35b	0.39a	0.91b
75 kg N/ha (N_{75})	0.31b	0.38a	0.86b
150 kg N/ha (N_{150})	0.39a	0.34b	1.19a
Irrigation × mulch × nitrogen interaction effect			
$I_0M_0N_0$	0.49a	0.38b	1.30c
$I_0M_0N_{75}$	0.30d	0.40b	0.77e
$I_0M_0N_{150}$	0.43bc	0.30c	1.44b
$I_0M_+N_0$	0.27d	0.31c	0.87e
$I_0M_+N_{75}$	0.38c	0.27c	1.40b
$I_0M_+N_{150}$	0.44ab	0.28c	1.60a
$I_+M_0N_0$	0.38c	0.40b	0.96d
$I_+M_0N_{75}$	0.27d	0.42ab	0.65f
$I_+M_0N_{150}$	0.38c	0.39b	0.97d
$I_+M_+N_0$	0.24d	0.46a	0.53 g
$I_+M_+N_{75}$	0.27d	0.42ab	0.65f
$I_+M_+N_{150}$	0.30d	0.40b	0.75f

* Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT.

mulch treatment was 0.44 Mg/ha/yr. Tisdall and Oades (1982) reported that the total SOC concentration is more in mulch treated soil as compared to un mulched soil. There is a positive correlation between crop residue mulch level and total SOC content. Duiker and Lal (1999) also reported similar observations. Das et al. (2018) also reported significant increase in SOC stock at 0–30 cm soil depth in the Indogangetic plain region due to residue retention under maize-wheat cropping system.

3.2. Permanganate oxidizable carbon (PmOC)

The distribution of PmOC, which is an indication of labile carbon at 0–5 and 5–15 cm soil depth have been presented in Table 4. PmOC constituted 8.2 and 9.3% of TOC at 0–5 and 5–15 cm soil depth, respectively. This implies that a major form of soil organic carbon remained in non-labile (NL) pool. The PmOC ranged between 0.27 and 0.49 mg/g with a mean value of 0.35 mg/g at 0–5 cm soil depth and between 0.27 and 0.46 mg/g with a mean value of 0.37 mg/g at 5–15 cm soil depth. Application of irrigation registered significantly reduced PmOC by 25.8% at 0–5 cm soil depth, whereas, at 5–15 cm soil depth, irrigation significantly increased the PmOC by 28.1% over rainfed treatment. There was significant decline in stratification ratio of PmOC due to irrigation. Application of crop residue mulch significantly reduced PmOC by 18.8% at 0–5 cm soil depth. Effect of crop residue mulch was not significant on PmOC at 5–15 cm soil depth. The decrease in PmOC due to CRM at 0–5 cm soil depth indicates increase in NL fraction of SOC as the crop residue (wheat straw) has high C/N ratio (80:1) and mainly constituted cellulose and lignin compound. The SR of PmOC reduced significantly due to crop residue mulch. Stratification ratio (SR) of PmOC declined by 6.3% due to crop residue mulch. Application of 150 kg N/ha significantly increased PmOC by 15.6% and 23.3% compared to control and 75 kg N/ha at 0–5 cm soil depth, whereas, there was no significant difference in PmOC between control and 75 kg N/ha at this depth. On the contrary, at 5–15 cm soil depth, application of 150 kg N/ha registered significantly lower PmOC compared to control and 75 kg N/ha. There was no significant difference in PmOC concentration at 5–15 cm soil depth between control and 75 kg N/ha. The SR of PmOC due to 150 kg N/ha was significantly higher than control and 75 kg N/ha, whereas there was no significant difference in SR and PmOC between 75 kg N/ha and control.

3.3. Distribution of soil microbial biomass carbon (SMBC)

Distribution of SMBC, which is another form of labile carbon, at 0–5 cm soil depth as influenced by irrigation, crop residue mulch (CRM) and nitrogen management has been depicted in Fig. 1. Application of irrigation significantly increased SMBC by 25% over rainfed treatment. Similarly application of crop residue mulch significantly increased the SMBC by 42% over the no mulch treatment. Application of nitrogen at 75 kg N/ha and 150 kg N/ha significantly increased SMBC by 98.7% and 83.6% over control, respectively. However, there was no significant difference between 75 kg N/ha and 150 kg N/ha with respect to SMBC. The increment of SMBC with irrigation, crop residue mulch and N application is mainly attributed to addition of fresh residue through root biomass, which might have triggered higher microbial activities in soil in these treatments. Marinari et al. (2006) found significant increases of microbial biomass carbon content with organic management in farming systems in Italy. SMBC constitute 3.7% of TOC, which is referred as microbial quotient. The microbial quotient increased with addition of CRM and N application compared to the no mulch treatment and no N control, respectively.

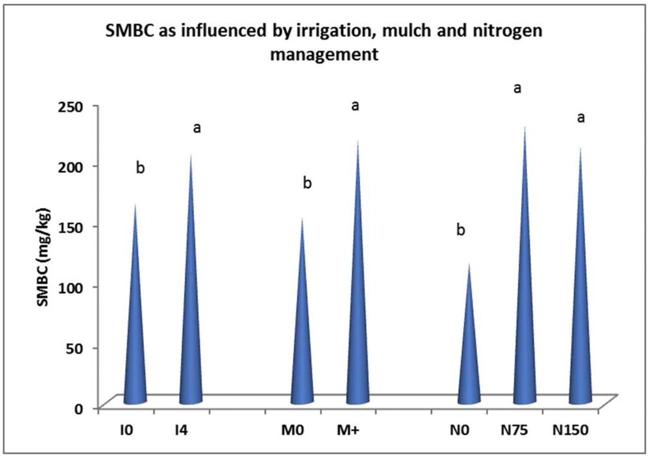

Fig. 1. Soil microbial biomass carbon after harvest of maize, 2013 at 0–15 cm soil depth as influenced by irrigation, mulch and nitrogen management; I0 = Raifed, I4 = Four irrigation at critical growth stages, M0 = without mulch, M+ = Wheat residue mulch @ 10 t/ha, N0 = No nitrogen, N75 = 75 kg N/ha and N150 = 150 kg N/ha; The cones with same letters are not significantly different at $p < 0.05$.

Table 5
Water stable aggregate associated carbon (g/kg) after maize harvest as influenced by irrigation, mulching and N management.

Treatment	Soil organic carbon (g/kg) in water stable aggregates		
	Large macro-aggregates (> 2000 μm)-SOC	Small macro-aggregate (250–2000 μm)-SOC	Microaggregate (53–250 μm)-SOC
Irrigation effect			
Rainfed (I_0)	3.3a*	2.5a	1.9a
Irrigated (I_+)	3.2a	2.4a	1.7b
Mulch effect			
Without mulch (M_0)	3.0b	2.4a	1.7b
With wheat residue mulch @ 10 t/ha (M_+)	3.5a	2.4a	1.9a
Nitrogen effect			
Control (N_0)	3.2a	2.3a	1.6b
75 kg N/ha (N_{75})	3.2a	2.4a	1.7b
150 kg N/ha (N_{150})	3.3a	2.5a	2.1a
Irrigation × mulch × nitrogen interaction effect			
$I_0M_0N_0$	3.3d	2.9b	2.2b
$I_0M_0N_{75}$	3.0ef	2.5de	1.6ef
$I_0M_0N_{150}$	2.5g	2.1fg	1.8d
$I_0M_+N_0$	3.5c	1.8h	1.1g
$I_0M_+N_{75}$	3.7b	2.4e	2.0c
$I_0M_+N_{150}$	4.0a	3.1a	2.6a
$I_+M_0N_0$	3.1e	2.6cd	1.5f
$I_+M_0N_{75}$	2.9f	2.1fg	1.2g
$I_+M_0N_{150}$	3.0ef	2.2f	1.7de
$I_+M_+N_0$	3.0ef	2.0g	1.5f
$I_+M_+N_{75}$	3.3d	2.5de	2.0c
$I_+M_+N_{150}$	3.6bc	2.7c	2.1bc

* Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT.

3.4. Water stable aggregate associated carbon (WSAC)

The concentration of water stable aggregate associated carbon (WSAC) after maize harvest at 0–5 cm soil depth has been presented in Table 5. The SOC concentration in large macro-aggregates ranged from 2.5 ($I_0M_0N_{150}$) to 4.0 g/kg ($I_0M_+N_{150}$) with a mean value of 3.2 g/kg whereas in small macro-aggregates it ranged from 1.8 ($I_0M_+N_0$) to 3.1 g/kg ($I_0M_+N_{150}$) with a mean value of 2.4 g/kg and in micro-aggregates in ranged from 1.1 ($I_0M_+N_0$) to 2.6 g/kg ($I_0M_+N_{150}$) with a mean value of 1.8 g/kg. There was decline in SOC concentration with decrease in size of the aggregates. Higher SOC concentration in macro-aggregates is mainly attributed to the fact that macro-aggregates constitute micro-aggregates and carbon enriched particulate organic matter (POM). This finding is in agreement with Saroa and Lal (2003). Greater SOC concentration and higher mineralization rate is often associated with macro-aggregates fractions (Bandyopadhyay and Lal, 2015). This result is also in conformity with the findings of Tisdall and Oades (1982). Conversely, SOC associated with micro-aggregates fractions may be more physically protected and are therefore, more biochemically recalcitrant, leading to development of stable micro-aggregates (Jastrow, 1996, Six et al., 2000a, b and Sohi et al., 2001). The effect of irrigation was not significant on SOC concentration in large and small aggregate. However there was significant decline in SOC concentration due to irrigation in micro aggregates compared to rainfed treatment. Application of crop residue mulch significantly increased the SOC concentration by 16.7% and 11.8% in large macro-aggregate and micro-aggregate, respectively than no mulch treatment. However, the effect of crop residue mulch was not significant on SOC concentration of

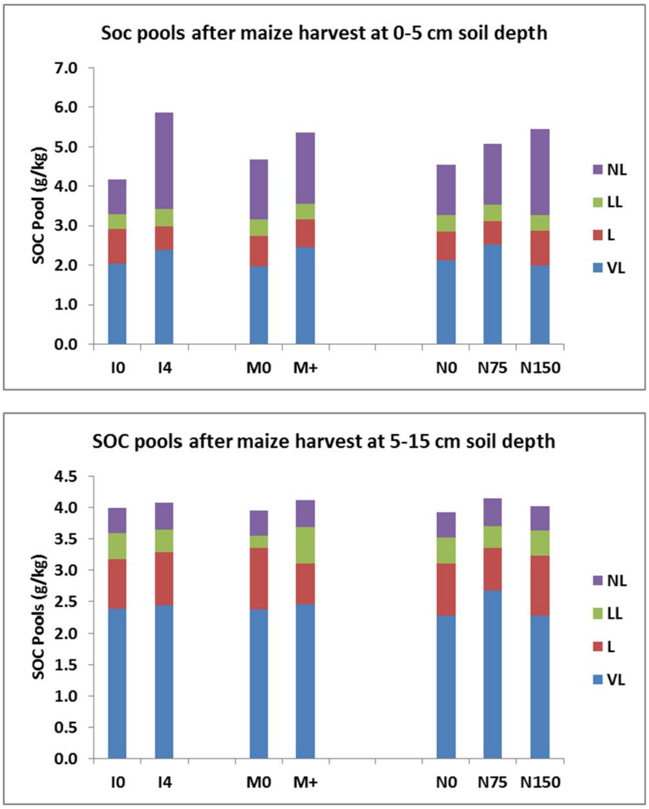

Fig. 2. Soil organic carbon pools at 0–5 and 5–15 cm soil depth after harvest of maize, 2013; I0 = Rainfed, I4 = Four irrigation at critical growth stages, M0 = without mulch, M+ = Wheat residue mulch @ 10 t/ha, N0 = No nitrogen, N75 = 75 kg N/ha and N150 = 150 kg N/ha.

small macro aggregates. Effect of nitrogen was not significant on SOC concentration of both large and small macro aggregates. However, the SOC concentration in micro aggregates significantly increased due to application of 150 kg N/ha but there was no significant difference between control and 75 kg N/ha with respect to SOC concentration in micro aggregates.

3.5. *Soil organic carbon (SOC) pools*

SOC pools, i.e. very labile (VL), labile (L), less labile (LL) and non-labile (NL) pools as influenced by irrigation, crop residue mulching and nitrogen management at harvest of maize, 2013 for of 0–5 and 5–15 cm soil depth have been depicted in Fig. 2. Application of irrigation resulted in decrease in labile pools of carbon (L) but increase in VL, LL and NL pools of carbon than that of rainfed treatment at 0–5 cm soil depth. However, at 5–15 cm soil depth, application of irrigation resulted in decrease in the LL pools of SOC but increased the VL, L and NL pools of SOC compared to rainfed treatment. Application of CRM resulted in decrease in the labile pools (L) of SOC but increase in the VL, LL and NL pools of SOC compared to no mulch treatment both at 0–5 and 5–15 cm soil depth. Among the labile pools of carbon, the maximum increase was recorded in VL pools. At 5–15 cm soil depth, the increase in labile pools of carbon due to crop residue mulch was mainly attributed to increase in VL and LL pools of carbon. Application of nitrogen at 150 kg N/ha resulted in lower VL and LL pools of carbon but higher NL pools of carbon at 0–5 cm soil depth, whereas, at 5–15 cm soil depth, there was decrease in LL pools and increase in L pools of SOC due to 150 kg N/ha compared to control. Application of 75 kg N/ha increased the VL and NL pools of SOC but reduced the L and LL pools of SOC in both the soil depths than control.

3.6. *Carbon Lability Index (CLI), Carbon Pool Index (CPI) and Carbon Management Index (CMI)*

The CLI, CPI and CMI of soil as influenced by irrigation, crop residue mulch and N fertilizer have been presented in Table 6. CLI, which is the weighted mean of labile carbon, ranged between 1.21 and 2.21 with a mean value of 1.75 at 0–5 cm soil depth and between 2.29 and 2.63 with a mean value of 2.52 at 5–15 cm soil depth. CLI reduced significantly by 32.5% due to irrigation at 0–5 cm soil depth, whereas, effect of irrigation was not significant on CLI at 5–15 cm soil depth. Crop residue mulching significantly reduced the CLI by 5.3% at

Table 6
Carbon Lability Index, Carbon Pool Index and Carbon Management Index at harvest of maize, 2013.

Treatments	Carbon Lability Index		Carbon Pool Index		Carbon Management Index	
Irrigation effect						
	0–5 cm	5–15 cm	0–5 cm	5–15 cm	0–5 cm	5–15 cm
Rainfed (I_0)	2.00a*	2.52a	1.29b	0.98a	254.9b	246.2b
Irrigated (I_+)	1.51b	2.53a	1.82a	1.00a	273.0a	252.5a
Mulch effect						
Without mulch (M_0)	1.76a	2.59a	1.45b	0.97a	243.6b	249.8a
With wheat residue mulch @ 10 t/ha (M_+)	1.74a	2.46b	1.66a	1.01a	284.3a	248.9a
Nitrogen effect						
Control (N_0)	1.87a	2.50b	1.41c	0.96b	255.4b	239.9c
75 kg N/ha (N_{75})	1.85a	2.58a	1.57b	1.02a	284.1a	262.1a
150 kg N/ha (N_{150})	1.53b	2.50b	1.69a	0.99b	252.3b	246.0b
Irrigation × mulch × nitrogen interaction effect						
$I_0M_0N_0$	2.20a	2.53d	1.00k	1.00d	219.8i	253.4d
$I_0M_0N_{75}$	2.21a	2.60b	1.15j	0.98e	253.9e	256.1cd
$I_0M_0N_{150}$	1.84d	2.63a	1.24i	0.92g	229.1h	242.6e
$I_0M_+N_0$	2.14b	2.33g	1.32h	0.97f	281.7b	226.4f
$I_0M_+N_{75}$	1.92c	2.51e	1.45g	0.97f	278.6bc	242.6e
$I_0M_+N_{150}$	1.67f	2.53d	1.59e	1.01c	266.3d	256.1cd
$I_+M_0N_0$	1.61g	2.63a	1.52f	0.86h	244.6f	226.4f
$I_+M_0N_{75}$	1.51i	2.58c	1.84c	1.00d	278.6bc	258.8bc
$I_+M_0N_{150}$	1.21k	2.53d	1.94b	1.03b	235.3g	261.5b
$I_+M_+N_0$	1.54h	2.50f	1.79d	1.01c	275.5c	253.4d
$I_+M_+N_{75}$	1.76e	2.63a	1.84c	1.11a	325.1a	291.1a
$I_+M_+N_{150}$	1.41j	2.29h	1.98a	0.98e	278.6bc	223.7f

* Values in a column followed by same letters are not significantly different at $p < 0.05$ as per DMRT.

5–15 cm soil depth, whereas the effect of crop residue mulch was not significant on CLI at 0–5 cm soil depth. The decrease in CLI due to application of crop residue mulch is supported by the decrease in PMOC. These results are in conformity with the findings of Majumder et al. (2007). Application of nitrogen at 75 kg N/ha registered significant increase in CLI by 20.9% and 3.2% compared to 150 kg N/ha at 0–5 and 5–15 cm soil depth, respectively. CLI in control treatment was statistically at par with 75 Kg N/ha at 0–5 cm soil depth and 150 kg N/ha at 5–15 cm soil depth.

Carbon Pool Index (CPI), which is the relative TOC content with respect to control, ranged between 1.00 and 1.98 with a mean value of 1.56 at 0–5 cm soil depth and between 0.86 and 1.11 with a mean value of 0.99 at 5–15 cm soil depth. Irrigation significantly increased the CPI by 41.1% over the rainfed condition at 0–5 cm soil depth, whereas, the effect of irrigation was not significant on CPI at 5–15 cm soil depth. Crop residue mulching significantly increased the CPI by 11.5% at 0–5 cm soil depth, whereas, the effect of crop residue mulch was not significant on CPI at 5–15 cm soil depth. The increase in CPI due to crop residue mulch application was attributed to carbon input from root biomass and crop residue mulch, which resulted in higher TOC pools in these treatments. Application of nitrogen at 75 Kg N/ha and 150 kg N/ha significantly increased the CPI by 11.3 and 19.9%, respectively compared to control at 0–5 cm soil depth. Application 75 Kg N/ha significantly increased the CPI by 6.3% over control at 5–15 cm soil depth. CPI in control plot at this stage was statistically at par with that of 150 kg N/ha.

Carbon Management Index (CMI) which is the product of CLI and CPI, ranged between 219.8 ($I_0M_0N_0$) to 325.1 ($I_+M_+N_{75}$) with a mean value of 263.9 at 0–5 cm soil depth and between 223.7 ($I_+M_+N_{150}$) to 291.1 ($I_+M_+N_{75}$) with a mean value of 249.3 at 5–15 cm soil depth. The range of CMI values reported here is in agreement with the values reported by Maharana et al. (2012) from a similar soil. Irrigation significantly increased CMI by 7.1 and 2.5% compared to the rainfed treatment at 0–5 and 5–15 cm soil depth, respectively. Crop residue mulching significantly increased the CMI by 16.7% than no mulch treatment at 0–5 cm soil depth, whereas, at 5–15 cm soil depth the effect of crop residue mulch was not significant on CMI. This is mainly attributed to increase in CPI under these treatments. Application of nitrogen at 75 Kg N/ha significantly increased the CMI by 11.2% and 9.3% compared to control at 0–5 and 5–15 cm soil depth, respectively. Application of 75 kg N/ha resulted in significantly higher CMI than that of 150 kg N/ha at 0–5 and 5–15 cm soil depth. This is mainly attributed to increase in CLI due to application of 75 kg N/ha compared to 150 kg N/ha. The CMI in control plot was statistically at par with that of 150 kg N/ha at 0–5 cm soil depth, whereas, at 5–15 cm soil depth, application of 150 kg N/ha significantly increased the CMI compared to control.

3.7. Grain yield of maize

The grain yield of maize ranged between 2370 kg/ha ($I_0M_0N_0$) to 7439 kg/ha ($I_+M_+N_{150}$) with a mean value of 5368 kg/ha during the year 2012 and from 2681 kg/ha ($I_+M_0N_0$) to 5898 kg/ha ($I_0M_+N_{150}$) with a mean value of 4387 kg/ha during the year 2013 (Fig. 3). The crop experienced aeration stress during the year 2013 due to unusually high rainfall (919.7 mm) received during this year than that of the year 2012 (482 mm), which may be the possible reason for lower yield in 2013 by 34.4% than that of the previous year. Application of crop residue mulch significantly increased the grain yield of maize by 11.5 and 28.4% compared to no mulch treatment during the year 2012 and 2013, respectively. Increased crop productivity due to crop residue mulch has also been reported by several workers (Khurshid et al., 2006; Pervaiz et al., 2009; Chakraborty et al., 2010; Uwah and Iwo, 2011). The grain yield of maize increased by 31% under irrigated condition during the year 2012, whereas the effect of irrigation on grain yield of maize was not significant during the year 2013. This is may be attributed to excess rainfall received during the year 2013 leading to aeration stress. Pradhan et al. (2013) also did not find any significant variation in grain and biomass yield due to irrigation in *kharif* maize. Application of N at 75 and 150 kg/ha increased the grain yield of maize compared to control by 68.4 and 72.8% during the year 2012 and by 52.5 and 44.6% during the year 2013, respectively. Pradhan et al. (2013) also reported significantly higher grain and biomass yield of maize due to nitrogen application. However there was no significant difference between 75 and 150 kg/ha with respect to grain yield of maize during both the years of study. The interaction between irrigation, crop residue mulch and N levels was not significant on grain yield of maize during both the years.

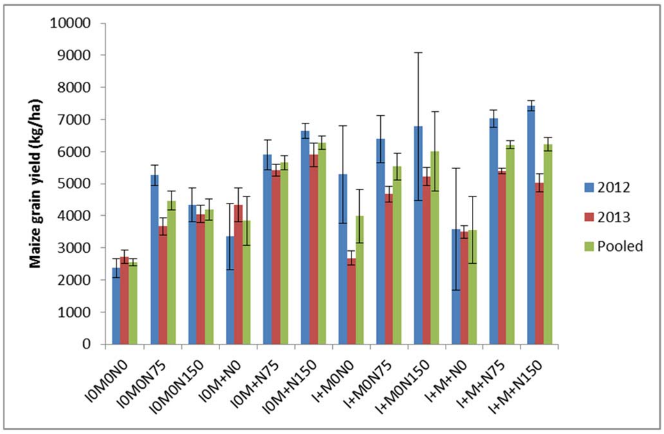

Fig. 3. Grain yield of maize for the year 2012, 2013 and the pooled over 2012 and 2013 as influenced by irrigation, crop residue mulch and N management; I0 = Raifed, I4 = Four irrigation at critical growth stages, M0 = without mulch, M+ = Wheat residue mulch @ 10 t/ha, N0 = No nitrogen, N75 = 75 kg N/ha and N150 = 150 kg N/ha. The error bars indicate standard error of mean.

3.8. Interrelationship between SOC pools, Carbon Management Index and grain yield of maize

The correlation matrix between different SOC pools showed that TOC is significantly correlated with nonlabile carbon ($r = 0.96$, $p < 0.01$) (Table 7). However permanganate oxidizable carbon (PmOC) was significantly positively correlated with small macro-aggregate (250–2000 μm) associated carbon and micro-aggregate (53–250 μm) but significantly negatively correlated with very labile-C ($r = -0.72$, $p < 0.01$). The less labile-C was also significantly negatively correlated with very labile-C ($r = -0.75$, $p < 0.01$). This is obvious as less labile and labile pools represent two complementary pools. Carbon Management Index was significantly positively correlated with very labile-C ($r = 0.96$, $p < 0.01$) but significantly negatively correlated with PmOC ($r = -0.72$, $p < 0.01$). Pooled grain yield of maize was significantly positively correlated with TOC ($r = 0.70$, $p < 0.05$) and SMBC ($r = 0.67$, $p < 0.05$) and non-labile-C ($r = 0.63$, $p < 0.05$). These three pools accounted for 65% variation in the grain yield of maize as evidenced from the regression analysis. Maharana et al. (2012) also reported a strong relationship between crop yields with different pools of carbon, which indicates that there appears to be a significant influence of SOC in enhancing crop yields.

4. Conclusions

From this study we can conclude that there was increase in the total organic carbon and soil microbial biomass carbon due to crop residue mulch, irrigation and nitrogen application compared to control at 0–5 cm soil depth. Water stable aggregate associated carbon concentration in large macro-aggregates and micro-aggregates increased due to crop residue mulch and nitrogen application. Crop residue mulch

Table 7
Pearson's correlation matrix between grain yield, Carbon Management Index and different soil carbon pools.

	GY	CMI	TOC	PmOC	SMBC	Large Maro aggregate-C	Small Maro aggregate-C	Miro aggregate-C	Very labile-C	Labile-C	Less labile-C	Non-labile-C
GY	1.00											
CMI	0.51	1.00										
Toc (%)	0.70*	0.52	1.00									
PmOC (%)	−0.18	−0.72**	−0.50	1.00								
SMBC (%)	0.67*	0.51	0.45	−0.13	1.00							
Large Maro aggregate-C	0.37	0.38	0.10	0.11	0.39	1.00						
Small Maro aggregate-C	0.20	−0.15	−0.12	0.58*	0.48	0.54	1.00					
Miro aggregate-C	0.33	−0.08	−0.03	0.61*	0.56	0.54	0.84**	1.00				
Very labile-C	0.50	0.96**	0.56	−0.72**	0.49	0.33	−0.11	−0.11	1.00			
Labile-C	−0.31	−0.56	−0.55	0.56	−0.25	−0.16	−0.04	0.21	−0.75**	1.00		
Less labile-C	0.09	0.11	0.30	−0.38	−0.07	0.19	0.11	−0.22	0.12	−0.42	1.00	
Non-labile-C	0.63*	0.28	0.96**	−0.33	0.36	−0.02	−0.09	−0.01	0.36	−0.46	0.24	1.00

* Significant at $p < 0.05$.

** Significant at $p < 0.01$.

resulted in significant increase in labile and non-labile pools of carbon at 0–5 cm soil depth compared to the no mulch treatment. Among the labile pools of carbon, the maximum increase due to crop residue mulching was recorded in very labile pools. The Carbon Lability Index decreased whereas Carbon Pool Index and Carbon Management Index increased due to irrigation and crop residue mulch application. Application of 75 kg N/ha resulted in significantly higher Carbon Management Index than that of 150 kg N/ha at 0–5 and 5–15 cm soil depth. Carbon Management Index is significantly positively correlated with very labile-C whereas grain yield of maize was significantly correlated with total organic carbon, soil microbial biomass-C and non-labile-C. So maize may be grown under irrigate condition with wheat residue mulch at 10 Mg/ha and 75 kg N/ha to achieve higher total organic carbon pool, labile pools of carbon, better Carbon Management Index and higher productivity. This treatment may lead to soil carbon sequestration in the long run due to contribution to non-labile pools of soil organic carbon under crop residue mulching.

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