Effect of Long-Term Conservation Tillage on Soil Physical Properties and Soil Health under Rice-Wheat Cropping System in Sub Tropical India

Article *in* Ama, Agricultural Mechanization in Asia, Africa & Latin America · March 2015

Ved Prakash Chaudhary
National Research and Education Network of India (ERNET)

Gangwar Shikha
Indian Council of Agricultural Research

Effect of Long-Term Conservation Tillage on Soil Physical Properties and Soil Health under Rice-Wheat Cropping System in Sub Tropical India

by
V. P. Chaudhary
vp_ch@yahoo.co.in

B. Gangwar

Shikha Gangwar

ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut (UP)-250 110, INDIA

Abstract

Tillage influence soil aggregation, microbial activity in the soil and enhance the oxidation of soil organic carbon (SOC). A long term study was carried out to investigate the impact of conservation tillage on soil aggregates, SOC and microbial biomass carbon (MBC) in rice (Oryza sativa)-wheat (Triticum aestivum) cropping system at experimental station of Varanasi, Uttar Pradesh under the aegis of All India Co-ordinated Research Project (AICRP) of Integrated Farming Systems (IFS) during 2003-10. The four rice crop establishment techniques i.e., direct seeding in zero tilled soil (P_1), wet seeding of sprouted rice seed with drum seeder in puddled condition (P_2), manual transplanting in puddled soil (P_3) and mechanical transplanting in puddled soil (P_4) served as horizontal treatments while four tillage practices in wheat (i.e. T_1- rotavator till drill, T_2- conventional sowing, T_3- strip till drilling, T_4- Zero till drilling) served as vertical treatments in strip plot design with three replications. Total water stable aggregates (WSA)(> 0.053 mm) in the soil at surface 0-15 cm depth, ranged between 69.92 and 88.78 % in rice crop, while in winter crop it varied between 74.62 and 83.57 %. According to mean weight diameter (MWD) different treatments in regard to crop establishment technique of rice could be ranked in the order $P_1 > P_4 > P_2 > P_3$ and $T_4 > T_3 > T_1 > T_2$ in wheat strip regarding tillage practices. However, the MWD decreased drastically in lower soil depth. The SOC ranged from 4.06 to 5.67 g kg^{-1} in soil samples from rice plots and from 4.32 to 5.24 g kg^{-1} in different tillage treatments in wheat at surface 0-15 cm layer. SOC contents in direct seeding in zero tilled rice strip (5.67 g kg^{-1}) and zero till drill in wheat strip (5.24 g kg^{-1}) were significantly higher than other treatments in all soil depth. The MBC of direct drilling zero tilled (441 µg g^{-1}) in rice strip and zero till drill in wheat strip (395 µg g^{-1}) had the highest values while the manually transplanted-puddled (383 µg g^{-1}) rice and conventional wheat sowing had the lowest values (334 µg g^{-1}) at all the depths. The differences were significant in at $P < 0.01$ for both SOC and MBC and ranked in order of $P_1 > P_2 > P_4 > P_3$ of rice crop strip and $T_4 > T_3 > T_1 > T_2$ in wheat crop strip under 0-15 cm soil depth. The decrease in SOC an average all treatments was about 51 and 89 percent from layer 0-15 to 15-30 and 30-45 cm, respectively. The interaction effects of P at same level of T and T at same level of P treatments on MWD, SOC and MBC were significant ($P < 0.01$) in 0-15 and 15- 30 cm soil depth.

Key Words: Zero tillage; Conservation tillage; Crop establishment method; Rice- wheat cropping system

Introduction

Rice (Oryza sativa)-wheat (Triticum aestivum) cropping system is the major cropping system in South Asia occupies about 13.5 million hectares (Mha) in the Indo-Gangetic Plains (IGP) in India, Pakistan, Bangladesh and Nepal and another 10 Mha in China (Sharma and Bhushan, 2001). The productivity of this system is declining and its sustainability is of utmost importance for ensuring regional food security.

The puddling of rice fields is one of the most common practices in India that consumes time, water, energy and results in subsurface compaction, which is not conducive to the succeeding wheat crop (Bajpai and Tripathi, 2000; Bhattacharyya *et al.*, 2009). The newer approach is now focuses on conservation agriculture in which 'no' or 'zero' tillage is propagated as it is characterized by higher soil organic carbon (SOC) sequestration (Dick *et al.*, 1991), better aggregation (Lal *et al.*, 1994) and improved pore size distribution (Bhattacharyya *et al.*, 2006). Conservation tillage practices, such as no tillage, can increase soil aggregation and improve microbial biomass and activities (Minoshima *et al.*, 2007; Zibilske and Bradford, 2007; Wright *et al.*, 2008).

Agricultural land management practices are one of the most significant anthropogenic activities that change the soil characteristics, including physical, chemical and biological properties and process. The microbial biomass can be altered by the different agricultural resource conservation practices (Liebig *et al.*, 2006; Yao *et al.*, 2006; Elfstrand *et al.*, 2007; Frey *et al.*, 2007; Govaerts *et al.*, 2008; Lauber *et al.*, 2008). However, improved knowledge of how tillage management regulates the interaction between soil aggregates and microbial community structure and function may help to understand better the mechanisms that lead to increase SOC sequestration and improving fertility in agricultural ecosystems. Conservation tillage is widely adopted to improve sustainability of agricultural ecosystems and reduce input cost and saves natural resources. However, differences in soil structure and function often develop as a result of application of conventional tillage or reduced tillage regimes. Previous studies have shown that microbial biomass is higher in soils under no till plot compared to conventional tillage practices (Alvear *et al.*, 2005; Bausenwein *et al.*, 2008; Spedding *et al.*, 2004).

Microbial biomass provides an indicator of SOC degradation since it has a turnover time of less than one year. It responds rapidly to changes in conditions and management that alter SOC levels. Tillage affects both soil microbial biomass carbon and mineralizable carbon because it allows fast breakdown of SOC. Tillage reduces aggregation (Jastrow, 1996) and results in decline of SOC (Sainju *et al.*, 2006; Bossuyt *et al.*, 2002). Tillage breaks down aggregates and alters aggregate size distribution, typically by decreasing the proportion of macroaggregates in soil (Wright *et al.*, 2008). Grandy and Robertson (2006) observed that years of soil regeneration can be lost after a single conventional tillage (CT) event, hence, no tillage (NT) is an option that can be used to reduce the adverse effects of CT.

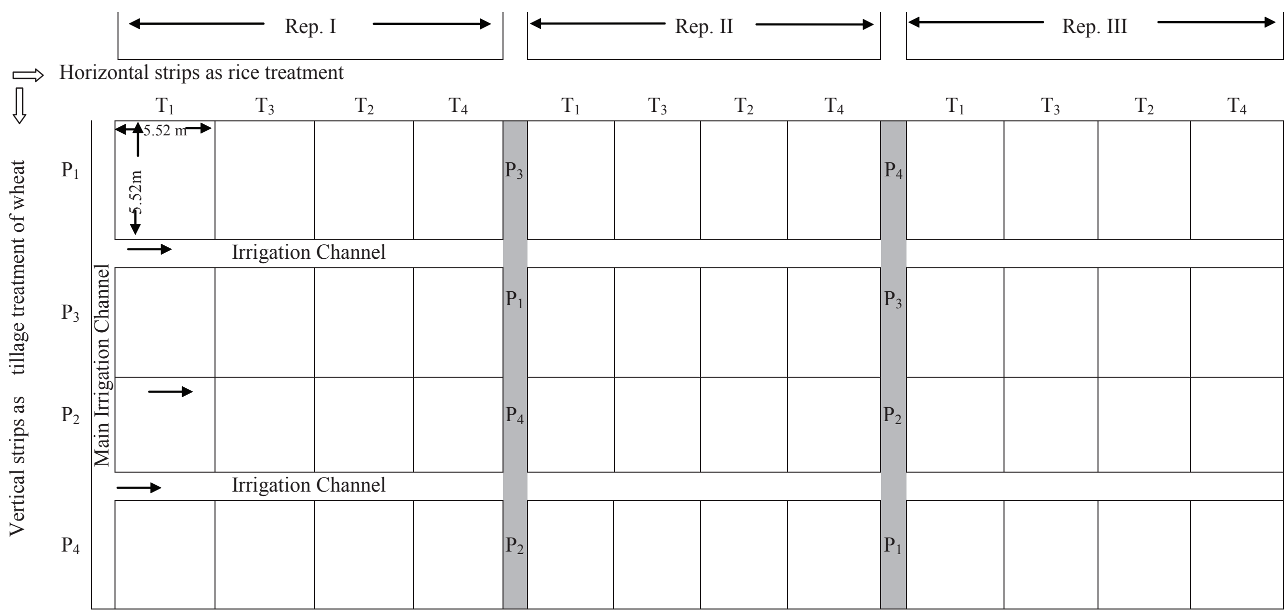
The objectives of this study were to determine the impact of different resource conservation technologies consisting establishment techniques of rice and different tillage practices of wheat on SOC, MBC and soil aggregation in rice-wheat cropping system.

Material and methods

Experimental Site

A field experiment was conducted for 7 years (2003-04 to 2009-10) at the research farm of Banaras Hindu University, Varanasi (25º18´N and 80030 E, 128.93 m above sea mean level), Uttar Pradesh, on a sandy

Fig. 1 Layout of the permanent experimental plots



loam soil (Typic Haplaquept) under the aegis of All India Co-ordinated Research Project on Integrated Farming System (AICRP IFS). The soil (0-15 cm deep) of the experimental site had a pH of 7.9, EC of 0.22 dS m^{-1}, bulk density of 1.34 Mg m^{-3}, SOC of 4.0 g kg^{-1}, available N of 185.2 kg ha^{-1}, $NaHCO_3$ extractable P of 12.1 kg ha^{-1} and 1N ammonium acetate extractable K of 212.0 kg ha^{-1}. As per the mean of 50 years, (1960-2010) the annual rainfall of the area remains around 1081 mm.

Experimental Design and Treatments

The trials consisted of four rice planting treatments in the rainy season and four tillage practices in winter wheat. The four rice crop establishment techniques in rainy season were P_1: direct drilling rice in zero tilled plot, P_2: sprouted rice seeded with drum seeder –wet seeded rice, P_3: manual transplanting in puddled plot, P_4: mechanical transplanting in puddled plot and four tillage practices in wheat during winter season were T_1: rotavator till drilling, T_2: conventional tilled sowing, T_3: strip till drilling, T_4: zero till drilling. They were placed in strips using strip plot design (Gomez and Gomez, 1984) and replicated three times. In this design, the rice crop establishment treatments were in strip plot of 5.5 × 22.1 m size horizontally within each replication. In winter season, sowing of wheat under varying tillage options, the same size strips were assigned randomly and arranged vertically or perpendicular to rice crop establishment plots within each replication to understand the interaction effect in a measured area of 5.5 × 5.5 m (**Fig. 1**).

Crop Management

The sowing of rice (cultivar PHB-71) in direct drilling under zero tilled plots before onset of monsoon (P_1), in nursery to get seedlings for manual transplanting (P_3) and mechanical transplanting by self propelled transplanter (P_4) and sprouted seeds (24 hour soaked) used in drum seeder (P_2) were performed on same day. The seed rate for rice in planting treatments was 70 kg ha^{-1} for direct seeding, 35 kg ha^{-1} sprouted seeds through drum seeder in wet field, while, 30 and 20 kg ha^{-1} seeds were used for growing of seedling for manual and self propelled transplanter, respectively. Direct seeding of rice in dry bed was performed under no till conditions of field through zero till drill while for transplanting (both through manual and mechanical transplanter) and drum seeder in puddled field consisted of one cultivator, two puddling and one planking. Twenty one days old seedlings were used for manual and mechanical transplanting. The seedlings were raised on mat type nursery and these seedlings were used for transplanting through self propelled rice transplanter. All direct seeded plots received frequent irrigation to keep the soil wet. After harvesting of rice, a pre sowing irrigation was given to the all plots to ensure optimum moisture in the soil at sowing. The wheat was sown by different methods immediately after harvest of rice. The rotavator till drilling (T_1) was done after one pass of rotavator. However, in conventional sowing of wheat (T_2), one cultivator, two harrows followed by one planking were performed before sowing of wheat. Under zero till drilling of wheat (T_4), sowing was done directly without land preparation in standing rice stubbles of about 20 cm height (about 2 Mg ha^{-1}) which was left in field as a mulch and for strip till drilling of wheat, sowing (T_3) was done directly using strip till drill in single pass where about 7.5 cm strip was tilled through PTO operated rotary blade in front of tynes before sowing.

The fertilizer dose for both crops i.e. rice and wheat were 120: 60: 60 kg N: P: K ha^{-1}. Full dose of P through single super phosphate and K through muriate of potash were applied at the time of land preparation in tilled plots, before seeding in the zero tilled plots. Nitrogen was applied in three splits, ½ at field preparation, ½ in two equal splits at the active tillering and at the panicle initiation stages of crops (rice and wheat) growth. The experimental plots were kept weed free in rice crop in zero till drill after application of glyphosate (N-(phosphonomethyl)-glycine) at the rate 1.5 kg ha^{-1} active ingredient as post emergence non selective herbicide followed by two hand weedings at 20 and 40 DAS (day after sowing) and in drum seeded rice, pendimethalin (N-(1-ethylpropyl)-2,6-dinitro-3,4-xylidine) 30 EC at the rate of 1.25 kg ha^{-1} and manually and mechanically transplanted, butachlor (N-(butoxymethyl)-2-chloro-N (2,6-diethylphenyl) acetamide) 50 EC at the rate of 2 kg ha^{-1} active ingredient after 5 days after transplanting followed by one hand weeding 30 days after transplanting. Wheat (cultivar HUW-234) was sown during the second week of November in all the years. Sulfosulfuron 1-(4,6-dimethoxypyrimidin-2-yl)-3-[(2-ethanesulfonylimidazo 1,2-a]pyridine) sulfonyl] urea at rate 30 g active ingredient ha^{-1} was applied 30 days after sowing in all plots to control weeds in wheat. Full dose of P and K were applied at the time of sowing, and N was applied in two equal splits at the time of sowing and grown root initiation stages. Both rice and wheat crop were irrigated according to the irrigation schedules in the different treatments.

Soil Sampling and Analysis

Undisturbed soil cores (15 cm long and 7.6 cm diameter) in triplicates were obtained from 0-15, 15-30, 30-45 and 45-60 cm soil layers after the harvest of wheat in 2010 from each plot randomly. Composite samples were prepared after mixing different cores of each depth. Samples were air-dried and each sample was divided in two parts. One part was used for chemical analysis while the other was used for determination of aggregate size distribution (Yoder, 1936) and mean weight diameter (MWD). SOC was estimated using the $K_2Cr_2O_7$ wet-digestion method (Walkey and Black, 1934).

Soil MBC was analyzed by the fumigation extraction method (Anderson and Ingram, 1993; Vance *et al.*, 1987). For MBC each sample was further sub-divided into two equivalent portions, one was fumigated for 24 h with ethanol free chloroform and other was the unfumigated control. Both fumigated and unfumigated soils were shaken for 30 min with 0.5 M K_2SO_4 (1 : 4 soil : extraction ratio) and centrifuged and filtered through a membrane filter with 0.45 µm pores. The MBC in the soil extracts was determined originally by wet digestion with $K_2Cr_2O_7$ followed by back- titration with ferrous ammonium sulphate and was calculated as difference in extractable C before and after fumigation using a KC value 0.45 (Wu *et al.*, 1990).

Soil water stable aggregates (WSA) > 0.053 were determined by wet sieving procedure (Cambardella and Elliot, 1993). Approximately 100 g of air dried soil were taken for aggregate (diameter 5-8 mm) analysis. Soil samples were immersed in water on a nest of sieves (4.76, 2.0, 1.0, 0.50, 0.25, 0.11 and 0.053 mm) for 10 min before start of wet sieving action. The sieve nest was then clamped and secured to the drum. The assembly was oscillated up-down by a pulley arrangement for 30 min at a frequency of 30-35 cycles min-1 with a stroke length of 4 cm in salt free water inside the drum. The WSA retained on the sieves were then backwashed into pre-weighed containers, oven-dried at 50 ºC for 2-3 days, and weighed. The weight of oven dried soil of each size was expressed as percentage of the total weight. The mean weight diameter (MWD, mm) was calculated using the following relationship (van Bavel, 1949):

$$MWD = (\sum\nolimits^{n}_{i=1} wixi) / W$$

Where, w_i is the weight of soil of the i^{th} size fraction x_i is the average diameter of that size class and W is the total weight of aggregates of all the size classes (n).

Geometric mean diameter (GMD, mm) was calculated as follows.

$$GMD = exp\ [\sum_{i=1}^{n} (Wi \times In\ (Xi)]$$

Where W_i is the mean proportion of aggregates fraction *i* and X_i is the mean diameter of aggregate fraction *i* (Kremper and Chepil 1965).

Statistical analysis was carried out using the methods suggested by Gomez and Gomez (1984). All parameters were analysed as a strip plot model (rice crop as horizontal and wheat crop as vertical factor). Tillage treatments for each crop establishment means were separated using least significant difference (LSD) at P < 0.01. The correlation matrix was developed among SOC, MBC, WSA and MWD. Regression equations were developed between SOC, MBC with WSA and MWD.

Results and Discussion

Effect of Tillage and Crop Establishment on Aggregate Size Distribution, Mean Weight Diameter (Mwd) and Geometric Mean Diameter (Gmd)

The total soil water stable aggregate (WSA) > 0.053 mm, at 0-15 cm depth, ranged between 69.92 and 88.78 % which ranked in order $P_1 > P_2 > P_4 > P_3$ in different rice strip as well as in wheat strip, ranged between 74.62 and 83.57 % that ranked in order $T_4 > T_3 > T_1 > T_2$ and both

Table 1 Effect of tillage and planting management on aggregate size distribution (%) of soil at (0-15) cm soil depth in rice-wheat cropping system

Treatment	Total WSA	> 4.76 mm	1.0-2.0 mm	0.5-1 mm	0.25-0.5 mm	< 0.25 mm	Macro aggregate	> 0.11 mm	< 0.053 mm	Micro aggregate
P_1	88.78	8.80	8.41	10.74	12.31	14.48	51.07	17.97	19.74	37.71
P_2	81.88	4.97	5.85	9.00	9.71	12.26	39.52	18.99	23.37	42.36
P_3	69.92	4.69	5.53	4.67	4.84	8.04	21.13	22.64	26.15	48.79
P_4	73.36	5.96	5.65	12.53	6.57	10.27	27.79	20.92	24.66	45.57
LSD (P = 0.05)	3.06	0.33	0.23	0.06	0.44	0.60	1.67	1.55	0.50	1.68
LSD (P = 0.01)	4.63	0.49	0.35	0.09	0.67	0.91	2.53	2.35	0.76	2.55
T_1	76.51	5.39	6.69	7.81	7.62	10.72	32.23	20.48	23.80	44.28
T_2	74.62	3.07	5.80	9.13	6.97	9.96	29.82	20.51	24.29	44.80
T_3	79.24	6.95	6.31	8.72	8.81	11.60	35.52	20.32	23.40	43.73
T_4	83.57	9.01	6.64	11.27	10.04	12.77	41.94	19.20	22.42	41.62
LSD (P = 0.05)	1.11	0.08	0.37	0.05	0.27	0.41	0.98	0.50	0.46	0.32
LSD (P = 0.01)	1.68	0.12	0.56	0.08	0.41	0.62	1.49	0.76	0.70	0.49

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at (P < 0.05 and P < 0.01)

strip treatments had significant values ($P < 0.01$). The treatment T_4 was significantly ($P < 0.01$) higher than other treatments (i.e. T_1, T_2 and T_3) which were significantly ($P < 0.05$) at par. However, T_1 and T_3 were statistically ($P < 0.05$) at par but higher than T_2. In lower depth (15-30 cm), the total WSA had similar trend but lower aggregate value. Among the different treatments (**Table 1**), in rice strip, the proportion of micro-aggregates (42.36, 48.80, 45.57 %) was greater as compared to macro-aggregates (39.53, 21.13, 27.79 %) in P_2, P_3 and P_4, respectively, however, P_1 had smaller proportion of micro-aggregates (37.71 %) than macro-aggregates (51.07 %) under surface (0-15 cm) depth. In wheat strip, higher proportion of micro-aggregates was observed which ranked in the order of $T_2 > T_3 > T_1$ than macro-aggregates. Among the macro-aggregates (0.25-4.76 mm), it ranked in order $P_1 > P_2 > P_4 > P_3$ in rice strip, whereas, in wheat crop, it ranked in order $T_4 > T_3 > T_1 > T_2$ and both had significant (at $P < 0.01$) differences each other and vice versa in micro-aggregates. The reason may be because of intensity of mechanical manipulation of soil through tillage had given higher proportion of micro-aggregates. Whereas, in 15-30 cm soil depth (**Table 2**), irre-

Table 2 Effect of tillage and planting management on aggregate size distribution (%) of soil at (15-30) cm soil depth in rice-wheat cropping system

Treatment	Total WSA	> 4.76 mm	1.0-2.0 mm	0.5-1 mm	0.25-0.5 mm	< 0.25 mm	Macro aggregate	> 0.11 mm	< 0.053 mm	Micro aggregate
P_1	72.62	1.05	1.27	3.51	6.42	13.33	25.57	18.68	28.37	47.05
P_2	69.62	0.68	2.03	4.27	6.21	13.55	26.74	20.09	22.79	42.88
P_3	47.48	0.65	1.14	2.58	2.16	10.16	16.69	9.51	21.28	30.79
P_4	59.88	0.92	1.73	3.96	3.23	11.14	20.98	14.30	24.60	38.90
LSD (P = 0.05)	3.13	NS	0.77	0.44	1.52	4.71	3.20	0.01	0.84	0.84
LSD (P = 0.01)	4.74	NS	1.17	0.67	2.30	7.13	4.85	0.01	1.27	1.27
T_1	62.94	0.71	2.26	3.74	4.33	10.86	21.89	17.07	23.98	41.05
T_2	56.64	1.01	0.99	3.11	3.14	10.21	18.46	14.81	23.37	38.18
T_3	61.16	0.59	1.58	3.85	5.39	13.20	24.61	12.58	23.97	36.55
T_4	68.85	0.98	1.35	3.63	5.15	13.92	25.02	18.11	25.72	43.84
LSD (P = 0.05)	2.11	NS	0.53	0.44	0.73	2.53	1.76	0.01	0.87	0.86
LSD (P = 0.01)	3.19	NS	0.81	0.67	1.11	3.83	2.66	0.01	1.31	1.31

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at ($P < 0.05$ and $P < 0.01$), **WSA:** Water Stable Aggregate

Table 3 Effect of tillage and planting management on MWD (mm) of total soil aggregate in different soil depth under rice wheat cropping system

Soil depth (cm)										
	(0-15)					(15-30)				
P/T	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
P_1	0.48	0.42	0.47	0.58	0.49	0.15	0.12	0.17	0.16	0.15
P_2	0.30	0.29	0.34	0.52	0.36	0.18	0.12	0.14	0.17	0.15
P_3	0.18	0.17	0.20	0.21	0.19	0.12	0.09	0.10	0.19	0.12
P_4	0.24	0.22	0.25	0.28	0.25	0.12	0.15	0.12	0.13	0.13
Mean	0.30	0.28	0.32	0.40	0.32	0.14	0.12	0.13	0.16	0.14
LSD of P (horizontal strip)				(P = 0.05)	0.018					NS
				(P = 0.01)	0.027					NS
LSD of T (vertical strip)				(P = 0.05)	0.009					NS
				(P = 0.01)	0.014					NS
LSD of P at same level of T				(P = 0.05)	0.033					NS
				(P = 0.01)	0.048					NS
LSD of T at same level of P				(P = 0.05)	0.022					NS
				(P = 0.01)	0.029					NS

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting –puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at ($P < 0.05$ and $P < 0.01$), **MWD-** Wet mean weight diameter.

spective of treatments in both strip, the proportion of micro-aggregates (0.25-4.76 mm) was greater as compared to macro-aggregates (0.053-0.11mm). In micro-aggregates, < 0 .053 mm fraction constituted significantly (P = 0.01) higher portion in P_1 than P_2, P_3 and P_4 as well T_4 as compared to T_1, T_2, T_3 in treatments of rice and wheat strip, respectively.

The highest MWD values were observed in P_1 (0.49 mm) and lowest in P_3 (0.19 mm) in rice strips while in wheat strip, the highest were in T_4 (0.40 mm) and lowest in T_2 (0.28 mm) in 0-15 cm soil layer (**Table 3**). The MWD values, however, drastically decreased from 0-15 to 15-30 cm soil depth, which varied from 0.12 to 0.15 mm in rice strip and 0.12 to 0.16 mm in wheat strip (Table 3). They ranked in the order of $P_1 > P_2 > P_4 > P_3$ in rice strip and $T_4 > T_3 > T_1 > T_2$ in wheat strip in 0-15 cm soil depth.

Significantly higher GMD was observed in P_3 (0.29) followed by P_4 (0.21), P_2 (0.19) and P_1 (0.15) in rice strip, however, in wheat strip, highest GMD was in T_2 (0.25) followed by T_3 (0.22), T_1 (0.19) and T_4 (0.17) under 0-15 cm soil depth (**Table 4**). The GMD values increased from 0-15 to 15-30 cm soil depth. At 15-30 cm depth, it was significantly (P < 0.01) higher in P_3 (0.48) than others treatments as P_4 (0.32), P_2 (0.19) and P_1 (0.19) in rice strip, and wheat strip, significantly greater GMD was in T_2 (0.37) as compared to T_1 (0.32), T_3 (0.27) and T_4 (0.23). Like SOC and MBC concentration, the interaction effects of P on MWD at same level of T and T at same level of P treatments were significant (at P < 0.01) at 0-15 cm soil depth, however, it was non- significant at soil depth layer (15- 30 cm). Whereas, GMD had shown significant (at P < 0.01) interaction effect at both level (i.e. effect of P at same level of T and T at same level of P treatments) and soil depths (i.e. 0-15 and 15-30 cm).

The effect of tillage practices in wheat strips and crop establishment methods in rice crop strips on soil structural properties deserved to be discussed in terms of tillage induced differences in: (i) SOC concentration and (ii) MBC. Higher SOC and MBC concentration in surface soil layer (0-15 cm) in "no till system" in both the crops may lead to greater aggregate stability (Lal *et al.*, 1994; Bhattacharyya *et al.*, 2008). The decreased aggregate size with reduced or conventional tillage either crop or both crops could be attributed to mechanical disruption of macro aggregates. That disruption may have exposed soil organic matter previously protected against oxidation (Pin-heiro *et al.*, 2004).

The higher amount of WSA in zero tillage plots can be ascribed to regular addition of organic matter through additional root biomass added to soil resulting in greater C availability and enhanced microbial activity, which helped in binding of aggregates. Puget *et al.* (1995) also reported reduction in the amount of WSA as a result of tillage. In this study, drum seeded (P_2), manual transplanting (P_3) and mechanical rice transplanting (P_4) fields were puddled in the standing water after wet tilling before transplanting and it was again cultivated in friable moisture level for wheat cultivation every year. This could have resulted in breaking down of macro-aggregates to smaller size aggregates. Further as opposed to milder wetting and sieving techniques, slaking

Table 4 Effect of tillage and planting management on GMD of total soil aggregate in different soil depth under rice wheat cropping system

	Soil depth (cm)									
	(0-15)					(15-30)				
P/T	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
P_1	0.13	0.20	0.16	0.11	0.15	0.20	0.26	0.11	0.18	0.19
P_2	0.19	0.25	0.22	0.10	0.19	0.20	0.26	0.18	0.13	0.19
P_3	0.24	0.31	0.32	0.28	0.29	0.49	0.67	0.40	0.37	0.48
P_4	0.19	0.26	0.20	0.19	0.21	0.38	0.28	0.39	0.23	0.32
Mean	0.19	0.25	0.22	0.17	0.21	0.32	0.37	0.27	0.23	0.30

		(0-15)	(15-30)
LSD of P (horizontal strip)	(P = 0.05)	0.031	0.024
	(P = 0.01)	0.048	0.037
LSD of T (vertical strip)	(P = 0.05)	0.032	0.023
	(P = 0.01)	0.049	0.035
LSD of P at same level of T	(P = 0.05)	0.071	0.053
	(P = 0.01)	0.036	0.031
LSD of T at same level of P	(P = 0.05)	0.072	0.052
	(P = 0.01)	0.033	0.024

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at (P < 0.05 and P < 0.01), **GMD-** Geometric mean diameter

destroys the relatively less stable macro aggregates leaving behind only more stable micro-aggregates. Occurrence of relatively lower proportion of micro aggregates in no tilled or less tilled plots was observed only due to less mechanical destruction of macro aggregates.

The greater sensitivity of soil aggregate to tillage effects is not surprising since analysis of components (Lupwayi *et al*., 2001). The primary effect of tillage results in physically disturbance of soil structure. Higher tillage usually disrupts soil aggregates and lowers SOC and MBC (Jiang and Xie, 2009; Jiang *et al*., 2011). The specific effect however depends largely on the disturbance that occurs at the spatial scale to which the microorganisms are most sensitive (Young and Ritz, 2000). Studies in Texas (Unger, 1982; Nuttall *et al*., 1986) showed that tillage decreased aggregate stability. The results of these studies showed that tillage affected C availability to the microbial biomass by disrupting soil structure and exposing protected organic material. This may be responsible for lower MWD recorded tillage plots. Soil organic matter stabilizes soil aggregates by acting as a binding material (Tisdall and Oades, 1982) and their hydrophobic properties reduce the destructive internal hydration (Chenu *et al*., 2000). In conventional agricultural systems, the soil aggregates are unstable and do not resist repeated wetting-drying cycles (Park and Smucker, 2005).

The crop rotation of maize and wheat on a sandy loam soil with minimum tillage and surface retention has been found to improve mean weight diameter aggregates and water retention and decreased soil bulk density (Ghuman and Sur, 2001). In tropical soils, an increase in soil aggregation has been found under no tillage practices (Six *et al*., 2002). The importance of micro aggregates to stabilize soil organic matter has been emphasised (Helfruch *et al*., 2008). Most of soil organic matter could be sequestered as a mineral associated fraction (Jastrow, 1996; Zotaralli *et al*., 2007). Long-term minimum tillage enhanced the physical protection of organic carbon and nitrogen in Haplic Luvisols (Jacob *et al*., 2009).

In this study, it was found that water stable aggregates responded to the tillage systems. In rice cropping, puddling could result in the destruction of soil aggregates (Sharma and De Dutta, 1985). A puddle soil consists of a solid-liquid system in which individual clay particles or clusters are oriented in parallel rows and are surrounded by capillary pores saturated with water (Sharma and De Dutta, 1985). Sand and clay particles and some aggregates are parts of soil matrix. However, the degree of aggregation destruction due to puddling irrigation or water logging is difficult to quantify because drying is necessary to measure aggregation. In the present study, the soil aggregates during the rice growing seasons were quantified only after crop harvest from the dry soil.

In tropical and sub tropical conditions, soil aggregation has been found to increase during the early years of no tillage adoption (Six *et*

Table 5 Effect of tillage and planting management on organic carbon (g kg^{-1}) at different soil depth in rice wheat cropping system

	Soil depth (cm)																			
	(0-15)					(15-30)					(30-45)					(45-60)				
/T	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
PP_1	5.66	4.83	5.76	6.44	5.67	3.93	2.96	4.22	4.68	3.95	2.49	2.44	3.51	3.71	3.04	1.46	1.37	1.61	1.76	1.55
P_2	4.54	4.44	4.93	5.71	4.90	3.65	3.60	3.72	4.22	3.80	2.49	2.34	2.63	3.66	2.78	1.17	1.12	1.32	1.61	1.30
P_3	3.89	4.04	4.09	4.22	4.06	2.29	2.24	2.44	2.57	2.38	2.01	2.00	2.11	2.12	2.06	1.00	1.00	1.01	1.02	1.01
P_4	4.24	3.95	4.54	4.59	4.33	2.75	2.13	2.46	2.60	2.48	2.15	2.13	2.18	2.20	2.16	1.05	1.03	1.06	1.19	1.08
Mean	4.58	4.32	4.83	5.24	4.74	3.16	2.73	3.21	3.52	3.15	2.28	2.23	2.61	2.92	2.51	1.17	1.13	1.25	1.40	1.24
LSD of P (horizontal strip)	(P = 0.05)				0.33					0.15					0.07					0.17
	(P = 0.01)				0.49					0.23					0.11					0.26
LSD of T (vertical strip)	(P = 0.05)				0.12					0.18					0.15					0.04
	(P = 0.01)				0.19					0.28					0.23					0.06
LSD of P at same level of T	(P = 0.05)				0.70					0.33					0.21					0.31
	(P = 0.01)				1.04					0.47					0.30					0.45
LSD of T at same level of P	(P = 0.05)				0.63					0.38					0.31					0.10
	(P = 0.01)				0.85					0.51					0.41					0.14

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at ($P < 0.05$ and $P < 0.01$)

al., 2002). Conventional tillage leads to increased soil disruption and increased decomposition of soils organic matter due to exposure of soil to wet and dry cycles (Beare *et al*., 1994 a, b) changes in soil conditions due to ploughing (Camberdella and Elliot, 1993) and disruption of the microbial community (Holland and Coleman, 1987) Madari *et al.* (2005) reported that no tillage along with residue covers improved aggregate stability, aggregate size classes and total organic carbon in soil aggregates. In this study, about seven years of zero, tillage improved soil micro aggregates in surface layer (0-15 cm) of soil. In minimum tillage systems new aggregates were formed due to incorporation of crop residues in the soil and storage of excess organic matter in biochemically degraded fraction especially in the surface soil (Jacobs *et al*., 2009a).

Effect of Tillage and Crop Establishment on Soil Organic Carbon (SOC)

The SOC ranged from 4.06 to 5.67, 2.38 to 3.95, 2.06 to 3.04, 1.01 to 1.55 g kg^{-1} in rice strip and from 4.32 to 5.24, 3.15 to 3.52, 2.23 to 2.92 and 1.13 to 1.40 g kg^{-1} in different tillage treatment in wheat strip in 0-15, 15-30, 30-45 and 45-60 cm soil layers, respectively (**Table 5**). The SOC ranked in order $P_1 > P_2 > P_4 > P_3$ which had significant (P< 0.01) differences in rice crop establishment treatment in all soil depths. However, in the different tillage treatments in wheat crop, the SOC content had significant ($P < 0.01$) differences and ranked in order $T_4 > T_3 > T_1 > T_2$ under 0-15 cm soil depth. The highest SOC of treatment P_1 (5.67 g kg^{-1}) in rice strip and T_4 (5.24 g kg^{-1}) in wheat strip was observed, however, the lowest values were 4.06 g kg^{-1} in P_3 and 4.32 g kg^{-1} in T_2 in 0-15 cm soil depth. Similar trends were noticed in all other soil layer. However, when it was compared in each strip to see overall effect, it was observed highest in P_1T_4 (6.4 g kg^{-1}) and lowest in P_3T_1 (3.89) and P_4T_2 (3.95 g kg^{-1}). The increase of SOC was observed 65.6 and 59.4 % with P_1T_4 over P_3T_1 and P_3T_2, respectively, It was because of treatment P_1T_4 in both the crops was grown in no till conditions from 2003 to 2010 (7 years). The interactions of P at same level of T and T at same level of P were significant at $P < 0.001$ at all soil depth. Treatment T_4 had shown significantly (at $P < 0.01$) highest and lowest in T_2 of SOC at same level of P_1, P_2, P_3 and P_4. It was due to no tilled condition maintained in both crop seasons. However, treatment P_1 had significantly (at $P < 0.01$) highest but lowest value was in P_3 at same level of T_1, T_2, T_3 and T_4.

The decrease in SOC an average all treatments was about 51 and 89 percent from layer 0-15 to 15-30 and 30-45 cm, respectively. However, very low SOC content (1.0 g kg^{-1}) was observed in 45 -60 cm soil depth. Edwards *et al.* (1992) had reported that conservation tillage increased the SOC about 56 % as compared to conventional tillage over a 10 year period. Increase in organic carbon content with reduced and no tillage treatment has been reported previously by others, al-

Table 6 Effect of tillage and planting management on MB-C (μg g^{-1} soil) in different soil depth under rice wheat cropping system

Soil depth (cm)																				
(0-15)						(15-30)					(30-45)					(45-60)				
/T	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
PP_1	420	419	438	489	441	377	368	401	452	399	313	305	343	386	337	248	240	260	307	263
P_2	367	363	397	441	392	343	327	352	409	358	287	275	298	354	304	202	180	217	270	217
P_3	282	260	291	299	283	233	209	242	247	232	145	125	164	175	152	68	47	86	100	75
P_4	307	296	318	351	318	276	252	296	300	281	196	189	219	234	210	128	118	139	165	138
Mean	344	334	361	395	359	307	289	323	352	318	236	224	256	287	251	162	146	175	211	173
LSD of P (horizontal strip)			(P = 0.05)		11.7					3.3					5.1					6.0
			(P = 0.01)		17.7					5.0					7.7					9.2
LSD of T (vertical strip)			(P = 0.05)		3.8					1.8					3.4					5.9
			(P = 0.01)		5.8					2.7					5.1					9.0
LSD of P at same level of T			(P = 0.05)		23.1					6.8					9.8					13.3
			(P = 0.01)		33.0					9.7					14.1					18.7
LSD of T at same level of P			(P = 0.05)		14.3					5.1					7.4					13.1
			(P = 0.01)		19.5					7.0					10.0					17.7

Horizontal strip for rice crop: P_1- Direct drilling in zero tilled plot, **P_2-** Seeding sprouted rice with drum-puddled plot, **P_3-** Manual transplanting–puddled plot, **P_4-** Mechanical transplanting–puddled plot. **Vertical strip for wheat crop: T_1-** Rotavator till drilling, **T_2-** Conventional tilled sowing, **T_3-** Strip till drilling, **T_4-** Zero till drilling.
LSD- Least Significant Difference at ($P < 0.05$ and $P < 0.01$)

though the results varied with soil type, crops, kind of management, and climate. Other studies have also indicated a higher organic carbon content under RT and NT practices compared to CT practices (Hooland, 2004). Many of the soil quality parameters (Bhattacharyya *et al.*, 2008) are generally related to soil organic matter content and its quality (Gregorich *et al.*, 1994), therefore it is of prime importance to increase or preserve the soil organic matter content for the physical, chemical and biological quality of soil (Bradford and Peterson, 2000). No tilled and reduced tillage could promote soil C storage due to a proportionate increase in both bacterial and fungal biomass (Van Groenigen *et al.*, 2010). According to Bell *et al.* (2003), soil management to increase SOC is due to less mixing and aeration of residues and the promotion and stabilization of aggregates especially in the surface soil layer. These data strengthen the statement that tillage has much more importance in SOC preservation than stubble management. In undisturbed soil in treatment P_1T_4 in both crop seasons (i.e. rice in rainy season and wheat in winter season) where plant residue of about 2 Mg ha^{-1} was left on the soil surface and not incorporated into the soil by tillage, the slow surface residue decomposition could provide additional organic N & C (Drinkwater *et al.*, 1998) to promote the growth of microorganisms that produce adhesive agents for the stabilization of the aggregates (Beare *et al.*, 1994). It has been reported that the conservation tillage systems increase the storage of soil organic matter and the stability of macro aggregates compared to conventional tillage in various types of soils and climatic regions (Paustian *et al.*, 2000; Six *et al.*, 2000; Kushwaha *et al.*, 2001; Jacobs *et al.*, 2009b). The zero tillage in rice -wheat systems has been found to be increase soil carbon, crop yield and nitrogen uptake (Neelam and Gupta, 2009). During tillage, soil aggregates are broken, increasing oxygen supply and surface area exposure of organic material, this promotes the decomposition of organic matter. In the addition to serving as a storage compartment for nutrients, soil also contributes to improving soil physical characteristics. In upland soils, SOM improves soil structures and trafficability, but the degree of improvement again depends on particle size distribution. Sandy soils with low SOM contents lack substantial structure and are prone to severe erosion. Adding crop residues or manure will increase microbial activity, which in some studies has led to the build up of SOM and the formation of macro and micro aggregates (Angers *et al.*, 1993; Sparling *et al.*, 1992). Differences in aggregate stability also depend on the sources of the organic materials (Tisdall, 1991). On the other end of the particle spectrum heavy clay soils are often characterised by poor structure and aeration, but they can be improved through the addition of organic amendments. Therefore, the positive effect of SOM on soil structure will be more pronounced for a clay soil than for a silty soil.

Effect of Tillage and Crop Establishment on Soil Microbial Biomass Carbon (Mbc)

The MBC ranged from 283 to 441 μg g^{-1} in 0-15 cm, 232 to 399 μg g^{-1} in the 15-30 cm and decreased with depth (i.e. 75 to 263 μg g^{-1} in 45 to 60 cm) in rice strip plot (**Table 6**). While in wheat strip, it ranged from 289 to 352 μg g^{-1} in 15-30 cm soil layer and 224 to 287 μg g^{-1} in 30-45 cm layer in wheat strip. MBC decreased with depth in wheat strip ranging from 146 to 211 μg g^{-1} in 45-60 cm depth. Significantly ($P < 0.01$) higher MBC was observed under treatment P_1 (441 μg g^{-1}) in rice strip and T_4 (395 μg g^{-1}) in wheat strip than other treatments and lowest was in P_3 (283 μg g^{-1}) and T_2 (334 μg g^{-1}) at 0-15 cm soil depth. Significant differences (at $P < 0.01$) in MBC were recorded in order $P_1 > P_2 > P_4 > P_3$ of rice crop strip and $T_4 > T_3 > T_1 > T_2$ in wheat crop strip under 0-15 cm soil depth. Similar trend were also observed in the other soil layer. MBC in all treatments decreased by 13 and 43 % from 0-15 to 15-30 and 30-45 cm soil depth, however, very low MBC content (75 μg g^{-1}) was observed in 45-60 cm soil depth. The strip of zero till drill in both crops had significantly (at $P < 0.01$) higher MBC contents. It was observed that an average MBC was about 8, 14, 13 and 19 % of the SOC in 0-15, 15-30, 30-45 and 45-60 cm soil layer, respectively.

The interaction of P at same level of T and T at same level of P were significant at ($P < 0.01$). It was observed highest in P_1T_4 (489 μg g^{-1}) and lowest in P_3T_2 (260 μg g^{-1}). Significantly highest MBC in T_4 and lowest in T_2 were observed at same level of P_1, P_2, P_3 and P_4. It was due to no tilled condition maintained in both crop seasons. However, treatment P_1 had significant at $P < 0.01$ highest and was lowest value in P_3 at same level of T_1, T_2, T_3 and T_4.

It has been widely reported that microbial biomass can be altered through tillage practices and is higher in soils under no tillage than conventional tillage (Feng *et al.*, 2003; Nyamadzawo *et al.*, 2009; Ganzalez-Chavez *et al.*, 2010). This study also confirms these findings. Soil microbial biomass was significantly greater in minimum/ no tillage treatments in both crops. Higher biomass under no tillage could be attributed to higher SOC under no tilled (Jiang *et al.*, 2011) and it was due to deposition and accumulation of residues in surface soil. Whereas, soil microbial biomass change associated with aggregates was different than the response for whole. Therefore, it was likely that tillage decreased soil microbial biomass mainly by decreasing the proportion in the whole soil. Soil microbial biomass carbon (MBC) was mainly concentrated within macro-aggregates and tillage initiated a shift from macro-aggregates to micro-aggregates and individual practices (Jiang *et al.*, 2011). It was likely that tillage decreased soil MBC mainly by decreasing the proportion of soil macro-aggregates in the whole soil. Microbial biomass can be altered through tillage practices and is greater in soils under no tilled plot (Mullen *et al.*, 1998). As observed for SOC, MBC decreased with soil depth. The enrichment of MBC in no tilled plot was generally related with SOC and WSA (Garcia- Gil *et al.*, 2000), and these parameters were positively correlated with MBC (Madejon *et al.*, 2007). In all treatments MBC decreased with the depth probably due to decrease of SOC which may have affected microbial growth.

Relationships Among SOC, MBC with Total WSA and MWD

Linear correlation coefficients between various properties measured in this study are shown **Table 7**. Soil organic carbon (SOC), microbial biomass carbon (MBC), water soluble aggregate (WSA) and mean weight diameter (MWD) were significantly (at $P < 0.01$) correlated with each other. Correlation matrix developed among SOC, MBC, WSA and MWD. The increase of SOC was positively and significantly ($P < 0.01$) correlated with MBC, WSA and MWD. Regression equation between SOC and total WSA ($y = 10.7x + 28.1$), SOC and MWD ($y = 0.11x - 0.19$) suggests a strong relationship which explained 95 % and 85 % variability respectively (**Fig. 2a**). Similarly, regression equation between MBC and total (WSA ($y = 0.18x + 10.7$), MBC and MWD ($y = 0.002x - 0.29$) also suggests strong relationship among MBC and soil aggregation which explained 77 and 52 % variability respectively (**Fig. 2b**). The similar results were also sown by Wang *et al.* (2011) and Madejon *et al.* (2007). The MBC was also positively and significantly ($P < 0.01$) correlated with WSA and MWD.

Table 7 Correlation matrix for SOC, MB-C, WSA and MWD

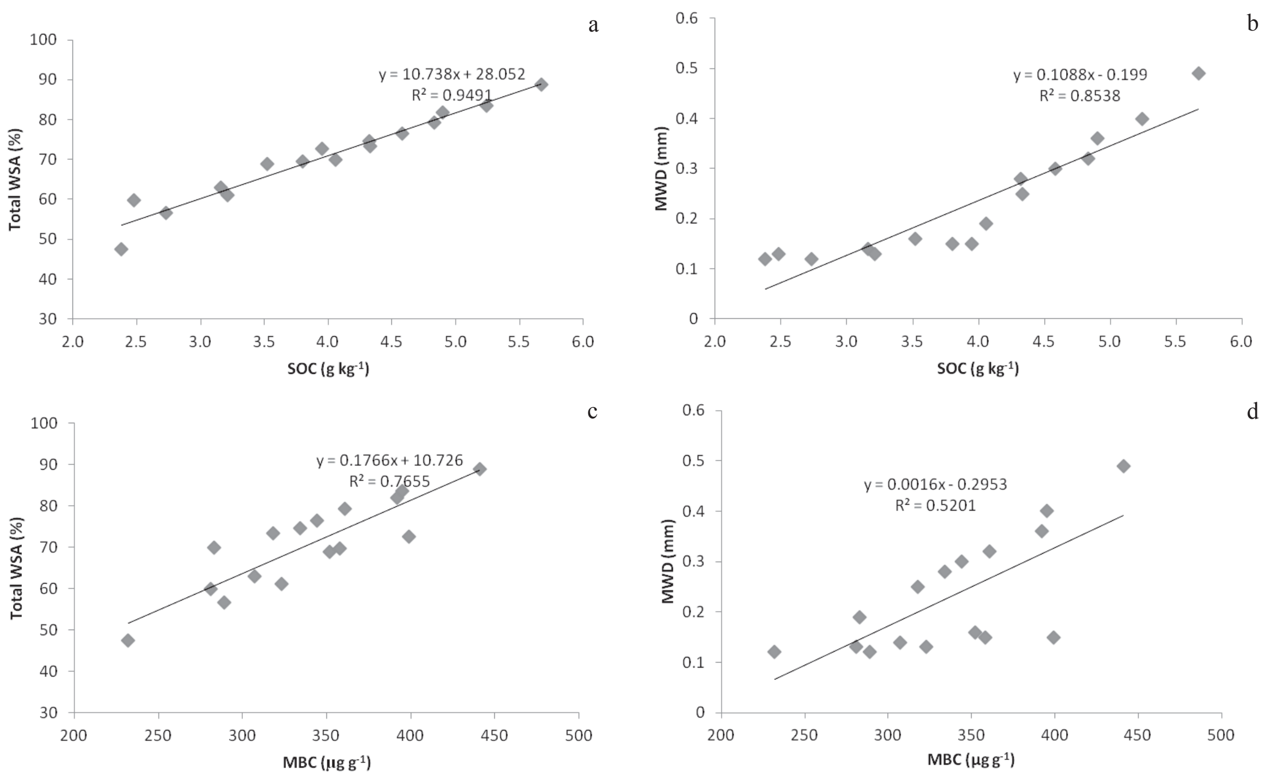
Parameters	SOC	MB-C	WSA	MWD
SOC	1			
MB-C	0.947**	1		
WSA	0.874**	0.963**	1	
MWD	0.671**	0.625**	0.638**	1

SOC: Soil organic carbon; MB-C: Microbial biomass carbon; WSA: Water soluble aggregate; MWD: Mean weight diameter
**Significant at (P=0.01)

Conclusions

It was concluded that direct drilling in zero tilled rice strip and

Fig. 2 Relationship between a: SOC with Total WSA, MWD and b: MBC with Total WSA, MWD



wheat sown in zero tilled strip had significantly higher SOC and MBC contents while it was lowest in conventionally sown wheat and manually transplanted rice in puddled field. However, the completely no till plots in both crops (i.e., P_1T_4) had shown the highest value of SOC and MBC and lowest was in conventional tilled plot in both seasons (i.e., P_3T_2). The total soil water stable aggregate content (WSA)> 0.053 mm and MWD (mm) had also shown similar trend like SOC and MBC. It may be recommended that in view of soil health (i.e., SOC and MBC) long term zero tilled /minimum tilled plot had shown higher value as compared to conventional tilled plot.

REFERENCES

Alvear, M. A., J. L. Rosas, and F. B. Rouanet. 2005. Effects of three soil tillage systems on some biological activities in an Ultisol from southern Chile. Soil Till. Res. 82, 195-202.

Anderson, J. M. and J. S. I. Ingram. 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Oxford, p. 221.

Angers, D. A., N. Samson, and A. Legere. 1993. Early changes in water-stable aggregation induced by rotation and tillage in soil under barley production. Can. J. Soil Sci. 73, 51-59.

Bajpai, R. K. and R. P. Tripathi. 2000. Evaluation of non-puddling under shallow water tables and alternative tillage methods on soil and crop parameters in a rice-wheat system in Uttar Pradesh. Soil Till. Res. 55, 99-106.

Bausenwein, U., A. Gattinger, U. Langer, A. Embcher, H. P. Hartmann, M. Sommer, J. C. Munch, and M. Schloter. 2008. Exploring soil microbial communities and soil organic matter: Variability and interactions in arable soils under minimum tillage practice. Appl. Soil Ecol. 40, 67-77.

Beare, M. H., M. L. Cabrera, P. F. Hendrix, and D. C. Coleman. 1994a. Aggregate-protected and unprotected organic matter pools in conventional and no-tillage soils. Soil Sci. Soc. Am. J. 58, 787-795.

Beare, M. H., P. F. Hendrix, and D. C. Coleman. 1994b. Water-stable aggregates and organic matter fractions in conventional and non-tillage soils. Soil Sci. Soc. Am. J. 58, 777-786.

Beare, M. H., P. F. Hendrix, and D. C. Coleman. 1994. Water stable aggregates and organic matter fractions in conventional and no tillage soils. Soil Sci. Soc. Am. J. 58, 77-786.

Bell, J. M., J. L. Smith, V. L. Bailey, and H. Bolton. 2003. Priming effect and C storage in semi-arid no tilled spring crop rotations. Biol. Fertil. Soils 37, 237-244.

Bhattacharyya, R., S. Kundu, S. C. Pandey, K. P. Singh, and H. S. Gupta. 2008. Tillage and irrigation effects on crop yields and soil properties under rice wheat system of the Indian Himalayas. Agric. Water Manage. 95, 993-1002.

Bhattacharyya, R., V. Prakash, S. Kundu, and H. S. Gupta. 2006. Effect of tillage and crop rotations on pore size distribution and soil hydraulic conductivity in sandy clay loam soil of the Indian Himalayas. Soil Till. Res. 82, 129-140.

Bhattacharyya, R., R. B. Ved-Prakash, S. Kundu, A. K. Srivastva, and H. S. Gupta. 2009. Soil aggregation and organic matter in a sandy clay loam soil of the Indian Himalayas under different tillage and crop regimes. Agric. Ecosyst. Environ. 132, 126-134.

Bossuyt, H., J. Six, and P. F. Hendrix. 2002. Aggregate protected carbon in no-tillage and conventional tillage agroecosystems usingc Carbon-14 labelled plant residue. Soil Sci. Soc. Am. J. 66, 1965-1973.

Bradford, J. M. and G. A. Peterson. 2000. Conservation Tillage. In: Sumner, M.E. (Ed.), Handbook of Soil Science. CRC Press, Boca Raton, USA, pp. 247-270.

Cambardella, C. A. and E. T. Elliot. 1993. Carbon and nitrogen distribution in aggregates of cultivated and native grassland soils. Soil Sci. Soc. Am. J. 57, 1071-1076.

Chenu, C., Y. Le Bissonnais, and D. Arrouays. 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Sci. Soc. Am. J. 64, 1479-1486.

Dick, W. A., E. L. McCoy, W. M. Edwards, and R. Lal. 1991. Continuous application of no-tillage to Ohio soils. Agron. J. 83, 65-73.

Drinkwater, L. E., P. Wagoner, and M. Sarrantonio. 1998. Legume based cropping systems have reduced carbon and nitrogen losses. Nature 396, 262-265.

Edwards, J. H., C. W. Wood, D. L. Thurlow, and M. E. Ruf. 1992. Tillage and crop rotation effects on fertility status of a Hapludult soil. Soil Sci. Soc. Am. J. 56, 1577-1582.

Elfstrand, S., B. Bath, and A. Martensson. 2007. Influence of various forms of green manure amendment on soil microbial community composition, enzyme activity and nutrient levels in leek. Appl. Soil Ecol. 36, 70-82.

Feng, Y., A. C. Motta, D. W. Reeves, C. H. Burmester, E. Van Santen, and J. A. Osborne. 2003. Soil microbial communities under conventional-till and no-till continuous cotton systems. Soil Biol. Biochem. 35, 1693-1703.

Frey, S. D., R. Drijber, H. Smith, and J. Melillo. 2007. Microbial biomass, functional capacity, and community structure after 12 years of soil warming. Soil Biol. Biochem. 40, 2904-2907.

Garcia-Gil, J. C., C. Plaza, P. Soler-Ravira, and A. Polo. 2000. Long term effects of municipal solid waste compost application on soil enzyme activities and microbial

biomass. Soil Biol. Biochem. 32, 1907-1913.
Ghuman B. S. and H. S. Sur. 2001. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a subhumid subtropical climate. Soil Till. Res. 58, 1-10.
Gomez, K. and A. Gomez. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons, New York, USA.
González-Chávez, C. A., J. A. Aitkenhead-Peterson, T. J. Gentry, D. Zuberer, F. Hons, and R. Loeppert. 2010. Soil microbial community, C, N, and P responses to long-term tillage and crop rotation. Soil Till. Res. 106, 285-293.
Govaerts, B., M. Mezzalama, Y. Unno, K. Sayre, M. Luna-Guido, K. Vanherck, L. Dendooven, and J. Deckers. 2008. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. Appl. Soil Ecol. 37, 18-30.
Grandy, A. S. and G. P. Robertson. 2006. Aggregation and organic matter protection pollowing tillage of a previously uncultivated. Soil Sci. Soc. Am. J. 70, 1398-1406.
Gregorich, E. G., M. R. Carter, D. A. Angers, C. M. Monreal, and B. H. Ellert. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can. J. Soil Sci. 74, 367-385.
Helfrich, M., B. Ludwig, M. Potthoff, and H. Flessa. 2008. Effect of litter quality and soil fungi on macroaggregate dynamics and associated partitioning of litter carbon and nitrogen. Soil Biol. Biochem. 40, 1823-1835.
Holland, E. A. and D. C. Coleman. 1987. Litter placement effects on microbial and organic matter dynamics in an agroecosystem. Ecology 68, 425-433.
Holland, J. M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ. 103, 1-25.
Jacobs, A., M. Helfrich, S. Hanisch, U. Quendt, R. Rauber, and B. Ludwig. 2009a. Effect of conventional and minimum tillage on physical and biochemical stabilization of soil organic matter. Biol. Fertil. Soils 46, 671-680.
Jacobs, A., R. Rauber, and B. Ludwig. 2009b. Impact of reduced tillage on carbon and nitrogen storage of two Haplic Luvisols after 40 years. Soil Till. Res.102, 158-164.
Jastrow, J. D. 1996. Soil aggregate formation and the accrual of particulate and mineral associated organic matter. Soil Biol. Biochem. 28, 665-676.
Jastrow, J. D., T. W. Boutton, and R. M. Miller. 1996. Carbon dynamics of aggregate-associated organic matter estimated by carbon-13 natural abundance. Soil Sci. Soc. Am. J. 60, 801-807.
Jiang, X., Y. Hu, J. H. Bedell, D. Xie, and A. L. Wright. 2011. Soil organic carbon and nutrient content in aggregate size fractions of a subtropical rice soil under variable tillage. Soil Use Manage. 28, 27-35.
Jiang, X. and D. Xie. 2009. Combining ridge with no-tillage in lowland rice-based cropping system: long-term effect on soil and rice yield. Pedosphere 19, 515-522.
Kemper W. D. and W. S. Chepil. 1965. Size distribution of aggregates. In: Black, C.A. (Ed.), Methods of soil analysis. Part 1. Physical and Mineralogical properties, including statistics of measurement and sampling. Agronomy Monograph. 9. ASA, Madison, WI, pp. 499-510.
Kushwaha, C. P., S. K. Tripathi, and K. P. Singh. 2001. Soil organic matter and water-stable aggregates under different tillage and residue conditions in a tropical dryland agroecosystem. Appl. Soil Ecol. 16, 229-241.
Lal, R., A. A. Mahboubi, and N. R. Fausey. 1994. Long-term tillage and rotation effects on properties of a central Ohio soil. Soil Sci. Soc. Am. J. 58, 517-522.
Lauber, C. L., M. S. Strickland, M. A. Bradford, and N. Fierer. 2008. The influence of soil properties on the structure of bacterial and fungal communities across land-use types. Soil Biol. Biochem. 40, 2407-2415.
Liebig, M., L. Carpenter-Boggs, J. M. F. Johnson, S. Wright, and N. Barbour. 2006. Cropping system effects on soil biological characteristics in the Great Plains. Renew. Agr. Food Syst. 21, 36-48.
Lupwayi, N. Z., M. A. Arshad, W. A. Rice, and G. W. Clayton. 2001. Bacterial diversity in water stable aggregates of soils under conventional and zero tillage management. Appl. Soil Ecol.16, 251-261.
Madari, B., P. L. O. A. Machado, E. Torres, A. G. de Andrade, and L. I. O. Valencia. 2005. No tillage and crop rotation effects on soil aggregation and organic carbon in a Rhodic Ferralsol from southern Brazil. Soil Till. Res. 80, 185-200.
Madejon, E., F. Moreno, J. M. Murillo, and F. Pelegrin. 2007. Soil biochemical response to long term conservation tillage under semi arid Mediterranean conditions. Soil Till. Res. 94, 346-352.
Minoshima, H., L. E. Jackson, T. R. Cavagnaro, S. Sánchez-Moreno, H. Ferris, S. R. Temple, S. Goyal, and J. P. Mitchell. 2007. Soil food webs and carbon dynamics in response to conservation tillage in California. Soil Sci. Soc. Am. J. 71, 952-963.
Mullen, M. D., C. G. Melhorn, D. D. Tyler, and B. N. Duck. 1998. Biological and biochemical soil properties in no-till corn with different cover crops. J. Soil Water Conserv. 53, 219-224.
Neelam R. and S. R. Gupta. 2009. Conservation Tillage Effects on Crop Yield, Carbon Accumulation and Soil Nitrogen Transformation in Rice-Wheat Systems in Northern India. Int. J. Ecol. Environ.

Sci. 35, 199-209.
Nuttall, W. F., K. E. Bowren, and C. A. Campbell. 1986. Crop residue practices and nitrogen and phosphorus fertilizer effects on crop response and some physical and chemical properties of black chernozem over 25 years in a continueous wheat rotation. Can. J. Soil Sci. 66, 159-171.
Nyamadzawo, G., J. Nyamangara, P. Nyamugafata, and A. Muzulu. 2009. Soil microbial biomass and mineralization of aggregate protected carbon in fallow-maize systems under conventional and no-tillage in Central Zimbabwe. Soil Till. Res. 102, 151-157.
Park E. J. and A. J. M. Smucker. 2005. Saturated hydraulic conductivity and porosity within macroaggregates modified by tillage. Soil Sci. Soc. Am. J. 69, 38-46.
Paustian, K., J. Six, E. T. Elliott, and H. W. Hunt. 2000. Management options for reducing CO_2 emissions from agricultural soils. Biogeochemistry 48, 147-163.
Pinheiro, E. F. M., M. G. Pereira, and L. H. C. Anjos. 2004. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. Soil Till. Res. 77, 79-84.
Sainju, U. M., A. Lenssen, T. Caesar-Tonthat, and J. Waddell. 2006. Tillage and crop rotation effects on dryland soil and residue carbon and nitrogen. Soil Sci. Soc. Am. J. 70, 668-678.
Sharma, P. K. and S. K. De Datta. 1985. Effect of puddling on soil physical properties and processes. pages 217-234. In: Tout, E.A. and Argosino G.S. (Editors) soil physics and rice international rice research institute, Los Banos, Philippines.
Six, J., R. T. Conant, E. A. Paul, and K. Paustian. 2002. Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. Plant Soil 241, 155-176.
Six, J., K. Paustian, E. T. Elliott, and C. Combrink. 2000. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate associated carbon. Soil Sci. Soc. Am. J. 64, 681-689.
Sparling, G. P., T. G. Shepherd, and H. A. Kettles. 1992. Changes in soil organic C, microbial C and aggregate stability under continuous maize and cereal cropping, and after restoration to pasture in soils from the Manawatu region, New Zealand. Soil Till. Res. 24, 225-241.
Spedding, T. A., C. Hamel, G. R. Mehuys, and C. A. Madramootoo. 2004. Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. Soil Biol. Biochem. 36, 499-512.
Tisdall, J. M. 1991. Fungal hyphae and structural stability of soil. Aust. J. Soil Res. 29, 831-835.
Tisdall, J. M. and J. M. Oades. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33, 141-163.
Unger, P. W. 1982. Surface soil physical properties after 36 years of cropping to winter wheat. Soil Sci. Soc. Am. J. 46, 796-801.
Van Bevel, C. H. M. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Sci. Soc. Am. Proc. 14, 20-23.
Van Groenigen, K. J., J. Bloem, E. Baath, P. Boeckx, J. Rousk, S. Bode, D. Firristal, and M. B. Jones. 2010. Abundance, production and stabilization of microbial biomass unde conventional and reduced tillage. Soil Biol. Biochem. 42, 48-55.
Vance, E. D., P. C. Brookes, and D. S. Jenkinson. 1987. An extraction method of measuring soil microbial biomass C. Soil Biol. Biochem. 20, 325-329.
Walkley, A. and I. A. Black. 1934. Estimation of soil organic carbon by chromic acid titration method. Soil Sci. 37, 29-38.
Changting, Wang, Wang Genxu, Liu Wei, and Wu Pengfei. 2011. The effects of plant –soil Enzymes interactions on plant composition, biomass and diversity of Alpine Meadows in the Qinghai- Tibetan Plateau. Int. J. Ecol. 23, 1-10.
Wright, A. L., F. M. Hons, R. G. Lemon, M. L. McFarland, and R. L. Nichols. 2008. Microbial activity and soil C sequestration for reduced and conventional tillage cotton. Appl. Soil Ecol. 38, 168-173.
Wu, J., R. G. Joergensen, B. Pommerening, R. Chaussod, and P. C. Brookes. 1990. Measurement of soil microbial biomass C by fumigationeextraction e an automated procedure. Soil Biol. Biochem. 22, 1167-1169.
Yao, H. Y., X. D. Jiao, and F. Z. Wu. 2006. Effects of continuous cucumber cropping and alternative rotations under protected cultivation on soil microbial community diversity. Plant Soil 284, 195-203.
Yoder, R. E. 1936. A direct method of aggregate analysis and study of the physical nature of erosion losses. J. Am. Soc. Agron. 28, 337-351.
Young, I. M. and K. Ritz. 2000. Tillage, habitat space and function of soil microbes. Soil Till. Res. 53, 201-213.
Zibilske, L. M. and J. M. Bradford. 2007. Soil aggregation, aggregate carbon and nitrogen, and moisture retention induced by conservation tillage. Soil Sci. Soc. Am. J. 71, 793-802.
Zotarelli, L., B. J. R. Alves, S. Urquiaga, R. M. Boddey, and J. Six. 2007. Impact of tillage and crop rotation on light fraction and intra-aggregate soil organic matter in two Oxisols. Soil Till. Res. 95, 196-206.

■■