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Long term effects of tillage and residue management on soil aggregation, soil carbon sequestration and energy relations under rice–wheat cropping system in *Typic Ustochrept* soil of Uttar Pradesh

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Abstract

A field experiment was conducted to investigate the influence of different combinations of tillage and residue management on carbon sequestration in different sized soil aggregates and also on crop yield after 4 years of continuous rice–wheat cropping system on *Typic Ustochrept* soil of Uttar Pradesh. Compared to conventional tillage, macro-aggregates in conservation tillage in wheat coupled with unpuddled transplanted rice (RT-TPR) was increased by 50.13% and micro-aggregates of the later decreased by 10.1% in surface soil.50% surface residue retention caused a significant increment of 15.65% in total aggregates in surface soil (0–5cm) and 7.53% in sub-surface soil (5–10 cm). In surface soil, the maximum (19.2%) and minimum (8.9%) proportion of total aggregated carbon was retained with >2mm and 0.1–0.05mm size fractions, respectively. WBed-TPR combined with zero tillage on permanent wide raised beds in wheat (with residue) (T_9) had the highest capability to hold the organic carbon in surface (11.57g kg^{-1}soil aggregates).From the study, it has been proved that higher SOC content of 8.14 g kg^{-1} of soil was found in reduced tilled residue retained plots followed by 10.34 g kg^{-1} in permanently wide raised bed with residue retained plots. Whereas, the lowest level of SOC content of 5.49 g kg^{-1} of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots. Conservation agriculture practices secure good soil health by improving soil aggregation (53.8%) and increased energy output with respect to the conventional tillage puddle transplanted rice (T_{10}) after four years of continuous rice–wheat cropping system in a *Typic Ustochrept* soil of Uttar Pradesh.

Keywords: Conservation tillage, Carbon sequestration, Residue management, Aggregate stability, Rice–wheat cropping system

1. Introduction

Any change in the productivity of rice–wheat cropping systems of the Indo-Gangetic Plains (IGP) would have crucial food security implications, as the region provides staple food for more than 20% of the global population (Chauhan *et al*., 2012) [4]. Even though the enhancement of cereal productivity in this tract accomplished the Green Revolution in the 1960s and 1970s in South Asia (Kumar *et al*., 2002) [20], the rate of productivity growth has come down lately, with a sluggish pace registered over the last two decades (GoI, 2009) [11]. Alongside other factors, degradation of the natural resource-base as a result of intensive farming and inappropriate use of inputs has been widely documented as the root-cause of the problem (Hira, 2009) [15]. This has compelled many agricultural scientists and policy makers to look toward a more sustainable path of cereal production viz., conservation agriculture (CA) and the associated resource conservation technologies (RCTs) (Erenstein *et al*., 2008a) [8]. The growth conditions required by rice are quite different from those required by upland crops. Rice will grow best under puddled, reduced, and anaerobic soil conditions; where as upland crops require unpuddled aerobic and oxidized soil conditions. Furthermore, because of long-term submergence and mineral fertilizer application, paddy soils experience degradation of soil quality, such as breakdown of stable aggregation and deterioration of soil organic matter, which negatively affects agricultural sustainability (Das *et al*., 2013; Naresh *et al*., 2013) [6, 30]. Currently, puddling induces high bulk density, high soil strength and low permeability in subsurface layers (Singh *et al*., 2014) [39].

The development of hardpan also leads to aeration stress in wheat crop at the time of the first irrigation and this problem is predominant in the region where rice–wheat system is being practiced. Thus, puddling in rice results in reduced grain yield of succeeding wheat crop (Malik *et al*., 2014) [27].

The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% of crop residues. Wheat ranks second with 22% of residues whereas fiber crops contribute 13% of residues generated from all crops. Sugarcane residues comprising tops and leaves generate 12 Mt i.e., 2% of crop residues in India. Generation of cereal residues is also highest in Uttar Pradesh (53 Mt) followed by Punjab (44 Mt) and West Bengal (33 Mt) (MNRE 2009) [26]. Burning of crop residues leads to 1) release of soot particles and smoke causing human health problems; 2) emission of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide causing global warming; 3) loss of plant nutrients such as N, P, K and S; 4) adverse impacts on soil properties and 5) wastage of valuable C and energy-rich residues. In addition to loss of entire amount of C, 80% of N, 25% of P, 50% of S and 20% of K present in straw are lost due to burning. If the crop residues are incorporated or retained, the soil will be enriched, particularly with organic carbon and N. Conservation agriculture (CA) offers a good promise in using these residues for improving soil health, increasing productivity, reducing pollution and enhancing sustainability and resilience of agriculture (Spohn and Giani, 2011; Verhulst *et al*., 2011) [43, 49]. Organic inputs to soil help in improving the aggregate stability (Bandyopadhyay *et al*., 2010; Karami *et al*., 2012) [1, 17]. The water stable aggregates are found mostly as macro-aggregates (>0.25mm) (Paul *et al*., 2013) [36] with a proportionately lower amount in the micro-aggregate fraction. This supports the hypothesis that factors that tend to increase the proportion of macro-aggregates by binding micro-aggregates reduce the proportion of micro-aggregates (Nayak *et al*., 2012) [34].

Conservation tillage (CT) systems have been observed to contribute to the role of soil as a carbon sink. By minimizing soil disturbance, reduced tillage decreases the mineralization of organic matter. The result is a larger store of soil organic carbon than with conventional tillage (Bhattacharyya *et al*., 2012b; Naresh *et al*., 2017) [2, 33]. The latter is used to mix topsoil to recover lost nutrients, prepare the seedbed and control weeds, but has been associated with losses in SOC, which lead to a significant decline in soil quality (Paul *et al*., 2013) [36]. Soil aggregation is an imperative mechanism contributing to soil fertility by reducing soil erosion and mediating air permeability, water infiltration, and nutrient cycling (Zhang *et al*., 2012) [54]. Soil aggregates are important agents of soil organic carbon (SOC) retention (Haile *et al*., 2008) [13] and protection against decomposition (Six *et al*., 2000) [42]. Quantity and quality of SOC fractions have an impact on soil aggregation that in turn physically protect the carbon from degradation by increasing the mean residence time of carbon (Das *et al*., 2013) [6]. Soil management through the use of different tillage systems affects soil aggregation directly by physical disruption of the macro-aggregates, and indirectly through alteration of biological and chemical factors (Naresh *et al*., 2014; Choudhury *et al*., 2014) [31, 5]. Crop residue plays an important role in SOC sequestration, increasing crop yield, improving soil organic matter, and reducing the greenhouse gas (Liu *et al*., 2006) [24]. CT practices with minimal soil disturbance and residue retention are becoming economically and ecologically more viable option as they save energy and provide more favorable soil conditions (Zibilske *et al*., 2007) [55] for sustainable crop production and SOC sequestration for future posterity. The objectives of this study were (i) to determine soil carbon sequestration affected by tillage management associated with rice-wheat cropping systems in *Typic Ustochrept* soil of Uttar Pradesh and (ii) to estimate the SOC decay rate for residue retention in relation with rice-wheat cropping systems and (iii) the effect of tillage and residue on soil aggregation potential and C sequestration increment for future posterity of the rice–wheat cropping systems.

2. Materials and methods

2.1. The experimental site

A long-term field experiment was established in the year 2008 at Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, (28°40′ 07″N to 29° 28′ 11″N, 77° 28′ 14″E to 77° 44 18″E, 237 m above mean sea level) Uttar Pradesh, India with rice (*Oryza sativa* L.)– Wheat (*Triticum aestivum* L.) cropping system. The region is characterized by a sub-tropical and semi-arid climate with a hot dry summer (March–June), wet monsoon season (late June–mid September) and a cool, dry winter (October–February). The mean minimum and maximum temperatures of the site are 16.2 ^{0}C and 30.1 ^{0}C, respectively and relative humidity of 67 to 83% throughout the year. Annual rainfall ranges between 685 and 805 mm of which about 80% is received during the monsoon months. Remaining 20% rainfall is received during the non-monsoon period in the wake of western disturbances and thunder storms. Soils are alluvium-derived and belong to *Typic Ustochrept*, and are neutral to slightly alkaline in reaction. The experiment was sandy loam in texture with 40.4, 24.2, 18.3 and 17.1% coarse sand, fine sand, silt and clay content, respectively. The soil had pH 7.9, EC 0.4 dS m^{-1} and an average bulk density of 1.55 Mg m^{-3} ha^{-1} and 42% water holding capacity.

2.2 Experimental design and treatments

Ten treatments (T_1 to T_{10}) involving four tillage methods (conventional tillage puddling and ZT planting on flat-beds and on raised-beds) and three residue management methods (straw removed, 50% straw retention and 100% straw retention) were evaluated in a rice–wheat rotation, replicated thrice in a randomized complete block design. Raised beds were permanent, that is, beds were not disturbed every season; they were reshaped at the time of wheat sowing in a single pass of a tractor. The plot size was 9.0 m × 6.7 m. Treatment details are given in Table 1.

Table 1: Description of cropping practices.

Treatment Code	Rice	Wheat	Rice		Wheat	
			Tillage	Transplanting	Tillage	Drill
T_1	RT-TPR	ZT-DSW-SR	Reduced tillage unpuddled	Transplanting (TPR)	Zero-tillage (ZT) straw removed	Drills seeding (DSW)
T_2	RT-TPR	ZT-DSW+ 50% SR	Reduced tillage unpuddled	Transplanting (TPR)	Zero-tillage (ZT) 50% straw retention	Drill seeding (DSW)
T_3	RT-TPR	ZT-DSW + 100% SR	Reduced tillage unpuddled	Transplanting (TPR)	Zero-tillage(ZT) 100% straw retention	Drill seeding (DSW)
T_4	N Bed-TPR	N Bed ZT-DSW - SR	Narrow raised Beds	Transplanting (TPR)	Narrow raised beds Zero- tillage (ZT) straw removed	Drill seeding (DSW)
T_5	N Bed-TPR	N Bed ZT-DSW + 50% SR	Narrow raised beds	Transplanting (TPR)	Narrow raised beds Zero-tillage(ZT) 50% straw retention	Drill seeding (DSW)
T_6	N Bed-TPR	N Bed ZT-DSW + 100% SR	Narrow raised Beds	Transplanting (TPR)	Narrow raised beds Zero-tillage(ZT)100%straw retention	Drill seeding (DSW)
T_7	W Bed-TPR	W Bed ZT-DSW - SR	Wide raised Beds	Transplanting (TPR)	Wide raised beds Zero-tillage (ZT) straw removed	Drill seeding (DSW)
T_8	W Bed-TPR	W Bed ZT-DSW + 50% SR	Wide raised Beds	Transplanting (TPR)	Wide raised beds Zero-tillage (ZT) 50% straw retention	Drill seeding (DSW)
T_9	W Bed-TPR	W Bed ZT-DSW + 100% SR	Wide raised Beds	Transplanting (TPR)	Wide raised beds Zero-tillage (ZT)100%straw retention	Drill seeding (DSW)
T_{10}	CT-TPR	CT-LS	Dry and wet tillage (puddling)	Transplanting (TPR)	Dry conventional tillage (CT)	Seeddrill line sowing

2.2.1 (T_1 – T_3) Transplanted rice after reduced tillage (R-TTPR)

Reduced tillage (2 dry-harrowing and 1 planking) is performed followed by manual transplanting of 21 days seedling at 20x20 cm spacing. The plots are kept flooded (5±2 cm submergence) for initial 2 weeks to establish the seedling, and the subsequent irrigations (5±2 cm) are applied at the appearance of hair-line cracks on the soil surface.

2.2.2 (T_4 – T_6) Transplanted rice on narrow raised beds (N Bed-TPR)

At the beginning of the experiment soil was tilled by three harrowing and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with inclined plate seed metering devices. The dimension of the narrow beds were 37 cm wide (top of the bed) x15 cm height x 30 cm furrow width (at top) and the spacing from centre of the furrow to another centre of the furrow was kept at 67 cm. Transplanting of one 21-day old seedling per hill in two rows at 20-cm spacing on the narrow raised beds. The plots are irrigated for initial 2 weeks to establish the seedling, and the subsequent irrigations (5±2 cm) are applied at the appearance of hair-line cracks at the soil surface at the bottom of the furrow.

2.2.3 (T_7 – T_9) Transplanted rice on wide raised beds (W Bed-TPR)

At the beginning of the experiment after harvest of the wheat crop soil was tilled by three harrowing and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with inclined plate seed metering devices. The dimension of the wide beds were 107 cm wide (top of the bed) x12 cm height x30 cm furrow width (at top) and the spacing from centre of the furrow to another centre of the furrow was kept at 137 cm. Transplanting of 21-day old seedling per hill in six rows at 20-cm spacing on the wide raised beds. The plots are irrigated for initial 2 weeks to establish the seedling, and the subsequent irrigations (5±2 cm) are applied at the appearance of hair-line cracks at the soil surface at the bottom of the furrow.

2.2.4 T_{10} Conventional puddle transplanted rice (CT-TPR)

Conventional puddling involving 2 dry-harrowing, 2 passes of cultivator followed by 2 wet-tillage operations and one field leveling with a wooden plank was done after that water was impended, followed by manual transplanting of 21-day old seedlings at 20- by 20-cm spacing. The plots were kept flooded (5-cm submergence) for an initial 2 week, and in subsequent irrigations, which were applied at the appearance of hair-line cracks at the soil surface, the field was flooded up to the point where 5 cm water was standing. Farmers in the study area commonly use the appearance of hairline cracks at the soil surface as an indicator to initiate irrigation. In the soil used in present study, the hair-line cracks appear at field capacity moisture regime (35 k Pa).

2.3 Seeding and seed rate

Rice variety PB-1 and Pusa 44 nursery was raised in 3rd week of May with seed rate (25 kg ha^{-1}). Nursery seedlings of 21 days older were uprooted manually from nursery plots and then transplanted in the main field was on 22nd, 20th, 26th and 27th June during year 2008, 2009, 2010 and 2011, respectively. Wheat variety 'PBW-17' was seeded at 100 kg seed ha^{-1} at 20-cm row spacing in flat beds, and a seed rate of 80 kg ha^{-1} was used in permanent raised beds. Two rows of the wheat were planted on both sides at the top of the narrow raised beds and six rows of the wheat were planted on top of the wide raised beds spaced at 20-cm on the same bed.

2.4 Crop residue management practices

The crops were harvested manually and the crop residues were removed keeping only stubbles of 3 inch height from ground level under all the tillage and residue treatments. In conventional-tillage practices, the stubbles were incorporated whereas under no-till practices, the stubbles were kept on surface.

2.5 Fertilizer application

All plots received rice, 120: 60:40 kg N: P: K, and 20 kg $ZnSO_4$ ha^{-1} and for wheat 150:60:40 N: P: K kg ha^{-1}. Half dose of N and full doses of P, K, and Zn was applied as basal and remaining N was applied in two equal splits in rice at the time of booting and panicle initiation stage. In wheat, half N was top dressed in two equal split doses; first split before 1st post-sowing irrigation at crown root initiation stage and the second split before 3rd irrigation at pre-flowering stage.

2.6 Weed management the crop was maintained weed free using following practices

Rice: Weeds that germinate prior to seeding of wheat in zero till plots were killed by spraying glyphosate @ 900 g a.i. ha^{-1}. The plots are then kept weed-free throughout the growing season. Butachlor @ 1300 g a.i. ha^{-1} at two days after transplanting (DAT) in case of transplanted rice followed by a spray application of bispyribac sodium (Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAT for narrow and broad leaf weeds. Additionally, one hand-weeding was done to keep the plots weed-free.

Wheat: grassy weeds were controlled by spraying of sulfosulfuron @ 35 g a.i. ha^{-1} at 30-45 DAS, and broad leaf weeds using 2, 4-D @ 500 g a.i. ha^{-1} at 35 DAS.

2.7 Crop harvest and yield determination

At maturity, rice and wheat were harvested manually at 10 cm above ground level. Grain and straw yields were determined from an area of 62.7 m^2 in flat beds and 53.3 m^2 in raised beds located in the center of each plot. The grains were threshed using a plot thresher, dried in a batch grain dryer and weighed. Grain moisture was determined immediately after weighing. Grain yields of rice and wheat were reported at 14% and 12% moisture content, respectively.

2.8 Soil sampling and analysis

Soil samples were collected after 4 years of rice–wheat cropping in May 2012 (after wheat harvest) from three replications of each treatment. Soil samples were taken from 0- 5; 5-10; 10-15 and 15 to 30 cm depth with a soil auger. Composite samples were made air-dried under shade. One portion of the sample was ground and the whole amount was passed through a 0.15 mm sieve. This sample was used for determining total inorganic carbon (TIC), oxidizable organic carbon (OC) and total carbon (TC) in whole soil. Total carbon (TC) was analyzed by using CHN Elemental analyzer (model Vario EL III); TIC and OC were estimated following the methods of Jackson (1973) [16] and Walkley and Black (1934) [51], respectively. The total soil organic carbon (SOC) was derived by subtracting TIC from TC. The other part of the air dried ungrounded samples were passed through 5-mm sieve and were used for estimating aggregate size distribution by wet sieving method (Yoder, 1936) [53] by using a nest of sieves having pore diameter 2.0, 1.0, 0.5, 0.25, 0.12 and 0.05 mm for the separation of four aggregate size classes namely coarse macro-aggregate (>2.0mm), meso-aggregate (2.0–0.25 mm), micro-aggregate (0.25–0.05 mm) and 'silt + clay' sized fractions (<0.05 mm). Before sieving, an 100 g subsamples (2.0–5.0 mm) of bulk soil was slaked by submerging it in deionizer water on top 2.0 mm sieve for 5 min at room temperature. Following wet sieving, a subsample was taken from the collected soil suspension in the oscillation cylinder that passed through 0.05 mm sieve ('silt+clay' sized fraction). Aggregate fractions retained on each sieve were transferred into a container, dried at 65 ºC in an oven. In this way, aggregates were then fractioned into water stable categories and their ratio was designated as aggregate ratio (AR). After correcting sand content in all aggregate fractions by dispersion with sodium hexametaphosphate, the mean weight diameter (MWD) and geometric mean diameter (GMD) were determined as follows:

1. **Macro and micro-aggregates:** The macro-aggregates were determined by adding the aggregates retained over 0.25- and 2-mm sieves (Oades and Waters, 1991) [35], while the micro-aggregates referred to aggregates retained on 0.053-to 0.25-mm sieves
2. The mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates (Kemper and Rosenau, 1986) [18] were calculated as:

(i) MWD = Σ xi wi,

(ii) GMD = $\exp [(\Sigma w_i \log x_i)/(\Sigma w_i)]$

Where w_i is the proportion of each aggregate class in relation to the bulk soil and x_i the mean diameter of the aggregate class (mm).

3. The aggregate stability (AS) of soils (Castro-Filho *et al.*, 2002) [3] was computed as:

$$AS = \left[\frac{(\text{weight of the aggregates} - \text{wp25} - S)}{(\text{weight of the dry sample} - S)} \right] 100$$

Where wp25 is the weight of aggregates < 0.25 mm (g) and S the weight of particles between 2 and 0.053 mm (g), that is, sand content.

2.9 Soil Organic Carbon Fractionation

Aggregate-associated organic C of the small macro-aggregates, micro-aggregates, and micro-aggregates within macro-aggregates was separated by density floatation with 1.85gcm^{-3} sodium polytungstate (Na PT) solution (Six *et al.*, 1999) [41]. A 5-g dry subsample was suspended in water in a 35-mL graduated conical centrifuge tube, and slowly shaken reciprocally by hand (10 times) without breaking the aggregates. The extra material adhered to the cap and sides of the centrifuge tube was washed into suspension with 10 ml of Na PT and kept under vacuum for 15 min to evacuate air entrapped within the aggregates. The samples were then centrifuged (~1250 g) at 20 °C for 1 h. The floating material in the tube was aspirated onto a filter paper, rinsed thoroughly with de-ionized water to remove Na PT, and dried at 50 °C. The heavy fraction was rinsed twice with 50 ml de-ionized water and dispersed in 0.5% hexa meta phosphate by reciprocally shaking for 18 h on a mechanical shaker. The dispersed heavy fraction was passed through 2-, 0.25-, and 0.053-mm sieves depending on the aggregate size being analyzed.

2.10. Total organic carbon

The TOC content was determined by using Walkley and Black's (1934) [51] rapid titration method and computed using Eq.:

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

Where,

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

2.10.1. Soil organic carbon

Soil organic carbon was determined by wet digestion with potassium dichromate along with 3:2 H_2SO_4: 85% H_3PO_4 digestion mixture in a digestion block set at 120°C for 2h (Snyder and Trofymow, 1984) [46]. A pre-treatment with 3 ml of 1N HCl g^{-1} of soil was used for removal of carbonate and bicarbonate. By using the bulk density value the SOC for each soil layer was calculated and expressed as Mg ha^{-1}.

2.11. Energy relations

The energy requirement for cultivation was estimated in terms of renewable and non-renewable energy. Renewable energy components were manual, animal/bullock drafts, seeds, and manure, while chemical fertilizers (NPK), tractor, diesel, electricity, lubricants, machinery, and agro-chemicals constituted the non-renewable energy inputs. The physical output was related to both grain and straw yields. The energy values for inputs (e.g. seeds, fertilizer and labor) and outputs (grain and stover) were estimated using energy equivalents as recommended by Singh *et al.* (1997) [40]; Mittal and Dhawan (1998). The details on energy equivalents are given in the Table 2. The following energy parameters were calculated as suggested by Singh etal. (1997) [40].

1. Energy efficiency = [Energy output ($MJha^{-1}$)/Energy input ($MJha^{-1}$)]
2. Net energy ($MJha^{-1}$) =[Energy output($MJha^{-1}$) – Energy input ($MJha^{-1}$)]
3. Energy productivity ($kgMJ^{-1}$) =[Output (grain+ straw) ($kgha^{-1}$)/Energy input ($MJha^{-1}$)]
4. Energy intensity (in physical terms,$MJkg^{-1}$)=[Energy output ($MJha^{-1}$)/Output (grain + straw) ($kgha^{-1}$)]

Table 2: Energy equivalents for different inputs and outputs. Source: Mittal and Dhawan (1988) [28]

Particulars	Units	Equivalent energy (MJ)
A. Input		
1. Human labor		
(a) Adult man	Man- hour	1.96
(b) Woman	Woman-hour	1.57
2. Diesel	L	56.31
3. Electricity	KW h	11.93
4.Machinery		
(a) Electric motor	kg	64.8
(b) Farm Machinery including self-propelled machines	kg	62.7
5. Chemical fertilizer		
(a) Nitrogen	kg	60.60
(b) Phosphate(P_2O_5)	kg	11.1
(c) Potash(K_2O)	kg	6.7
7. Chemicals		
(a) Superior chemicals	Kg	120
8. Seed	As output of crop production system	
B. Output		
I. Main product		
(a) Grain	Kg	14.7
II. By product		
(a) Straw	Kg	12.5

2.12. Statistical analysis

Statistical analysis was performed by the Windows-based SPSS program (Version 10.0, SPSS, 1996, Chicago, IL). The SPSS procedure was used for analysis of variance to determine the statistical significance of treatment effects. Duncan's Multiple Range Test (DMRT) was used to compare means through least significant difference (LSD). The 5.0% probability level is regarded as statistically significant.

Results

Aggregate distribution and stability

In 0–5 cm soil layer, the greatest proportion of large macro-aggregates was found in W Bed-TPR, W Bed ZT-DSW +100%SR [T_9] (47%), RT-TPR, ZT-DSW+100% SR [T_3] (43%) and N Bed-TPR, N Bed ZT-DSW +100% SR [T_6] (41%), followed by W Bed-TPR, W Bed ZT-DSW +50% SR [T_8] (33%), while the lowest proportion was found in CT-TPR, CT-LSW [T_{10}] with monoculture of rice (7.5 %), monoculture of wheat (10.5%) and rice-wheat cropping system (11.7%). The proportion of small macro-aggregates was the largest in CT-TPR (64.2%) and CTR-LSW (61%) [T_{10}] and the lowest in W Bed-TPR, W Bed ZT-DSW +100% SR [T_9] (32%), RT-TPR, ZT- DSW+100% SR [T_3] (34 %) and N Bed-TPR, N Bed ZT-DSW +100% SR [T_6] (41%). The greatest percentage of micro-aggregates was found in CT-TPR (36.0%) and the lowest in W Bed-TPR, W Bed ZT DSW +100% SR (32%), N Bed-TPR, N Bed ZT-DSW+100%-SR (both 19%). Residue management had a highly significant ($P<0.01$) effect on the percentage of large macro-aggregates in soil under wheat and rice-wheat cropping system and on the percentage of micro-aggregates in soil under monoculture of rice. Tillage had a highly significant ($P<0.01$) effect on the percentage of large macro-aggregates for all residues retention and on the percentage of small and micro-aggregates in soil under monoculture of rice (Table 3 & 4).

In the 5–10 cm layer, the N Bed-TPR, N Bed ZT-DSW +100% SR; W Bed-TPR, W Bed ZT-DSW +100%SR and RT-TPR, ZT-DSW+100%SR treatments had the highest proportion of large macro-aggregates (38%, 35% and 34% respectively).Conventional tillage without residues under rice-wheat cropping system and RT-TPR,ZTDSW-SR had the lowest proportion of large macro-aggregates (11.5%, 12.5% and 13.7% respectively). All the treatments with monoculture of wheat (regardless residues management or type of tillage) had the greatest proportion of small macro-aggregates (average 62%) (Table 4). Residue management had a significant ($P<0.05$) effect on large macro-aggregates for rice-wheat cropping system and on small macro-aggregates in soil with monoculture of rice. Tillage significantly ($P<0.05$)

affected the percentage of large macro aggregates in soil with rice-wheat cropping system.

The MWD and GMD of soil aggregates were significantly influenced by tillage (Table 3 & 4). At 0–5 cm, MWDs and GMDs were significantly lower under CT-TPR, CT-LSW than RT-TPR, ZT-DSW; N Bed-TPR, N Bed ZT-DSW or W Bed-TPR, W Bed ZT-DSW, whereas the differences between RT and RB (raised beds) were not significant (Table 3 & 4). The greatest MWD was found in the W Bed-TPR, W Bed ZT-DSW +100% SR (1.88 mm), W Bed-TPR, W Bed ZT-DSW+50% SR (1.70 mm) and N Bed-TPR, N Bed ZT-DSW + 100% SR (1.68 mm) treatments and the lowest in the CT-TPR treatment (0.52 mm). At 5–10 cm, RT and RB had higher MWD and GMD than CT, but the differences were only significant between CT and RB (Table 3 & 4). The greatest MWD was found in N Bed-TPR, N Bed ZT-DSW +100% SR (1.53 mm), N Bed-TPR, N Bed ZT-DSW+50% SR (1.40 mm) and W Bed-TPR, W Bed ZT-DSW +100% SR (1.47 mm) and the lowest in CT-TPR (0.70 mm), CT-LSW (0.71 mm) and ZTDSW-SR (0.72 mm). Both MWDs and GMDs decreased with increase in soil depth for all tillage treatments (Table 3 & 4).

Table 3: Effect of tillage and residue management practices on distribution of different aggregate indices at rice harvest

Soil depths (cm)	Crop establishment	Aggregation indices		g aggregate g^{-1} dry soil		Aggregate stability
		MWD (mm)	GMD (mm)	Macro-aggregates	Micro-aggregates	
0–5	T$_{1}$ RT-TPR	0.80^{a}	0.632^{c}	0.503^{b}	0.325^{ab}	0.46^{b}
	T$_{2}$ RT-TPR	0.85^{b}	0.693^{c}	0.513^{b}	0.321^{a}	0.49^{b}
	T$_{3}$ RT-TPR	0.94^{b}	0.698^{c}	0.553^{b}	0.302^{a}	0.^{55b}
	T$_{4}$ N Bed-TPR	0.93^{b}	0.657^{c}	0.534^{b}	0.312^{ab}	0.56^{b}
	T$_{5}$ N Bed-TPR	1.13^{ab}	0.726b^{c}	0.591^{ab}	0.264^{ab}	0.61^{ab}
	T$_{6}$ N Bed-TPR	1.85^{a}	1.070^{a}	0.795^{a}	0.176 ^{b}	0.77^{a}
	T$_{7}$ W Bed-TPR	1.56 ^{b}	0.832^{c}	0.541^{b}	0.186^{b}	0.58^{b}
	T$_{8}$ W Bed-TPR	1.70^{a}	0.996^{ab}	0.785^{a}	0.165^{b}	0.80^{a}
	T$_{9}$ W Bed-TPR	2.03 ^{a}	1.374^{c}	0.933^{a}	0.156^{b}	0.87^{a}
	T$_{10}$ CT-TPR	0.76^{a}	0.619^{c}	0.489^{b}	0.357^{a}	0.42^{b}
5–10	T$_{1}$ RT-TPR	0.86^{a}	0.637^{a}	0.467^{b}	0.291^{a}	0.53^{a}
	T$_{2}$ RT-TPR	0.92^{b}	0.532^{a}	0.486^{b}	0.260^{a}	0.54^{a}
	T$_{3}$ RT-TPR	1.27^{b}	0.607^{a}	0.547^{a}	0.223^{a}	0.61^{a}
	T$_{4}$ N Bed-TPR	1.05^{b}	0.566^{a}	0.501^{b}	0.108^{b}	0.58^{a}
	T$_{5}$ N Bed-TPR	1.34 ^{b}	0.648^{a}	0.561^{a}	0.215^{b}	0.69^{b}
	T$_{6}$ N Bed-TPR	1.41^{a}	0.801^{a}	0.583^{a}	0.207^{b}	0.70^{b}
	T$_{7}$ W Bed-TPR	1.23^{b}	0.631^{a}	0.510^{a}	0.196^{b}	0.63^{a}
	T$_{8}$ W Bed-TPR	1.40^{a}	0.651^{a}	0.617^{a}	0.203^{b}	0.71^{b}
	T$_{9}$ W Bed-TPR	1.56 ^{b}	0.826^{a}	0.640^{a}	0.185^{b}	0.76^{b}
	T$_{10}$ CT-TPR	0.84^{a}	0.516a	0.432^{b}	0.329^{a}	0.48^{a}

Table 4: Effect of tillage and residue management practices on distribution of different aggregate indices at wheat harvest.

Soil depths (cm)	Crop establishment	Aggregation indices		g aggregate g^{-1} dry soil		Aggregate stability
		MWD (mm)	GMD (mm)	Macro-aggregates	Micro-aggregates	
0–5	T$_{1}$ ZT-DSW -SR	0.58^{c}	0.97^{a}	0.625^{b}	0.208^{b}	0.42^{b}
	T$_{2}$ ZT-DSW+ 50% SR	0.60^{d}	0.70^{c}	0.678^{b}	0.192^{b}	0.44^{b}
	T$_{3}$ ZT-DSW+100% SR	0.88^{b}	0.68^{c}	0.705^{a}	0.176^{b}	0.55^{a}
	T$_{4}$ N Bed ZT-DSW - SR	0.61^{d}	0.73^{c}	0.695^{a}	0.173^{b}	0.53^{a}
	T$_{5}$ NBedZT-DSW+50% SR	0.89^{c}	0.89^{b}	0.725^{a}	0.139^{a}	0.59^{a}
	T$_{6}$NBedZT-DSW+100% SR	0.88^{c}	0.87^{b}	0.745^{a}	0.123^{a}	0.65^{a}
	T$_{7}$ W Bed ZT-DSW - SR	0.85^{b}	0.84^{b}	0.704^{a}	0.136^{a}	0.56^{a}
	T$_{8}$ WBedZT-DSW+50% SR	1.11^{b}	0.94^{ab}	0.762^{a}	0.128^{a}	0.63^{a}
	T$_{9}$WBedZT-DSW+100%SR	1.57^{a}	1.14^{a}	0.763^{a}	0.116^{a}	0.67^{a}
	T$_{10}$ CT-LSW	0.54^{c}	0.68^{c}	0.613^{b}	0.214^{b}	0.40^{a}
5–10	T$_{1}$ ZT-DSW -SR	0.66^{ab}	0.62^{b}	0.654^{b}	0.212^{b}	0.34^{b}
	T$_{2}$ ZT-DSW+ 50% SR	0.61^{a}	0.65^{b}	0.674^{b}	0.182^{b}	0.37^{b}
	T$_{3}$ ZT-DSW+100% SR	0.74^{a}	0.77^{a}	0.713^{b}	0.149^{b}	0.42^{a}
	T$_{4}$ N Bed ZT-DSW - SR	0.65^{a}	0.74^{a}	0.678^{b}	0.143^{b}	0.39^{b}
	T$_{5}$ NBedZT-DSW+50% SR	0.77^{a}	0.79^{a}	0.768	0.138^{a}	0.44^{a}
	T$_{6}$NBedZT-DSW+100% SR	0.79^{a}	0.80^{a}	0.774^{a}	0.132^{a}	0.46^{a}
	T$_{7}$ W Bed ZT-DSW - SR	0.71^{a}	0.78^{b}	0.703^{b}	0.141^{b}	0.41^{a}
	T$_{8}$ WBedZT-DSW+50% SR	0.79^{a}	0.81^{b}	0.742^{a}	0.126^{a}	0.47^{a}
	T$_{9}$WBedZT-DSW+100%SR	0.82^{b}	0.83^{b}	0.776^{a}	0.120^{a}	0.48^{a}
	T$_{10}$ CT-LSW	0.50^{b}	0.60^{a}	0.624^{b}	0.220^{b}	0.32^{b}

Values followed by different letters within a column at particular depth are significant at $p < 0.05$.

Distribution in the aggregate fractions and contribution to Aggregate Associated Carbon

Reduced and zero tillage treatments had significantly higher amount of total aggregate associated carbon within all the aggregate size classes in surface soil depth as compared to the conventional tillage treatment (T$_{10}$). In the 0–5 cm layer of soil with residue retention the organic C content in the large macro-aggregates was greater (average 2.4%) than in soil where residue was removed (average 1.3%), except in the RT-TPR;ZT-DSW +100% SR treatment where it was similar (1.5%) to treatments without residues and in the W Bed-TPR;W Bed ZT-DSW-SR (2.1%) where it was similar to treatments with residues (Table 5).In the small macro-aggregates, the greatest organic C was found for W Bed ZT-DSW + 100% SR regardless of crop rotations (average 2.32%), while the lowest organic C was found in soil without residues cultivated with wheat and rice-wheat in rotation (average 1.3%) (Table 5). No differences between treatments were found for the micro-aggregates. Residue management had a significant ($P<0.05$) effect on C content in large and small macro-aggregates for soil cultivated with wheat.

In sub-surface soil layer (Table 5), conventional tillage with transplanted rice treatments (T_{10}) resulted in 12.2% higher total soil aggregated carbon as compared to the reduced till transplanted rice with wheat in zero tillage without residue retained treatment (T_1). In surface soil, the maximum (17.2%) and minimum (7.9%) proportion of total aggregated carbon was retained with >2 mm and <0.053 mm size fractions, respectively. Similarly, in the sub-surface layer, >2 mm size particles occluded highest proportion (17.0%) of total aggregated carbon followed by 0.25 - 2.0 mm, 0.053 – 0.25 mm and <0.0530 containing 16.73%, 14.10%, 12.83% and 7.37%, respectively. A higher proportion of the total SOC was found to be captured by the macro-aggregates under both surface and sub-surface layers leaving rest amount in micro-aggregates sized particles (Table 5).

Table 5: Organic carbon content in aggregate size classes under different tillage and residue management practices at rice and wheat harvest.

Soil depths (cm)	Treatment	Size distribution of aggregates, mm							
		At rice harvest				At wheat harvest			
		2–4	0.25–2	0.053–0.25	<0.053	2–4	0.25–2	0.053–0.25	<0.053
		g C kg^{-1} soil in aggregate fraction							
0-5	T_1	5.8^{a}	5.2^{a}	4.6^{a}	2.2^{a}	6.3^{b}	5.1^{bc}	2.8^{b}	1.8^{b}
	T_2	6.2^{a}	5.4^{b}	4.8^{a}	2.3^{a}	6.5^{b}	5.3^{bc}	3.1^{b}	2.1^{b}
	T_3	7.0^{b}	6.1^{b}	5.3^{b}	2.9^{ab}	7.2^{ab}	6.1^{ab}	4.5^{ab}	2.3^{b}
	T_4	6.8^{b}	5.9^{b}	5.1^{ab}	2.4^{a}	6.8^{b}	5.2^{bc}	3.3^{b}	2.2^{b}
	T_5	7.2^{b}	6.8^{ab}	5.3^{ab}	2.8^{ab}	7.6^{bc}	5.8^{bc}	4.6^{ab}	2.6^{a}
	T_6	7.4^{b}	6.9^{ab}	5.5^{ab}	3.1^{ab}	8.0^{bc}	6.3^{ab}	5.1^{a}	2.7^{a}
	T_7	7.1^{b}	6.0^{b}	5.4^{b}	2.7^{a}	7.3^{bc}	5.4^{bc}	3.9^{b}	2.4^{b}
	T_8	8.2^{a}	7.7^{a}	6.0^{a}	3.7^{b}	9.1^{a}	6.9^{a}	5.2^{a}	2.8^{a}
	T_9	8.4^{a}	7.6^{a}	5.6^{a}	3.9^{b}	9.3^{a}	7.0^{a}	5.5^{a}	2.9^{a}
	T_{10}	5.2^{c}	4.6^{c}	3.9^{b}	2.1^{c}	5.8^{c}	4.8^{c}	2.3^{c}	1.3^{c}
5-10	T_1	4.8^{b}	4.7^{b}	4.9^{a}	2.9^{a}	6.1^{a}	4.2^{a}	4.1^{b}	1.7^{bc}
	T_2	5.6^{c}	5.1^{b}	5.1^{a}	2.6^{a}	6.3^{ab}	4.3^{ab}	3.8	1.8^{b}
	T_3	6.3^{c}	6.1^{a}	5.4^{abc}	2.8^{a}	6.6^{b}	4.7a	3.6^{a}	2.3^{a}
	T_4	6.1^{c}	5.3^{b}	5.5^{b}	2.7^{ab}	5.3^{c}	4.0^{ac}	4.0	1.9
	T_5	6.7^{bc}	6.2^{b}	5.2^{c}	2.5^{a}	5.8^{bc}	4.1^{a}	3.9^{a}	2.1^{a}
	T_6	7.2^{ab}	6.4^{a}	6.4^{a}	2.4^{a}	7.1^{b}	4.2^{a}	3.4^{a}	2.3^{a}
	T_7	6.9^{bc}	5.8^{a}	5.3^{bc}	2.4^{a}	5.9^{bc}	4.3^{a}	4.2^{a}	2.1^{a}
	T_8	7.3^{ab}	6.3^{a}	5.8^{a}	2.7^{a}	6.4^{ab}	4.6^{a}	4.1^{a}	2.4^{a}
	T_9	7.6^{a}	6.5^{a}	5.7^{ab}	2.6^{a}	7.3^{a}	4.8^{a}	4.3^{a}	2.4^{a}
	T_{10}	5.4^{c}	4.2^{c}	4.3^{b}	1.9	5.1^{bc}	3.6^{bc}	3.2^{bc}	1.7^{c}

Different forms of soil carbon

Conservation tillage practices significantly influenced the total soil carbon (TC), Total inorganic carbon (TIC), total soil organic carbon (SOC) and oxidizable organic carbon (OC) content of the surface (0–15 cm) soil (Table 6). Wide raised beds transplanted rice and zero till wheat with 100% (T_9) or with 50% residue management (T_8) showed significantly higher TC, SOC content of 11.93 and 10.73 g kg$^{–1}$, respectively in T_9 and 10.98 and 9.38 g kg^{-1}, respectively in T_8 (Table 6) as compared to the other treatments. Irrespective of residue incorporation/retention, wide raised beds with zero till wheat enhanced 53.6%, 33.3%, 38.7% and 41.9% of TC, TIC, SOC and OC, respectively, in surface soil as compared to conventional tillage with transplanted rice cultivation. Simultaneously, residue retention caused an increment of 6.4%, 7.4%, 8.7% and 10.6% in TC, TIC, SOC and OC, respectively over the treatments without residue management. There was no significant effect of conservation practices on different forms of carbon under sub-surface (15–30 cm) soil (Table 6).

Table 6: Effect of tillage and residue management practices on distribution of different forms of carbon in soil.

Treatments	TC (g kg^{-1})		TIC (g kg^{-1})		SOC (g kg^{-1})		OC (g kg^{-1})	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
T_1	8.42ef ± 0.01	7.81d± 0.01	0.45bc± 0.05	0.30c±0.03	6.67de±0.02	8.36c±0.02	5.43de±0.03	5.32d±0.01
T_2	8.95de± 0.01	8.57bc± 0.01	0.60abc±0.06	0.45bc±0.05	7.89bc±0.01	8.50c±0.02	7.56abc±0.04	5.47cd±0.01
T_3	10.03bc± 0.10	8.91ab± 0.05	0.60abc±0.06	0.60b±0.06	8.73ab±0.10	9.27b±0.01	7.78ab±0.03	6.00bc ±0.01
T_4	8.24ef± 0.11	7.36d±0.01	0.34c±0.03	0.26c±0.03	5.79e± 0.02	7.13d±0.03	4.61e±0.01	4.09e±0.01
T_5	8.36ef±0.01	7.63d±0.01	0.41bc±0.03	0.30c±0.03	6.13de±0.02	7.67d±0.08	5.14de±0.03	4.24e±0.01
T_6	9.49cd± 0.04	8.22cd±0.07	0.60abc±0.06	0.60b ±0.06	7.05cd±0.01	9.05cd±0.01	6.77bcd±0.01	5.51cd±0.09
T_7	8.63de±0.02	8.10cd ±0.02	0.60abc± 0.06	0.45bc±0.05	6.79de±0.09	8.62c± 0.04	5.58cde±0.10	5.58cd±0.03
T_8	10.98ab± 0.03	9.24a± 0.01	0.75ab ±0.08	0.60b±0.06	9.38a±0.06	9.31ab±0.02	7.59abc±0.08	6.37b±0.03
T_9	11.93a± 0.05	10.40a± 0.01	0.90a±0.09	0.80a±0.09	10.73a±0.02	9.94a±0.01	8.41a±0.07	7.38a±0.04
T_{10}	6.39f ±0.01	6.12e± 0.06	0.30c±0.03	0.22c±0.03	4.16e±0.02	6.82d±0.03	3.53e±0.01	3.07e±0.01

TC=Total carbon; TIC=Total inorganic carbon; SOC=Total soil organic carbon; OC= Oxidizable organic carbon Different small letters within the same column show the significant difference at P = 0.05 according to Duncan Multiple Range Test for separation of mean.

Grain yield and its attributes

Yield attributes i.e. number of panicles m^{-2}, filled grains $panicle^{-1}$, test weight and panicle length varied significant among the methods of planting, during the year of study. The pooled rice grain and straw yields was 5.7 Mg ha^{-1}. Tillage treatments performed before wheat sowing had pronounced effect on the yield during experimentation (Table 7). Wide raised Beds with 100% residue retention produced 10.9 and 22.9% higher overall mean yield than conventional and reduced tillage without residue retention. This was because of low soil moisture; lack of seed cover, seed damage by birds and compactness of the soil in tillage causing lower values of yield contributing characters (grains, length and weight of ear-head and 1000 grain weight) and lower grain yield (Table 7).

Crop residue management practices also influenced the wheat yield significantly during the year of study. The highest mean yield was recorded under 100% rice residue retention followed by 50% rice residue retention and the conventional practice of straw removal. This clearly indicated that in-situ of residue was beneficial in improving the productivity of wheat only with tillage operations, which were essentially required for retention/incorporating residue into soil for its proper and timely decomposition (Table 7).

Table 7: Effect of tillage residue management practices on yield attributes and yields of rice and wheat.

Treatments	Rice						Wheat					
	Panicle length (cm)	**No. of panicle's m^{-2}**	**Filled grains $panicle^{-1}$**	**Test weight (g)**	**Grain yield (tha^{-1})**	**Straw yield (tha^{-1})**	**Spike length (cm)**	**No. of spikelet $spike^{-1}$**	**No. of grains $spike^{-1}$**	**Test weight (g)**	**Grain yield (tha^{-1})**	**Straw yield (tha^{-1})**
T_1	18.2^{d}	297^{d}	57.6^{de}	23.88^{b}	5.07^{cd}	6.08^{de}	7.7^{e}	11.0^{d}	39.9^{e}	38.65^{c}	3.88^{de}	4.59^{d}
T_2	19.4^{cd}	319^{bc}	60.4^{cd}	24.50^{b}	5.36^{a}	6.96^{ab}	8.3^{bcde}	11.6^{cd}	41.6^{cde}	39.04^{bc}	3.82^{de}	4.55^{d}
T_3	20.5^{bc}	326^{b}	66.9^{a}	25.24^{a}	5.43^{a}	6.52^{abc}	8.4^{bcde}	12.6^{b}	41.7^{cd}	39.20^{bc}	4.02^{d}	4.75^{d}
T_4	18.8^{d}	296^{d}	53.9^{f}	23.94^{b}	3.76^{g}	4.56^{f}	8.1^{cde}	12.5^{b}	40.6^{de}	39.58^{bc}	4.11^{bc}	4.96^{cd}
T_5	21.8^{ab}	308^{cd}	56.4^{ef}	25.45^{a}	4.61^{f}	5.62^{e}	8.6^{abcde}	13.4^{a}	42.3^{cd}	39.99^{bc}	4.04^{bcd}	4.80^{d}
T_6	21.8^{ab}	330^{ab}	66.3^{ab}	25.88^{a}	4.78^{ef}	6.13^{c}	8.9^{abcd}	13.6^{a}	43.2^{b}	40.50^{a}	4.17^{ab}	5.40^{abc}
T_7	20.2^{c}	321^{b}	63.2^{bc}	24.65^{b}	4.97^{de}	6.36^{bcd}	9.1^{abc}	13.4^{a}	44.8^{ab}	40.18^{a}	4.27^{ab}	5.72^{ab}
T_8	20.5^{bc}	331^{b}	67.9^{a}	25.21^{ab}	5.19^{bc}	6.74^{abc}	9.2^{ab}	13.6^{a}	45.5^{a}	40.75^{a}	4.39^{ab}	6.06^{ab}
T_9	22.1^{a}	338^{a}	69.8^{a}	25.85^{a}	5.39^{ab}	7.11^{a}	9.6^{a}	14.1^{a}	46.5^{a}	41.98^{a}	4.53^{a}	6.25^{a}
T_{10}	21.9^{a}	342^{a}	68.3^{a}	26.68^{a}	5.56^{a}	7.22^{a}	7.9^{d}	12.3^{bc}	40.8^{de}	39.14^{bc}	3.63^{e}	4.72^{d}

Different small letters within the same column show the significant difference at P = 0.05 according to Duncan Multiple Range Test for separation of mean.

Discussion

Suitable soil tillage practice can increase the SOC content, and improve SOC density of the plough layer (Duan *et al*., 2012) [7]. The effect size of tillage methods on SOC dynamics depends on the tillage intensity (Haile *et al*., 2008) [13]. Compared to conventional tillage (CT), no-tillage and reduced tillage could significantly improve the SOC content in cropland. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates, which could increase aggregates stability thus improving the concentration of SOC and increasing C sequestration (Liqun *et al*., 2014; Naresh *et al*., 2017) [25, 33]. The increased aggregate stability in ZT+r compared to ZT-r and CT practices resulted in increased infiltration (Govaerts *et al*. 2009) [12] and soil water content (Verhulst *et al*. 2011) [49]. Nayak *et al*., (2012) [34] found a greater accumulation of organic C in the top-soil of systems with ZT compared to CT due to a better preservation of aggregates in ZT. The C not exposed is longer retained in the soil (Spohn and Giani, 2011) [43]. It has been reported that the stability of a soil can be related to the proportion of large macro-aggregates, normally containing most of the C in the soil (Kong *et al*., 2005) [19]. In our study, ZT and residue retention increased the proportion of large macro-aggregates in most of the treatments.

The W Bed-TPR; W Bed ZT-DSW+100%SR (T_9) treatment had the highest proportion of large macro- aggregates, organic C and MWD (Table 3&4). A possible explanation for the high proportion of large macro-aggregates in treatments with residue retention is that they are formed around fresh organic matter, while micro-aggregates contain older organic matter (Simansky *et al*., 2013) [38]. In the majority of the treatments, the small macro-aggregates contained less C than the large macro-aggregates (Table 3 & 4). This behavior can be explained by the concept of aggregate hierarchy (Tisdall and Oades 1982) [48] which stated that large macro-aggregates tend to be richer in organic matter compared to smaller aggregates because fresh organic matter is the precursor in the formation of macro-aggregates. Zibilske (2007) [55] showed that increasing organic C content is related to increasing aggregate size. It is important to note that the organic matter in macro-aggregates is labile while the one in smaller aggregates is more stable. Therefore, tillage operations generate a larger loss of organic matter in large macro-aggregates than in small macro-aggregates.

Our study found that the conservation tillage treatments produced significantly higher amounts of >2 mm macro-aggregates compared with conventional tillage. This was because conservation tillage practices decreased tillage times (Wang *et al*., 2013) [52], and reduced the mechanical destruction to soil aggregates. Conventional tillage with frequent tillage operations disturb soil, and increase the effect of drying–rewetting and freezing–thawing, which increase macro-aggregate susceptibility to disruption (Tian *et al*., 2010). In our study, macro-aggregates are less stable than micro-aggregates and more susceptible to the disruptive forces of tillage, and the >2 mm macro-aggregates showed the lowest percentage distribution at both depths. This might be attributable to the mechanical disruption of macro-aggregates with frequent tillage operations and reduced aggregate stability. The proportion of the micro-aggregates in all treatments was small and they had the lowest organic C content. However, micro-aggregate formation (Zhang *et al*., 2012) [54] and micro-aggregates within the macro-aggregates (Kumari *et al*., 2011) [21] can play an important role in C storage and stabilization in the long term. The formation of micro-aggregates occurs in advanced stages of organic C decomposition, so the organic matter in the micro-aggregates is more stable or recalcitrant compared to the organic C found in other aggregates, thereby favoring aggregate stability and C retention (Mohanty *et al*., 2011; Paul *et al*., 2013; Naresh *et al*., 2015) [36, 32].

Stewart *et al*. (2008) [48] stated that the C sequestration capacity of a soil is determined mainly by the protection of C in the aggregates. Soil C stocks change with tillage and management practices (Srinivasarao *et al*., 2012) [44]. Fuentes *et al*. (2009) [9] reported for the same experiment as this study that the SOC content in the 0–15 cm layer was affected by tillage and residue management. The highest SOC content was found in the 0–5 cm layer of the W Bed-TPR; W Bed ZT-DSW+100% SR (T_9) compared other treatments (Table 6). The SOC stock in the 0–15 cm showed a similar tendency (Table 6). The soils with W Bed-TPR; W Bed ZT-DSW+100% SR, showed higher percentages of SOC and SOC stock than CT-TPR and CT−LS (Table 6). Consequently, the combination of ZT and RT with residue retention is what makes aggregates more stable, protects C and thus increases C sequestration and not zero tillage or residue retention separately. Crop residue on the soil surface forms a barrier against evaporation thereby maintaining the water stored in the plant root zone (Lichter *et al*. 2008) [23]. In our study, wheat yields with conservation tillage treatments were higher than conventional tillage. This was because the interval with ZT and residue retention can significantly improve the soil physical and chemical properties and increase soil water storage. Higher grain yield in residue retention plots were because of increase in water stable aggregates and porosity and reduction in bulk density thereby facilitating crop establishment and better crop growth contributing towards the higher yield of wheat (Verma and Bhagat, 1992) [50]. Ghuman and Sur (2001) [10] observed in sub-humid sub-tropical climate that minimum tillage in conjunction with crop residue management practices improved and sustained the higher wheat yield. In our study W Bed ZT-DSW+100% SR, showed significantly higher wheat yield as compared to without residue retention treatments and conventional till plots (T_{10}) (Table 7).

Conclusion

Reduction in soil disturbance combined with residue retention increased the C retained in the small and large macro-aggregates of the top soil due to greater aggregate stability with conservation tillage with residues retention. Zero tillage with residue retention and monoculture of rice or rotation with wheat was the most attractive system to maximize C retention in the aggregates of the top-soil, under the experimental conditions. Our results showed that the retention of C in the top-soil depends mainly on the C content in the small and large macro-aggregates of the 0–10 cm soil layer while aggregate stability depends primarily on the large macro-aggregates. In semi-arid areas of western Uttar Pradesh, an interval with ZT and residue retention was effective in improving soil physical and chemical properties, and increasing grain yields. Compared with the CT treatment, the conservation tillage significantly increased macro-aggregate content of the soil tilth, and greatly improved soil structure. Conservation tillage significantly increased the soil water storage and it improved the soil water status during the rice-wheat cropping system. The results of the present study showed that the zero tillage with residue retention is a feasible management technology for farmers producing rice and wheat in the agro-ecological zone studied.

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References

1. Bandyopadhyay PK, Saha S, Mani PK, Mandal B. Effects of organic inputs on aggregate associated organic carbon concentration under long-term rice–wheat cropping system. *Geoderma*, 2010; 154:379-386.
2. Bhattacharyya R, Tuti MD, Bisht JK, Bhatt JC, Gupta HS. Conservation tillage and fertilization impacts on soil aggregation and carbon pools in the Indian Himalayas under an irrigated rice–wheat rotation. Soil Sci. 2012b; 177:218-228.
3. Castro-Filho C, Lourenco Guimaraes A, deF M, Fonseca ICB. Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. Soil Till. Res. 2002; 65:45-51.
4. Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Adv. Agron.* 2012; 117:315-369.
5. Choudhury GS, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK *et al.* Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. Soil Till. Res, 2014; 136:76-83.
6. Das TK, Bhattacharyya Ranjan, Sharma AR, Das S, Saad AA, Pathak H. Impacts of conservation agriculture on total soil organic carbon retention potential under an irrigated agro-ecosystem of the western Indo-Gangetic Plains. Europ. J. Agron. 2013; 51:34-42.
7. Duan HP, Niu YZ, Bian XM. Effects of tillage mode and straw return on soil organic carbon and rice yield in direct seeding rice field. Bulletin of Soil Water Conser. 2012; 32(3):23-27.
8. Erenstein O, Farooq U, Malik RK, Sharif M. On-farm impacts of zero tillage wheat in South Asia’s rice-wheat systems. Field Crops Res. 2008a; 105:240-252.
9. Fuentes M, Govaerts B, De León F, Hidalgo C, Sayre KD, Etchevers J *et al.* Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. Eur J Agro. 2009; 30:228-237.
10. Ghuman BS, Sur HS. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in a sub-humid sub-tropical climate. Soil Till Res. 2001; 58:1-10.
11. GoI. Agricultural Statistics at a Glance, Ministry of Agriculture, Government of India, New Delhi, India, 2009.
12. Govaerts B, Sayre KD, Goudeseune B, De Corte P, Lichter K, Dendooven L *et al.* Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Till. Res. 2009; 103:222-230.
13. Haile SG, Nair PKR, Nair VD. Carbon storage of different soil-size fractions in Florida silvopastoral systems. J. Environ. Qual. 2008; 37:1789-1797.
14. He J, Kuhn NJ, Zhang XM, Zhang XR, Li HW. Effects of 10 years of conservation tillage on soil properties and

productivity in the farming-pastoral ecotone of Inner Mongolia, China. Soil Use Manage. 2009; 25:201-209

15. Hira GS. Water management in northern states and the food security of India. J. Crop Improv. 2009; 23(2):136-157.
16. Jackson ML. Soil Chemical Analysis. Prentice Hall India Pvt. Ltd., New Delhi, 1973, 498.
17. Karami A, Homaee M, Afzalinia S, Ruhipour H, Basirat S. Organic resource management: impacts on soil aggregate stability and other soil physico-chemical properties. *Agric. Ecosyst. Environ*. 2012; 148:22-28.
18. Kemper WD, Rosenau RC. Aggregate stability and size distribution.p. 425–442. *In* A. Klute (ed.) Methods of soil analysis.Part I.2nd ed. Agron. Monogr. 9. *ASA and SSSA*, Madison, WI, 1986.
19. Kong AYY, Six J, Bryant DC, Denison RF, and C. van Kessel. The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil. Sci. Soc. Am. J. 2005; 69:1078-1085.
20. Kumar P, Jha D, Kumar A, Chaudhary MK, Grover RK, Singh RK *et al*. Economic analysis of total factor productivity of crop sector in Indo-Gangetic Plain of India by district and region. In: Agricultural Economics Research Report 2, Indian Agricultural Research Institute, New Delhi, India, 2002.
21. Kumari M, Chakraborty D, Gathala MK, Pathak H, Dwivedi BS, Tomar RK. Soil aggregation and associated organic carbon fractions as affected by tillage in a rice-wheat rotation in North India. Soil Sci. Soc. Am. J. 2011; 75:562-567.
22. Lal R. Farming carbon. Soil Till. Res. 2007; 96:1-5.
23. Lichter K, Govaerts B, Six J, Sayre KD, Deckers J, Dendooven L. Aggregation and C and N contents of soil organic matter fractions in the permanent raised-bed planting system in the Highlands of Central Mexico. Plant Soil. 2008; 305:237-252.
24. Liu SP, Nie XT, Zhang HC, Dai QG, Huo ZY *et al*. Effects of tillage and straw returning on soil fertility and grain yield in a rice-wheat double cropping system. Transactions of the CSAE. 2006; 22(7):48-51.
25. Liqun Zhu, Naijuan Hu, Minfang Yang, Xinhua Zhan, Zhang Z. Effects of Different Tillage and Straw Return on Soil Organic Carbon in a Rice-Wheat Rotation System. Soil Till. Res, 2014; 106:85-94.
26. Ministry of New and Renewable Energy Resources, 2009.
27. Malik RK, Kumar A, Dar SR, Sharma R, Jat ML, Singh S. On-farm impacts of agronomic management optimization on wheat productivity in a rice–wheat system of eastern Gangetic Plains of South Asia. *Exp. Agric.* (submitted for publication) 2014.
28. Mittal JP, Dhawan KC. Research manual on energy requirements in agricultural sector New Delhi: ICAR, 1988, 20-23.
29. Mohanty M, Painuli DK, Misra AK, Ghosh PK. Soil quality effects of tillage and residue under rice-wheat cropping on a vertisol in India. Soil Till. Res. 2007; 92:243-250.
30. Naresh RK, Singh SP, Kumar Vineet. Crop establishment, tillage and water management technologies on crop and water Productivity in the rice-wheat cropping system of North West-India. Int. J. Life Sc. Bt & Pharm. Res. 2013; 2(3):237-248.
31. Naresh RK, Tomar SS, Samsher Purushottam, Singh SP, Kumar D, Dwivedi Ashish *et al*. Experiences with Rice grown on Permanent Raised Beds: Effect of Water Regime and Planting Techniques on Rice yield, Water use, Soil Properties and Water productivity. Rice Science. 2014; 21(3):170-180.
32. Naresh RK, Gupta RK, Pal G, Dhaliwal SS, Kumar D, Kumar Vineet *et al*. Tillage crop establishment strategies and soil fertility management: resource use efficiencies and soil carbon sequestration in a rice-wheat cropping system. Eco. Env. & Cons. 21 (December Suppl.) 2015, 127-134.
33. Naresh RK, Arup Ghosh, Kumar Vivak, Gupta RK, Singh SP, Purushottam Kumar *et al*. Tillage Crop Establishment and Organic Inputs with *Kappaphycus* - Sap Effect on Soil Organic Carbon Fractions and Water Footprints under a Six Year Rice-Wheat Rotation. Int. J. Curr. Res. Aca. Rev. 2017; 5(5):57-69.
34. Nayak AK, Gangwara B, Shukla AK, Mazumdar P, Kumar A, Rajab R *et al*. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. Field Crop Res. 2012; 127:129-139.
35. Oades JM, Waters AG. Aggregate hierarchy in soils. Aust. J. Soil Res. 1991; 29:815-828.
36. Paul BK, Vanlauwe B, Ayuke F, Gassner A, Hoogmoed M, Hurisso TT *et al*. Medium-Term Impact of Tillage and Residue Management on Soil Aggregate Stability, Soil Carbon and Crop Productivity. Agric, Ecosyst Environ, 2013; 164:14-22.
37. Puget P, Chenu C, Balesdent J. Total and young organic matter distributions in aggregates of silty cultivated soils. Eur. J. Soil Sci. 1995; 46:449-459.
38. Simansky V, Bajcan D, Ducsay L. The effect of organic matter on aggregation under different soil management practices in a vineyard in an extremely humid year. In Catena, 2013; 101:108-113.
39. Singh Ajeet, Phogat VK, Dahiya R, Batra SD. Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice–wheat cropping system. Soil Till. Res. 2014; 140:98-105.
40. Singh MK, Pal SK, Thakur R, Verma VN. Energy input–output relationship of cropping systems. Indian J Agri Sci, 1997; 67:262-264.
41. Six J, Elliott ET, Paustian K. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Sci. Soc. Am. J. 1999; 63:1350-1358.
42. Six J, Elliott ET, Paustian K. Soil macro-aggregate turnover and micro-aggregate formation: a mechanism for C sequestration under no-tillage agricultural. Soil Biol. Biochem. 2000; 32:2099-2103.
43. Spohn M, Giani L. Impacts of land use change on soil aggregation and aggregate stabilizing compounds as dependent on time. Soil Biol. Biochem. 2011; 43:1081-1088.
44. Srinivasarao Ch, Venkateswarlu B, Lal R, Singh AK, Vittal KPR, Sumanta Kundu *et al*. Long-term effects of soil fertility management on carbon sequestration in a rice-lentil cropping system of the Indo-Gangetic plains. Soil Science Society of America Journal. 2012; 76(1):168-178.
45. Stewart C, Plante A, Paustian K, Conant R, Six J. Soil Carbon Saturation: Linking concept and measurable carbon pools. SSSAJ. 2008; 72:379-392.
46. Snyder D, Trofymow JA. Rapid accurate wet oxidation diffusion procedure for determining organic and

inorganic carbon in plant and soil samples. Comm. Soil Sci. Plant Anal. 1984; 15:1587-1597.

47. Tangyuan N, Bin H, Nianyuan J, Shenzhong T, Zengjia L. Effects of conservation tillage on soil porosity in maize-wheat cropping system Plant Soil Environ. 2009; 55(8):327-333.
48. Tisdall JM, Oades JM. Organic matter and water stable aggregates in soil. J. Soil Sci. 1982; 33:141-16.
49. Verhulst N, Kienle F, Sayre KD, Deckers J, Raes D, Limon-Ortega A, Tijerina-Chavez L, Govaerts B. Soil quality as affected by tillage-residue management in a wheat–maize irrigated Bed planting system. Plant Soil, 2011; 340:453-466.
50. Verma TS, Bhagat RM. Impact of rice straw management practices on yield, nitrogen uptake and soil properties in a wheat–rice rotation in northern India. Ferti Res. 1992; 33:97-106.
51. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934; 37:29-38.
52. Wang DD, Zhou L, Huang SQ, Li CF, Cao CG. Short-term Effects of Tillage Practices and Wheat-straw Returned to the Field on Topsoil Labile Organic Carbon Fractions and Yields in Central China. J. Agro-Environment Sci. 2013; 32(4):735-740.
53. Yoder RE. A direct method of aggregate analysis of soils and the study of the physical nature of erosion losses. J. Am. Soc. Agron. 1936; 28:337-351.
54. Zhang S, Li Q, Zhang X, Wei K, Chen L, Liang W. Effects of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. Soil Till. Res. 2012; 124:196-202.
55. Zibilske LM, Bradford JM. Soil aggregation, aggregate carbon and nitrogen, and moisture retention induced by conservation tillage. Soil Sci. Soc. Am. J. 2007; 71:793-802.