

## Long term effect of crop residue and tillage on carbon sequestration, soil aggregation and crop productivity in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system under partially reclaimed sodic soils

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### ABSTRACT

A long-term field experiment (2006–2016) was laid out at Karnal, Haryana, to evaluate long-term effect of crop residue and tillage management on carbon sequestration potential, soil aggregates and wheat (*Triticum aestivum* L.) productivity under rice (*Oryza sativa* L.)–wheat cropping sequence on partially reclaimed sodic soil. Residue incorporation in conventional (CV + R) and reduced tillage (RT + R) resulted in significantly higher system productivity (13.01 t/ha and 12.48 t/ha respectively) than other treatments used in present study. Soil properties also improved with zero tillage and residue incorporation. The soil organic carbon (SOC) under tillage with residue treatments (CV+R, RT+R and ZT+R) increased from 14.81 to 39.47% at 0–15 cm soil depth over the control. The highest carbon sequestration potential (0.67 t/ha/year) was obtained in zero tillage + residue (ZT+R) treatment at 0–15 cm soil depth. Crop residue in zero tillage favoured a higher amount of carbon to be preferentially stabilized in fine and coarse aggregates. Crop residue either incorporated in conventional and reduced tillage or anchors in zero tillage proved a useful indicator for assessing soil carbon and sustaining crop productivity in the partially reclaimed sodic soil.

**Key words:** Reduced tillage, Residue incorporation, Rice residue, Soil organic carbon, System productivity, Tillage, Wheat-equivalent yield, Zero tillage

Present-day intensive agriculture faces many challenges to sustain the requirement of food production for burgeoning population with limited chances of horizontal expansion on cultivable area (Stevenson *et al.*, 2013). Rice–wheat cropping system, which covers 13.5 million ha area, representing prime agricultural regions of India, Pakistan, Bangladesh and Nepal, is vital for food security, rural development and natural resource conservation (Gupta *et al.*, 2003). Conventional rice–wheat cropping system is quite exhaustive in nature, requiring huge volume of water and nutrients, more labour and energy intensive. Tillage and crop establishment accounts for nearly 25 to 30% of the total production cost of rice–wheat cropping system

(Gathala *et al.*, 2011). Farmers prefer multiple tillage operations (harrowing, cultivation) to prepare fine seed-beds. These results in higher energy consumption, increasing costs of production, destroy the soil structure and lower the benefit: cost ratio.

Numerous strategies have indicated the usefulness of resource-conservation technologies (reduced, zero tillage and crop-residue incorporation) towards sustaining agricultural productivity under intensive cropping system (Malik *et al.*, 2005). In India, about 6.74 million ha of land is salt-affected, out of which 56% area is sodicity affected. Sodicity affects plant growth and development directly by causing osmotic stress and ion toxicity and indirectly through increased soil dispersion and decreased infiltration rate (Wakeel, 2013).

Crop-residue incorporation develops continuous organic mass, energy flow and improves infiltration rate of sodic soil through the release of organic compounds and enhances the activity and biomass of soil microorganisms and enhances the aggregation of soil particles (Song *et al.*, 2016). Integration of crop residue incorporation with mini-

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mum tillage helps to improve soil health, nutrient-use efficiency and finally crop productivity. Keeping in view, the field experiment was conducted to explore the effect of crop residue and tillage on carbon sequestration potential, soil aggregation and wheat productivity in sodic environment under rice–wheat cropping system.

## MATERIALS AND METHODS

A long-term field experiment was initiated in June 2006 at Research Farm of ICAR-Central Soil Salinity Research Institute, Karnal (28°43' N, 73°58' E, 244 m above mean sea-level), Haryana, India, with rice–wheat cropping system. The experimental site was typical reclaimed sodic soil (pH 7.92 and electrical conductivity 0.32 dS/m) and subtropical monsoonal climate with mean max. and min. temp of 29.1 °C and 18.3 °C, respectively, and 700 mm average rainfall, of which 70% precipitation received within a short span of July to September months. An account of soil physico-chemical properties at the initiation of field experiment is given in Table 1.

A total of 6 tillage and residue-incorporation treatments, viz. conventional wheat sowing (CV), wheat sowing after rice residue incorporation (CV+R), wheat in reduced tillage (RT), wheat in reduced tillage after rice residue incorporation (RT+R), wheat in zero tillage (ZT) and wheat in zero tillage with anchored rice residue (ZT+R), were laid out in a randomized-block design with 3 replications.

Rice residue incorporation (CV+R, RT+R and ZT+R) was done by incorporating one-third of left-over biomass with disc harrow 3 weeks before wheat sowing, while it was totally removed from the field under non-residue management treatments (CV, RT and ZT). Conventional wheat sowing (CV and CV+R) was done after ploughing the fields 4 times (2 with disc harrow and 2 with cultivator), followed by planking. Under reduced tillage (RT and RT+R), 50% of tillage operations of conventional wheat

sowing were followed while zero tillage wheat sowing (ZT and ZT+R) was done with the help of zero-till seed-drill machine. The wheat cv. 'HD 2967' was sown using 100 kg/ha seed in the first week of November and harvested manually in the second week of April each year. Fertilizer dose of 150 kg N, 60 kg P and 40 kg K through urea, diammonium phosphate and muriate of potash, respectively, was applied to wheat each year. The crop was irrigated, using 60 cm water at critical phenological stages.

Plot-wise soil sampling (0–15, 15–30, 30–60, 60–90 and 90–120 cm) was done after 10 years of field experimentation in the last week of April 2016 after wheat harvesting. Soil composite samples were made and air-dried under shade before soil analysis. Standard analytical methods were followed for determining soil EC<sub>2</sub> (Richards, 1954), pH<sub>2</sub> (Jackson, 1967), OC (Walkley and Black, 1934), MBC (Witt *et al.*, 2000) and aggregates (Yoder, 1936).

### Carbon sequestration potential (CSP)

Carbon sequestration potential was calculated by using the formula described by (Li *et al.*, 2012).

$$C \text{ sequestered (t/ha/yr)} = (\text{SOC}_{\text{current}} - \text{SOC}_{\text{initial}}) / n$$

where, SOC initial, soil organic carbon stock before initiation of experiment; SOC current, soil organic carbon stock in treatment plots at present; n, number of years of field experimentation.

Soil carbon buildup rate was calculated for buildup rate of all treatments over their respective conventional practice (CV) in 5 different depths (0–15, 15–30, 30–60, 60–90 and 90–120 cm) of soil as:

$$\text{Soil carbon buildup rate (t/ha/year)} = (\text{SOC}_{\text{TX}} - \text{SOC}_{\text{TC}}) / n$$

where x, treatment number (2, 3, 4, 5, 6); C, control treatment; and n, number of years.

Wheat-equivalent yield (WEY) was calculated to compare system performance by converting the yield of rice

**Table 1.** Chemical and physical characteristics of soil of the experimental site before initiation of the experiment in 2006

Soil Property	Depth (cm)				
	0–15	15–30	30–60	60–90	90–120
pH (1:2)	7.92	8.10	8.10	8.00	7.90
EC (dS/m)	0.32	0.37	0.33	0.35	0.34
Organic Carbon (t/ha)	10.32	6.50	4.26	3.36	2.31
Texture	<u>Silty loam (0–15 cm)</u>		<u>Silty loam (15–30 cm)</u>		
Available N (mg/kg)	91.4		81.1		
Available P (mg/kg)	20.1		78.8		
Available K (mg/kg)	118.4		79.4		
Bulk density (g/cm <sup>3</sup> )	1.55		1.57		
Hydraulic conductivity (cm/hr)	0.08		0.07		

crop into equivalent wheat yield on a price basis.

All the data were analyzed using analysis of variance (ANOVA) as applicable to randomized block design using Cropstat. Treatment means were compared at 5% level of significance.

## RESULTS AND DISCUSSION

### Soil pH and electrical conductivity

Long-term effect of resource-conservation technologies (crop residue and tillage) had non-significant effect on soil pH and electrical conductivity (EC). The initial soil pH and EC which were 7.92 and 0.32 dS/m, respectively, at 0–15 cm soil depth ranged from 7.86 to 8.24 and 0.34 to 0.38 dS/m after 10 years of field experimentation (Table 2). Reduced tillage resulted in the highest soil pH (8.24), while CV+R had the highest EC value (0.38 dS/m).

A generalized decreasing pattern in soil pH was observed with increasing soil depth. This scenario can be explained by the fact that, higher organic matter content

**Table 2.** Effect of tillage and residue-management treatments on soil pH<sub>2</sub> and electrical conductivity EC<sub>2</sub>, (dS/m) depth-wise after 10 years of experimentation

Treatment	Depth (cm)	EC <sub>2</sub> (dS/m)	pH <sub>2</sub>
CV	0–15	0.34	7.90
	15–30	0.39	8.00
	30–60	0.36	8.04
	60–90	0.37	8.10
	90–120	0.37	8.00
CV + R	0–15	0.38	7.96
	15–30	0.43	8.12
	30–60	0.37	8.00
	60–90	0.39	8.19
	90–120	0.38	8.16
RT	0–15	0.34	8.24
	15–30	0.39	8.34
	30–60	0.35	8.30
	60–90	0.37	8.36
	90–120	0.36	8.30
RT + R	0–15	0.37	8.21
	15–30	0.42	8.43
	30–60	0.38	8.44
	60–90	0.40	8.40
	90–120	0.39	8.10
ZT	0–15	0.36	7.86
	15–30	0.41	8.13
	30–60	0.37	8.20
	60–90	0.39	8.23
	90–120	0.35	8.21
ZT + R	0–15	0.36	7.96
	15–30	0.42	8.02
	30–60	0.38	7.92
	60–90	0.40	7.82
	90–120	0.39	7.80

Details of treatments are given under Fig. 1.

observed in the surface soils across all land uses resulted in higher soil pH. Humified organic matter binds tightly with aluminum ions and reduces their activity in the soil solution which thereby raises soil pH and reduces acidity on the soil surface. Also, increasing clay percentage with depth has the tendency to furnish hydrogen ions from clay colloidal surface to the soil solution which finally reduce soil pH. Our findings are in agreement with those of Emiru and Gebrekidan (2013).

The lowest soil EC was obtained in treatment CV and RT at 0–15 cm depth. The highest value of soil EC was reported in CV + R (0.38) where residue was incorporated. Indeed returning crop residues into soil caused increase in soil solution salinity. Decomposition of crop residue releases components that can increase the amount of ions in soil solution which eventually increase soil EC. Similar results were reported by Kabirinejad *et al.* (2014).

### Organic carbon

Residue incorporation over the years reflected their effectiveness in improving the net increase in organic carbon (OC) content. The organic carbon contents in treatments with crop residues, i.e. CV + R, RT + R and ZT + R, were significantly higher than respective treatments without crop residues CV, RT and ZT at 0–15 cm soil depth. Significantly higher organic carbon (17.02 t/ha) was reported under ZT + R treatment than all the other treatments at 0–15 cm soil depth (Table 3).

Majumder (2007) also reported beneficial effect of residue incorporation on increment in organic carbon. This could be due to the fact that soil carbon is more susceptible to tillage operations when wetter; however, ploughing done on drier soils has lesser impact on carbon loss, indicating the advantage of zero tillage with crop-residue incorporation for association of mineralization and accumulation of carbon in the soil. The data presented in Table 3 indicated a decreasing trend for organic carbon with the increase in soil depth.

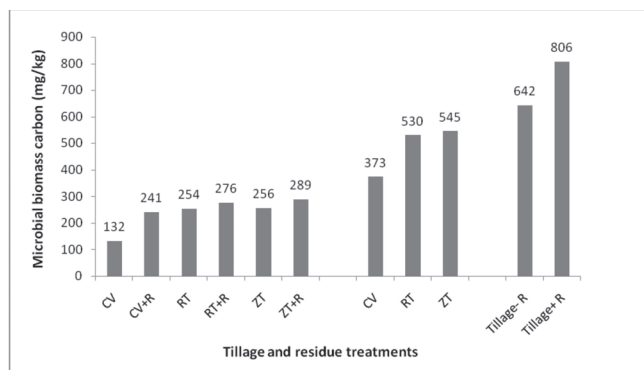
### Microbial biomass carbon

Integration of different tillage operations and crop-residue management combinations on microbial biomass carbon (MBC) (mg/kg) content of soils is shown in Fig 1. The results showed significant improvement in MBC in all tillage treatments with crop-residue incorporation over their respective treatments without residue incorporation.

The MBCs under CV + R, RT + R and ZT + R treatments were 241, 276 and 289 mg/kg, respectively, while these were 132, 254 and 256 mg/kg, respectively, under CV, RT and ZT at 0–15 cm soil depth. The highest MBCs were recorded under zero tillage with crop residue (ZT + R). Similar findings were reported by Sayre *et al.* (2005).

The data indicate higher MBCs in crop-residue treatments and the lowest in the control. The lowest value of MBCs under conventional treatment (CV) might be related to depletion of nutrients due to continuous rice–wheat cropping without any addition of residue. Mean microbial biomass carbon under different tillage treatments, i.e. under conventional, reduced and zero tillage, were 187, 265 and 273 mg/kg soil respectively. Likewise, mean MBCs under tillage without residue and tillage with residue incorporation were 214 and 269 mg/kg respectively. So, residue incorporation increased the microbial biomass carbon by 25.7% compared to without residue treatments.

Crop residue helps in providing balanced fertilization with carbon supplementation, thereby provides suitable environment for microbial growth, low degradability, resulting in accumulation of organic carbon in soil. The availability of easily decomposable organic matter and also readily availability provided a conducive environment for microbial activity, resulting in a higher rate of respiration (Sayre *et al.*, 2005).



**Fig. 1.** Effect of different residue and tillage practices on microbial biomass carbon (mg/kg soil) at 0–15 cm soil depth after 10 years of the experimentation; Cv, Conventional wheat sowing; CV+R, wheat sowing after rice residue incorporation; RT, wheat in reduced tillage; RT+R, wheat in reduced tillage after rice residue incorporation; ZT, wheat in zero tillage; ZT+R, wheat in zero tillage with anchored rice residue

### Carbon sequestration potential

Depth-wise analysis of data indicated that significant improvement in carbon sequestration potential (CSP) was observed owing to residue incorporation. The CSP decreased with the soil depth irrespective of tillage and residue-incorporation treatments; the highest CSP was observed in 0–15 cm soil depths following the trend of 0–15 > 15–30 > 30–60 > 60–90 > 90–120 cm for all the treatments.

The CSP was significantly higher in crop-residue treatments, CV + R, RT + R and ZT + R compared to their respective non-crop-residue treatments at 0–15 cm soil

depth (Table 4). Among all the treatments, significantly higher CSP was recorded under ZT + R treatment, followed by RT + R at all soil depths. The lowest value of CSP was reported in conventional treatment (control) at all soil depths. These results corroborate the findings of Kong *et al.* (2005).

### Soil aggregates and associated carbon (g/kg)

The data on aggregate size fractions under various resource-conservation practices are given in Fig 2. Fraction of fine aggregates (0.05–0.25 mm) and coarse aggregates (0.25–2.0 mm) increased as compared to their initial values under reduced and zero tillage management practices and crop-residue management treatment.

The fine aggregates under crop-residue treatments, CV + R, RT + R and ZT + R, were significantly lower than non-residue treatments, i.e. CV, RT and ZT at 0–15 cm soil depth. Similar trend being observed at other soil depth upto 120 cm.

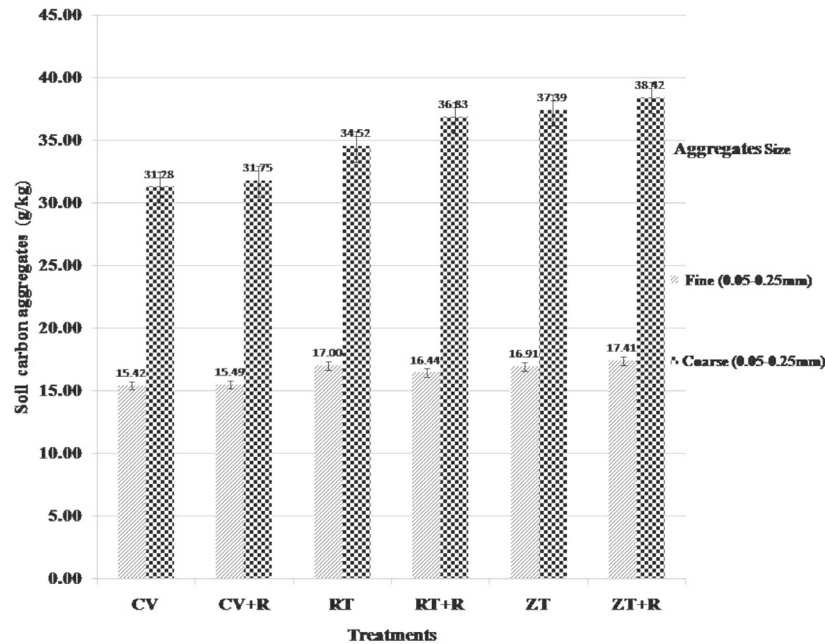
Choudhary *et al.* (2014) also reported that, tillage practices (conventional and conservation) with residue incorporation/ retention resulted in 18.6% and 16.7% higher macro-aggregates than non-residue treatments in surface and sub-surface soil respectively. The residues and soil particulates are getting bound into macro-aggregates in higher proportion in surface than subsurface soil layer (Benbi and Senapati, 2010). However, incorporation of crop residue raising the sequestration potential of conventionally tilled soils might be owing to physical protection of organic carbon by the macro-aggregates that sustain most of the carbon in the soil.

Reduced and zero tillage treatments had significantly higher amount of total aggregate associated carbon within all aggregate size classes in surface soil depth than conventional treatment. Zero tillage with or without residue resulted in higher coarse aggregates (38.42 and 37.39 g/kg) compared to conventional tillage (31.28 and 31.75 g/kg) at surface layer (0–15 cm).

Puddling causes dispersion of aggregates and changes in soil physical properties, including creating a layer with low hydraulic conductivity to support ponding of water (Choudhary *et al.*, 2014).

### Soil carbon build-up rate

Effect of different tillage and crop-residue management practices on soil carbon build-up rate is shown in Table 5. Residue incorporation significantly improved the soil carbon build-up rate, irrespective of the tillage treatments. Under conventional practice, residue incorporation increased soil carbon build-up rate from 0.016 to 0.43 t/ha/year after 10 years of experimentation. In non-residue treatments (reduced tillage and zero tillage), the soil car-



**Fig. 2.** Effect of different crop residue and tillage treatments on soil carbon aggregation (g/kg soil) at 0–15 cm soil depth after 10 years of the experimentation (Details of treatments are given under Fig. 1)

bon build-up rate was lower (0.022 and 0.112 t/ha/year), while in residue treatments (RT+R and ZT+R) it was significantly higher (0.448 and 0.493 t/ha/year respectively) at 0–15 cm soil depth. Similar trend was observed at all other soil depths.

*Wheat grain yield and wheat equivalent yield (WEY)*

The average of 10 years data (2006–2016) on wheat grain yield and system productivity in terms of wheat equivalent yield (WEY) is given in Table 6. Average grain yield under different tillage treatments with residue (CV+R, RT+R and ZT+R) was higher than respective tillage without residue incorporation, i.e. CV, RT and ZT. Residue incorporation resulted in 7.89, 3.08 and 3.65%

increase in wheat yield when integrated into CV, RT and ZT, respectively, over their respective non-residue treatments. The highest average grain yield was obtained under RT+ R, which being statistically at par with CV + R and ZT + R while significantly higher than rest of the treatments.

Higher grain yield under different tillage treatments with residue incorporation might be owing to better and prolonged nutrient availability, soil carbon build-up favouring better soil aeration and mineralization, proliferation thereby contributing to favourable growing conditions and increased crop yield.

The highest system productivity was recorded under conventional tillage with residue incorporation (CV+R),

**Table 3.** Effect of resource conservation practices on organic carbon content after 10 years of experimentation

Treatment	Organic carbon (t/ha)				
	Soil depth (cm)				
	0–15	15–30	30–60	60–90	90–120
CV	12.11	6.83	4.50	3.49	2.37
CV + R	16.13	10.30	4.84	3.76	2.42
RT	12.32	7.39	4.52	3.63	2.49
RT + R	16.58	11.65	5.13	5.13	2.51
ZT	12.51	7.45	4.77	3.70	2.53
ZT + R	17.02	9.86	5.33	4.01	2.49
SEm±	0.05	0.03	0.04	0.03	0.01
CD (P=0.05)	0.12	0.07	0.08	0.07	0.02

Details of treatments are given under Fig.1.

followed by reduced tillage with residue incorporation and conventional tillage. The system productivity under zero tillage with anchored rice residue (11.72 t/ha) was lower because of poor plant stands owing to high weed infestation. Also, Singh *et al.* (2013) reported that, anchored wheat residue in zero tilled rice might be a reason of yield reduction of rice due to poor weeds control. Several flush of weeds come in rice with dominance of different weeds at different growth stage of rice. Also, wheat anchors in zero tillage creates problem in uniform spreading of herbicides. So, it becomes difficult to control complex weed flora in rice and thus poor yield.

A combination of appropriate resource conservation technologies (crop residue and tillage) might help in enhancing soil quality by carbon build-up in the soil. The present study revealed that wheat in zero tillage with rice residue retention (ZT+R) is a suitable management practice for enhancing soil carbon sequestration in partially reclaimed sodic soil.

Addition of crop-residue incorporation under zero tillage favoured soil carbon build-up preferentially stabilized

in fine (17.41 g/kg) and coarse aggregates (38.42 g/kg). Zero tillage with residue (ZT+R) had 40.54% higher soil organic carbon with improved carbon sequestration potential (0.672 t/ha/year), organic carbon (17.02 t/ha), carbon build-up rate (0.493 t/ha/year) and microbial biomass car-

**Table 6.** Effect of different resource conservation practices on average wheat grain yield and system productivity after 10 years of experimentation

Treatment	Wheat grain yield (t/ha)	System productivity (t/ha)
CV	5.57	12.27
CV + R	6.01	13.01
RT	5.84	11.99
RT + R	6.02	12.48
ZT	5.74	11.51
ZT + R	5.95	11.72
SEm±	0.07	0.06
CD (0.05)	0.15	0.13

Details of treatments are given under Fig. 1

**Table 4.** Effect of resource-conservation practices on carbon sequestration potential (CSP) after 10 years of experimentation

Treatment	Carbon sequestration potential (t/ha/year)				
	Depth				
	0–15 cm	15–30 cm	30–60 cm	60–90 cm	90–120 cm
CV	0.179	0.034	0.025	0.013	0.007
CV + R	0.582	0.381	0.058	0.040	0.011
RT	0.202	0.090	0.027	0.027	0.018
RT + R	0.627	0.515	0.087	0.040	0.020
ZT	0.291	0.096	0.052	0.034	0.022
ZT + R	0.672	0.336	0.108	0.065	0.018
SEm±	0.005	0.003	0.004	0.001	0.002
CD (P=0.05)	0.016	0.010	0.012	0.004	0.008

Details of treatments are given under Fig. 1.

**Table 5.** Effect of different resource-conservation practices on soil carbon build-up rate after 10 years of experimentation

Treatment	Soil carbon build-up rate (t/ha/year)				
	Soil depth (cm)				
	0–15	15–30	30–60	60–90	90–120
CV	0.016	0.05	0.001	0.011	0.009
CV + R	0.403	0.347	0.034	0.027	0.004
RT	0.022	0.056	0.002	0.013	0.010
RT + R	0.448	0.482	0.063	0.027	0.013
ZT	0.112	0.063	0.027	0.02	0.016
ZT + R	0.493	0.302	0.083	0.052	0.011
SEm±	0.002	0.006	0.001	0.001	0.001
CD (P=0.05)	0.004	0.014	0.003	0.003	0.002

Details of treatments are given under Fig. 1

bon (289 mg/kg soil) compared to the control (CV). Reduced tillage with residue has significant advantage over conventional tillage without residue. Significantly higher grain yield of wheat was recorded under all tillage + residue treatments than non-residue treatments.

Continuous cultivation with rice–wheat cropping system, key to national food security, has ignited the secondary generation problems of mineral mining, depleted ground watertable, soil health and environmental issues. Resource-conservation technologies have the potential to address these issues under the present climate related concerns.

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