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Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil

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ABSTRACT

Conservation tillage and residue management are the options for enhancing soil organic carbon stabilization by improving soil aggregation in tropical soils. We studied the influence of different combinations of tillage and residue management on carbon stabilization in different sized soil aggregates and also on crop yield after 5 years of continuous rice–wheat cropping system on a sandy loam reclaimed sodic soil of north India. Compared to conventional tillage, water stable macroaggregates in conservation tillage (reduced and zero-tillage) in wheat coupled with direct seeded rice (DSR) was increased by 50.13% and water stable microaggregates of the later decreased by 10.1% in surface soil. Residue incorporation caused a significant increment of 15.65% in total water stable aggregates in surface soil (0–15 cm) and 7.53% in sub-surface soil (15–30 cm). In surface soil, the maximum (19.2%) and minimum (8.9%) proportion of total aggregated carbon was retained with >2 mm and 0.1–0.05 mm size fractions, respectively. DSR combined with zero tillage in wheat along with residue retention (T_6) had the highest capability to hold the organic carbon in surface (11.57 g kg^{-1} soil aggregates) with the highest stratification ratio of SOC (1.5). Moreover, it could show the highest carbon preservation capacity (CPC) of coarse macro and mesoaggregates. A considerable proportion of the total SOC was found to be captured by the macroaggregates (>2–0.25 mm) under both surface (67.1%) and sub-surface layers (66.7%) leaving rest amount in microaggregates and 'silt + clay' sized particles. From our study, it has been proved that DSR with zero tillage in wheat (with residue) treatment (T_6) has the highest potential to secure sustainable yield increment (8.3%) and good soil health by improving soil aggregation (53.8%) and SOC sequestration (33.6%) with respect to the conventional tillage with transplanted rice (T_1) after five years of continuous rice–wheat cropping in sandy loam reclaimed sodic soil of hot semi-arid Indian sub-continent.

1. Introduction

Soil aggregation is an imperative mechanism contributing to soil fertility by reducing soil erosion and mediating air permeability, water infiltration, and nutrient cycling (Spohn and Giani, 2011; Zhang et al., 2012). Soil aggregates are important agents of soil organic carbon (SOC) retention (Haile et al., 2008) and protection against decomposition (Six et al.,

Abbreviations: AR, aggregate ratio; AS, aggregate stability; CPC, carbon preservation capacity; CMacA, coarse macroaggregate; CMacAC, coarse macroaggregated carbon; CMicA, coarse microaggregate; CMicAC, coarse microaggregated carbon; CT, conventional tillage; DSR, direct seeded rice; EWY, equivalent wheat yield; FMicA, fine microaggregate; FMicAC, fine microaggregated carbon; GMD, geometric mean diameter; MWD, mean weight diameter; MesoA, mesoaggregate; MesoAC, mesoaggregated carbon; OC, oxidizable organic carbon; RT, reduced tillage; SOM, soil organic matter; TC, total soil carbon; TIC, total soil inorganic carbon; SOC, total soil organic carbon; TPR, transplanted rice; WSA, water stable aggregates; WSMacA, water stable macroaggregates; WSMicA, water stable microaggregates; ZT, zero tillage.

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Table 1
Tillage and residue management treatments.

Treatments	Rice (Kharif)	Wheat (Rabi)
T_1	Conventional rice transplanting (TPR)	Conventional wheat sowing (CWS)
T_2	Conventional rice transplanting after wheat residue incorporation (TPR + WRI)	Wheat sowing after rice residue incorporation (CWS + RRI)
T_3	Direct seeded rice in reduced tillage (DSR + RT)	Wheat in reduced tillage (WRT)
T_4	Direct seeded rice after wheat residue incorporation (DSR + RT + WRI)	Wheat in reduced tillage after rice residue incorporation (WRT + RRI)
T_5	Direct seeded rice in zero tillage (DSR + ZT)	Wheat in zero tillage (WZT)
T_6	Direct seeded rice in zero tillage with wheat residue retention (DSR + ZT + WRR)	Wheat in zero tillage with rice residue retention (WZT + RRR)
T_7	Direct seeded rice in zero tillage + Sesbania brown manuring (DSR + ZT + BM)	Wheat sowing in zero tillage (WZT)
T_8	Conventional rice transplanting after Sesbania green manuring (TPR + GM)	Wheat sowing in zero tillage (WZT)

2000a). Quantity and quality of SOC fractions have an impact on soil aggregation (Lal, 2000) that in turn physically protect the carbon (C) from degradation by increasing the mean residence time of C (Bajracharya et al., 1997). Soil management through the use of different tillage systems affects soil aggregation directly by physical disruption of the macroaggregates, and indirectly through alteration of biological and chemical factors (Barto et al., 2010). Conventional tillage (CT) generally abrades the network of mycelium by mechanical breakdown of macro-aggregates (Borie et al., 2006), and decreases the content of soil organic C (SOC), microbial biomass and faunal activities (Mikha and Rice, 2004; Sainju et al., 2009; Curaqueo et al., 2011). Conservation tillage practices with minimal soil disturbance and residue retention are becoming economically and ecologically more viable option as they save energy and provide more favourable soil conditions (Husnjak et al., 2002) for sustainable crop production and SOC sequestration for future posterity.

Rice–wheat cropping rotation has been spread over an area of about 10 Mha in Indo-Gangetic Plains (IGP) of India (Kumar et al., 1998) and together contributes 85% to India's cereal production (Timsina and Connor, 2001). Intensive tillage, residue removal and burning practised during the whole crop season accelerate soil erosion, environmental pollution, soil degradation (Montgomery, 2007) and affects ecosystem functions (Srinivasan et al., 2012). Therefore, adoption of the rational cropping practices, such as crop residue recycling (Aoyama et al., 1999; Blair et al., 2006), manure application (Hao et al., 2003; Rudrappa et al., 2006), conservation tillage (Gale and Cambardella, 2000; Six et al., 2000a), and farmland fallow (Nair et al., 2009), would be a century need for improving the soil quality and ecosystem function. Available database on on-station farm trials across the Indo-Gangetic Plains in India, divulges the wheat yield increment under conservation tillage ranging from 1% to 12% with an average of 240 kg ha^{-1} across the area of study (Erestein and Laxmi, 2008). Thus, the cultivation of rice (transplanted/direct seeded) and wheat crops grown rotationally with different tillage and residue management practices has been advocated to evaluate its long-term effect on yield attributes, aggregation and C stabilization in different size aggregates in reclaimed sodic soil of north Indian sub-continent. We hypothesize that direct seeded rice under reduced/zero tillage along with crop residue retention could lead to improved soil aggregation and C sequestration and sustainable yield 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 2006 at Central Soil Salinity Research Institute, Karnal, (29°43′ N 76°58′ E, 245 m above mean sea level), Haryana, India, with rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system. The mean minimum and maximum temperatures of the site are 18.8 °C and 29.2 °C, respectively. Annual rainfall ranges between 700 and 800 mm and more than 70% of it occurs during the monsoon months of July to September. The experimental plot had a sandy loam reclaimed sodic (pH – 7.72 and EC – 0.32 dS m^{-1}) soil (before reclamation classified as Typic Natrustalf; US Taxonomy) having 59.0% sand, 18.0% silt and 23.0% clay with 8 tillage and residue management treatments aimed at developing resource conservation technologies in a strip plot design replicated four times. The treatments included combinations of tillage practices (both conventional and conservation) and residue (with or without) management coupled with system of rice cultivation (transplanted rice; TPR/direct seeded rice; DSR) and also application of brown/green manuring to rice crop (Table 1). Rice seeds (var. CSR 30 in the year 2006, 2007 and Pusa 44 in the year 2008, 2009 and 2010) were sown both in plots (for DSR) and nursery bed (for TPR) in the first week of June. Later, one-month-old seedlings were transplanted in the first week of July with standard package of practices. Each of the treatment was fertilized with 150 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5 and 6.3 kg ha^{-1} Zn. Nitrogen, phosphorus and zinc were supplied through urea, di-ammonium phosphate (DAP) and zinc sulphate heptahydrate fertilizers. One third of recommended N and full of phosphorus and zinc were applied at the time of transplanting and direct sowing. Remaining nitrogen was applied in two equal splits after 30 days and 60 days of sowing. Dhaincha (*Sesbania aculeate*) was sown in the first week of June for brown and green manuring in T_7 and T_8 treatments, respectively. For DSR, Pendimethalin (3 L ha^{-1}) was applied before rice sowing as pre-emergence herbicide. Seeds were sown through seed drill. For brown manuring in DSR (T_7), *Sesbania* seeds @ 20 kg ha^{-1} were broadcasted three days after rice sowing and allowed to grow for 30 days and then were dried and killed by spraying 2,4-D ethyl ester. After killing, the colour of the *Sesbania* residue became brown and it was allowed to lie and decompose in situ on field. Wheat straw (33.0% of the total stalk biomass) was incorporated in the soil under T_2, T_4 and T_6 treatments. During the early 20 days of establishment, water was allowed to stand for soil submergence in the transplanted rice. In the later stage, 7.5 cm irrigation was scheduled at one day after disappearance of ponded water. In DSR, 7.5 cm irrigation was scheduled at four days after disappearance of ponded water. The rice crop was harvested in the last week of October. Rice straw (33.0% of the total stalk biomass) was incorporated in the relevant plots in the top 10 cm soil with disc harrow before 3 weeks of wheat sowing. In the plots without rice straw incorporation, the straw was removed from the field. Before seeding of wheat the field was disked four and two times under conventional and reduced tillage treatments, respectively, at the field capacity moisture. Wheat (variety DBW 17) was sown @ 110 kg ha^{-1} in the second week of November and harvested manually in the third week of April each year. A basal dose of 60 kg P_2O_5 and 30 kg K_2O ha^{-1} was applied to wheat each year. Wheat was irrigated with groundwater on phenological stages with 7.5 cm water.