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Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate-associated carbon content in an intensive rice–wheat system

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ABSTRACT

We studied the impact of integrated nutrient management practices on the physical properties and structural stability of soil aggregates, and the associated C contents after 18 years of rice–wheat rotation on a sandy loam soil at Project Directorate for Farming Systems Research, Modipuram. Treatments included fertilizer nutrients (NPK), NPK with Zn and/or S; and partial (25%) substitution of N with farmyard manure (FYM), sulphitation press mud (SPM), green gram residue (GR) or rice/wheat residue (CR) in various combinations. Soil aggregate properties and its stability, aggregate associated and particulate fractions of C at 0–7.5, 7.5–15 and 15–30 cm depths were studied to document C sequestration potential of different nutrient management options. The aggregate strength and density were lower with organic substitution ($p < 0.05$) while water retention by aggregates at field capacity was 2–4% higher with organic inputs. Macroaggregates (>0.25 mm) constituted 58–92% of water stable aggregates and varied significantly among treatments and soil depths. Organic material incorporation improved soil aggregation and structural stability and resulted in higher C content in macroaggregates. The strong linear positive response to C additions indicated C sequestration potential in soils, with preferential location in macroaggregates. However, the kind and source of organic inputs strongly influenced both the soil aggregation and C accumulation in aggregates. A combination of GR in rice and FYM in wheat significantly improved C content in macroaggregates, and residue incorporation was beneficial compared to 100% N application through inorganic fertilizer or GR to rice. Coarse particulate organic matter (*cPOM*, >0.25 mm) accounted most of the increase in C content within macroaggregates and was substantially higher with CR incorporation. A relatively higher C content in microaggregates-within-macroaggregates (isolated following Six et al., 2002a) in organic-amended soil implies potential in bringing higher C stabilization in intensive rice–wheat system through combination of inorganic and organic fertilizers and crop residues.

1. Introduction

Continuous use of imbalanced fertilizers under intensive rice–wheat cultivation in the Indo-Gangetic Plains had adverse impact on the soil. Integrated nutrient management practice is seen as a viable option in restoring the soil physical structure and chemical fertility, improving soil organic C and therefore, sustaining the system productivity. Literature is replete with studies on the effects of organic matter on soil structure and other properties, but frequently at the bulk soil scale. Little attention has been given to understand the soil mechanical properties at the aggregate scale, which is quite different in manifestation, but may largely influence the bulk soil properties.

The study of aggregates has been useful to evaluate soil response to management (e.g. Blanco-Canqui et al., 2005; Blanco-Canqui and Lal, 2007). The tensile strength (TS) of aggregates is one important property, which is a measure of aggregate resistance against breaking (Perfect and Kay, 1994) and an indicator of soil structural stability (Dexter and Kroesbergen, 1985; Watts and

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Dexter, 1998). Aggregate density (ρ_{agg}) and water retention (WR) by aggregates explain the intra-aggregate porosity and available water relations. The water stability of aggregates evaluates soil's resistance against disintegration, while aggregate size distribution quantifies the impact of management on the soil structure (Oades and Waters, 1991).

Organic inputs to soil help in improving the aggregate stability (Hati et al., 2007; Benbi and Senapati, 2010; P.K. Bandyopadhyay et al., 2010; Karami et al., 2012). The water stable aggregates are found mostly as macroaggregates (>0.25 mm) (Six et al., 2000b; Mikha and Rice, 2004; P.K. Bandyopadhyay et al., 2010) with a proportionately lower amount in the microaggregate fraction. This supports the hypothesis that factors that tend to increase the proportion of macroaggregates by binding micro-aggregates reduce the proportion of micro-aggregates (Tisdall and Oades, 1982; Biswas et al., 2009).

It is understood that organic matter or its fractions are basic to the aggregation process and consequently, C within aggregates is protected against degradation. Many workers gave emphasis to the physical location of organic C in soil in relation to the soil functional properties, as influenced by agri-management practices (Denef et al., 2007; P.K. Bandyopadhyay et al., 2010; Mamta Kumari et al., 2011). More precisely, preferential accumulation of C in aggregates (intra-aggregate C) may indicate relative benefits of soil management practices. Aggregates provide physical protection to C and delay its degradation. This can have a significant contribution on improving soil C stock under intensive cropping system like rice–wheat rotation.

Formation and stabilization of aggregates are linked to soil C dynamics. We hypothesize that long-term rice–wheat rotation with balanced fertilization in combination with organic amendments has significant impact on aggregate properties and water stability, and stabilization of C in aggregates, thereby protecting C from rapid degradation over time. To test the hypothesis, a long-term experiment (since 1993) at Project Directorate for Farming Systems Research (PDFSR), Modipuram, Meerut (29°4′ N, 77°46′ E, 237 m asl), India was selected for the study. The experiment involves combinations of integrated and balanced nutrition to rice and wheat crops viz., farm yard manure, green manuring, organic waste and crop residues with inorganic fertilizers. Our objectives were (i) to evaluate the effect of integrated and balanced nutrient management options on soil aggregate properties and stability and (ii) to study balanced fertilization impact on aggregate-associated and particulate fractions of C for C sequestration potential under these practices.

2. Materials and methods

2.1. Climate and soils of the experimental site

The climate is semi-arid, sub-tropical with average annual rainfall of 863 mm, two-third of which is received through southwest monsoons during July to September. The hottest months are May–June with 45–46 °C of maximum temperature, whereas December–January are the coldest months with minimum temperature of ~5 °C. Soils are alluvium-derived and belong to Typic Ustochrept, and are neutral to slightly alkaline in reaction. The soil (0–15 cm) samples at the beginning of the experiment was sandy loam in texture with 55, 18 and 27% sand, silt and clay content, respectively. It had pH 7.98, EC 0.4 dS m^{-1}, oxidizable organic C 4.1 g kg^{-1}, Olsen P, available K and S 16.4, 96 and 14.5 kg ha^{-1}, respectively. The soil had an average bulk density of 1.55 Mg m^{-3} ha^{-1} and 42% water holding capacity.

2.2. Experimental details

Eight treatments (T_1–T_8) comprising fertilizer nutrients (NPK) alone and substitution (25%) of N with farmyard manure (FYM), sulphitation press mud (SPM), green gram residue (GR) and rice/wheat residue (CR) in various combinations under rice and wheat were evaluated in a randomized block design with 3 replications (Table 1).

Fertilizers are applied at the rate of 120, 26 and 33 kg N, P and K ha^{-1}, respectively for both rice and wheat crops, through urea (46.4% N), diammonium phosphate (18% N, 20% P) and muriate of potash (49.8% K), respectively, except in treatment with S where single super phosphate (7% P, 12% S) was applied as a source of P and additionally, S (40 kg ha^{-1}). In T_2 and T_3, zinc@ 5 kg ha^{-1} is applied through zinc sulphate (21% Zn) to rice. One-third of N and full dose of P, K, S and Zn are applied during transplanting/sowing and remaining N is top-dressed in two equal splits at maximum tillering and panicle/ear emergence. The individual plot size is 8 m × 8 m.

Twenty five day-old rice (cv. Saket 4) seedlings are transplanted at 20 cm × 10 cm spacing in puddled plots during 1st week of July and harvested during 3rd week of October. Succeeding wheat crop cv. HD 2338 is sown in 20 cm gaps (row-to-row), using 100 kg seed ha^{-1}, during 2nd fortnight of November, and harvested during 2nd fortnight of April. The rice crop is grown under continuous submergence (5 cm standing water) while wheat receives irrigations at 5 major growth stages viz., 21, 45, 65, 85 and 115 days after sowing (DAS). Recommended plant protection measures are taken to keep the crops healthy and disease free.

Table 1
Details of the treatments adopted for the study.

Treatment	Crop	
	Rice	Wheat
T1	Unfertilized	Unfertilized
T2	Recommended N, P, K and Zn through fertilizers	Recommended N, P and K through fertilizers
T3	Recommended N, P, K, Zn and S through fertilizers	Recommended N, P and K through fertilizers
T4	75% of recommended N, P and K through fertilizers + 25% substitution of recommended N through farm yard manure (FYM)	Recommended N, P and K through fertilizers
T5	75% of recommended N, P and K through fertilizers + 25% substitution of recommended N through sulphitation press mud (SPM)	Recommended N, P and K through fertilizers
T6	75% of recommended N, P and K through fertilizers + incorporation of green gram residues after pod-picking	Recommended N, P and K through fertilizers
T7	75% of recommended N, P and K through fertilizers + incorporation of green gram residues (GR) after pod picking	75% of recommended N, P and K through fertilizers + 25% substitution of recommended N through FYM
T8	75% of recommended N, P and K through fertilizers + 25% substitution of recommended N through wheat straw (CR)	75% of recommended N, P and K through fertilizers + 25% substitution of recommended N through rice straw (CR)