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Research Article

Soil Aggregation and Associated Organic Carbon as Affected by Long Term Application of Fertilizer and Organic Manures under Rice-Wheat System in Middle Gangetic Plains of India

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ABSTRACT

The long-term impact of integrated nutrient management practices on soil organic carbon (SOC), aggregate stability and distribution of C in different aggregate fractions were studied. The experiment is being conducted in a sandy clay loam (Udic Ustrochepts) at Bihar Agricultural University, Sabour since 1984 under rice-wheat rotation. Changes in total water stable aggregates (WSA), mean weight diameter (MWD), aggregate associated C and bulk soil C were measured. Application of 50%NPK+ 50% N through FYM in rice, 100% NPK in wheat increased the SOC, WSA, MWD and associated C over the control (no NPK fertilizer or organics). The SOC content in 0-15 cm soil layer increased from 3.6 g kg^{-1} under no-fertilizer (control) to 7.7 g kg^{-1} soil under the INM treatments. Macroaggregates constituted 37-60% of total WSA and the proportion of microaggregates ranged from 19 to 30%. Addition of FYM, wheat straw and green manure increased macroaggregate fractions, with a concomitant decrease in microaggregate fractions. Among the macroaggregates, 0.25-0.50 mm fraction constituted the largest proportion and had higher C density compared to microaggregates. The MWD was significantly higher in plots receiving 50%NPK+ 50% N through FYM in rice (1.36 mm), 100% NPK in wheat or 50%NPK+ 50% N through CR in rice (1.28 mm), 100% NPK in wheat or 50%NPK+ 50% N through GM in rice (1.29), 100% NPK in wheat (1.18mm) as compared to control (0.89 mm). It may be concluded that application of 50%NPK+ 50% N through FYM in rice and 100% NPK in wheat can sustain the soil C in a better way and contribute in mitigation of global warming.

Key words: Water stable aggregates; Soil organic carbon; Organic amendments; Rice-wheat cropping system

Introduction

Rice and wheat are the major cereal crops in the Indo Gangetic Plains, grown in rotation in 13.5 mha of land, provides food for 400 million people. The productivity in this region is appearing to a plateau because of fatigued natural resource base (Ladha *et al.*, 2003). Among the factors, continuous use of imbalanced fertilizers and decline in soil physical productivity and soil organic matter are considered responsible (Dawe *et al.*, 2000, Yadav *et al.*, 2000). To improve the soil physical condition, and to improve organic C status in soil, incorporation of crop residues or organic amendments such as FYM, livestock excreta, green manure, compost, vermicompost etc. are recommended (Singh *et al.*, 2007; Bandyopadhyay *et al.*, 2010). These organic inputs are distributed as different SOC pools in bulk soil and aggregates (Majumdar *et al.*, 2008).

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Soil aggregates physically protect the organic matter. Organic inputs like crop residues, organic manures etc. improve soil aggregation and aggregate stability (Hati *et al.*, 2007; Benbi and Senapati, 2010; Bandopadhyay *et al.*, 2010; Karami *et al.*, 2012) and could be a possible way to counteract organic matter depletion. Organic amendments help in improving the formation of macroaggregates (Mikha and Rice, 2004; Bandyopadhyay *et al.*, 2010) with a proportionate decrease in microaggregates and this imply that addition of organics support formation of macroaggregates through binding of microaggregates (Biswas *et al.*, 2009; Huang *et al.*, 2010)

It is known that soil aggregate formation and stabilization are linked to SOC dynamics. Organic inputs have significant impacts on both the bulk soil and aggregate C contents and manures significantly increase C in aggregates (Benbi and Senapati, 2010; Bandyopadhyay *et al.*, 2010; Sui *et al.*, 2012). Comparison of SOC content in different WSA sizes shows macroaggregates are the main source of enriched SOC fractions (Das *et al.*, 2014). The C sequestration in soil through enhanced aggregation is an important approach of judicious soil management to mitigate the increasing concentration of atmospheric CO_2. Aggregate associated C is an important reservoir of soil C, protected from mineralization because it is less subjected to physical, microbial and enzymatic degradation. Carbon inputs from different organics may affect SOC distribution and stabilization in soil aggregate size fractions and for maintaining productivity of rice-wheat cropping system. The present study, therefore, investigated the effect of nutrient management practices on SOC, aggregate size distribution, structural properties and aggregate associated C on a sandy loam soil (Udic Ustochrept) of Middle Gangetic plains after 25 years of rice-wheat rotation.

Materials and Methods

Site description

The long-term experiment is being conducted at Bihar Agricultural University research farm Sabour (25°14′N, 87°04′E and 43 m above sea level) since 1984. The experimental area is characterized as semiarid sub-tropical with hot and desiccating summer but frostless winter with a mean annual precipitation of 1358 mm. Most of the rain is received in rice growing season (June-October). The mean air temperature is recorded at 29.6°C in rice and 24.1°C in wheat seasons. The soil is Udic Ustochrept with sandy loam texture (50, 22 and 28% sand, silt and clay, respectively). At the start of the experiment, the field soil (0-15 cm) had pH 8.1, SOC 4.6 g kg^{-1}, available P 4.5 mg kg^{-1} and available K 58 mg kg^{-1}.

Experimental design and treatments

Treatments represented combinations of inorganic and organic sources of nutrients. In rice, the full recommended levels of N, P and K were supplemented with N through FYM, crop residue (wheat straw) and sesbania, a leguminous green manure (GM) so that the 100% recommended N dose was available to rice crop. The wheat did not receive any organic sources of nutrients but received NPK fertilizer. The experiment included two crops per year, rice and wheat with 12 treatment combinations which were laid in a randomized design and replicated thrice. Out of the total 12 treatments, five selected for the present study. These were (i) control (no fertilizer, no organic manure), (ii) NPK (100% recommended NPK through fertilizer), (iii) NPK+FYM (50% NPK through fertilizer + 50% N through FYM in rice; and 100% NPK dose through fertilizer in wheat), (iv) NPK+PS/WS [(50% NPK through fertilizer + 50% N through wheat straw in rice; and 100 % recommended NPK dose through fertilizer in wheat], and (v) NPK + GM (50% NPK through fertilizer + 50% N through organic manure in rice; and 100 % NPK through fertilizer in wheat).

Soil sampling and analysis

Soil samples were collected from the experimental plots after the harvest of wheat. Samples were taken from different depths (0-15cm, 15-30cm, 30-45 cm and 45-60 cm). Each sample was a composite of four spots in a plot. All the samples were brought to the laboratory and air-dried. Part of the undisturbed soil sample collected from 0-15 cm depth was used for estimating aggregate size distribution. The air dried soil were passed through a set of 5 and 8 mm sieves and the clods retained on the 5 mm sieve were used for estimating aggregate size distribution by wet sieving method (Yoder 1936). The clods were spread uniformly on the top of a nest of sieves (2, 1, 0.50, 0.25 and 0.11 mm), and was moved up and down by a pulley arrangement for 30 min at a frequency of 30 cycles min^{-1} in a salt free water. The WSA were collected from respective sieves, oven-dried and weighed at 65°C. In this way, aggregates were fractioned into water stable macroaaggregate (WSMA) and microaggregates (WSMI). The aggregate ratio was calculated following the procedure as given below.

$$\text{Aggregate ratio of soil, } AR = \left(\frac{\text{Percent macroaggregates}}{\text{Percent microaggregates}}\right) = \left(\frac{\Sigma Q}{\Sigma S}\right) \quad \ldots(1)$$

where Q is the percent of soil particles > 0.25 mm diameter determines by aggregate analysis and S is the percent of soil particles < 0.25 mm diameter determined by aggregate analysis.

Mean weight diameter (MWD) and geometric mean diameter (GMD) were estimated following Van Bavel (1949) method. 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 2 h (Snyder and Trofymow, 1984). A pre-treatment with 3 ml of 1N HCl g^{-1} of soil was used for removal of carbonate and bicarbonate. Dry soil aggregates were ground with a pestle-mortar to <0.25 mm size. The C associated with different aggregate size fractions were estimated

Soil organic C stock (kg ha^{-1}) is calculated as

$$\frac{A \times D \times SOC \times BD}{100} \quad \ldots(2)$$

where A is area in ha (10000 m^2); D is depth of the soil in cm; SOC is soil organic C; BD is bulk density (Mg m^{-3})

C-sequestration rate or rate of net SOC increase (Mg ha^{-1} yr^{-1}) is calculated as

$$\frac{\text{SOC stock (treated plot)} - \text{SOC stock (control plot)}}{\text{Time (years)}} \quad \ldots(3)$$

C build up in soil (%)is calculated as

$$\frac{\text{SOC stock (treated plot)} - \text{SOC stock (control plot)}}{\text{SOC stock (control plot)}} \quad \ldots(4)$$

Analysis of variance (ANOVA) was carried out using the randomized complete block design. Significant difference among the means of different treatments were analysed by Duncan's multiple-range test using SAS v9.2.

Results and Discussion

Sustainable yield index

For yields averaged over years, the comparison of treatments revealed that the percent yield increase in treated plots over control ranged from 202 to 229% in rice and 291 to 335 % in wheat (data not presented), indicating the importance of application of adequate quantity of nutrients in recommended doses with or without partial substitution for organics for sustaining the productivity of rice-wheat system in IGP. The sustainable yield index (SYI) of both the crops was higher in NPK+FYM (0.69 and 0.67 in rice and wheat, respectively) followed by NPK+GM (0.65 and 0.64), NPK+CR (0.64 and 0.63), NPK (0.63 and 0.62) and the lowest in control (0.20 and 0.16) (Fig. 1). The SYI was greater for rice, indicating that rice yield is more sustainable than the yield in wheat. Similarly, the SYI of rice-wheat system was the highest in NPK+FYM (0.63) followed by NPK+GM (0.60), indicating a higher sustainability of rice-wheat system in these treatments.

Depth distribution of SOC

Organic C distribution in soil profile differed significantly among the treatments and with depths (Table 1). At the surface (0-15 cm) layer,

Table 1. Long term effect of fertilizer and organic matter application on SOC content, SOC stock and SOC sequestration rate under rice-wheat cropping system

	SOC content (g kg^{-1})				SOC stock (Mg ha^{-1})				Total SOC stock (Mg ha^{-1})	C build up (per cent)	SOC sequestration rate (Mg C ha^{-1} yr^{-1})
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60			
Control	3.6c	2.3d	2.0d	1.7b	8.4	5.5	4.7	4.0	22.5		
NPK	5.6b	3.1c	2.3c	1.7b	12.3	7.0	5.2	3.8	28.3	25.7	0.231
NPK+FYM	7.7a	3.8a	2.8a	2.0a	15.9	8.4	6.4	4.7	35.4	57.2	0.515
NPK+CR	7.5a	3.6ab	2.6b	1.7b	15.3	7.9	6.0	4.0	33.1	47.1	0.424
NPK+GM	7.4a	3.5b	2.5b	1.7b	15.5	7.7	5.7	4.0	32.9	45.8	0.413

FYM: Farmyard manure; CR: Crop residue; GM: Green manure; Means in a column followed by the same lower case letter do not differ significantly at P<0.05 according to Duncan's Multiple Range test.

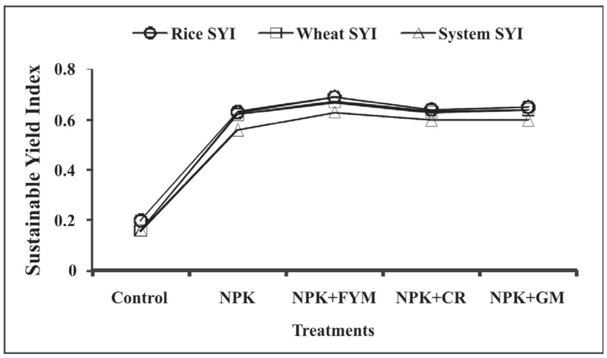

Fig. 1. Sustainable yield index (SYI) of rice, wheat and rice-wheat system as affected by nutrient management practices

NPK+FYM contained the highest SOC concentration (7.7 g kg^{-1}) followed by NPK+CR (7.5 g kg^{-1}) and NPK+GM (7.4 g kg^{-1}). A similar build up of SOC due to cropping with combined applications of chemical fertilizer and manure (Aoyama and Kumakura, 2001; Rudrappa *et al.*, 2006), paddy straw (Verma and Bhagat, 1992), green manure (Yadav *et al.*, 2000) was reported from long term experiments conducted at other places. There was a significant reduction in SOC concentration with the sole application of inorganic fertilizers (NPK) compared with those in the mixed organic and inorganic treatments. The lowest SOC concentration (3.6 g kg^{-1}) in 0-15 cm layer was observed in treatment of a continuous cropping of rice-wheat over 25 years without any amendments. Mean SOC concentration in the profile increased from 2.4 g kg^{-1} in control to 4.1 g kg^{-1} in NPK+FYM. All the treatments showed higher accumulation of SOC in surface layer. Significant variations in SOC content were also observed in the sub-soil layers; mean SOC content decreased from 6.4 at surface 0-15 cm to 1.8 g kg^{-1} at 45-60 cm soil layer.

Bulk density of soil

Soil bulk density (BD) values were lower at surface layer (Fig.2), due to presence of greater organic matter and clay content, tillage and cultivation. Among the treatments, application of NPK together with organics resulted in significantly lower BD compared to control at 0-15 and 15-30 cm layers. Maximum BD was recorded in no-fertilizer and no-manure treatment (1.56 Mg m^{-3}) and the least was in NPK +FYM (1.36 Mg m^{-3}) treatment at 0-15 cm layer. Lower BD on organic-amended plots was due to greater organic matter content (Tiarks, Mazurak and Chesnin, 1974), increased root growth, better aggregation and increased volume of micropores (Schjonning *et al*. 1994).

Profile SOC stock, C build up, and C sequestration rate

The profile SOC stock was the highest in NPK+FYM treatment (35.4 Mg C ha^{-1}) followed by NPK+CR (33.1 Mg C ha^{-1}), NPK+GM (32.9 Mg C ha^{-1}) and the lowest was in control (22.5 Mg C ha^{-1}) (Table 1). Higher biomass and C input in NPK+FYM treatment may be due to increased

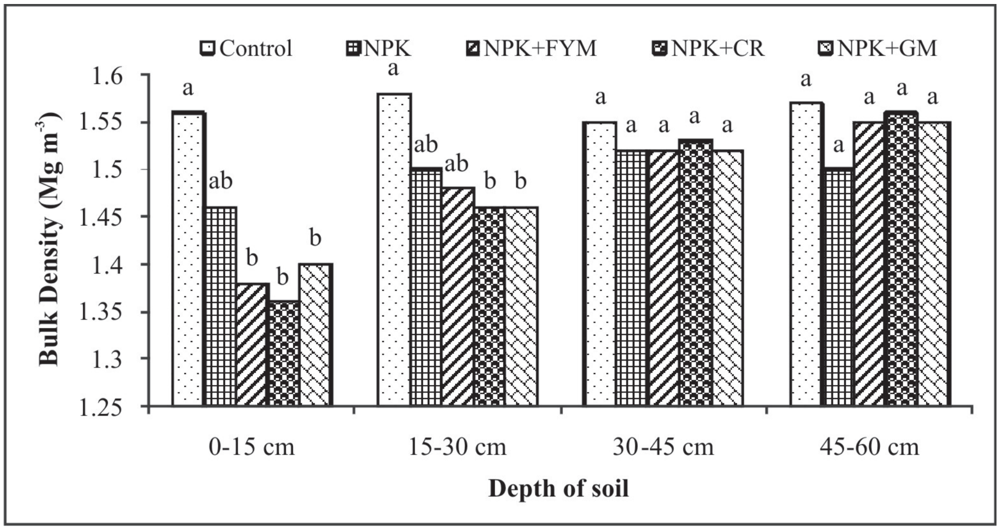

Fig. 2. Effect of integrated nutrient management practices on soil bulk density after 25 years of rice-wheat cropping system [Bars with the same lower case letter in a soil are not significantly different at P<0.05 according to Duncan's Multiiple Range test]

availability of deficient nutrients such as N, K, Ca. Mg, S, Zn and B with addition of organic manure (Srinivasrao and Vittal, 2007). Differences in SOC might be due to the difference in biochemical composition of organic materials, like the amount of C, lignin and polyphenol content in FYM, CR and GM and their array with mineral particles. The highest rate of SOC build up was observed in NPK+FYM treatment (57.2%) followed by NPK+CR (47.1%), NPK+GM (45.8%) and the lowest in NPK (25.7%). A similar trend was also observed in the profile SOC stock and the C sequestration rate in the respective treatments. In comparison with the control, mean rate of SOC build up during the 25 years of cropping was the highest in NPK+FYM. It varied from 0.231 to 0.515 Mg C ha^{-1} yr^{-1} under different nutrient management treatments. Among the treatments, NPK +FYM recorded significantly higher sequestration rate over all other treatments. Benefits of sequestering C to sustain crop productivity by applying organic amendments have been aptly documented (Aulakh *et al.*, 2001)

Aggregation and structural indices

Total WSA at wheat harvest ranged between 66.9 and 79.3% under different treatments. The size distributions of WSA under different treatments are depicted in Fig 3. Macroaggregates (0.25 to >2 mm) comprised of 37- 60% of the total WSA compared to 19-30% as microaggregates. Amount of macroaggregates was lowest in the control plot and was the highest in the plots with organics. Highest proportion of WSA in organic amended plots can be ascribed to regular addition of organic matter through organics and additional root biomass added to soil resulting in greater C availability and enhanced microbial activity, which helps in binding of aggregates. Application of FYM, crop residues and green manure significantly improved the formation of macroaggreagtes. On the contrary, proportion of microaggregates decreased with application of organics (Fig. 4). Increase in proportion of macroaggregates and decrease in proportion of microaggregates with organic application may also be due to binding of the soil particles into microaggregates, and microaggregates into macroaggregates. Among the macroaggregates, the 0.25-0.50 mm fraction constituted the greatest proportion (14-23%). Incorporation of crop residues increased macroaggregates by 44-81% over the control. Application of green manure along with NPK also increased the amount of macroaggregates of different sizes by 44-81%. Formation of

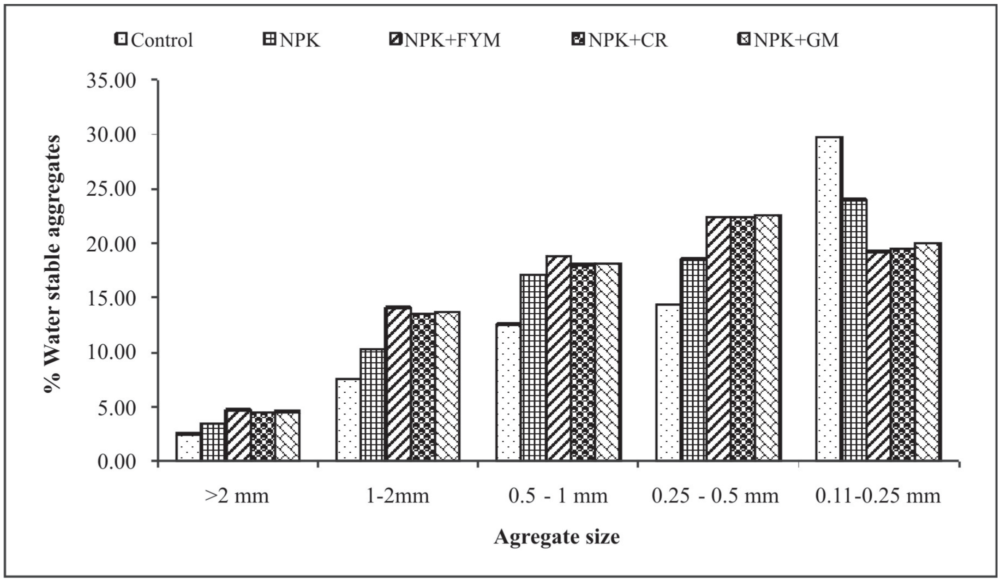

Fig. 3. Proportion of different size fractions of water stable aggregates at 0-15 cm layer as affected by long-term application of different sources of manure along with the fertilizer

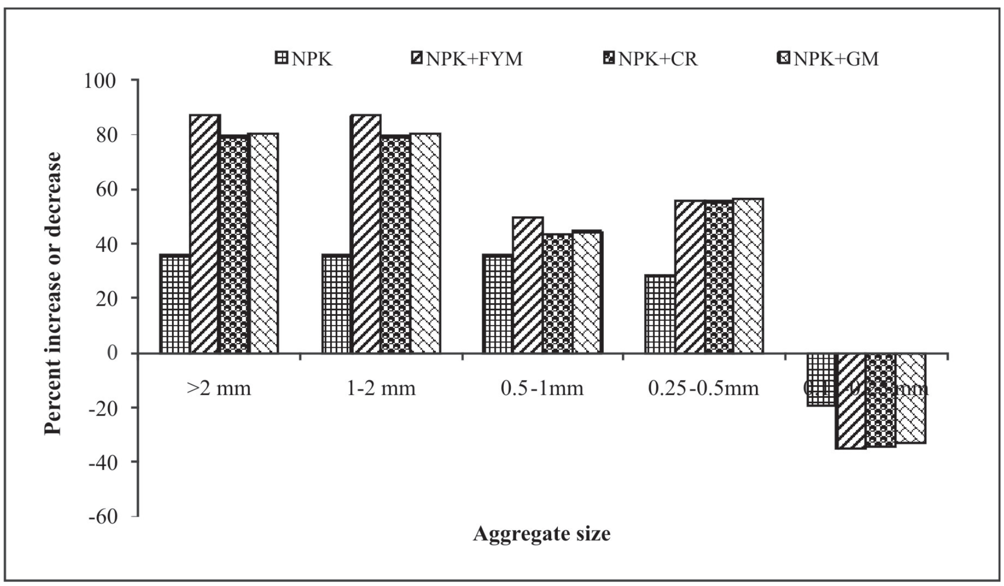

Fig. 4. Influence of long-term integrated nutrient management treatments on macroaggregates and microaggregates amount at 0-15 cm

macroaggregates was the maximum in NPK+FYM plots and the increase over control ranged from 50 to 87% (Fig. 4).

Soils receiving organic amendments (FYM, CR and GM) together with NPK had more WSA, higher AR and MWD than the others (Table 2). Singh *et al.* (2007) have shown that addition of various organic manures along with inorganic fertilizers in rice-wheat system improved the aggregation status of the soil. Aggregate ratio varied significantly with treatments. Compared with the control, treatments where more organic matter was added either through FYM, CR and GM maintained a greater fraction of macroaggregates. The MWD was significantly higher in organic-amended plots as compared to

Table 2. Water stable aggregates and structural indices under different treatments after 25 years of rice-wheat cropping

Treatments	% Water stable aggregates			AR	MWD (mm)
	WSMA (%)	0.11-0.25 (%)	Total WSA (%)		
Control	37.1c	29.8a	66.9c	0.59c	0.89c
NPK	49.3b	24.0b	73.3b	0.98b	1.18b
NPK+FYM	60.1a	19.3c	79.3a	1.51a	1.36a
NPK+CR	58.5a	19.5c	78.0a	1.41a	1.28a
NPK+GM	58.9a	20.0c	78.9a	1.44a	1.29a

FYM: Farmyard manure; CR: Crop residue; GM: Green manure, WSMA= water stable macroaggregates (>0.25mm), WSMIA= water stable microaggregates (0.25-0.11mm), AR= Aggregate ratio, MWD= Mean weight diameter; Means with in a column, followed by same lower case letter do not differ significantly at P<0.05 by Duncan's Multiple Range test.

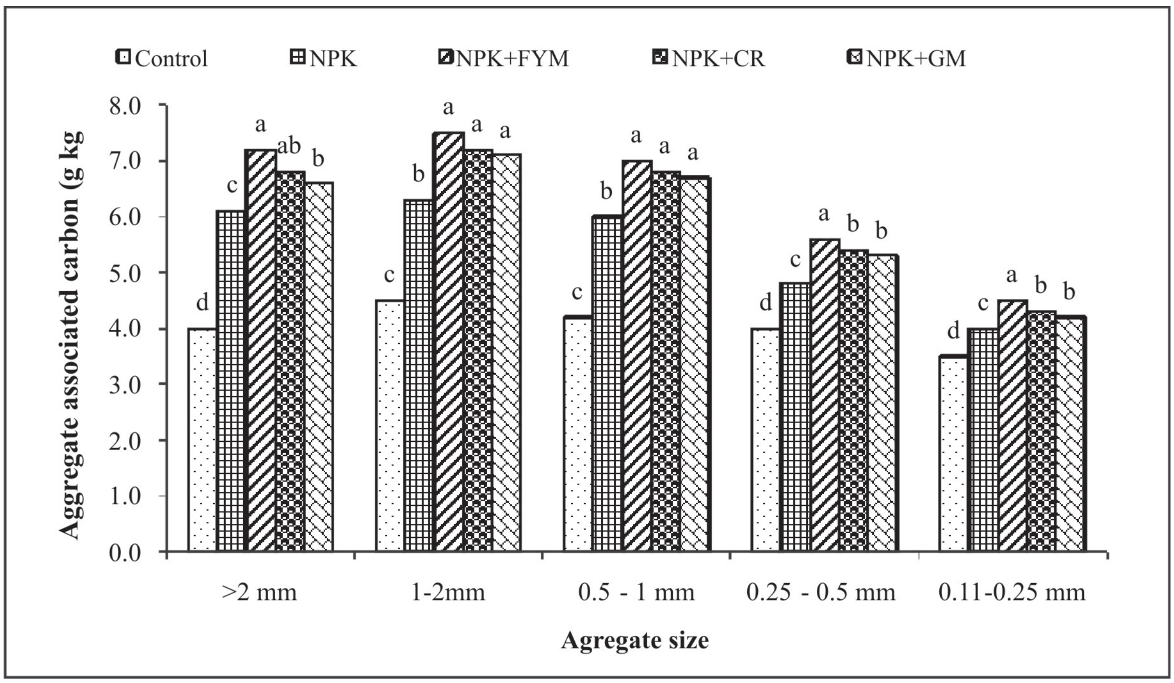

Fig. 5. Effetc of long term integrated nutrient management practices on aggregate associated carbon in the soil [Treatment means of the same size fraction with the same letter are not significantly different at P<0.05]

control and NPK treatments. The plots receiving NPK+FYM showed the largest MWD (1.36 mm) compared to the control plots (0.89 mm). However the variation of MWD among the treated organics might be influenced by their biochemical composition. Positive effects of manure and crop residues on MWD have also been reported by several other researchers (Tripathy and Singh, 2004; Singh *et al.*, 2007; Bandyopadhyay *et al.*, 2010).

Aggregate associated carbon

Concentration of C was higher in macroaggregates as compared to microaggregates. Irrespective of treatments, C concentration was highest in 1-2 mm followed by 0.5-1mm size of macroaggregates and the concentration decreased as the aggregates became smaller in size (Fig. 5). Incorporation of organic manures induces decomposition of organic matter where roots, hyphae and polysaccharides bind mineral particles into microaggregates and then these microaggregates bind to form C rich macroaggregates. This type of C is physically protected within macroaggregates. Similar results of C accumulation in aggregates have reported earlier by several other researchers (Sodhi *et al.*, 2009, Benbi and Senapati, 2010; Das *et al.*, 2014). Long term application of organics increased aggregate associated C as compared in all aggregate size fractions; the highest increase was observed in plots receiving NPK and FYM in combination. These results show that long-term application of organics in combination with inorganic fertilizers helps in C accumulation in macroaggregates, and thereby improving soil C status.

Conclusions

Application of organics in combination with inorganic fertilizers in rice-wheat system significantly improved water stable aggregates, aggregation indices and C sequestration in soil. Higher amount of C is sequestered in macro aggregates. These help in sustaining the soil C in a better way, which may help in controlling the rising levels of atmospheric carbon dioxide.

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