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Soil aggregation and distribution of carbon in a sandy loam soil of Trans Gangetic plains under integrated nutrient management practices in rice-wheat cropping system

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ABSTRACT

The effects of different integrated nutrient management practices on soil aggregation, bulk density and aggregate associated carbon after 26 years of rice-wheat cropping system on a sandy loam soil of Ludhiana were studied. The total Water Stable Aggregates (WSA) at wheat harvest ranged between 78.6 and 85.8% under different treatments. Application of NPK either through inorganic fertilizers or through combination of inorganic fertilizers and organics such as Farm Yard Manure (FYM) or Crop Residue (CR), or Green Manure (GM) significantly increased the amount of water stable aggregates, aggregate ratio, Mean Weight Diameter (MWD) and Geometric Mean Diameter (GMD). The macro-aggregates comprised 35.3 to 48.9% of the total WSA compared to 36.5 to 43.3% as micro-aggregates. The amount of macro-aggregates was lowest in the control plot and it was higher in the plots treated with organics. Application of FYM, CR and GM significantly improved the formation of macro-aggregates as compared to control. The proportion of micro-aggregates decreased with the application of organics. Among the macro-aggregates, the 0.25-0.50 mm fraction constituted the greatest proportion (17-21.6%). Plots receiving FYM showed the highest MWD (0.56 mm) and the control plots had the lowest MWD (0.43 mm). Meagre variation was observed in all the structural indices among the organically amended treatments. Carbon concentration was higher in macro-aggregates as compared to micro-aggregates and application of organics resulted in the greatest increase in C concentration in various aggregate size fractions over control.

1. INTRODUCTION

There is a clear evidence of yield decline or stagnation, deterioration in soil quality, especially soil organic matter in many soils due to intensification of agriculture in India and adopting good or recommended farming practices is an important and effective strategy for soil conservation (Lal, 1989). Rice-wheat cropping system occupies around 13.5 m ha in the Indo Gangetic Plains of Bangladesh, India, Nepal, and Pakistan and 10.3 m ha in China (Ladha *et al.,* 2003). The rice-wheat rotation is an important and profitable crop rotation practised in the Indo-Gangetic plains, contributing most of the food grains and responsible for food security of this region. In Punjab, rice-wheat is a major cropping system and it occupies an area of 2.6 m ha (Benbi and Senapati, 2010). The cultivation of rice-wheat cropping system is showing symptoms of fatigue, witnessed by stagnating or declining yield trend (Ladha *et al.*, 2003). With intensive cropping, continuous application of inorganic fertilizers at high doses without proper nutrient management and indiscriminate use of agrochemicals on soils has resulted in declining yield trend and multi nutrient deficiencies in many soils as a consequence (Bhandari *et al.*, 2002; Singh *et al.*, 2004), while on the other hand balanced application of nutrients through organics and inorganic sources improved and sustained crop yields and maintained soil fertility. Major reason for such stagnation in yield is the decline in soil organic matter quantity and soil quality (Dawe *et al.*, 2000; Yadav *et al.*, 2000; Ladha *et al.*, 2003).

Therefore, maintenance of Soil Organic Carbon (SOC) is considered essential for long-term sustainability and increase productivity. Several long-term studies showed build up of SOC with varying degree using different practices like improved fertilizer management, manure and compost application, incorporation of crop residues, crop rotation, use of green manures, reduced tillage, altering irrigation methods and restoration of waste lands (Kimble *et al.*, 2002; Nayak *et al.*, 2012; Neogi *et al.*, 2014; Srinivasrao *et al.*, 2015; Manna *et al.*, 2015).

Soil aggregation plays an important role in maintaining soil structure and sustaining soil fertility. Aggregates physically protect SOM and addition of organic inputs like crop residues, organic manures *etc.* improve soil aggregation and aggregate stability (Yang *et al.*, 2005; Hati *et al.*, 2007; 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 macro aggregates (Six *et al.*, 2000; Mikha and Rice, 2004; Bandyopadhyay *et al.*, 2010) with a proportionate decrease in micro aggregates and this imply that addition of organics support formation of macro-aggregates through binding of micro-aggregates (Tisdall and Oades, 1982; 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 supplementing fertilizer significantly increase C in aggregates (Schjønning *et al.*, 2007; Benbi and Senapati, 2010; Bandyopadhyay *et al.*, 2010; Sui *et al.*, 2012). Comparison of SOC content in different sized WSA classes showed macro aggregates are the main source of higher enriched fraction of SOC (Cambardella and Elliott 1994; Bappa Das *et al.*, 2014). Soil acts both as source or sink of atmospheric C depending on land use, cropping system and management practices. 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 C, protected from mineralization because it is less subjected to physical, microbial and enzymatic degradation. Soil organic matter is of central importance in maintaining soil quality and is now receiving attention due to the potential for carbon sequestrations in soils. 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, it is imperative to improve soil C storage and structural status of the soil. Therefore, the present study investigated the effect of nutrient management practices on SOC, aggregate size distribution, structural properties and aggregate associated Carbon on sandy loam soil (Typic Ustochrept) of Trans Gangetic plains after 26 years of rice-wheat cropping system.

2. MATERIALS AND METHODS

Site Description

The experiment with continuous application of fertilizers and organic amendments to rice-wheat cropping system has been conducted since 1983 at Punjab Agricultural University Research Farm, Ludhiana (30°56'N, 75°52'E and 247 m above msl), India. The experimental area is characterized as semi-arid sub-tropical with monsoonal climate with a mean annual precipitation of 500 mm, most of the rain falling between July to September, and mean temperature of 28.84°C during rice growth season (June-October) and 17.27°C during wheat. The soil is Typic Ustochrept and sandy loam in texture (54% sand and 18% clay). At the start of the experiment, the field soil (0-15 cm) tested 8.1 in pH, 3.1 g kg^{-1} in SOC, 65 mg kg^{-1} in available N, 5.8 mg kg^{-1} in available P and 46 mg kg^{-1} in available K.

Experimental Design and Treatments

Rice and wheat crops were grown annually with necessary plowing. The treatments represented different combinations of inorganic and organic sources of nutrients to rice and wheat. 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 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 $year^{-1}$, rice and wheat with 12 treatment combinations which were laid out in a randomized design and replicated thrice. Out of the 12 treatments, five selected for the present study were Control (No fertilizer, no organic manure both in *kharif* and *rabi*), NPK (100% recommended NPK dose through fertilizer both in rice and wheat), NPK+FYM (50% recommended NPK dose through fertilizer + 50% N through FYM in rice, 100% recommended NPK dose through fertilizer in wheat), NPK+CR (50% recommended NPK dose through fertilizer + 50% N through wheat straw; 100% recommended NPK dose through fertilizer in wheat), NPK+GM (50% recommended NPK dose through fertilizer + 50% N through green manuring in rice; 100 % recommended NPK dose through fertilizer in wheat). The 100% NPK dose used in rice and wheat were 120:30:30 and120:60:30 kg N: P_2O_5:K_2O ha^{-1}. During June, the land was prepared and rice crop was transplanted at 20x15 cm spacing. Calculated amount of FYM was manually spread uniformly on the surface of the specified plots and incorporated into the moist soil two weeks before the transplanting of rice. The appropriate amount of sesbania [*Sesbania sesban* (L.) Merr] was chopped into pieces and incorporated in the puddled soil a day before transplanting of rice. CR *i.e.,* Wheat Cut Straw (WCS) was added to soil itself after harvest of wheat in the same field to supply required amount of nitrogen based on the laboratory tests. After rice harvest, wheat was sown in the second week of November and harvested in April. A basal application of half dose of N and full dose of P and K was made each year and the remaining N was top dressed 21 days after sowing. Other recommended management practices were followed.

Soil Sampling and Analysis

Soil samples were collected from an on-going field experiment after the harvest of wheat crop. Soil samples were taken from different depths (0-15, 15-30, 30-45 and 45-60 cm). Each sample was a composite of four spots in a plot. All the samples were brought to laboratory and air-dried. The part of the ungrounded sample of 0-15 cm depth was used for estimating aggregate size distribution. Air dried soil clods were passed through a set of 5 and 8 mm sieves and the clods retained on the 5 mm size 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 having pore diameter 2, 1, 0.5, 0.25 and 0.11 mm. The nest of sieves was oscillated up and down by a pulley arrangement for 30 min at a frequency of 30 cycles per minute in salt free water. The materials were collected from respective sieves and weighed after oven drying at 65°C. After correcting sand content in all aggregate size fractions by dispersion with sodium hexametaphosphate, the water-stable aggregates were estimated. In this way, aggregates were fractioned into Water Stable Macro-aggregate (WSMA) and micro-aggregate (WSMI) categories and the aggregate ratio was calculated following the procedure as given below.

Aggregate ratio: $AR = \left(\frac{\text{Percent macroaggre gates}}{\text{Percent microaggre gates}}\right) = \left(\frac{\Sigma Q}{\Sigma S}\right)$
(AR) of soil

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

The MWD and 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 hr (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 and mortar to <0.25 mm size. The C associated with different aggregate size fractions was estimated.

Calculation of Soil Organic Carbon stock (kg ha^{-1}).

$$\frac{A \times D \times SOC \times BD}{100}$$

Where, A is area in ha (10000 m^2); D is depth of the soil in cm; OC is soil organic carbon (g kg^{-1}); and BD is bulk density (Mg m^{-3}).

Calculation of C-sequestration rate or rate of net SOC increase (Mg ha^{-1} yr^{-1}).

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

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

3. RESULTS AND DISCUSSION

Soil Organic Carbon

Continuous application of NPK for 26 years in rice-wheat system has resulted in significantly higher SOC over control in the 0-15 cm soil depth. Intensive rice-wheat system without application of fertilizers (control) has more or less maintained the SOC level. As the initial SOC concentration was very low, the SOC concentration in the control plot was also maintained despite declining yield trend. Application of recommended dose of NPK resulted in increased SOC in surface soil over the initial level. The higher stubble and root biomass retention commensuration with higher yield in NPK fertilized plot might have improved the SOC concentration in surface soil. All the treatments showed higher accumulation of soil organic carbon in surface soil as compared to sub-surface soil. Substitution of 50% N through FYM or CR or GM to rice has improved SOC significantly over NPK treated plots. Greatest accumulation of SOC (6.8 g kg^{-1}) was observed with NPK + FYM treatment while control plot showed the lowest value (Table 1). A similar build up of SOC due to cropping with the applications of chemical fertilizer combined with manure (Christensen, 1996; Smith *et al.*, 1997; Aoyama and Kumakura, 2001; Rudrappa *et al.*, 2006; Swapana Sepehya *et al.*, 2012), paddy straw (Verma and Bhagat, 1992), green manure (Yadav *et al.*, 2000) was also reported from long term experiments. The SOC stock in 0-60 cm layer was 30.3 Mg ha^{-1} for NPK+FYM treated soils compared with 26.1 Mg ha^{-1} for NPK and 20.1 Mg ha^{-1} for the unfertilized control plots. The SOC distribution among the various organically amended plots up to 60 cm deep soil was NPK+FYM> NPK+CR>NPK+GM, accounting 30.3, 28.9, 27.3 Mg ha^{-1}, respectively. Differences in SOC may be due to the differences in biochemical composition of organic materials, *i.e.,* the amount of C, lignin and polyphenol content in FYM, CR and GM and their array with mineral particles. Cropping with the use of NPK alone or in combination with organics (FYM, CR, GM) brought about an increase in the SOC content to the tune of 29.85, 50.74, 43.78 and 35.82%, respectively over that in the control, up to 60 cm depth. Thus

Table: 1
Long term effect of fertilizer and different organics application on SOC concentration, SOC stock and SOC sequestration rate under rice-wheat cropping system

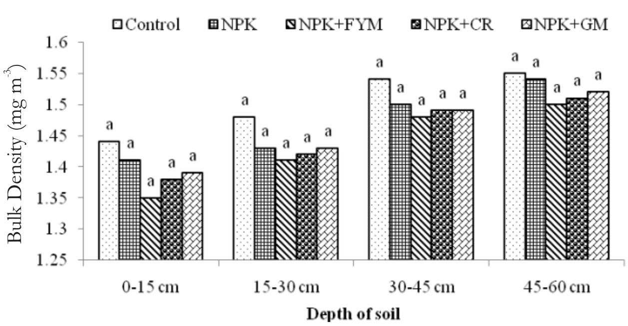
	SOC stock (g kg^{-1})				SOC stock (Mg ha^{-1})				Total SOC stock in 0-60 cm rate (Mg ha^{-1} yr^{-1})	SOC sequestration soil profile (Mg ha^{-1})
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60		
Control	3.0 d	2.5 c	2.0 b	1.5 c	6.5	5.6	4.6	3.5	20.1	
NPK	5.1 c	3.2 b	2.0 b	1.7 b	10.8	6.9	4.5	3.9	26.1	0.228
NPK+FYM	6.8 a	3.5 a	2.2 a	1.9 a	13.8	7.4	4.9	4.3	30.3	0.392
NPK+CR	6.1 b	3.3 ab	2.2 a	1.9 a	12.6	7.0	4.9	4.3	28.9	0.336
NPK+GM	5.9 b	3.2 b	2.1 ab	1.5 c	12.3	6.9	4.7	3.4	27.3	0.275

FYM: Farmyard manure; CR: Crop residue; GM: Green manure ; Values followed by the same lower case letter under same soil layer indicate that the values are not significantly different according to Duncan's Multiple Range test

overall gain in SOC in 0-60 cm soil in the plots under NPK+FYM treatment compared to NPK treated plots was 164 kg ha^{-1}yr^{-1} of C. The sequestration rate was estimated by using the mass of SOC in the control treatment as reference point and number of years of intervention. It varied from 0.228 to 0.392 Mg ha^{-1}yr^{-1} in different nutrient management treatments. Among the treatments, NPK +FYM recorded significantly higher sequestration rate over all other treatments. The benefits of sequestering C to sustain crop productivity by applying organic amendments are well documented (Majumder *et al.*, 2008; Sodhi *et al.*, 2009; Bandyopadhyay *et al.*, 2010).

Bulk Density (BD)

Among the treatments, application of NPK along with organics has resulted in lower BD compared to control, but no significance difference in BD was found between fertilized and unfertilized plots (Fig. 1). Application of FYM, CR and GM decreased BD by 0.09, 0.06 and 0.05 Mg m^{-3}, respectively over the control. The control treatment recorded highest BD (1.44 Mg m^{-3}) while it was lowest with NPK+FYM (1.35 Mg m^{-3}). Lower BD on organically amended plots was due to greater organic matter content of soil (Tiarks *et al.*, 1974), increased root growth, better aggregation and increased volume of micropores (Schjonning *et al.*, 1994). The BD



FYM: Farmyard manure; CR: Crop residue; GM: Green manure

Fig. 1. Effect of different integrated nutrient management treatments on bulk density after 26 years of rice-wheat cropping system. Bars with the same lower case letter in a soil are not significantly different according to Duncan's Multiiple Range test

values were lesser in the surface layer as compared to the subsurface layers. This may be due to presence of organic matter in the top layer and greater compaction in the subsurface layer due to the absence of cultivation and mass of the soil above (Bandyopadhyay *et al.,* 2010).

Water Stable Aggregates and Structural Indices

Soil aggregation represented by percentage of WSA, Aggregate Ratio (AR), MWD and GMD was significantly affected by long term application of fertilizer and organic amendments (Table 2). Soils receiving organic amendments (FYM, CR and GM) along with NPK had more water stable aggregates, higher aggregate ratio, mean weight diameter and geometric mean diameter than those without them or control. Significantly higher WSA in the size fraction (0.25 mm) due to FYM and crop residues (wheat straw) application in the present study is similar to that obtained by Yang *et al.* (2005). Singh *et al.* (2007) have also shown that addition of various organic manures along with inorganic fertilizers in rice-wheat system improved the aggregation status of the soil. Application of organics along with inorganic fertilizer increase SOC that affects the soil physical quality through its positive effect on development of stable soil aggregates.

The total water stable aggregates at wheat harvest ranged between 78.6 and 85.8% under different treatments.

Table: 2
Water stable aggregates and structural indices under different treatments after 26 years of rice-wheat cropping

Treatments	WSMA (%)	WSMIA (%)	AR	TWSA (%)	MWD (mm)	GMD (mm)
Control	35.3d	43.3a	0.55d	78.6b	0.43d	0.99c
NPK	41.7c	40.9b	0.72c	82.7a	0.50c	1.01b
NPK+FYM	48.9a	36.8c	0.96a	85.8a	0.56a	1.03a
NPK+CR	45.8b	37.3c	0.85b	83.2a	0.53b	1.02ab
NPK+GM	45.2b	36.5c	0.83b	81.8a	0.54b	1.02ab

FYM: Farmyard manure; CR: Crop residue; GM: Green manure; WSMA= water stable macroaggregates (>0.25mm), WSMIA= water stable microaggregates (<0.25mm), AR= Aggregate ratio, MWD= Mean weight diameter, GMD= geometric mean diameter with in a column, number followed by lower case letter are significantly different between treatments by Duncan's Multiple Range test

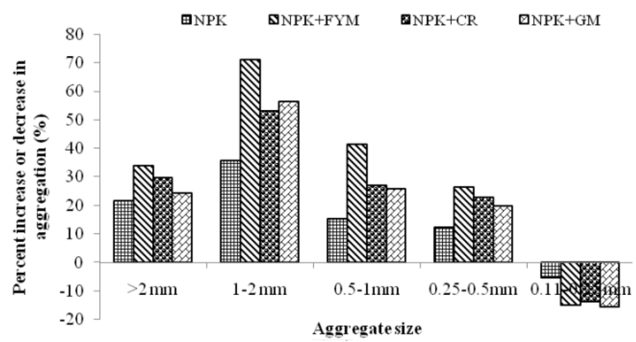
The WSA of all the treatments were significantly greater than the control, indicating that C inputs through balanced fertilization maintained aggregate stability to some extent. Differences in aggregation between the treatments may have been due to the differences in C inputs returned to the soil. The size distributions of WSA under different treatments are depicted in Table 3. The NPK treated plots recorded a significantly greater proportion of aggregates in the ranges >2, 1-2, 0.5-1 mm and 0.25-0.5 mm than did the control plots but the treatment effect were not significant in smaller size fractions. The macro-aggregates comprised 35.3 to 48.9% of the total WSA compared to 36.5 to 43.3% as micro-aggregates. The amount of macro-aggregates was lowest in the control plot and it was highest in the plots treated with organics. Application of FYM, crop residues and green manure significantly improved the formation of macro-aggregates as compared to control. Contrarily, the proportion of micro-aggregates decreased with the application of organics. Higher amount of macro-aggregates through organic amendments and a lower proportion of micro-aggregates imply that organics support formation of macro-aggregates through binding of micro-aggregates (Huang *et al.,* 2010). Greater proportion of macro-aggregates with fertilizer + manure application than chemical fertilizers alone is in agreement with Schjønning *et al.* (2007), Bandyopadhyay *et al.* (2010) and Sui *et al.* (2012). Among the macro-aggregates, the 0.25-0.50 mm fraction constituted the greatest proportion (17-21.6%). Incorporation of crop residues increased the occurrence of macro-aggregates of different sizes by 22.8-53% over control. The effect of green manure was slightly more and its application along with NPK increased the amount of macro-aggregates of different sizes by 19.6-56.2%. Formation of macro-aggregates was maximum in NPK+FYM plots and the increase over control ranged between 26.5 to 71.1% (Fig. 2). Several theories on how organic matter stabilizes the aggregates have been proposed (Jastrow, 1996; Monreal *et al.*,1995; Tisdall and Oades, 1982). According to generally proposed theory, the release of polysaccharides and organic acids during decomposition of organic sources play a key role in stabilization of soil macro-aggregates (Cheshire, 1979; Martin, 1971). Since polysaccharides and organic acids do not spread far from the site of production, freshly added residues function as a nucleation site for the growth of fungi and other soil microbes. This results in the binding of residues and soil particulates into macro-aggregates.

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 macro-aggregates but lower fraction of micro-aggregates. The MWD under different treatments revealed that organic amendments of FYM, CR and GM increased MWD by 30.2, 23.2 and 25.58%,

Table: 3
Effect of different integrated nutrient management treatments on aggregate size distribution in 0-15 cm soil after 26 years of rice-wheat cropping system

Treatments	Water Stable Aggregates %				
	>2 mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	0.11-0.25 mm
Control	3.8b	6.2d	8.3d	17.1c	43.3a
NPK	4.7a	8.4c	9.5c	19.2b	41.0a
NPK+FYM	5.1a	10.6a	11.7a	21.6a	36.8b
NPK+CR	5.0a	9.5b	10.5b	21.0a	37.3b
NPK+GM	4.8a	9.7b	10.4b	20.4a	36.5b

FYM: Farmyard manure; CR: Crop residue; GM: Green manure; Within a column, of an aggregate size class, numbers followed by different lower case letters are significantly different between treatments by Duncan's Multiple Range test



FYM: Farmyard manure; CR: Crop residue; GM: Green manure

Fig. 2. Influence of different integrated nutrient management treatments on improvement in the occurrence of macroaggregates and decrease in the proportion of microaggregates over unfertilized soil in 0-15 cm after 26 years of rice-wheat cropping system

respectively, over control. Positive effects of manure and crop residues on MWD have been reported in a number of studies (Tripathy and Singh, 2004; Singh *et al.*, 2007; Bandyopadhyay *et al.*, 2010; Li *et al.*, 2010; Bappa Das *et al.*, 2014). The organic matter stabilizes aggregates by forming and strengthening bonds between clay domains and between quartz particles and the variation among the treated organics might be influenced by their biochemical composition. A meagre variation was observed in all the structural indices among the organics and the variation of structural indices among the treated organics might be influenced by their biochemical compositions. Bandyopadhyay *et al.* (2010) reported similar variation in structural indices.

A correlation matrix was developed among SOC, BD, WSA, WSA>2 mm, MWD and GMD. Data on Pearson's correlation matrix (Table 4) revealed that SOC was significantly ($P< 0.01$) and positively correlated with WSA, WSA>2 mm, MWD and GMD. This result suggests that aggregation is positively affected by SOC. Plante *et al.* (2006) and Gupta Choudhury *et al.* (2008) reported that increased SOC content was associated with increased aggregation. But significantly negative relationship was found between

BD and SOC, and between BD and MWD in 0-15 cm soil depth.

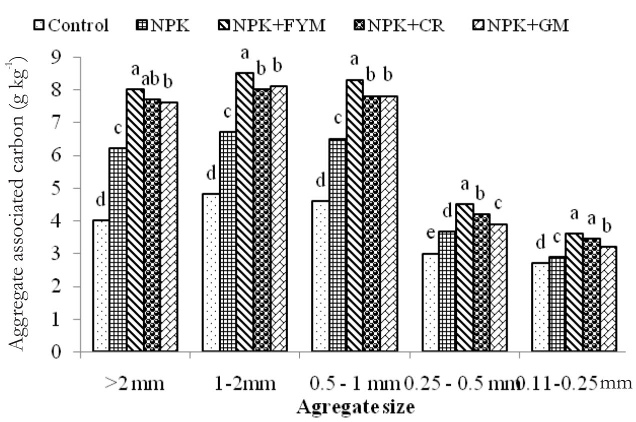
Aggregate Associated Carbon

Macro-aggregates had higher C density as compared to micro-aggregates, suggesting that macro-aggregates play an important role in C sequestration in soil. Among the macro-aggregates, the highest C density was observed in 1-2 mm and it decreased as aggregates became smaller than 1-2 mm (Fig. 3). Similar results of C accumulation in aggregates have been published in literature (Buyanovsky *et al*., 1994, Sodhi *et al*., 2009, Benbi and Senapati, 2010). Long term application of organic and inorganic fertilizer significantly increases the C concentration as compared to control in all aggregate size fractions. Highest increase in C concentration was observed in plots receiving NPK+FYM. Amount of C stabilization in soil depended on the amount of C input through organic sources and these results show that long term application of organics along with inorganics results in C stabilization in macro-aggregates. Greater C accumulation in macro-aggregates could be due to lower decomposable soil organic matter associated with these aggregates and also the direct contribution of soil organic matter to the stability of macro aggregates resulting in only C rich macro-aggregates being able to withstand slaking. The amount of organic matter in aggregate size fraction depends on the intra aggregate particulate organic matter. This fraction is more in macro-aggregates, because once incorporated, decomposition occurs at a slower rate when held within macro-aggregates due to physical protection within the macro aggregates and probably due to more chemically recalcitrant nature of the partially decomposed intra aggregate particulate organic matter (iPOM).

Table: 4
Correlation matrix for soil organic carbon and structural properties of the soil for the surface soil (0-0.15 m) layer

Parameter	BD	SOC	TWSA	WSA	MWD
SOC	-0.959**				
TWSA	-0.939*	0.923*			
WSA	-0.915*	0.986**	0.923*		
MWD	-0.945*	0.992**	0.888*	0.966**	
GMD	-0.971**	0.997**	0.922*	0.970**	0.995**

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level; BD= bulk density; SOC= soil organic carbon; TWSA = total water stable aggregate; WSA = water stable aggregate; MWD= mean weight diameter



FYM: Farmyard manure; CR: Crop residue; GM: Green manure

Fig. 3. Aggregate associated carbon under different treatments after twenty six years of cultivation. Treatment means of the same size fraction with the same letter are not significantly different according to Duncan's Multiiple Range test

4. CONCLUSIONS

The study indicated that application of recommended dose of NPK either through inorganic fertilization or through inorganic fertilizer NPK with 50% nitrogen substituted by FYM or crop residues or green manure to rice and NPK to wheat increased SOC concentration as well as improved structural properties of the soil. Results suggest that management practices such as application of organics supply additional fresh organic residues and C to the soil resulting in formation of soil macro-aggregates which can provide a similar protective mechanism in an annually tilled cropping sysytem. Our study also showed that organic amendments derived organic carbon accumulated preferentially in macro-aggregates. Thus, it can be concluded that fertilization that augmented residue C and residue N return to the soil in rice-wheat system improves soil aggregation and enhances C sequestration for sustainable productivity in rice-wheat system and thereby helps in controlling the rising levels of atmospheric CO_2.

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