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Changes in soil aggregate fractions under long-term double rice cropping system with application of inorganics and organics

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ABSTRACT

Studying the aggregate fractions of soil is important for understanding the C-stabilization. Carbon sequestration in soils has the potential to curb global warming besides maintaining sustainability of agricultural system under tropical and subtropical climate. Thus a 14-year old experiment was adopted to assess the impact of double rice cropping system with manuring and grades of fertilization on aggregate stability and aggregate-associated carbon in an inceptisol in southern India. Among the treatments FYM had the highest value of different size distributions of water-stable aggregates (WSA) (>2000, 2000-1000 and 250-100 µm) followed by RDF + FYM, fallow, N, 50 per cent RDF, RDF and control. The meso-aggregates (MesoA 2000-250 µm) comprised 7.6-12.0 per cent of total WSA compared to 79.0-86.7 per cent as coarse macro-aggregates (CMacA >2000 µm) and 4.8-13.3 per cent as coarse micro-aggregates (CMicA 250-100 µm). The values of mean weight diameter (MWD) and geometric mean diameter (GMD) ranged between 2.0 and 2.3 and 1.42 and 1.65 mm respectively. Irrespective of the treatment a maximum amount of C was found with meso-aggregate fractions (250-2000 µm, 22.63-37.21 g/kg) followed by silt + clay fraction (<53 µm, 9.27-12.45 g/kg), fine micro-aggregates (53-100 µm, 5.68-16.69 g/kg), coarse macro-aggregates (>2000 µm, 7.54-8.47 g/kg) and coarse micro-aggregates (100-250 µm, 3.94-7.31 g/kg) in a decreasing order constituting on an average 43.1, 18.0, 16.7, 13.1 and 9.0 per cent respectively of the total aggregate-associated C.

Keywords: Soil aggregates; mean weight diameter; aggregate-associated carbon; double rice cropping

INTRODUCTION

Analyses of physical structure of soil are usually done using physical fractionation methods which are based on the premise that the association of the soil particles and their spatial arrangement play a key role in the function of soil organic matter (SOM) (Gregorich et al 2006). The aggregation is a means to both protect and conserve soil organic carbon (SOC) and allow the stored organic matter to function as a reservoir of plant nutrients. Crop cultivation is known to adversely affect the distribution and stability of soil aggregates and reduce SOC stock in soils (Six et al 2000, Kong et al 2005). The impacts of cultivation on C stock have commonly been observed to be restricted mostly to surface soils and/or to root zone depth (Paustian et al 1997). However different crop species have different effects on soil aggregation and C-accumulation with varying soil depth. Altering soil physico-chemical properties by management practices may increase one or more of the protective attributes which ultimately increase C in soils provided C inputs to soil do not decrease.

Tillage disturbs large aggregates more than smaller aggregates making SOC more susceptible to mineralization (Six et al 1998). Clay particles have a higher protective effect on chemical and biophysical processes of carbon stabilization (Christensen 1996). Clay plus silt serve as a fixed capacity level (Hassink and Whitmore 1997) while the combination of micro-, meso- and macro-aggregated-carbon provides an additional variable capacity. The former is soil specific while the latter tends to be contingent on both amount of carbon input and soil type. The distribution of SOC in different aggregate size classes (viz micro-, meso- and macro-aggregates) may affect soil erosion and more rapid loss may occur from macro-aggregates than micro-aggregates (Eynard et al 2005).

The mean weight diameter (MWD) and geometric mean diameter (GMD) have smaller values in the cultivated than the fallow soils indicating more disturbances through tillage and lower accumulation as well as protection of SOC in macro-aggregates (Choudhury et al 2010). Cultivated soils have a smaller WSA within >2 and 1-2 mm aggregate size fractions but a greater aggregation in <0.25 mm size fraction than the fallow. Tillage operations may enhance the susceptibility of aggregates to disruption by wet-dry cycles that lead to a loss of C-rich macro-aggregate fractions.

The stability of intact water-stable aggregates showed higher values in uncultivated than in cultivated soils. There were no significant differences in MWD between forest and pasture soils (Emadi et al 2008). Although the importance of organic matter to improve soil aggregate stability is well known the experiments showing the beneficial effects of organic matter on aggregate stability varied. For instance some workers (Christensen 1986) found a significant correlation between organic matter and aggregate stability.

MATERIAL and METHODS

Site description

A long-term experiment was established in the year 2000 at the experimental farm of the Regional Agricultural Research Station (18°45’ N, 78°45´ E), Jagtial, Telangana with double rice (*Oryza sativa* L) cropping system. The area receives on an average annual rainfall of approximately 600-900 mm. The mean annual minimum and maximum temperatures are 10.0 and 37.6°C respectively. The soil was classified as inceptisol, Typic Ustochrept, black clay with clayey texture. The site had the soil moisture and temperature regimes of ustic and isohyperthermic respectively.

Two rice (*Oryza sativa* L) crops (cv JGL 3855) were grown annually in the experiment. The experiment was laid out in randomized block design with three replications (plot size 12 × 9 m) and consisted of the treatments 50 per cent RDF (NPK 60-30-20), 100 per cent RDF (NPK 120-60-40), 100 per cent N, 100 per cent RDF + farmyard manure (10 tons/ha, in each Kharif), farmyard manure (10 tons/ha in each Kharif and Rabi), control (plots without RDF fertilizers and organics) and fallow.

Aggregate analysis and structural indices

Two sets of six nested sieves of 2000, 1000, 500, 250, 100 and 53 µm diameter size class were used for the separation of water stable aggregates and subsequent calculation of different structural indices. Aggregate separation was done by using wet sieving apparatus (Yoder 1936). After removing visible pieces of crop residues and roots from the field-moist soil sample aggregates ranging in diameter from 2000 to 5000 µm were obtained from the air-dried bulk soil that had been broken apart by hand before air-drying for the wet sieving procedure. Exactly 100 g of soil aggregates (2000 to 5000 µm) in duplicate were slaked by submerging in deionized water placing on top 2000 µm sieve for a while at room temperature. Water-stable aggregates were then separated by moving the sieves up and down in a Yoder apparatus for 30 minutes. After correcting sand content in all the aggregates by dispersion with sodium hexametaphosphate soil aggregate indices were calculated. Aggregates were fractioned into coarse macro-aggregates (CMacA >2000 µm), meso-aggregates (MesoA 250-2000 µm) and coarse micro-aggregates (CMicA 100-250 µm). The sum of aggregates >250 µm was clubbed as macro-aggregates (MacA) while aggregates <250 µm were grouped into micro-aggregates (MicA). With the data of soil aggregates and primary particles the following soil aggregate indices were calculated:

Water stable aggregates: From the weight of the soil particles (aggregates + primary particles) in each size group its proportion to the total sample weight was determined. Water-stable aggregates (WSA) were the mass of stable aggregates divided by the total aggregate (stable + primary particles) mass as:

$$\text{Water-stable aggregates (\%)} = \frac{(\text{Weight of soil + sand})_i - (\text{Weight of sand})_i}{\text{Weight of sample}} \qquad \text{........ (1)}$$

where *i* denotes the size of the sieve

The percentage weight of water stable macro-aggregates is the summation of soil aggregate-size fractions >250 µm while the percentage weight of water stable micro-aggregates are those retained in <250 µm.

Aggregate ratio: Aggregate ratio (AR) is denoted by:

$$\text{Aggregate ratio} = \frac{\text{Aggregates retained in} > 250\ \mu m}{\text{Aggregates retained in} < 250\ \mu m} \quad \text{..... (2)}$$

Mean weight diameter: After correction of sand content the amount of aggregates remaining in each size fraction was used to calculate the mean weight diameter (MWD) of the water-stable aggregates following van Bavel (1949) as:

$$\text{Mean weight diameter (mm)} = \frac{\sum_{i=1}^{n} XiWi}{\sum_{i=1}^{n} Wi} \quad \text{..... (3)}$$

where n= The number of fractions (100-250, 250-500, 500-1000, 1000-2000, > 2000 µm, *Xi*= Mean diameter (µm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0 mm), *Wi*= Weight of soil (g) retained on each sieve

Geometric mean diameter: Geometric mean diameter (GMD) an exponential index of aggregate stability was expressed as:

$$\text{Geometric mean diameter (mm)} = \frac{\sum_{i=1}^{n} Wi \log Xi}{\sum_{i=1}^{n} Wi} \quad \text{..... (4)}$$

where n= Number of fractions same as MWD size, *Xi*= Mean diameter (mm) of the sieve size class same as MWD size, *Wi*= Weight of soil (g) retained on each sieve

Per cent aggregate stability: The index per cent aggregate stability or degree of aggregation (AS) of soil was calculated as:

$$\frac{\text{Per cent soil particle} > 250\ \mu m - \text{Per cent primary particles} > 250\ \mu m}{\text{Per cent primary particles} < 250\ \mu m} \quad \text{..... (5)}$$

Readily oxidisable organic carbon (OC): The oxidizable organic carbon (OC) was determined by Walkley and Black's wet oxidation method (Walkley and Black 1934). One and a half gram of ground (<2.0 mm) soil was placed in a 500 ml Erlenmeyer flask to which 10 ml of 1.0 *N* $K_2Cr_2O_7$ was added followed by 20 ml concentrated sulphuric acid. After half an hour of the reaction under dark the excess dichromate was determined by titrating against 0.5 *N* $Fe(NH_4)_2(SO_4)_2 6H_2O$. The amount of dichromate consumed by the soil was used to calculate the amount of OC based on the theoretical value that 1.0 ml 1.0 *N* $K_2Cr_2O_7$ oxidises 3.0 mg C.

Statistical analysis

Means of three replicates and standard errors of the means were calculated for all the pools of soil organic carbon (on dry weight basis). The data were analysed using randomized block design (RBD). Statistical analysis was performed by DOS-based SPSS version 12.0. The SPSS procedure was used for analysis of variance (ANOVA) to determine the statistical significance of treatments as well as of cropping systems. Two factor factorial ANOVA was used to determine the existence of interaction effect between treatments and cropping systems. Simple correlation coefficients and regression equations were also developed to evaluate relationships between the response variables using the same statistical package. The 5.0 per cent probability level was regarded as statistically significant.

RESULTS and DISCUSSION

Water-stable aggregates and structural indices

The total water-stable aggregates (WSA) in the experimental soils ranged from 66.21 to 93.78 per cent under different treatments. Among the treatments FYM had the highest value of different size distributions of WSA (> 2000, 2000-1000 and 250-100 µm) followed by RDF + FYM, fallow, N, 50 per cent RDF, RDF and control (Table 1). The meso-aggregates (MesoA) (2000-250 µm) comprised 7.6-12.0 per cent of total WSA compared to 79.0-86.7 per cent as coarse macro-aggregates (CMacA > 2000 µm) and 4.8-13.3 per cent as coarse micro-aggregates (CMicA 250-100 µm).

Irrespective of the treatments the meso-aggregates (MesoA 250-2000 µm) comprised 9.2 per cent of the total WSA compared to 83.2 per cent as

Table 1. Influence of treatments on distribution of water-stable aggregates into different size fractions at surface layer (0-15 cm)

Treatment	Water-stable aggregates (%)						
	CMacA > 2000 µm	MesoA (µm)			Total macro-aggregates	CMicA 250-100 µm	Total water stable aggregates
		2000-1000	1000-500	500-250			
50% RDF	68.24^{ab}	2.51^{ab}	2.78^{a}	0.95^{ab}	74.47^{ab}	4.27^{b}	78.75^{bc}
RDF	63.02^{bc}	3.37^{ab}	2.77^{a}	2.99^{ab}	72.15^{cd}	3.60^{b}	75.75^{bc}
N	63.30^{bc}	2.77^{ab}	2.00^{a}	1.35^{ab}	69.42^{cd}	10.67^{a}	80.09^{ab}
RDF + FYM	72.08^{ab}	1.67^{b}	2.15^{a}	3.38^{a}	79.29^{ab}	4.54^{b}	83.83^{ab}
FYM	75.32^{a}	5.76^{a}	2.56^{a}	1.83^{ab}	85.47^{a}	8.31^{a}	93.78^{a}
Control	55.17^{c}	2.98^{ab}	2.71^{a}	0.57^{b}	61.43^{c}	4.79^{b}	66.21^{c}
Fallow	71.66^{ab}	2.01^{b}	1.60^{a}	2.95^{ab}	78.22^{ab}	5.31^{b}	83.53^{ab}

Different small letters within the same column show the significant difference at p= 0.05 according to Duncan's Multiple Range Test for separation of mean

coarse macro-aggregates (CMacA >2000 µm) and 7.4 per cent as coarse micro-aggregates (CMicA 250-100 µm). Among the meso-aggregates the 1000-2000 µm fraction exhibited a higher value followed by 500-1000 and 250-500 µm fractions constituting on an average 40.8, 32.1 and 27.1 per cent of the total meso-aggregates respectively.

Application of organics alone (FYM) significantly ($p <0.01$) improved the coarse macro- (CMacA), total macro-aggregates and total water stable aggregate formation compared to the control. On the other hand the proportion of micro-aggregates increased significantly ($p <0.05$) in N and FYM treatments as compared to the control (Table 1). This indicated a higher formation of bigger aggregates with the supplementation of organics.

The values of mean MWD and GMD ranged from 2.0 to 2.3 and 1.42 to 1.65 mm respectively. Results showed that the MWD and GMD were significantly ($p <0.01$) higher in soils under N (2.30 and 1.65 mm respectively) compared with other treatments. Aggregate ratio (AR) showed significant increase in FYM treatment (5.97) as compared to control (1.69) while aggregate stability (%) was significantly ($p <0.01$) lower in soils under control (80.69) compared to other treatments as depicted in Table 2.

Application of organics alone and along with inorganics significantly ($p < .05$) improved the meso- and micro-aggregate formation compared to the control (Table 1). This indicated a higher formation of bigger aggregates with the supplementation of organics. Similar results were also observed by Huang et al (2010) and Bandyopadhyay et al (2010). The organic matter is classified as an important binding agent for aggregation and is responsible for the formation and stability of soil aggregates (Tisdall and Oades 1982) through biotic mechanism (Schjonning et al 2006). The added organics could supply additional fresh organic residues (water soluble and hydrolysable substrates) and C to the soil resulting in production of microbial polysaccharides that increased aggregate cohesion which could explain the observed progressive increase in aggregate stability to mechanical breakdown. Positive effects of FYM application on aggregate stability have also been reported by Bandyopadhyay et al (2010) and Singh et al (2007).

The proportion of large macro-aggregates within the total soil aggregates is the most important fraction to evaluate the effect of management practices on soil aggregation as it exerts a strong influence on the MWD, a comprehensive index for evaluating soil aggregation (Jiao et al 2006). Higher crop residue-C might have an effect on aggregate stability as plant roots are important binding agents at the scale of macro-aggregates (Six et al 2004). The presence of soil microbial biomass may also influence aggregate formation (Six et al 2005). FYM-applied soils exhibited higher values of aggregate indices. The organic matter is classified as an important binding agent for aggregation and is responsible for the formation and stability of soil aggregates (Tisdall and Oades 1982) through biotic mechanism (Schjonning et al 2006) as mentioned earlier. The variation of structural indices

Table 2. Influence of treatments on aggregate indices of experimental soils at 0-15 cm soil depth

Treatment	MWD (mm)	GMD (mm)	AR	AS (%)
50% RDF	2.08[b]	1.44[bc]	3.05[bc]	90.67[bc]
RDF	2.00[b]	1.40[c]	3.00[bc]	89.04[c]
N	2.30[a]	1.65[a]	2.33[bc]	90.14[bc]
RDF + FYM	2.04[b]	1.42 [c]	3.92[b]	96.98[a]
FYM	2.15 [b]	1.51 [b]	5.97[a]	92.33[abc]
Control	2.05[b]	1.43[bc]	1.69 [c]	80.69[d]
Fallow	2.07[b]	1.44[bc]	3.05[bc]	94.97[ab]

Different small letters within the same column show the significant difference at p= 0.05 according to Duncan's Multiple Range Test for separation of mean

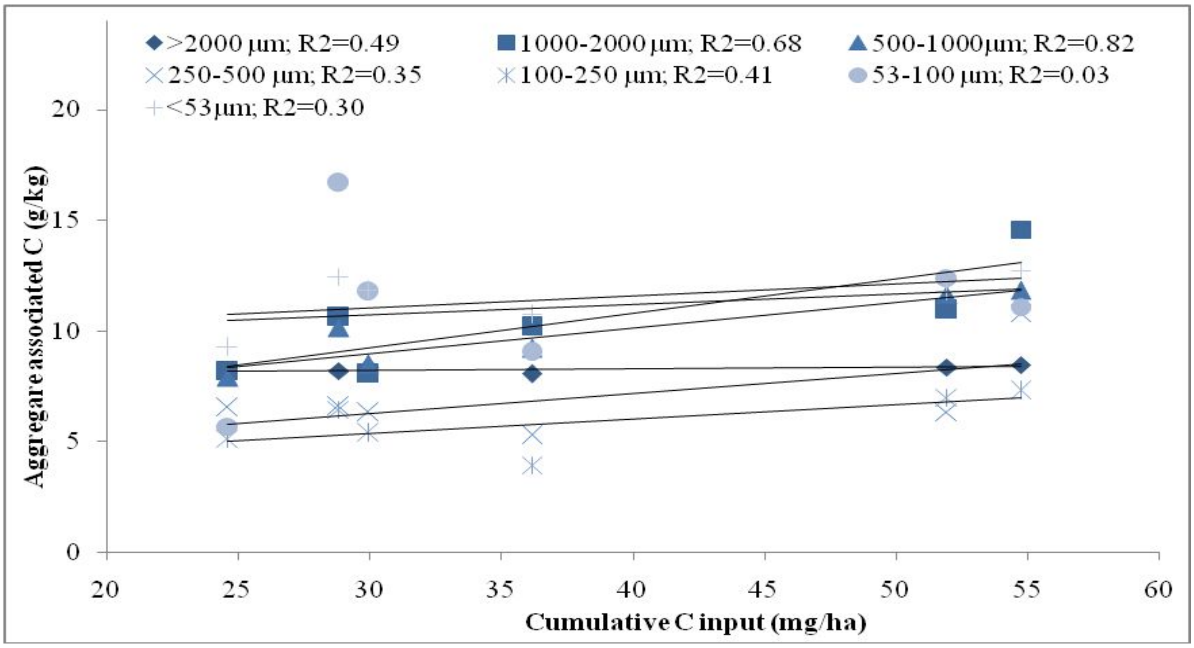

Fig 1. Relationship between cumulative carbon inputs and C associated with different-sized aggregates

among the treated organics might be influenced by their biochemical compositions.

Aggregate-associated carbon fractions

The aggregate-associated C in different-sized fractions is presented in Table 3. Incorporation of FYM alone significantly (p <0.05) increased C concentration in meso- and total macro-aggregates over the other treatments. The maximum amount of SOC was retained in fine micro-aggregate (53-100 µm) fraction under N treatment. Total macro-aggregate-associated carbon was higher under FYM and total micro-aggregate-associated carbon was higher under N treatments.

Of the total aggregate-associated C and macro-aggregates (>250 µm) had higher amounts (56.2%) compared to micro-aggregates (<250 µm, 43.8%). Application of organics increased C accumulation in different aggregates and the effect was more pronounced with macro-aggregates than micro-aggregates. Irrespective of the treatment a maximum amount of C was found with meso-aggregate fractions (250-2000 µm, 22.63-37.21 g/kg) followed by silt + clay fraction (<53 µm, 9.27-12.45 g/kg), fine micro-aggregates (53-100 µm, 5.68-16.69 g/kg), coarse macro-aggregates (> 2000 µm, 7.54-8.47 g/kg) and coarse micro-aggregates (100-250 µm, 3.94-7.31 g/kg) in a decreasing order constituting on an average 43.1, 18.0, 16.7, 13.1 and 9.0 per cent respectively of the total aggregate-associated C (Table 4).

Aggregate-associated C strongly influences C-sequestration and dynamics of C-cycling in soils.

Table 3. Aggregate-associated C under different size fractions under different treatments

Treatment	Macro-aggregated C (g/kg) CMac AC >2000	CMac 1000-2000	Meso AC 500-1000	Meso 250-500	Total Macro AC	Micro-aggregated C (g/kg) CMic AC 100-250	FMic AC 53-100	(Silt + clay) AC <53	Total Micro AC
50% RDF	8.33[a]	8.06[d]	8.52[bc]	6.32[b]	31.23[b]	5.39[a]	11.79[b]	11.84[ab]	29.01[ab]
RDF	8.08[a]	10.19[bcd]	9.20[bc]	5.30[b]	32.78[b]	3.94[a]	9.04[bc]	10.73[bc]	23.71[bc]
N	8.20[a]	10.64[bc]	10.14[ab]	6.61[b]	35.45[b]	6.45[a]	16.69[a]	12.45[a]	35.60[a]
RDF + FYM	8.36[a]	10.96[b]	11.64[a]	6.34[b]	37.30[b]	7.01[a]	12.40[ab]	11.80[ab]	31.21[ab]
FYM	8.47[a]	14.58[a]	11.82[a]	10.81[a]	45.68[a]	7.31[a]	11.10[b]	12.69[a]	31.10[ab]
Control	8.17[a]	8.18[cd]	7.91[c]	6.54[b]	30.80[b]	5.14[a]	5.68[c]	9.27[d]	20.09[c]
Fallow	7.54[a]	8.92[bcd]	9.47[bc]	6.61[b]	32.53[b]	4.29[a]	6.46[c]	10.12[cd]	20.87[c]

Different small letters within the same column show the significant difference at p= 0.05 according to Duncan's Multiple Range Test for separation of mean

Table 4. Per cent distribution of aggregate-associated C into different aggregate fractions and per cent change over 50% RDF (values within the bracket)

Treatment	Macro-aggregate	Meso-aggregate	Micro-aggregate
RDF	14.31	43.72	41.97
RDF+FYM	12.20 (3.42)	42.24 (17.2)	45.56 (31.7)

Macro-aggregates had higher C concentration as compared to micro-aggregates suggesting the existence of higher amount of water-stable macro-aggregates that might play an important role in C-sequestration and aggregate stability. Similar results on C-stabilization in macro-aggregates have been reported by Cambardella and Elliot (1994), Mikha and Rice (2004) and Benbi and Senapati 2010).

A positive linear relationship was observed between the cumulative C inputs into the soils (during the whole period of experimentation) and the aggregate-associated C (Fig 1). Such relationship was stronger particularly with the C associated with the size fraction 500-1000 (R^2= 0.82) and 1000-2000 µm (R^2= 0.68). Kong et al (2005) and Majumder et al (2007) also reported similar results. However there was a little influence of increasing C inputs for C associated with aggregates of 53-100 and 250-500 µm size. The steeper relationship with meso- and coarse micro-aggregated fraction than with coarse macro-aggregated fraction (Fig 1) indicated that the former fractions are more responsive to preserving C on C addition.

An attempt was made to find out if application of FYM could influence the distribution of carbon among macro-, meso- and micro-sized aggregates. On an average about 14.3, 43.7 and 42.0 per cent of the native aggregate-associated C was allocated to the macro-, meso- and micro-sized aggregates. On external application of C in the form of FYM there was a significant change in the proportion of such allocation into different fractions. A higher amount of the applied C found its way to micro-aggregates (Table 4). C associated with micro-aggregates was more stable. Hence it shows that a higher amount of C stabilized in soils when applied as FYM was due to its preferential association with micro-aggregates.

CONCLUSION

Meso-aggregates (9.2% of WSA) were directly related to the aggregate-associated C (43.2% of total aggregated C), 'silt + clay'-sized fraction, fine micro-aggregates and coarse micro-aggregates accumulated 18.0, 16.7 and 9.0 per cent respectively of the total aggregate-associated C. A higher amount of the applied C found its way to micro-aggregates hence it can be predicted that higher amount of applied C stabilized in soils. It can be concluded that even in inceptisols under hot semi-arid region and soil with different management practices (application of FYM) could sequester C.

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