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Effect of Long-Term Use of Different Source of Organics on Soil Aggregate Fractions

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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 28-year old experiment was used to assess the impact of rice-wheat cropping system with different sources of organics and grades of fertilization on aggregate stability and aggregate associated carbon in an Inceptisol in India. Among the treatments, 50% RDF+FYM had the highest value of different size distributions of water stable aggregates (WSA) (>2000 µm, 2000-1000 µm, 1000-500 µm, 500-250 µm, 250-100 µm). Irrespective of the treatments, the mesoaggregates (MesoA,250-2000 µm) comprised of 22.6% of the total WSA compared to 72.6% as coarse macro aggregates (CMacA, > 2000µm) and 4.7% as coarse micro aggregates, (CMicA, 250-100 µm). Of the total aggregate associated C, macro aggregates (> 250 µm) had higher amounts (65.8%) compared to micro aggregates (< 250 µm, 34.2%).Application of organics increased C accumulation in different aggregates, the effect was more pronounced with macroaggregates than microaggregates.

Key words: *Microaggregate, Aggregate cssociated carbon, Mesoaggregate.*

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 SOM[1]. 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 reduces SOC stock in soils[2,3]. The impacts of cultivation on C stock have commonly been observed to be restricted mostly to surface soils and/or to root zone depth[4]. However, different crop species have different effects on soil aggregation and C accumulation with varying soil depth. Altering soil physicochemical properties by management practices may increase one or more of the protective attributes which ultimately increases C in soils provided C inputs to soil do not decrease.

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Tillage disturbs large aggregates more than smaller aggregates, making SOC more susceptible to mineralization[5]. Clay particles have a higher protective effect on chemical and biophysical processes of carbon stabilization[6]. Clay plus silt serves as a fixed capacity level[7] while the combination of micro, meso, and macro aggregated carbon provide 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 soil organic carbon (SOC) in different aggregate size classes (i.e. micro, meso, and macroaggregates) may affect soil erosion and more rapid loss may occur from macroaggregates than microaggregates[8].

The MWD and 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[9]. Cultivated soils have a smaller WSA within >2 mm and 1-2 mm aggregate size fractions but a greater aggregation in <0.25 mm size fraction than the fallow is found. 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 soils than in cultivated soils. There were no significant differences in MWD between forest and pasture soils[10] 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 have been varied. For instance, some workers[11] 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 were 10.0oC and 37.6oC 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 m × 9 m) and consisted of the following treatments: (i) 50% RDF (*i.e.*, 60-30-20), (ii) 100% RDF (*i.e.*, 120-60-40), (iii) 100% N, (iv) 100% RDF + farmyard manure (10 t ha-1, in each *kharif*), (v) farmyard manure (10 t ha-1, in each *kharif* and *rabi*) (vi) control (plots without RDF fertilizers and organics) and (vii) Fallow.

Aggregate analysis and structural indices

Two sets of six nested sieves with 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[12]. After removing visible pieces of crop residues and roots from the field-moist soil samples, 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 was slaked by submerging it 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 then fractioned into coarse macro aggregates (CMacA, >2000 µm), mesoaggregates (MesoA, 250-2000 µm) and coarse microaggregates (CMicA, 100-250 µm). The sum of aggregates >250 µm was clubbed as macroaggregates (MacA) while aggregates <250 µm grouped into microaggregates (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) was the mass of stable aggregates divided by the total aggregate (stable + primary particles) mass as

$$\text{Water stable aggregates (\%)}=\left[\frac{(\text{Weight of soil}+\text{sand})i-(\text{Weight of sand})i}{\text{Weight of sample}}\right] \text{.. (1)}$$

Where, *i* denotes the size of the sieve. The percentage weight of water stable macroaggregates is the summation of soil aggregate-size fractions > 250 µm; while the percentage weight of water stable microaggregates are those retained in < 250 µm.

Aggregate ratio

Aggregate ratio (AR) is denoted by

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

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[13] as:

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

Where, n is the number of fractions (100-250, 250-500, 500-1000, 1000-2000, > 2000 µm, *Xi* is the mean diameter (µm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0 mm) and *Wi* is the weight of soil (g) retained on each sieve.

Geometric mean diameter

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

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

Where, n is the number of fractions same as MWD size, *Xi* is the mean diameter (mm) of the sieve size class same as MWD size and *Wi* is the weight of soil (g) retained on each sieve.

Percent aggregate stability

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

$$\left(\frac{\text{Percent soil particle} > 250\ \mu\text{m} - \text{Percent primary particles} > 250\ \mu\text{m}}{\text{Percent primary particles} < 250\ \mu\text{m}}\right) \text{..... (5)}$$

Readily oxidisable organic carbon (OC)

The oxidizable organic carbon (OC) was determined by Walkley and Black wet oxidation method[14]. One-half g 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 first 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 $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$. The amount of dichromate consumed by the soil was used to calculate the amount of OC based on the theoretical value of 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% probability level is 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 61.2 to 87.1% under different treatments. Among the treatments, 50% RDF+FYM had the highest value of different size distributions of water stable aggregates (WSA) (>2000 µm, 2000-1000 µm, 1000-500 µm, 500-250 µm, 250-100 µm) followed by 75%RDF+FYM, 50% RDF+PS, 50% RDF+ GM, 75% RDF+PS, 75% RDF+GM and control (Table 1).

Irrespective of the treatments, the mesoaggregates (MesoA,250-2000 µm) comprised of 22.6% of the total WSA compared to 72.6% as coarse macro aggregates (CMacA, > 2000µm) and 4.7% as coarse micro aggregates, (CMicA, 250-100 µm).

Application of organics alone and with inorganics significantly improved the coarse macroaggregate formation compared to the control. Contrarily, the proportion of micro aggregates decreased with the application of organics (Table 1). This indicated a higher formation of bigger aggregates with the supplementation of organics. Similar results also were observed by Huang et al[15] and Bandyopadhyay et al.[16]. The organic matter is classified as an important binding agent for aggregation and is responsible for the formation and stability of soil aggregates[17] through biotic mechanism[18]. 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 increase aggregate cohesion. This explained the observed progressive increase in aggregate stability to mechanical breakdown. Positive effects of green manure and FYM application on aggregate stability have been reported in a number of studies[16,19].

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, because it exerts a strong influence on the mean weight diameter (MWD), a comprehensive index for evaluating soil aggregation[20]. Again, higher crop residue-C might have an effect on aggregate stability as plant roots are important binding agents at the scale of macro aggregates[21, 22]. The presence of soil microbial biomass may also influence aggregate formation[23]. FYM applied soils exhibited higher values of aggregate indices. The variationsin structural indices among the treated organics might also be influenced by their bio-chemical compositions.

Results showed that the mean weight diameter was significantly ($p< 0.05$) higher in soils under the treatments with combination of organics and inorganics compared to control (Table 2). Geometric mean diameter (GMD) also exhibited similar trend which ranged from 0.94 to 1.28 mm. Aggregate ratio (AR) and aggregate stability (AS) showed similar trend, with the highest values in soils under 50% RDF+FYM treatment (6.37 and 88.6%) but lowest values in soil under control (1.16 and 55.3%). GuptaChoudhury[25] and Datta[26] also reported similar findings.

Aggregate associated carbon fractions

The aggregate associated C in different sized fractions is presented in Table 3. Incorporation of organics like FYM, PS and GM significantly ($p < 0.05$) increased C concentration in different sized aggregates over the other treatments (control and RDF). The maximum amount of SOC was retained in 500-1000 µm sized fraction followed by 1000-2000 µm, coarse macro (> 2000 µm), 250-500 µm, coarse micro, fine micro and silt + clay fractions. Total macro and micro aggregate associated carbon was higher under 50% RDF+FYM treatment.

Of the total aggregate associated C, macro aggregates (> 250 µm) had higher amounts (65.8%) compared to micro aggregates (< 250 µm, 34.2%).Application of organics increased C accumulation in different aggregates, the effect was more pronounced with macroaggregates than microaggregates.

Aggregate associated C strongly influences C sequestration and dynamics of C cycling in soils. Following 28 years of continuous cropping with different management practices, the experimental soils demonstrated preferential sequestration of SOC in the mesoaggregate fraction(250-2000 µm). In fact, such sequestration was more with particles of decreasing sizes.A higher surface area for smaller particles may be responsible for this. Christensen[11] and Kong et al.[3] also reported similar results.GuptaChoudhury[24] and Datta[25] also reported similar findings in Indian subcontinent.

An attempt was made to find out if application of different sources of organics could influence the distribution of carbon among macro, meso and micro sized aggregates. On average, about 16.7, 48.1 and 35.2% of the native aggregate associated C was allocated to macro, meso and micro sized aggregates. On external application of C in the form of FYM, PS and GM there was a significant change in the proportion of such allocation into different fractions. A higher amount of the C applied through FYM and GM found its way to mesoaggregates, however, PS-C to meso and macroaggregates.

A positive linear relationship was observedbetween 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 aggregate size fractions of >2000 µm (R^2=0.74), and also showed good correlation with 250-500 µm (R^2=0.61). This indicated that smaller particles with greater surface area may be responsible for scavenging a sizable amount of C in micro aggregates. Kong et al.[3] and Majumder et al.[26] also reported similar results.

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**			**Total macro aggregates**	**CMicA 250-100 µm**	**Total water stable aggregates**
		2000-1000 µm	**1000-500 µm**	**500-250 µm**			
Control	26.95 ^{f}	4.42 ^{ab}	8.44 ^{a}	13.81 ^{a}	53.62 ^{e}	7.58 ^{a}	61.20 ^{d}
100% RDF	45.07 ^{e}	4.02 ^{ab}	5.24 ^{bc}	11.67 ^{ab}	66.0 ^{d}	6.18 ^{ab}	72.18 ^{c}
50 % RDF +FYM	74.37 ^{a}	2.81 ^{bc}	3.41 ^{c}	5.83 ^{c}	86.42 ^{a}	0.68 ^{d}	87.10 ^{a}
75% RDF+FYM	71.37 ^{ab}	1.73 ^{c}	3.03 ^{c}	6.31 ^{c}	82.44 ^{ab}	3.34 ^{c}	85.7 ^{a}
50% RDF +PS	64.17 ^{abc}	4.09 ^{ab}	5.36 ^{bc}	8.09 ^{bc}	81.71 ^{ab}	2.77 ^{cd}	84.48 ^{ab}
75% RDF+PS	50.71 ^{de}	5.17 ^{a}	6.67 ^{ab}	10.82 ^{ab}	73.37 ^{c}	6.09 ^{ab}	79.46 ^{b}
50% RDF + GM	60.54 ^{bcd}	4.31 ^{ab}	5.49 ^{bc}	8.31 ^{bc}	78.65 ^{bc}	0.63 ^{d}	79.28 ^{b}
75% RDF + GM	57.45 ^{cd}	1.95 ^{c}	5.46 ^{bc}	10.45 ^{ab}	75.31 ^{c}	3.79 ^{bc}	79.10 ^{b}

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

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

Treatment	**MWD (mm)**	**GMD (mm)**	**AR**	**AS (%)**
control	1.20 ^{d}	0.94 ^{d}	1.16 ^{e}	55.33 ^{f}
100% RDF	1.46 ^{c}	1.06 ^{c}	2.00 ^{de}	67.05 ^{e}
50 % RDF +FYM	1.85 ^{a}	1.28 ^{a}	6.37 ^{a}	88.95 ^{a}
75% RDF+FYM	1.77 ^{a}	1.22^{ab}	4.85 ^{b}	84.57^{ab}
50% RDF +PS	1.70^{ab}	1.20^{ab}	3.69^{bc}	81.38^{bcd}
75% RDF+PS	1.50 ^{c}	1.08 ^{c}	2.77 ^{cd}	75.11 ^{d}
50% RDF + GM	1.69^{ab}	1.19^{ab}	4.73 ^{b}	83.15^{abc}
75% RDF + GM	1.60^{bc}	1.13^{bc}	3.00 ^{cd}	77.14 ^{cd}

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

Table 3: Aggregate associated C under different size fractions under different treatment

Treatment	**Size fraction (µm)**								
	Macro aggregated C (g kg $^{-1}$)					**Micro aggregated C (g kg $^{-1}$)**			
	CMac AC > 2000	**MesoAC**			**Total Macro AC**	**CMic AC 100-250**	**FMic AC 53-100**	**(Silt + clay) AC < 53**	**Total Micro AC**
		1000-2000	**500-1000**	**250-500**					
control	7.46 ^{c}	9.52 ^{a}	8.26 ^{c}	7.74 ^{c}	32.98 ^{c}	7.36 ^{c}	6.37 ^{cd}	4.77 ^{c}	18.50 ^{c}
100% RDF	9.19 ^{b}	9.32 ^{d}	8.83 ^{c}	8.29 ^{c}	35.63 ^{d}	7.65^{bc}	5.41 ^{e}	6.31^{abc}	19.36 ^{c}
50 % RDF +FYM	12.25 ^{a}	13.11 ^{a}	14.74^{a}	15.21^{a}	55.31 ^{a}	10.02 ^{a}	6.94^{bc}	7.78 ^{a}	24.74 ^{a}
75% RDF+FYM	10.02 ^{b}	11.90 ^{b}	11.38 ^{b}	10.53 ^{b}	43.83 ^{b}	9.01^{ab}	6.07 ^{de}	5.55^{bc}	20.63^{bc}
50% RDF +PS	11.94 ^{a}	11.34^{bc}	10.79 ^{b}	10.33 ^{b}	44.41 ^{b}	8.78^{abc}	5.93 ^{de}	6.35^{abc}	21.07^{bc}
75% RDF+PS	9.50 ^{b}	10.23 ^{cd}	11.69 ^{b}	7.87 ^{c}	39.30 ^{c}	10.01 ^{a}	6.16^{cde}	6.36^{abc}	22.52^{ab}
50% RDF + GM	10.19 ^{b}	11.70 ^{b}	12.00 ^{b}	10.10 ^{b}	43.99 ^{b}	9.12^{ab}	7.59^{ab}	7.20^{ab}	23.91 ^{a}
75% RDF + GM	10.11 ^{b}	9.89 ^{d}	11.21 ^{b}	7.83 ^{c}	39.04 ^{c}	7.43 ^{c}	8.01 ^{a}	7.36 ^{a}	22.81^{ab}

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

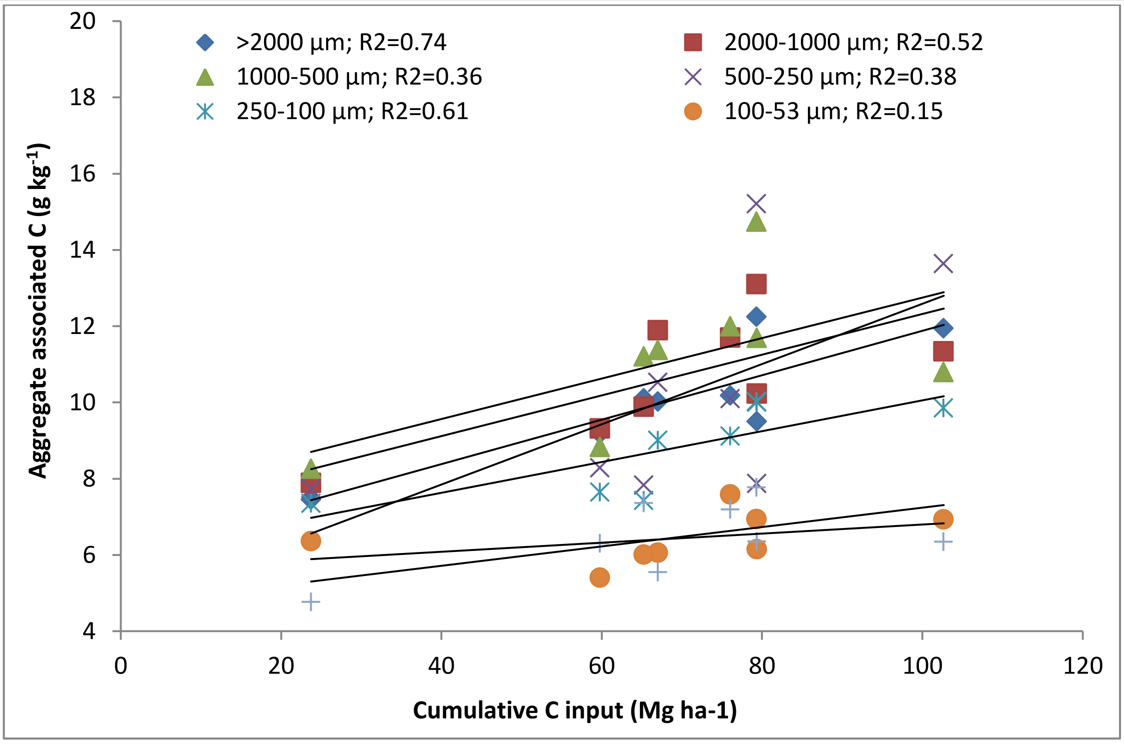

Fig. 1:Relationship between cumulative carbon inputs and C associated with different sized aggregates

CONCLUSION

Out of the total WSA, coarse macroaggregates shared the maximum proportion (72.6%) followed by meso (22.6%) and coarse microaggregates (4.8%). The aggregate associated C in general, preferentially, resided with mesoaggregates followed by coarse macroaggregates, coarse microaggregates, ‘silt+clay’ sized aggregates and fine microaggregates in decreasing order constituting 50.0, 15.9, 13.7, 10.3 and 10.2%, respectively, of the total aggregate associated C.

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