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Effect of long-term tillage on soil aggregate fractions

A. Krishna Chaitanya*[1], Biswapati Mandal. Prasanta Kumar Bandyopadhyay
[1]Bidhan Chandra Krishi Viswavidyalaya, Kalyani-741235, West Bengal
*Corresponding author email id: krch3737@outlook.com

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 used to assess the impact of degrees of tillage and organics on aggregate stability and aggregate associated carbon in a Vertisol in southern India. Low tillage+Farmers practice+ Green manure had the highest value of different size distributions of water stable aggregates (WSA) followed by LT+GM, LT+FM, Conventional tillage +FP+GM, CT+GM and CT+FP. The mesoaggregates, MesoA (2000-250 µm) comprised of 68.4 to 80.8% of total water stable aggregates compared 4.7 to 25.1%as coarse macro aggregates (CMacA, > 2000µm) and 6.6 to 14.5% as coarse micro aggregates, (CMicA, 250-100 µm). Application of organics alone improved the mesoaggregate formation compared to the other treatments. Contrarily, the proportion of micro aggregates decreased with the application of organics in combination with inorganic under low tillage system. On average, about 15.2, 43.9 and 40.9% of the native aggregate associated C was allocated to macro, meso and micro sized aggregates.
Key words: *tillage, soil aggregates, mean weight diameter, aggregate associated carbon*

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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 [18 13]. The impacts of cultivation on C stock have commonly been observed to be restricted mostly to surface soils and/or to root zone depth [15]. 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.

Tillage disturbs large aggregates more than smaller aggregates, making SOC more susceptible to mineralization [18]. Clay particles have a higher protective effect on chemical and biophysical processes of carbon stabilization [2]. Clay plus silt serves as a fixed capacity level [10] 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 [6].

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 [8]. 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 [5]. 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 [3] found a significant correlation between organic matter and aggregate stability.

MATERIAL AND METHODS

Site description

The present long-term experiment was started in 2000 with sunflower-sorghum cropping system at Regional Agricultural Research Station, Bijapur, Karnataka, (16°77' latitude, 75°74' longitude and 578 m above mean sea level). The area receives, on an average, annual rainfall of approximately 585 mm. The mean annual minimum and maximum temperatures were 9.4^0C and 47.9^0C, respectively. The soil was classified as *vertisol*, alkaline and calcareous with clay texture. The site had the soil moisture and temperature regimes of aridic-ustic and isohyperthermic, respectively.

Sunflower (*Helianthus annuus* L.) – sorghum (*Sorghum bicolour* L.) were grown annually under rainfed condition. The variety M35-1 for sorghum and DSSH-3 or morden for sunflower was used in the present experiment. The experiment was laid out in split plot design with tillage (conventional and low tillage) as main plot and nutrient supply as sub-plot treatment, with three replications. Low tillage was practiced by one harrowing, one hoeing and hand weeding. The treatments considered in present experiment were: (i) conventional tillage + green manure (5 t ha^{-1}) (CT+GM), (ii) conventional tillage + farmers' practice (CT+FP), (iii) conventional tillage + farmers' practice + green manure (5 t ha^{-1}) (CT+FP+GM), (iv) low tillage + green manure (5 t ha^{-1}) (LT+GM), (v) low tillage + farmers' practice (LT+FP), (vi) low tillage + farmers' practice + green manure (5 t ha^{-1}) (LT+FP+GM).

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 (Yoder, 1936). 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 (1949) as:

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

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:

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

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:

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

Readily oxidisable organic carbon (OC)

The oxidizable organic carbon (OC) was determined by Walkley and Black wet oxidation method (Walkley and Black, 1934). 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. 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 67.0 to 73.2% under different treatments. Among the treatments, LT+FP+GM had the highest value of different size distributions of water stable aggregates (WSA) followed by LT+GM, LT+FM, CT+FP+GM, CT+GM and CT+FP (Table 1). The mesoaggregates, MesoA (2000-250 µm) comprised of 68.4 to 80.8% of total WSA compared 4.7 to 25.1%as coarse macro aggregates (CMacA, > 2000µm) and 6.6 to 14.5% as coarse micro aggregates, (CMicA, 250-100 µm). Application of organics alone improved the mesoaggregate formation compared to the other treatments. Contrarily, the proportion of micro aggregates decreased with the application of organics in combination with inorganic under low tillage system (Table 1). This indicated a higher formation of bigger aggregates with the supplementation of organics. Similar results also were observed by Huang et al.(2010) and Bandyopadhyay *et al.* [1]. The organic matter is classified as an important binding agent for aggregation and is responsible for the formation and stability of soil aggregates [23] through biotic mechanism [26]. 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 [1, 17].

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 [12]. 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 [19]. The presence of soil microbial biomass may also influence aggregate formation [20]. 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 LT+FP+GM (1.34 mm). Geometric mean diameter (GMD) also exhibited similar trend which ranged from

0.95 to 1.1 mm. Aggregate ratio (AR) showed similar trend, with the significantly higher values in soils under LT+FP+GM treatment (2.2) but lowest values in soil under CT+FP and CT+GM (1.3). FP+GM under low tilled soils showed higher MWD, GMD, AR and AS than those under the other treatments (Table 2).

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 2000-1000 µm	1000-500 µm	500-250 µm	Total macro aggregates	CMicA 250-100 µm	Total wsa
CT+GM	3.1 c	8.7 c	24.2 a	21.3 a	57.3 d	9.7 a	67.0 b
CT+FP	6.4 bc	17.0 b	27.9 a	5.2 c	56.5 d	6.3 ab	62.8 c
CT+FP+GM	12.0 ab	14.4 b	23.4 a	10.3 bc	60.1 cd	8.1 ab	68.2 b
LT+GM	8.2 bc	10.1 c	26.4 a	19.7 b	64.5 b	6.7 ab	71.1 ab
LT+FP	9.6 bc	15.0 b	24.2 a	13.7 ab	62.5 bc	6.5 ab	69.1 b
LT+FP+GM	18.3 a	21.8 a	21.6 a	6.7 bc	68.4 a	4.8 b	73.2 a

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 ; CT+GM=Conventional tillage+ green manure, CT+FP=conventional tillage + Farmers practice, CT+FP+GM= conventional tillage+ farmers practice+ green manure, LT+GM=low tillage+ green manure, LT+FP= low tillage+ farmers practice, LT+FP+GM=low tillage+ farmers practice+ green manure

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

Treatment	MWD(mm)	GMD(mm)	AR	AS(%)
CT+GM	0.92 d	0.96 c	1.3 d	50.5 b
CT+FP	1.20 ab	1.08 ab	1.3 d	74.2 a
CT+FP+GM	1.25 ab	1.10 a	1.5 cd	74.7 a
LT+GM	0.99 cd	0.95 c	1.8 b	74.9 a
LT+FM	1.13 bc	1.03 b	1.7 bc	76.2 a
LT+FP+GM	1.34 a	1.10 a	2.2 a	80.0 a

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. Percent distribution of aggregate associated C into different aggregate fractions and percent change over 50% RDF (values within the bracket)

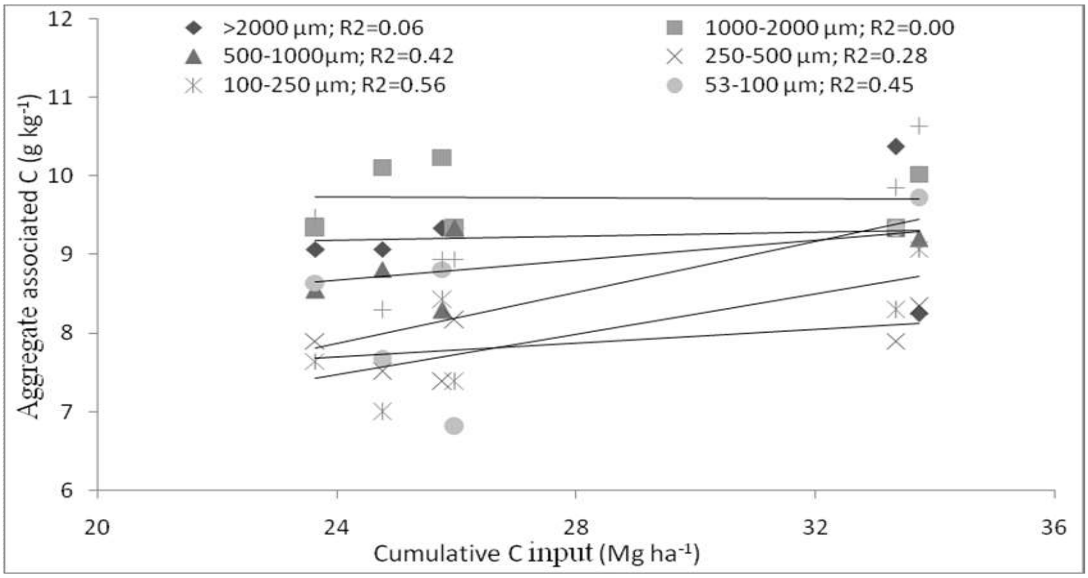
Treatment	CmacA	MesoA	MicroA
CT+FP	15.51	45.21	39.28
CT+FP+GM	12.65 (-9.0)	42.25 (4.3)	45.10 (28.1)
LT+FM	14.97	42.55	42.48
LT+FP+GM	16.10 (14.3)	41.24 (3.0)	42.66 (6.8)

Table 4. Aggregate associated C under different size fractions under different treatment

Treatment	Size fraction (µm)								
	Macro aggregated C (%)					Micro aggregated C (%)			
	CMac AC > 2000 µm	MesoAC 1000-2000 µm	500-1000 µm	250-500 µm	Total Macro AC	CMic AC 100-250 µm	FMic AC 53-100 µm	(Silt + clay) AC < 53 µm	Total Micro AC
CT+GM	9.3 ab	9.3 a	9.3 a	8.2 a	39.3 a	7.4 d	6.8 d	8.9 c	25.3 d
CT+FP	9.1 ab	10.1 a	8.8 ab	7.5 b	38.7 a	7.0 d	7.7 c	8.3 d	25.1 d
CT+FP+GM	8.2 b	10.0 a	9.2 ab	8.3 a	39.0 a	9.1 a	9.7 a	10.6 a	31.5 a
LT+GM	9.3 ab	10.2 a	8.3 b	7.4 b	38.4 a	8.4 ab	8.8 ab	8.9 c	28.3 c
LT+FM	9.1 ab	9.3 a	8.6 ab	7.9 ab	38.0 a	7.6 cd	8.6 b	9.5 b	27.9 c
LT+FP+GM	10.4 a	9.3 a	9.3 a	7.9 ab	40.1 a	8.3 bc	9.3 ab	9.9 b	29.6 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

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



Aggregate associated carbon fractions

The aggregate associated C in different sized fractions is presented in Table 4. Incorporation of organics like GM with inorganic significantly ($p<0.05$) increased C concentration in different sized aggregates over the treatment with sole inorganics under both the tillage systems. The maximum amount of SOC was retained in 1000-2000 µm sized fraction followed silt+clay (< 53 µm), coarse macroaggregate (>2000 µm), 500-1000 µm, fine micro aggregate (53-100 µm), coarse micro aggregate (100-250 µm) and 250-500µmfractions. Total macroaggregate associated carbon was higher under LT+FP+GM while total micro aggregate associated carbon was higher under CT+FP+GM treatments. Of the total aggregate associated C, macro aggregates (> 250 µm) had higher amounts (58.2%) compared to micro aggregates (< 250 µm, 41.7%).Application of organics increased C accumulation in different aggregates, the effect was more pronounced with macroaggregates than microaggregates.

Irrespective of the treatments, a maximum amount of C was found with mesoaggregate fractions (250-2000 µm, 25.8-27.6 g kg^{-1}) followed by silt + clay (< 53 µm) fraction (8.3-10.6 g kg^{-1}), coarse macro aggregates (> 2000 µm, 8.3-10.4 g kg^{-1}), fine micro aggregates (53-100 µm, 6.8-9.7 g kg^{-1}), coarse micro aggregates (100-250 µm, 7.0-9.1 g kg^{-1}) in a decreasing order, constituting, on an average, 39.6, 14.0, 13.8, 12.7 and 11.9%, respectively, of the total aggregate associated C (Table 4).

Aggregate associated C strongly influences C sequestration and dynamics of C cycling in soils. Following 14 years of continuous cropping with different management practices, the experimental soils demonstrated preferential sequestration of SOC in the meso-aggregate fraction (250-2000). In fact, such sequestration was more with particles of decreasing sizes.A higher surface area for smaller particles may be responsible for this. Christensen [2] and Kong et al. [14] also reported similar results. Gupta Choudhury [9] and Datta [4] also reported similar findings in Indian subcontinent.

An attempt was made to find out if application of GM/FYM could influence the distribution of carbon among macro, meso and micro sized aggregates. On average, about 15.2, 43.9 and 40.9% of the native aggregate associated C was allocated to macro, meso and micro sized aggregates (Table 3). On external application of C in the form of GM/FYM, there was a significant change in the proportion of such allocation into different fractions under both the tillage treatments. A higher amount of the applied C found its way to macro aggregates under low tillage, however under conventional tillage more C was stabilized in microaggregates. We know that the C associated with micro aggregates was more stable. Hence, it is reasonable to conclude that a higher amount of C stabilized in soils when applied as GM/FYM under conventional tillage was due to its preferential association with microaggregates.

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 < 53 µm (R^2=0.65). 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*. [13] and Majumder *et al*. [14] also reported similar results. However, there was a little influence of increasing C inputs on C associated with aggregates of coarse macro and 1000-2000 µm size aggregate fractions.

CONCLUSION

Out of the total aggregate associated C, mesoaggregates shared the maximum proportion (39.6%) followed by silt + clay fraction (14.0%), coarse macroaggregate (13.8), fine macro aggregate (12.7%) and coarse microaggregates (11.9%). Thus, it can be concluded that long-term cultivation with balanced fertilization and organic supplementation under arid region caused a net C sequestration in soil under both the tillage practices. A higher amount of stabilization was observed in soils with conventional tillage compared with low tillage and a tendency of SOC to be sequestered to long-term storage of C in soils.

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