International Journal of Environment and Climate Change

10(4): 14-23, 2020; Article no.IJECC.56102
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Aggregates Characterization and Its Associated Organic Carbon in Two Contrasting Lowland Rice Soils of West Bengal

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Authors' contributions

This work was carried out in collaboration among all authors. Author RN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SM, PG, AK and DM helped in laboratory analysis of soil samples. Author PKB checked and improved the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2020/v10i430191
Editor(s):
(1) Dr. Anthony R. Lupo, University of Missouri, USA.
Reviewers:
(1) Javier De Grazia, Lomas de Zamora University, Argentina.
(2) Paul Kweku Tandoh, Kwame Nkrumah University of Science and Technology, Ghana.
(3) Enjugu Achukwu Manasseh, Usmanu Danfodiyo University, Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/56102

Original Research Article

Received 06 February 2020
Accepted 14 April 2020
Published 20 April 2020

ABSTRACT

Aims: The present study investigated the effect of lowland rice soils of two regions viz. new alluvial and red-laterite on aggregate characterization and their associated organic carbon (SOC).
Study Design: Randomized block design (RBD).
Place and Duration of Study: New alluvial soils were collected from Jangipara block of Hooghly, West Bengal and Red-laterite soils were collected from Raghunathpur block of Purulia, West Bengal during 2017-18.
Methodology: For each soil types (New alluvial and Red-laterite) five locations were identified and soil samples were collected from three depths i.e. 0-10, 10-20 and 20-30 cm. The aggregate characteristics i.e. water-stable aggregates (WSAs), mean weight diameter (MWD), aggregate stability and aggregate size fractions along with the distribution of carbon in those aggregate size fractions were critically studied.

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Results: The aggregate size as well as the stability decreased with increasing soil depth from 0 to 30 cm in both soils. New alluvial soils showed higher aggregate stability than red-laterite soils. Mean weight diameter (MWD) values of new alluvial soils were 34, 29 and 87% more than red-laterite soils at 0-10, 10-20 and 20-30 cm depth, respectively. Presence of higher amount of clay and organic matter in new alluvial made the difference in structural coefficient. The surface soil (0-10 cm) had more coarse aggregate (Cmac A >2000µ) fraction, however, microaggregates (<250µ) were dominant in lower depths in both soils. Water stable aggregates (WSA) in surface soils of new alluvial and red-laterite were 57 and 36%, respectively and were decreased with depth. Red-laterite produced higher micro aggregates as compared to new alluvial soils. Coarse macro aggregate fractions (>2000µ) retained maximum amount of soil organic carbon in both soils however, coarse micro aggregate associated carbon (Cmic AC<250µ) was captured in lower depths. New alluvial soils yielded aggregates with higher in diameter and stability coefficient that is due to higher amount of carbon stored in aggregates.

Conclusion: The abundance of macro aggregate of New alluvial soils indicates better soil physical quality than Red-laterite soil which was dominated in higher micro aggregates leads to poor in structure and susceptible to water erosion.

Keywords: Water-stable aggregates; mean weight diameter; aggregate stability; aggregate size fractions; aggregate associated carbon.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important crops and a primary source of food for more than half of the world's human population [1]. More than 90% of the world's rice is grown and consumed in Asian countries like India, China, Indonesia, Bangladesh, Vietnam, Thailand, and Myanmar. The crop occupies about 165.2 Mha worldwide, with an annual production and productivity of 740.9 mt and 4485.87 kg ha^{-1} [2]. In India, rice is cultivated either in upland or in lowland conditions in almost all part of the country in an area of 43.39 Mha with a production of 104.32 Mt and productivity of 2.40 t ha^{-1} [3]. It is one of the important food security crops of India and provides 43 per cent of calorie requirement for more than 70.0 per cent of the Indian population [4].

Lowland rice contributes about 76% of the global rice production [5]. The anaerobic soil environment created by puddling and flood irrigation of lowland rice brings several physical and biological changes in the rice rhizosphere that may influence the chemistry of the submerged soil [6]. The frequency of tillage associated with various physical reactions between soil and water depends on different soils structural characteristics resulting in a spatial and temporal water logging condition. The alluvial and red-laterite soils present in West Bengal i.e. the eastern part of India with a sub-tropical climate where rice is very common in the monsoon period of the year. Soils from these agro-climates show different processes under water logging by creating a variant structural behaviour.

Soil structure exerts important influences on the conditions and workability of soil. Hence soil structure becomes the foremost factor that determines the soil physical attributes. A stable porous surface soil structure is important for maintaining favorable soil physical condition for plant growth [7]. Whereas, artificial stress by various management practices including tillage and traffic with agricultural machines could accelerate aggregate breakdown and inhibit aggregate formation [8]. Especially, it is important in region under monsoon climate because aggregate break down processes including slaking is largely dependent on its water stability, the pressure of entrapped air and the extent of differential swelling [9]. Thus, aggregate characteristics are worth to study water-stable aggregates (WSAs), mean weight diameter (MWD), and geometric mean diameter (GMD) have been widely used to analyze aggregate stability [10,11]. Furthermore soil type has been found also to affect the structural stability of the soil aggregates.

Additionally, the existence of soil organic matter (SOM) affects aggregate stability and soil structure [12]. Plenty of influential work reported by various researchers has suggested that SOM can improve the formation of soil aggregates and increase the mechanical stability of aggregates by binding soil mineral particles, which determines the coherence of inter-particle bonds [13,14]. Similarly, the presence of soil organic carbon (SOC) in different soil layers or in aggregate sizes is imperative for soil quality assessments, which can be easily lost in the erosion process (since large aggregates are more stable). There are three size classes of soil aggregates, i.e., primary particles (sand, silt and clay), micro aggregates (53-250 μm) and macro aggregates (> 250 μm) and the soil organic matter stabilizes soil aggregates by acting as a binding material [15] and their hydrophobic properties reduce the destructive internal hydration [16].

Therefore, in view of the above said context, the present study had three objectives: first, to determine the distribution of soil aggregates in two soil types; second, to evaluate the effects of water stable aggregates (WSA) and aggregate sizes on soil organic carbon (SOC) in relation to two different soil types; and, third, to determine the impact of soil types on soil physical properties. This study mainly focuses on the effects of different soil types of West Bengal, India.

2. MATERIALS AND METHODS

2.1 Site Description

Soil samples were collected from lowland rice field where only rice was being cultivated. These include two soil types- New alluvial and Red-laterite soil. New alluvial soils were collected from Jangipara block of Hooghly, West Bengal and Red-laterite soils were collected from Raghunathpur block of Purulia, West Bengal. From each block five different spots were selected randomly and soil samples were collected from three depths i.e. 0-10, 10-20 and 20-30 cm. The collected soil samples were then dried in shade and samples were prepared according to aggregate and chemical analysis.

2.2 Characteristics of Soil

The texture of New alluvial soils was clay loam and Red-laterite was sandy clay loam (Table 1). Average soil organic carbon was more in surface

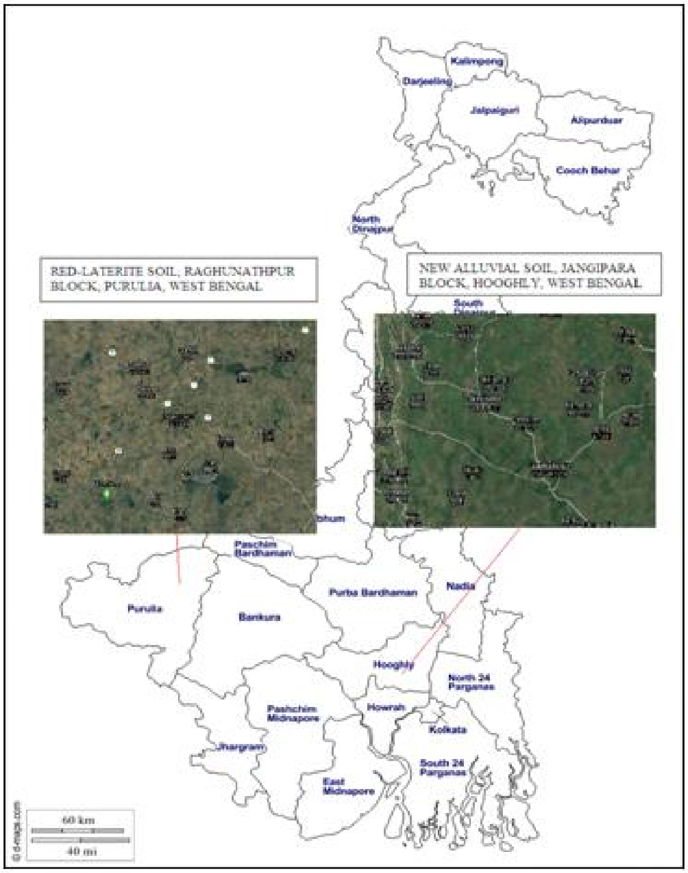

Fig. 1. Sampling site of new alluvial and red-laterite zone of West Bengal, India

Table 1. Physical and chemical properties of new alluvial and red-laterite (Average values of five different spots from each block) soil with depths

	Clay	Silt	Sand	Texture	SOC (%)	pH	EC (ds/m)
NA -D1	32.0	26.5	41.5	Clay loam	0.98	6.8	0.3
NA-D2	27.6	29.2	43.2		0.76	6.5	0.56
NA-D3	29.8	24.6	45.6		0.22	6.3	0.35
RL-D1	26.5	18.0	55.5	Sandy clay loam	0.77	4.6	0.19
RL-D2	26.5	13.9	59.6		0.48	4.5	0.16
RL-D3	24.6	7.7	67.7		0.16	5.1	0.09

NA – New alluvial, RL- Red-laterite, D1, D2 and D3 - depth 0-10 cm, 10-20 cm and 20-30 cm. SOC - soil organic carbon

soil and decreased with the depth in both the soil types. Surface soil of New alluvial and Red-laterite soil contained 0.98 and 0.77% organic carbon, respectively. The pH in New alluvial soil ranged from 6.3 to 6.8 and in Red-laterite soil ranged between 4.5-5.1. The EC value ranged 0.3-0.56 and 0.09-0.19 ds/m in New alluvial and Red-laterite soil.

2.3 Aggregate Analysis and Structural Indices

Two sets of six nested sieves with 2000, 1000, 500, 250 and 100 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 [17]. 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 50 g of Soil aggregates (2000 to 5000 µm) in duplicate was slaked by submerging it in 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), 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). With the data of soil aggregates and primary particles the following soil aggregate indices were calculated.

2.4 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

$$Waterstableaggregates\ (\%) = \frac{(\text{Weight of soil + sand}) - (\text{Weight of sand})}{\text{weight of sample}} \times 100$$

The percentage weight of water stable macro aggregates is the summation of soil aggregate-size fractions > 250 µm.

2.5 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 [18] as:

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

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.

2.6 Readily Oxidisable Organic Carbon (OC)

The oxidisable organic carbon (OC) was determined by Walkley and Black wet oxidation method [19]. 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 K2Cr2O7 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 (NH4)2(SO4)2. 6H2O. 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 K2Cr2O7 oxidises 3.0 mg C.

2.7 Statistical Analysis

Means of three replicates and standard errors of the means were calculated from the data. The data were analysed using randomized block design (RBD). Statistical analysis was performed by SPSS. One-way ANOVA was carried out using Post hoc multiple comparison from the Duncan's test at a significance level of $p < 0.05$. Simple correlation coefficients were determined to evaluate relationships between the response variables using the same statistical package.

3. RESULTS AND DISCUSSION

3.1 Mean Weight Diameter

The mean weight diameter (MWD) is commonly used to express aggregate stability as it determines the size distribution of aggregates. The results indicated that soil aggregate size fractions differed significantly with agro-ecological zone as well as the depths (Fig. 2). The results showed that the value of MWD had the widest range from 0.71 to 1.41 and 0.38 to 1.05 mm for NA and RL zone, respectively. MWD values of NA soils were 34, 29 and 87% more than RL soils at 0-10, 10-20 and 20-30 cm depth, respectively. This may be due to the presence of the lowest amount of soil organic matter (SOM), limited microbial activity, and the lowest root biomass, which may play a major role in the formation of soil aggregates [20]. In both the cases of NA and RL soil, MWD was found maximum at 0-10 cm depth and its value decreased with the depth. MWD at surface soil (0-10 cm) of NA was significantly 39.6 % higher than 10-20 cm (D2) and quite double the value of 20-30 cm (D3) depth. Similarly, the MWD of surface soil of RL was significantly 34.6% higher than 10-20 cm and three times higher than the value of 20-30 cm depth. It was obvious from the result that NA conceived better aggregate size (MWD) than RL soils irrespective of the depths.

3.2 Stability Coefficient

Aggregate stability has importantly a multiparameter effect on the soil properties and Fig. 3 presents its values under NA and RL soils. Stability coefficient of soils under NA and RL agroclimatic zone with different depths differed significantly (Fig. 3). The surface soil (0-10 cm) resulted the highest value of stability coefficient followed by 10-20 cm and the least value was observed under 20-30 cm. This result was found as soil aggregate stability is controlled by binding agents between soil particles [21] and the presence of organic materials are the dominant binding agents in these surface soils [22]. In NA soils, stability coefficient in D1 was significantly 53.5% and 79.1% higher than D2 and D3, respectively. There was significant difference between D2 and D3 in stability coefficient value. The RL soil observed in the study soils had extreme values range from 0.13 to 0.56. The surface soil of RL attributed to the maximum

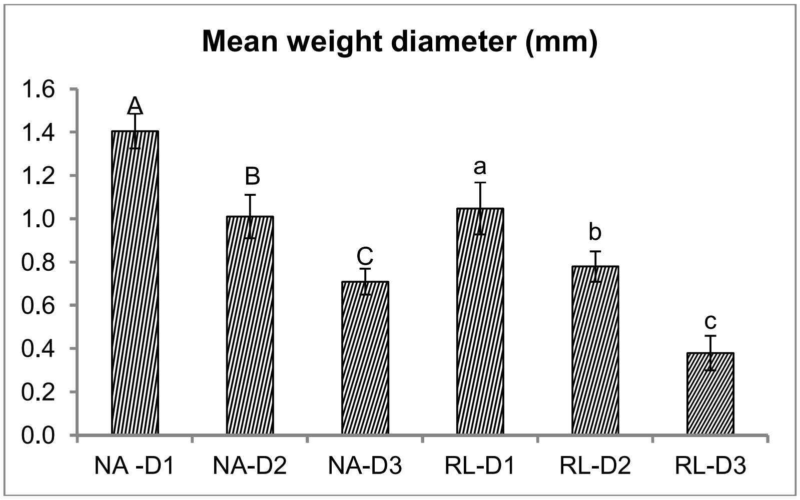

Fig. 2. Mean weight diameter of new alluvial and red-laterite soil with three depths (NA – New alluvial, RL- Red-laterite, D1, D2 and D3- depth 0-10 cm, 10-20 cm and 20-30 cm. Different letters at the same soil show significant differences at 0.05 level (DMRT-Duncan's Multiple Range test)

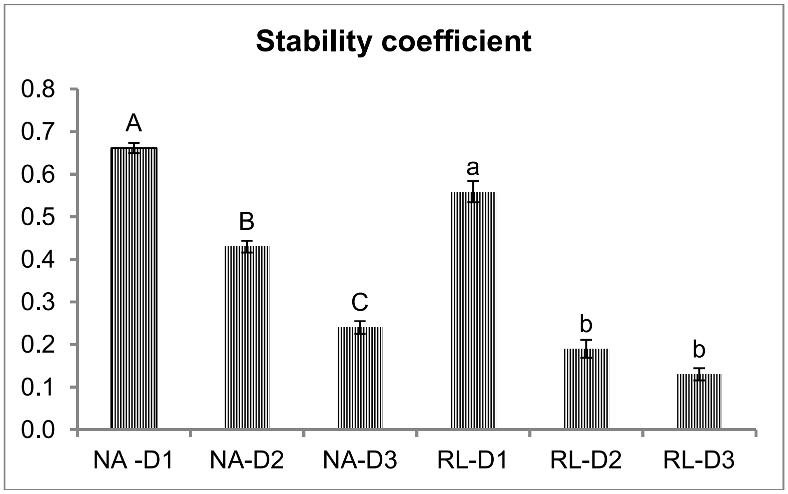

Fig. 3. Stability coefficient of new alluvial and red-laterite soil with three depths (NA – New alluvial, RL- Red-laterite, D1, D2 and D3- depth 0-10 cm, 10-20 cm and 20-30 cm. Different letters at the same soil show significant differences at 0.05 level (DMRT-Duncan's Multiple Range test)

value of stability coefficient (0.56) and was significantly three times higher than D2 and D3. The reason may be, due to maximum destructive soil disturbance during wet tillage operations up to 20 cm depth and below 20 cm depth soil remained undisturbed. Furthermore, the observations of this study showed that the NA soils experienced a higher stability coefficient value than RL soil and with the increasing depth the value of stability coefficient decreased evidently under RL soils in comparison to NA. This is because Soil aggregates bound by inorganic agents generally have less water stability than organic agents [23]. The aggregate in acidic soils (Red-laterite) with low clay and soil organic matter content was mainly contributed by both Al^{3+} and Fe^{3+} [24].

3.3 Water Stable Aggregates

Size distribution of different water stable aggregates (WSA) under different soil (NA and RL) and its depths are shown in Table 2. Aggregation is the result of rearrangement of the particles, flocculation, and cementation by SOC, biota, clay and carbonates, ions, plant roots, and organisms and their exudates [25,26]. Distribution of aggregate sizes was different between NA and RL soils as well as for their different depths. It was also found from the result that the total WSA in the experimental soils at various depths ranged from 16.9 to 53% and the surface soil of both the regions (NA nd RL) had the highest WSA in comparison to the lower depths. Individual soil depths of each soil types had statistically significant influence on changes in size of aggregates. The coarse macro aggregates (Cmac A>2000µ) was observed maximum for surface soil and with the increase in depth the meso (250-2000 µ) and micro aggregates (100-205 µ) became dominant fraction of WSA. The presence of macro-aggregates in surface soil are mainly due to carbohydrate-rich roots [27,28]. Among all the soil types Cmac A fraction was the highest under NA-D1 and it was significantly 16.1% higher than RL-D1. Meso aggregates distribution in different depths of NA soils showed that 0-10 cm soil had the highest value of 2000-1000 µ size of aggregates while 20-30 cm was noticed the maximum in 500-250 µ size fraction. The lesser value of WSA in RL may be due to higher temperature influence microbial decomposition [29] in mineralization of organic matter and reduction of SOC content [30]. However the total meso aggregate fraction was statistically insignificant between D1 and D2 which were about 17% higher than D3.

In case of RL, the surface soil (0-10 cm) resulted the maximum in CmacA as well as mesoA than other depths. The total Meso A (2000-250 µ) fraction of D2 and D3 of RL were statistically at par. Again, among the meso aggregates, the 1000-500 µ fraction exhibited a higher value followed by 500-250 µ and 2000-1000 µ fraction

Table 2. Mean value percent water stable aggregates of new alluvial and red-laterite soil with three depths

	Per cent water stable aggregates							
	Cmac A (>2000µ)	Meso A				Total Mac A	Cmic A (250-100µ)	Total water stable aggregate
		2000-1000µ	1000-500µ	500-250µ	Total Meso A			
NA -D1	23.4A	10.0A	14.4A	5.1B	29.5A	52.9A	0.1B	53.0A
NA-D2	5.4B	4.9B	13.2A	12.4A	30.5A	35.9B	0.6B	36.5B
NA-D3	3.1C	2.7C	5.0B	5.9B	13.6B	16.7C	3.8A	20.5C
RL-D1	7.3a	5.8a	21.6a	0.9b	28.3a	35.6a	2.8c	38.4a
RL-D2	4.0b	1.9b	3.0b	3.6a	8.5b	12.5b	4.8b	17.3b
RL-D3	1.2c	0.7c	2.5b	3.8a	7.0b	8.2c	8.7a	16.9b

NA – New alluvial, RL- Red-laterite, D1, D2 and D3- depth 0-10 cm, 10-20 cm and 20-30 cm. CmacA- coarse macro aggregate, Meso A- meso aggregate and CmicA- coarse microaggregate. Different letters at the same column show significant differences at 0.05 level (DMRT-Duncan's Multiple Range test)

Table 3. Aggregate associated carbon of new alluvial and red-laterite soil with three depths

	Aggregate associated carbon (g C/kg)				
	Cmac AC (>2000µ)	Meso AC			Cmic AC
		2000-1000µ	1000-500µ	500-250µ	250-100µ
NA -D1	1.23A	0.84A	0.67A	0.36A	0.22C
NA-D2	0.82B	0.66B	0.56B	0.34A	0.65B
NA-D3	0.47C	0.17C	0.59B	0.15B	0.95A
RL-D1	0.91a	0.77a	0.34c	0.70a	0.58a
RL-D2	0.62b	0.51b	0.41b	0.53c	0.43b
RL-D3	0.23c	0.49b	0.78a	0.62b	0.41b

NA – New alluvial, RL- Red-laterite, D1, D2 and D3- depth 0-10 cm, 10-20 cm and 20-30 cm. CmacAC- coarse macro aggregate associated carbon, Meso AC- meso aggregate associated carbon and CmicAC- coarse microaggregate associated carbon. Different letters at the same column show significant differences at 0.05 level (DMRT-Duncan's Multiple Range test)

Table 4. Correlation matrix of different variables in new alluvial soil

NA	MWD	Stability coefficient	SOC	Clay content	Aggregate weight
MWD	1				
Stability coefficient	0.33	1			
SOC	0.61**	0.61**	1		
Clay content	0.43*	0.52**	0.58**	1	
Aggregate weight	0.46*	0.35	0.62**	0.42*	1

Table 5. Correlation matrix of different variables in red-laterite soil

RL	MWD	Stability coefficient	SOC	Clay content	Aggregate weight
MWD	1				
Stability coefficient	0.36	1			
SOC	0.42*	0.39*	1		
Clay content	0.41*	0.67**	0.44*	1	
Aggregate weight	0.32	0.44*	0.40*	0.27	1

constituting an average of 16, 8.1 and 3.8% of WSA respectively. The distribution series of total macro aggregates fall under NA-D1> NA-D2> RL-D1> NA-D3> RL-D2> RL-D3. It was found from our study that a clear trend of increasing value of coarse micro aggregates (Cmic A, 250-100 µ)with depth indicated their dominance in lower depth than surface soil. The average Cmic A fraction of RL (5.4% of WSA) was more than NA soil (1.5 % of WSA). Similarly Six et al. [25] found that the aggregating role of oxides was mainly at the micro aggregate level rather than at macro- and meso-aggregate levels. The CmicA had the highest value under RL-D3 (8.7% of WSA) followed by RL-D2 (4.8% of WSA) and fall in the order of RL-D3>RL-D2>NA-D3>RL-D1>NA-D2>NA-D1.

3.4 Aggregate Associated Carbon Fractions

Aggregate associated carbon of new alluvial and Red-laterite soils comprising three depths are presented in Table 3. It was observed that the aggregate associated C content decreased with the increase in soil depth for both the soils of two agroclimatic zones. Irrespective of the soils and depths, aggregate associated carbon ranged from 0.23-1.23 in CmacAC, 0.40-0.84 in 1000-2000 µm, 0.34-0.78 in 500-1000 µm, 0.15-0.70 in 250-500 µm and 0.22-0.95 in CmicAC. Bandyopadhyay et al. [31] reported that microaggregate fractions with their higher surface area stored large amount of C. The maximum amount of SOC was retained in coarse macro (>2000 µm) sized fractions and C distribution within the soil aggregates were in the following order Cmac AC (>2000µ) >Meso AC (2000-250µ)>Cmic AC (<250µ) for surface soils; whereas, lower depths in NA increased Cmic AC and followed the order Cmac AC (>2000µ) >Cmic AC (<250µ) >Meso AC (2000-250µ). The NA soils retained higher C in all type of aggregate sizes than RL soils. The presence of high amount of Fe and Al oxides in soils reduce the effect of C in aggregating agent [32]. The result indicated that the Cmac AC fraction in surface soil of NA was quite the double of Meso AC and six times higher than Cmic AC. However, Cmac AC was 25% higher than Meso and Cmic AC for NA-D2. The Cmic AC increased over Cmac and Meso AC in lower depth (D3) of NA soils. On an average, among the Meso AC (2000-250µ), the size fraction resulted the highest contribution in C storage was 2000-1000µ over other two size fractions under New alluvial soils.

The aggregate associated C in Red-laterite soils in Cmac, Meso and Cmic AC fractions contributed an average of 57, 58 and 47 gC/kg. The difference in C content in Cmac A in between surface and lower most depth (D3) was 4.5 times; however, Meso and Cmic AC fractions showed no such significant differences. No significant difference variation of aggregate associated C content within Cmic A was also observed under Red-laterite soils.

3.5 Relationship between Soil Aggregates and Soil Properties

Aggregate associated indices, soil clay and organic carbon content are correlated with Pearson's correlation coefficients (Tables 4 and 5). The results demonstrated positive correlation among fraction sizes (MWD), aggregate weight, stability coefficient, SOC and clay content for both the soil types (Table 4). A highly significant correlation($p<0.01$) was found between MWD and soil organic carbon in NA soil, whereas the relationship was less significant in RL, because of factors other than SOC help in formation of aggregate in these soils. Duiker et al. [33] similarly observed that Fe oxides was responsible for the aggregation when soils is consist of low concentration of SOC. In NA, MWD was positively related to SOC and increase in SOC explained 60% of the increase in MWD. The increase of MWD can be explained by the role of SOC to bind the particles forming aggregates and provide strength against water forces [34,35]. However, clay content in NA and RL was positively correlated with MWD indicated similar role of clay in aggregate formation in both the soils. The study showed a significant positive correlation ($p<0.05$) between stability coefficient and soil organic carbon content for both the soils. Our result also showed a significant positive correlation between clay content and stability coefficient of aggregates. Aggregate weight was positively correlated to SOC and the relation was more pronounced in NA soils. The linear correlation was observed in RL that indicated that SOC was the most important factor for soil aggregation. SOC is the key compound i.e. both biological-living and organic-non-living entities, affecting the breakdown of aggregates by the action of natural and manmade forces. At low SOC, the clay content decreased with increasing SOC but higher SOC was positively correlated with clay content. That implied the SOC and clay association highly influenced above 0.45% SOC.

4. CONCLUSION

Lowland rice soils under new alluvial zone produced more aggregate associated C resulting improved aggregate size and stability than red-laterite soils. The macro aggregate dominance of NA soils indicates higher soil physical quality. Predominating higher micro aggregates and lower aggregate associated carbon made red-laterite soils poor in structure and susceptible to erosion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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