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STRUCTURAL STABILITY UNDER DIFFERENT ORGANIC FERTILIZERS MANAGEMENT IN PADDY SOIL

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Abstract

The present study was conducted to determine the effects of organic carbon on soil structural stability and establish a correlation between soil aggregates with carbon (C) sequestration and different ratios of basic cations. Five treatments viz. control, cowdung, vermicompost, rice straw and poultry manure were laid out in a randomized complete block design in Boro rice cultivation where organic materials were applied considering 2 t C ha^{-1} except the control. The data revealed that different organic amendments insignificantly influenced soil carbon sequestration and water stable soil aggregates. However, a positive effect was found on C enhancement of soil with vermicompost and poultry manure treatments. Nonetheless, a positive relationship between total stable soil aggregates and C sequestration at crop harvest was also noticed. Improvement in soil aggregates followed the order of rice straw>poultry manure>vermicompost>cowdung treatments. Monovalent cationic ratios and cationic ratios on structural stability of soil significantly increased the stable soil aggregates of 0.25 mm sized particles at crop harvest.

Keywords: Soil aggregates, organic carbon, carbon sequestration, basic cations.

Introduction

Soil aggregates and carbon (C) sequestration play a vital role in conserving soil, maintaining soil health and sustaining crop productivity. Degradation of soil health in the tropical and sub-tropical regions occurred hastily due to intensive cultivation of land with high yielding crop varieties, applying mostly inorganic fertilizers and using small quantities of organic fertilizers (Rahman, 2013). Soil aggregation essentially depends on organic matter (OM) content of the soil, while C sequestration depends on annual C inputs, their mineralization rates and soil and crop management practices. C sequestration is important in maintaining soil productivity and environmental quality, which plays an important role in the global C cycle and mitigation of climate change. The addition of C enriched materials like crop residues, rice straw (RS), cowdung (CD) and poultry manure (PM), Vermicompost (VC), farmyard manure, composts etc. improves soil physical, chemical and biological characteristics which favor the development of a crop root system elongating both at the surface level and in deep soil, and ultimately helps to accumulate more C in soil. It was also found that a combined application of organic and inorganic nutrients to soils increased soil structural stability and crop yields (Rahman, 2012; Rahman, 2013). The application of organic carbon (OC) through RS, CD and PM accounted for 10, 30

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and 49% C sequestration, respectively, and contributes to soil aggregation (Rahman et al., 2016). When a group of soil particles cohere more strongly it improves soil structural stability, which is advantageous for plant growth and development. Such stability in soil structure depends not only on OC but also on phosphorus, clay fractions and different basic cations present in soils (Rahman and Yakupitiyage, 2006).

Rice straw ensures good soil health through improving soil aggregates and a good supply of soil nutrients (Rahman *et al.,* 2017). The soil OC pool in agricultural land is capable of enhancing agricultural sustainability and serving as a potential sink of atmospheric CO_2 though depending on how we manage our soils and crops (Gnanavelrajah *et al.,* 2008). Soil C sequestration can improve soil quality through its structural development and reduce the contribution of agriculture to CO_2 emissions to the atmosphere. Well aggregated soils are structurally stable and stronger with a high potential of holding more C in soils. More stable organic fraction in soil is humus, which is negatively charged and has the potential of holding more nutrients in soil, as its cation exchange capacity is high. Both organic (humus) and inorganic (clay) colloids can act as glue in soils with a strong bonding of soil particles collectively. Micro-aggregates (<0.25 mm) establish linkages between organic colloids and clays and thus help in the formation of macro-aggregated (>0.25 mm) soils and increase structural stability and thereby C sequestration (Oades, 1984). Well aggregated soil may contribute greatly to C sequestration in soils by occluding organic residues and making them less accessible to microbial decomposition. In the process of soil structural development, roles of different ratios of basic cations viz. sodium adsorption ratio (SAR), mono-valent cationic ratio (MCAR) and cationic ratio of soil structural stability (CROSS) are also contributory. The study of Rengasamy and Marchuk (2011) revealed that mono-valent cations sodium (Na^+) and potassium (K^+) indicated dispersive effects, while divalent cations calcium (Ca^{2+}) and magnesium (Mg^{2+}) showed flocculation effects. However, similar types of study are lacking in Bangladesh. Therefore, the present study was undertaken to determine the effects of organic carbon on soil structural stability and ascertain a relationship of soil aggregation with carbon sequestration and different ratios of basic cations in soil.

Materials and Methods

Study area

The study was conducted in the research field of the Department of Soil Science, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur, Bangladesh during January to April 2018. The area is located at 24.09° N latitude and 90.25° E longitudes, with an elevation of 8.2 m. The soil of the study site has been classified as Shallow Red Brown terrace soil under the taxonomical soil order Inceptisols (Brammer, 1978). This study site is under the agro-ecological zone of Madhupur Tract, having silty clay loam soil within 50 cm from the surface and acidic in nature. The experimental area experiences sub-tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperature and humidity.

Treatments and design of the experiment

Five treatments viz. control, CD, VC, RS and PM were laid out in a randomized completely block design with Boro rice (BRRI dhan28) as a test crop. The organic materials were applied at the rate of 2 t C ha^{-1}. The unit plot size was 4 m × 5 m, the plots being separated by 0.5 m levees. Well decomposed CD, VC, RS and PM were applied to the assigned plots one week before final land preparation. The different organic materials and their nutrient concentrations are shown in the Table 1.

Inorganic fertilizer elements N, P, K, S and Zn were applied @ 115, 47, 93, 16 and 2 kg ha^{-1}, respectively, for all the treatments including the control. Phosphorous (P), potassium (K), sulphur (S), and zinc (Zn) were applied at the time of final land preparation in the form of gypsum, muriate of potash (MoP) and zinc sulphate (Monohydrate), respectively. Nitrogen (N) as urea was applied in three equal splits. One third of urea was applied at the time of final land preparation. Then remaining two-thirds of urea were top-dressed at active tillering and panicle initiation stages. The total amount of nutrients, especially, N, P and K added to the experimental plots from organic and inorganic sources are shown in Table 2. Seeds of BRRI dhan28 were sown in a seedbed. Thirty-five day old rice seedlings were transplanted on January 3, 2018.

Soil and plant sampling

The crop was harvested on April 24, 2018 and 5 hills/plots were collected randomly from the harvest area to measure nutrient concentrations (N, P and K) in rice grain and straw. The final soil samples were collected at harvesting time from the plough depth layer (0-15 cm) to analyze for pH, OC, soil texture, water stable soil aggregate (WSA) and basic cations (Na, K, Ca and Mg).

Carbon stock and C sequestration were calculated using the following equation (Rahman *et al*., 2016).

Carbon stock (t ha^{-1}) = Carbon concentration (%) x bulk density (g cm^{-3}) × depth (cm).

Sodium adsorption ratio (SAR), mono-valent cationic ratio (MCAR) and cationic ratio of soil structural stability (CROSS) were calculated (Rengasamy and Marchuk, 2011) as total concentration of the cations, SAR, MCAR and CROSS values would parameterize soil structural effects of the relative amounts of mono-valent and di-valent cations in the soil solution. Soil pH was measured with a glass electrode pH meter (Horiba Model No.M-8L) maintaining a soil: water ratio of 1:2.5 (Jackson, 1973). Organic carbon was

Table 1. Nutrient concentrations in the different organic materials used in the experiment

Treatments	C rate (kg ha^{-1})	C content (%)	Org. materials (kg ha^{-1})	Nutrient concentration (%)		
				N	P	K
Control	-	-	-	-	-	-
Cowdung	2000	22	9090.91	0.5	0.15	0.23
Vermicompost	2000	25	8000.00	0.65	0.35	0.5
Rice straw	2000	41	4878.05	0.2	0.05	0.45
Poultry manure	2000	20	10000.00	0.6	0.35	0.45

Table 2. Total amounts of N, P and K added to experimental plots using organic and inorganic sources

Treatments	Organic sources (kg ha^{-1})			Inorganic sources (kg ha^{-1})			Total nutrient applied (kg ha^{-1})		
	N	P	K	N	P	K	N	P	K
Control	-	-	-	115	47	93	115	47	93
Cowdung	45.45	13.64	20.91	115	47	93	160.45	60.64	113.91
Vermicompost	52.00	28.00	40.00	115	47	93	167.00	75.00	133.00
Rice straw	9.76	2.44	21.95	115	47	93	124.76	49.44	114.95
Poultry manure	60.00	35.00	45.00	115	47	93	175.00	82.00	138.00

determined by the wet oxidation method (Walkley and Black, 1935) outlined by Piper (1950). Thomas (1982) method was followed to determine exchangeable cations using Atomic absorption Spectrophotometer. The fine earth fraction of soil was passed through a 2 mm sieve and taken for mechanical analysis using Bouyoucos Hydrometer method described by Gee and Baunder (1986). After saturated hydraulic conductivity and moisture retention measurement, the core samples were oven dried at 105^0 C for 24 hours and the bulk density calculated (Rowell, 1994). For aggregate stability, soil was divided into macro (>0.25 mm) and micro (<0.25 mm) aggregates and water stable soil aggregates were determined by wet sieving method (Castellanos-Navarrete *et al.,* 2013).

Statistical analysis

The data collected on different parameters were subjected to statistical analysis using procedures described by Gomez and Gomez (1984). Microsoft EXCEL and Statistix 10 software programs were used wherever appropriate to perform statistical analysis. Relationships among the parameters were established through correlation and regression analysis. Treatment differences were determined using the least significant difference (LSD) test at the 5% level of significance.

Results and Discussion

Soil pH, OC and basic cations in soil of the experimental field

Soil pH, OC and basic cations of the experimental field before starting the experiment and after crop harvest are reported in the Table 3 and Table 4, respectively. The pH indicated that the soil was slightly acidic to neutral in reaction. OC was found very low, while K was medium to optimum. The Ca and Mg contents of the studied soil were very low. At crop harvest, all the soil parameters as mentioned improved to some extent, especially OC contents in soils because of addition of different organic materials. Islam *et al.* (2013) also reported that application of different organic materials influenced the pH, OM and soil nutrient concentration of post-harvest soil. Presumably, continuous cultivation with little or no application of organic materials the soil OC was found very low. High temperature and humidity favors faster mineralization of OM resulting in low C in soil. Because of the faster mineralization rate of added organic materials the C enrichment in soils might be low. Nonetheless, even the increment of OC in soil is small it greatly contributes to sustaining soil health and crop productivity (Rahman *et al.*, 2016).

After crop harvest OC content in the soil was found low, while Na and K were medium to optimum, and Ca and Mg were found low. As the soil is acidic in nature and it is a terrace soil the concentrations of basic cations are also low. There was no significant difference among the different OM amendments on the enrichment of post-harvest soil OC and basic cations.

Effects of organic carbon on carbon sequestration and soil structural stability

The effects of different types of organic fertilizers and rice straw on soil C sequestration and water stable soil aggregates were found insignificant (Table 5). The study was conducted only for one rice season and, therefore, the effect of different organic treatments in improving different soil properties might not have been evident. The high temperature and high humidity conditions of Bangladesh favor intense microbial mineralization of added organic materials. Therefore, increasing soil C in the crop fields is a great challenge (Rahman *et al.,* 2016).

Increment of C in soil through the addition of organic materials also depends on labile and non-labile fractions of C of organic materials. If organic materials contain higher fractions of non-labile C then C increment in soils will generally be higher. A positive trend in the C increment in soil with VC and PM applied fields was noticed showing the potential for the improvement of soil health and sustainability of agriculture. In the control treatment where no OM was applied, C increment was found 1.26 g kg^{-1} soil, while in the VC and PM treated soils the C increment rates were 1.72 and 1.56 g kg^{-1} soil (Table 5). Even though organic materials were not applied in the control treatment the accumulated C was the contribution of crop residues including roots and biomass C. A significant amount of biomass C accumulates in soils from the

Table 3. Initial pH, OC and basic cations in soil of the experimental field

Treatments	Soil characteristics					
	pH	OC	Na	K	Ca	Mg
		(%)	C-mol (+) kg^{-1}			
Control	6.2	0.50	0.15	0.19ab	1.15	0.25
Cowdung	6.0	0.64	0.15	0.19ab	1.15	0.26
Vermicompost	6.2	0.76	0.15	0.17b	1.14	0.25
Rice straw	6.2	0.58	0.14	0.25a	1.16	0.25
Poultry manure	6.3	0.57	0.14	0.18ab	1.16	0.24
CV (%)	3.97	18.59	7.26	12.40	1.13	1.02
S.E. (±)	0.156	0.08	0.007	0.016	0.009	0.002

Different letters in the column under each element indicate significant differences among the treatments.

Table 4. At crop harvest pH, OC and basic cations in soil of the experimental field

Treatments	Soil characteristics *					
	pH	OC	Na	K	Ca	Mg
		(%)	C-mol (+) kg^{-1}			
Control	6.3	0.63	0.17	0.19	1.17	0.29
Cowdung	6.1	0.75	0.18	0.24	1.33	0.30
Vermicompost	6.4	0.93	0.17	0.26	1.40	0.27
Rice straw	6.5	0.70	0.16	0.20	1.11	0.29
Poultry manure	6.7	0.73	0.17	0.22	1.20	0.30
CV (%)	4.88	17.96	34.12	21.01	17.41	7.36
S.E. (±)	0.188	0.095	0.054	0.033	0.153	0.015

*Treatments' effects on soil characteristics were insignificant

biomass of bacteria, fungi and actinomycetes (Brady and Weil, 2016).

Soil aggregate stability in all treatments somewhat increased over the initial condition (Table 5). Among the organic materials applied, rice straw was found to be the most efficient in increasing soil aggregates (9.87%) followed by PM, VC and CD. Compared with the initial conditions, water stable soil aggregates were increased by 1.5, 4.8, 9.9 and 7.9% with CD, VC, RS and PM, respectively (Table 5). After crop harvest in the control treatment the water stable soil aggregates increased 1.66% compared to the initial aggregates. The variation in aggregates in initial soils under different treatment plots was probably because of differences in inherent C contents. Organic matter acts as glue in binding soil particles together and makes soil aggregates stronger. The improvement in soil structure might contribute to nutrient retention and as well as erosion control. Water stable soil aggregates of different sized particles indicated that smaller the size the more stable the aggregates and such trend is applicable in case of all plots assigned to different treatments (Fig.1). Initial particle size of 0.25 mm gave the highest number of WSA in case of all treatments' plots. With the increase of the particle size (i.e. 0.5, 1 and 2 mm) the number of WSA decreased in all soils (Fig.1). Similar scenarios of WSA were also observed at crop harvest i.e. the smaller sized soil particles contributed to the higher number of soil aggregates (Fig. 2). Among the different organic treatments, PM was found comparatively better in the formation of soil aggregates probably because of its well decomposed finer particles. Simansky (2013) reported that soil management practices had a significant influence on the C sequestration capacities and WSA.

Relations between WSA with nutrient use efficiencies

Correlation coefficient between WSA of 0.5 mm sized particles of initial soil and apparent recovery efficiency of K was found significant having coefficient (r) value of 0.623 ($p<0.05$).

Table 5. Effect of organic matter application on C sequestration and aggregate stability

Treatments	C sequestration (g kg^{-1} soil)	Water stable soil aggregates (%)		
		Initial soil	Final soil at crop harvest *	Increased (%)
Control	1.26	23.86	25.52	1.66
Cowdung	1.14	25.19	26.69	1.50
Vermicompost	1.72	31.61	36.46	4.85
Rice straw	1.10	23.96	33.83	9.87
Poultry manure	1.56	21.53	29.44	7.91
CV (%)	34.56	19.60	26.57	-
S.E. (±)	0.06	3.49	5.71	-

* Treatments' effects on water stable soil aggregates were insignificant

The correlation between WSA of 2 mm sized particles in soil at crop harvest and apparent recovery efficiency of P was also found significant with a coefficient (r) value of 0.518 ($p<0.05$). In all other cases, correlations between WSA and nutrient use efficiencies were observed insignificant ($p>0.05$). It was observed that WSA of 0.5 mm sized particles in soils at crop harvest positively correlated with different types of nutrient use efficiencies except physiological efficiency of P and apparent recovery efficiency of K.

Application of different OM increases the organic colloid i.e. humus in soil. The humus is negatively charged particle, which holds different cations on its edges and can form different organo-mineral complexes. Such humus and organo-mineral complexes

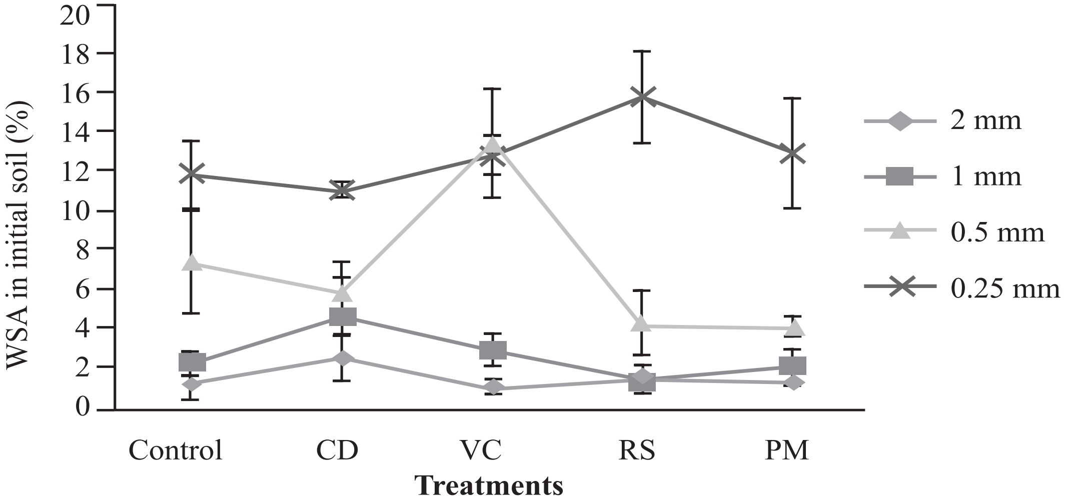

Fig. 1. **Water stable soil aggregates (WSA) of different sized particles in initial soil (CD = cowdung, VC = vermicompost, RS = rice straw, PM = poultry manure).**

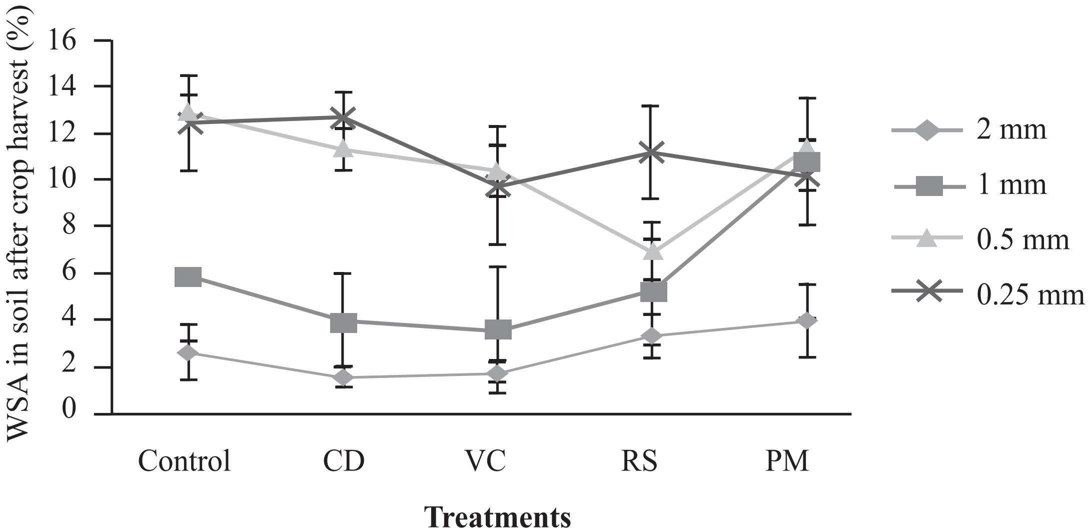

Fig. 2. **Water stable soil aggregates (WSA) of different sized particles under different treatments at crop harvest (CD = cowdung, VC = vermicompost, RS = rice straw, PM = poultry manure).**

contribute in improving soil structure, increasing stable soil aggregates. Structural improvement of soil might contribute in reducing nutrient loss against leaching through surface adsorption. Likewise, adsorbed nutrients may be released back to soil solution again, which plant can take up and thus contribute in higher crop yields and thereby nutrient use efficiency.

Relations between WSA with C sequestration and different ratios of basic cations

Different soil parameters have both positive and negative relationships with WSA of different sized soil particles. There was a positive relationship between OC in initial soil and OC in the final soil at crop harvest. WSA in initial soil of 0.5 mm sized particles was significantly and positively correlated with C contents in initial soil before experimentation and final soil at crop harvest with r-values 0.606 and 0.569, respectively ($p<0.05$). C sequestration was positively correlated with OC content in soil at crop harvest. Though the relationship between total soil aggregates at crop harvest with C sequestration was weak ($r = 0.253$), yet it indicated a positive relationship, i.e. the higher the WSA the more was the C sequestration. Significant and positive correlations between WSA of 0.25 mm sized particles with mono-valent cationic ratios (MCAR) and cationic ratios on soil structural stability (CROSS) were observed having r values of 0.529 and 0.524, respectively ($p<0.05$). Besides, soil aggregates of 0.25 mm sized particles positively correlated with SAR ($r = 0.425$), Na content in soil at crop harvest ($r = 0.349$) and K content in soil at crop harvest ($r = 0.276$).

One of the most important binding agents for forming stable aggregates is soil organic matter (SOM), which can be retained in various size fractions of aggregates. The amount of OM and its degree of decomposition are vital factors for the formation and stabilization of aggregate structure for soil C sequestration. OM binds the soil particles together and builds aggregates. As the SOM decomposition proceeds, organic particles associate with soil matrix to form macro-aggregates (>250 um) and micro-aggregates (<250 um) and sequester organic carbon in soil. The C sequestration capacity depends not only on the return of OM into the soil, but also on the capacity of soil to accumulate OC, which has certain limits. In some cases, the long-term application of high rates of organic fertilizers is accompanied by a continuous rise in the soil OC. Mahmoodabadi and Heydarpour (2014) found that the application of OM, especially farmyard manure incorporation led to a significant increase in the final soil OC content and thereby increased WSA and C sequestration. Thus, organic amendment promoted soil aggregates and helped OC stabilization. Several empirical data showed that soil aggregation fundamentally depends on inherent and added OM content of soil, while C sequestration depends on annual C inputs, their mineralization rates and different options for soil and crop management (Holeplass *et al.*, 2004; Rahman *et al.*, 2016). In addition, application of organic manure resulted in significantly higher SOC concentration in the 0–10 cm layer and SOC concentration increased linearly with the application of manure.

Conclusion

Application of RS, CD, VC and PM played a positive role to some extent for maintaining soil health and increasing nutrient use efficiencies through development of soil aggregates and C sequestration. Mineralization of organic matter in soils of Bangladesh is fast, therefore, the study recommends continuous replenishment of soil organic matter using available sources to maintain a sustained production environment.

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