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CARBON SEQUESTRATION IN SOIL AGGREGATES UNDER DIFFERENT CROPPING PATTERNS IN GANGES RIVER FLOODPLAIN, BANGLADESH

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Abstract: The Five different cropping patterns such as Fallow-Fallow-Fallow (F-F-F), Sugarcane-Sugarcane-T Aman (S-S-R), Vegetables-Fallow-T Aman (V-F-R), Fallow-Fallow-T Aman (F-F-R) and Fallow-Mung bean- T Aman (F-M-R) from Jessore district were investigated for carbon sequestration in soil aggreagates. Highest value of bulk density (1.53 g cm^{-3}) was found in S-S-R and lowest (1.27 g cm^{-3}) in F-M-R. The soil under V-F-R exhibited highest porosity (47.76%). F-M-R exhibited highest saturated hydraulic conductivity (15.36 cm day^{-1}). The state of aggregation and degree of aggregation was found high under F-F-R. The dispersion factor was highest under F-F-F (13.32%) and lowest under F-F-R (7.04%). The soil organic carbon (SOC) associated with >0.05 mm aggregates was generally higher than that with 0.05-0.002 mm and <0.002 mm aggregates. The clay associated (<0.002 mm) SOC was higher than SOC in 0.05-0.002 mm aggregates. The highest SOC in >0.05 mm aggregate and <0.002 mm particles were found under F-M-R and S-S-R patterns, respectively.

Key words: Carbon sequestration, cropping pattern, soil aggregates, Bangladesh

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Introduction

Global warming is a major threat to the environment and soil management practices are now believed to contribute significantly to changing environmental conditions (Lal, 2004). Attention has been increasingly paid to soil organic carbon (SOC) pool and its dynamics in land use changes concerning terrestrial ecosystem carbon sink and the uprising atmospheric carbon dioxide (Lal, 2004). The global soil carbon (C) pool of 2500 gigatons (Gt) includes about 1550 Gt of SOC and 950 Gt of soil inorganic carbon (SIC). The soil C pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt). The SOC pool to 1-m depth ranges from 30 tons/ha in arid climates to 800 tons/ha in organic soils in cold regions, and a predominant range of 50 to 150 tons/ha. The SOC pool represents a dynamic equilibrium of gains and losses. Conversion of natural to agricultural ecosystems causes depletion of the SOC pool by as much as 60% in soils of temperate regions and 75% or more in cultivated soils of the tropics. Severe depletion of the SOC pool degrades soil quality, reduces biomass productivity, and adversely affects water quality, and the depletion may be exacerbated by projected global warming (Lal, 2004).

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Urgency of meeting increased demand for agricultural produce is rapidly degrading soil quality and exacerbating degradation. Most agricultural soils have low soil organic matter (SOM) reserves due to fertility- mining practices and widespread problem of soil degradation. This decline is also attributed to removal of crop residue, changes in cropping systems, *etc*. Reduction in SOC pool sets-in-motion other degradation processes including decline in soil structure and aggregation, reduction in exchangeable bases, decrease in plant available nutrients, and reduction in plant-available water capacity. Crop yield and fertilizer use efficiency are also adversely affected by low levels of SOC pool (Anandacoomaraswamy *et al*., 2001).

Appropriate land use and soil management can lead to an increase in SOC, improve soil properties and partially mitigate the rise in atmospheric CO_2 (Bernoux *et al*., 2006; Lal and Kimble, 1997). Soil carbon sequestration can be accomplished by management systems that add high amounts of biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, and enhance soil fauna activity (Lal *et al*., 1998). Lal (2004) proposed residue return as surface mulch, no-tillage, crop rotation with high diversity, integrated nutrient management, *etc*. for increasing carbon sequestration in agricultural soils.

Land use practices that result in a net accumulation of SOM are said to be C sequestering because they result in a net removal of C from the atmosphere (Rice and Angle, 2004). Several studies in temperate and tropical regions reported that no-tillage practices substantially increase SOM storage and improve soil aggregation (Six *et al*., 2002b). Soil aggregation can increase SOC storage by reducing loss by erosion and from mineralization. SOM can be physically protected from microbial mineralization through sorption to clay minerals and enclosure within soil aggregates (Tisdall and Oades, 1982). The objective of the research was to investigate the carbon sequestration in various soil aggregate size ranges under different cropping patterns.

Materials and Methods

The fields were under conventional tillage practices. Chemical fertilizers were added for nutrient management and pesticides were applied where needed. The soils were calcareous and non saline (EC <4 dS m^{-1}). Soil samples were collected from the surface layer (0 to 6 cm) of agricultural fields under different cropping patterns (Table 1) in Jessore district in November, 2007. Soil samples were taken to the laboratory in poly bags, air dried and sieved with 2 mm sieve and stored in plastic container for physical and chemical analysis. Core samples were also collected for determination of bulk density and saturated hydraulic conductivity.

Table 1. Cropping patterns of the selected area.

Cropping pattern	*Cropping code*
Fallow-Fallow-Fallow	F-F-F
Sugarcane-Sugarcane-T.Aman	S-S-R
Vegetables-Fallow-T. Aman	V-F-R
Fallow-Fallow-T. Aman	F-F-R
Fallow-Mung bean-T. Aman	F-M-R

Particle size analysis was carried out using Hydrometer method (Day, 1965). Bulk density and particle density were determined following Blake and Hartge (1986). Total porosity of soil was calculated following Strickling (1956).

Hydraulic Conductivity of soil was determined in the laboratory by constant head method (Klute, 1965). Soil structure was evaluated by microaggregate analysis following Kachinskii (1965). The state of aggregation, degree of aggregation and dispersion factor were determined by the equations of Baver and Rhoades (1932).

State of aggregation = $a - b$

$$\text{Degree of aggregation} = \frac{a-b}{100-b} \times 100$$

$$\text{Dispersion factor} = \frac{x}{y} \times 100$$

Here a = percentage of aggregates larger than a specified size in microaggregate analysis, b = percentage of particles larger than a specified size in particle size analysis, x = percentage of clay in microaggregate analysis and y = percentage of clay in particle size analysis. For the determination of SOC associated with aggregates of >0.05 mm, 0.05-0.002 mm and <0.002 mm size ranges, soils were kept submerged in distilled water over night and then transferred to 1L sedimentation cylinder. After 2 hours the suspended clay particles were taken in a beaker by siphoning. This suspension consisted of particles <0.002 mm. The rest of the soil in the sedimentation cylinder was passed through 0.05 mm sieve. The particles retained on the sieve (>0.05 mm) were collected in a beaker. The suspension that passed through the 0.05 mm sieve (0.05-0.002 mm) was also collected. Soil samples of these three fractions were then oven dried at 70ºC for 24 hours. The carbon content of each size fractions were determined by the method as described by Tyurin (1936).

Results

Particle size distribution: The percentage of sand was highest under V-F-R (31.17%) and lowest under F-F-R (11.93%). The percentage of silt and clay ranged from 29.02 to 56.41% and 30.41 to 59.05%, respectively (Table 2). The percentage of silt was highest (56.41%) under F-M-R and lowest (29.02%) under F-F-R whereas clay was highest (59.05%) under F-F-R and lowest (30.41%) under F-F-F.

***Particle density, bulk density and porosity*:** Particle density varied from 2.25 to 2.46 g cm^{-3} under different cropping patterns (Table 2). The highest particle density was under F-F-F pattern and lowest was found under F-F-R. Highest bulk density was 1.53 g cm^{-3} under S-S-R and lowest 1.27 g cm^{-3} under F-M-R (Table 2). Highest soil porosity (47.76%) was under V-F-R at surface soil, whereas lowest 37.55% was in S-S-R. The variations in the particle density, bulk density and porosity values under different cropping patterns were significant ($p<0.01$).

Table 2. Physical properties of soil under different cropping patterns.

Cropping Pattern	Particles			Textural Class	Particle Density g cm^{-3}	Bulk Density g cm^{-3}	Porosity %	Hydraulic conductivity cm day-^{1}	State of Aggregation >0.05 mm %	Degree of Aggregation <0.05 mm. %	Dispersion Factor %
	Sand %	Silt %	Clay %								
F-F-F	26.06	43.53	30.41	Clay Loam	2.46	1.41	42.68	3.84	0.77	1.04	13.32
V-F-R	31.17	38.41	30.42	Clay Loam	2.45	1.28	47.76	4.8	3.32	4.82	13.31
S-S-R	30.97	35.95	33.08	Clay Loam	2.45	1.53	37.55	0.72	3.34	4.84	12.24
F-M-R	13.13	56.41	30.46	Silty clay Loam	2.43	1.27	47.74	15.36	3.33	3.83	13.30
F-F-R	11.93	29.02	59.05	Clay	2.25	1.35	40.00	3.84	12.66	14.37	7.04

***Saturated hydraulic conductivity*:** The hydraulic conductivity varied from 0.72-15.36 cm day^{-1}. The hydraulic conductivity was lowest (0.72 cm day^{-1}) under S-S-R and highest (15.36 cm day^{-1})

under F-M-R (Table 2). The variation in the saturated hydraulic conductivity under different cropping patterns were statistically significant (*p<0.01*).

***State of aggregation*:** State of aggregation (>0.05 mm) ranged from 0.77 to 12.66% in the soils (Table 2). Soils under F-F-R had the highest state of aggregation (12.66%). The lowest state of aggregation (0.77%) was found under F-F-F pattern. Changes in the state of aggregation in different cropping pattern were statistically significant (*p<0.01*).

***Degree of aggregation*:** Degree of aggregation (<0.05 mm size) varied from 1.04 to14.37 % (Table 2). The highest degree of aggregation was observed in F-F-R and lowest in F-F-F. Degree of aggregation varied significantly (*p<0.01*) in different cropping patterns.

***Dispersion factor*:** The dispersion factor of soils under different cropping patterns varied from 7.04 to13.32% (Table 2). The dispersion factor was highest under F-F-F and lowest under F-F-R. The variations in the dispersion factors under different cropping patterns were statistically significant (*p<0.01*).

***Distribution of SOC in different aggregates*:** The percentages of SOC associated with >0.05 mm aggregates varied from 0.31 to 3.78% under different cropping patterns (Fig.1). The highest SOC associated with >0.05 mm aggregates was found under F-M-R and lowest was found under S-S-R. The percentages of SOC associated with 0.05-0.002 mm aggregates were lower than that with >0.05 mm aggregates with exception under S-S-R pattern. The OC in 0.05-0.002 mm aggregates varied from 0.33 to 0.70% under different cropping patterns. The highest SOC associated with 0.05-0.002 mm aggregates was found under F-F-R and lowest under F-M-R patterns. The clay (<0.002 mm) associated SOC under different cropping patterns was higher than the carbon associated with 0.05-0.002 mm aggregates. The SOC associated with <0.002 mm particles was varied from 0.68 to 0.86% under different cropping patterns. Highest value of SOC was observed under S-S-R and the lowest under F-F-R. The variations of SOC under different cropping patterns were not statistically significant.

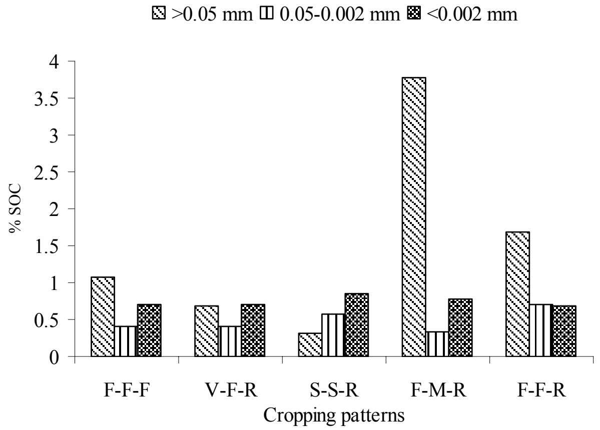

Fig 1. Soil organic carbon (SOC) associated with different aggregate size ranges under different cropping patterns.

***Relationship among soil physical properties*:** The clay percentages of soil significantly increased the state (r=0.974 and *p*<0.005) and degree (r=0.960 and *p*<0.009) of aggregation whereas decreased the dispersion factor (r=-0.99 and *p*<0.00) (Table 3). State (r=-0.971 and *p*<0.006) and degree (r=-0.962 and *p*<0.009) of aggregation had significant negative correlation with dispersion factor of soil. There existed a significant positive correlation between hydraulic conductivity and SOC associated with >0.05 mm aggregates (r=0.949 and *p*<0.014).

Table 3. Correlation among soil physical properties.

	Sand	Silt	Clay	BD	HC	SA	DA	DF
Silt	-0.190							
	0.759							
Clay	-0.600	-0.672						
	0.285	*0.214*						
BD	0.461	-0.406	-0.017					
	0.434	*0.497*	*0.979*					
HC	-0.600	0.845	-0.236	-0.717				
	0.285	*0.072*	*0.702*	*0.173*				
SA	-0.625	-0.617	**0.974**	-0.139	-0.123			
	0.260	*0.268*	*0.005*	*0.824*	*0.843*			
DA	-0.553	-0.667	**0.960**	-0.107	-0.181	**0.995**		
	0.334	*0.219*	*0.009*	*0.864*	*0.771*	*0.000*		
DF	0.566	0.699	**-0.997**	-0.051	0.278	**-0.971**	**-0.962**	
	0.320	*0.189*	*0.000*	*0.935*	*0.651*	*0.006*	*0.009*	
>0.05mm	-0.809	0.714	0.028	-0.624	**0.949**	0.109	0.038	0.010
	0.097	*0.176*	*0.964*	*0.261*	*0.014*	*0.861*	*0.952*	*0.987*
0.05-0.002mm	-0.180	**-0.884**	0.857	0.448	-0.633	0.806	0.831	**-0.891**
	0.772	*0.047*	*0.064*	*0.449*	*0.252*	*0.099*	*0.082*	*0.043*
<0.002mm	0.274	0.239	-0.402	0.572	0.006	-0.349	-0.314	0.337
	0.655	*0.698*	*0.502*	*0.313*	*0.992*	*0.565*	*0.606*	*0.580*

	>0.05mm	0.05-0.0
0.05-0.002mm	-0.395	
	0.511	
<0.002mm	-0.030	-0.064
	0.962	*0.918*

Cell Contents: Pearson correlation
P-Value
[Where, BD = Bulk density, HC = Hydraulic Conductivity, SA = State of Aggregation, DA = Degree of Aggregation, DF = Dispersion factor]

The SOC content in 0.05-0.002 mm aggregates were negatively correlated with silt content (r=-0.884 and $p<0.047$) and dispersion factor (r=-0.891 and $p<0.043$) of soil. Clay percentages of soil did not significantly increase the percentages of SOC associated with <2µm particles (Table 3).

Discussion

Soil management systems have pronounced effect on SOM and hence affect the tilth of soil. Soil structure plays a dominant role in controlling microbial access to organic substrates. The labile organic material may be physically protected from decomposition by its incorporation into soil aggregates (Gregorich *et al.*, 1989). SOM can be: (1) physically stabilized, or protected from decomposition, through microaggregation, or intimate association with silt and clay particles, and (2) can be biochemically stabilized through the formation of recalcitrant SOM compounds (Six *et al.*, 2002a). Hence, Soil aggregation is an important process of C sequestration and a useful strategy to mitigate the increase in concentration of atmospheric CO_2 (Shrestha *et al.*, 2007).

The state of aggregation, degree of aggregation and dispersion factor were low in the present case but varied significantly with cropping patterns. Rabbi *et al.* (2005) reported that state of soil aggregation in south western areas of Bangladesh might be as high as 34.58% in some instances. The degree of aggregation was higher than state of aggregation under different cropping patterns which indicates the significance of finer particles (silt and clay) in aggregation. The higher dispersion factor and lower state and degree of aggregation of soil samples indicated the aggregate destruction by the conventional tillage operations. The role of conventional tillage practices on the destruction of soil macroaggregates was also reported by Six *et al.* (1999). The average SOC associated with >0.05 mm aggregates was higher than the carbon associated with finer aggregates. The highest SOC associated with >0.05 mm aggregates was found in F-M-R which indicated importance of legumes in cropping pattern and their ability to supply OC to soil. Valzano *et al.* (2005) found that cropping pattern with legume produce positive impact on SOC storage whereas sugarcane and vegetable base cropping patterns had lower SOC storage. This study is in good agreement with that of Valzano *et al.* (2005). The higher SOC content of >0.05 mm was due to incorporation of fresh organic matter from the crops. The fresh organic carbon was first incorporated to larger aggregates and then shunted to microaggregates after decomposition by soil microbes and this process was stimulated by disturbance due to conventional tillage (Franzluebbers and Arshad, 1997; Elliot, 1986). The carbon content of 0.05-0.002 mm aggregates was lower than the other aggregates because of their less SOC protective capacity. Although the cropping patterns were not same, the SOC content in <0.002 mm particles did not vary significantly. The soils were under conventional tillage for many years and chemical fertilizers were being applied to soils. These tillage and cultural practices may hinder the accumulation of SOC in <0.002 mm particles even though the SOC accumulation within >0.05 mm aggregates under F-F-R and F-M-R were higher than other cropping patterns. The higher carbon mineralization rate under F-M-R might have played an important role in SOC decomposition in >0.05 mm aggregates and their association with <0.002 mm particles. Adiku *et al.* (2008) observed that the mineralization rate of SOC under maize-legume rotation was higher than maize-fallow rotation and less promising for SOC sequestration. The SOC associated with 0.05-0.002 mm fraction was decreased with increasing silt percentage and dispersion factor (Table 3) but carbon associated with <0.002 mm particles was not influenced by clay percentages of soil. Wiseman and Puttmann (2005) described the importance of specific surface of clays rather than percentage of clays in SOC sorption. Wattel-Koekkoek *et al*. (2001) showed that smectites have large sorptive capacity for SOC. In the Ganges River Floodplain of Bangladesh illite is the dominant clay mineral (Ahmed *et al*., 2004) which has a surface area of about 70-120 m^2 g^{-1} which is about 7-9 times less than that of montmorillonite (Bohn *et al*., 1979). The capacity of illite to sorb SOC at <0.002 mm scale may play an important role which demands further investigation.

Conclusion

The aggregation indices of soils varied significantly under different cropping patterns. The SOC associated with >0.05 aggregates was higher than that with 0.05-0.002 mm aggregates. SOC associated with clay (<0.002 mm) was higher than that with 0.05-0.002 mm aggregates.

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