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RESEARCH ARTICLE

CARBON SEQUESTRATION IN SOIL AGGREGATES UNDER DIFFERENT CROPPING PATTERN IN GANGES MEANDER AND GANGES TIDAL FLOODPLAINS OF KHULNA REGION

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Abstract: Sequestering carbon in soil aggregates is a long term solution to global warming that will keep CO_2 out of the atmosphere. The study was conducted to investigate the state of carbon sequestration in soil aggregates under different cropping patterns of Khulna region. Twelve different cropping patterns were selected. Soil particle size distribution, microaggregate analysis, aggregate stability, normalized stability index (NSI) and organic carbon were determined. The soil organic carbon (SOC) associated with aggregate size ranges (8-2, 2-0.25 and 0.25-0.05 mm) were separated and determined. The SOC associated with 2-0.25 mm aggregates was generally higher than SOC associated with 8-2 mm and 0.25-0.05 mm aggregates. The state of aggregation (7.5%) and degree of aggregation (13.04%) were found high under Til (Sesame)-Fallow-T.aman cropping pattern and low under Aus-Fallow-Vegetable/ Vegetable-Sugarcane cropping pattern. The dispersion factor (28.25%) was highest under Vegetable cropping pattern. The highest NSI value (0.95) was under Fallow-Fallow-T.aman cropping pattern at Dhulirhat union in Satkhira district and the lowest value (0.29) was under Fallow-Fallow-T.aman cropping pattern at Aatlia union in Khulna district. The highest organic carbon content in aggregate size ranging from 8-2, 2-0.25 and 0.25-0.05 mm was found 2.28, 3.00 and 2.63%, respectively under Fallow-Fallow-T.aman cropping pattern at Dhulirhat union in Satkhira district. The lowest organic carbon content was found 0.53, 0.58 and 0.51%, respectively under Boro-Fallow-T.aman cropping pattern at Sokhipur union in Satkhira district. Organic carbon associated with 8-2 mm and 0.25-0.05 mm aggregate was negatively correlated with sand and positively with clay contents of the soils. Carbon associated with different aggregates was also positively correlated.

Key words: Carbon sequestration, cropping pattern, soil aggregates

Introduction

Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so that it is not immediately reemitted. Thus, soil C sequestration means increasing SOC (soil organic carbon) and SIC (soil inorganic carbon) stocks through judicious land use and RMPs (recommended management practices) (Lal, 2004).

Important RMPs for enhancing SOC include conservation tillage, mulch farming, cover crops, and integrated nutrient management including use of manure and compost, and agroforestry. Restoration of degraded/desertified soils and ecosystems is an important strategy. The global potential of SOC sequestration is estimated at 0.6 to 1.2 Gt C year^{-1}, comprising of 0.4 to 0.8 Gt C year^{-1} through adoption of RMP on cropland (1350 Mha), and 0.01 to 0.03 Gt C year^{-1} on irrigated soils (275 Mha), and 0.01 to 0.3 Gt C year^{-1} through improvements of rangelands and grasslands (3700 Mha) (Lal *et al.*, 2007). In addition, there is a large potential of C sequestration in biomass in forest plantations, short rotation woody perennials, and so on. The attendant improvement in soil quality with increase in SOC pool size has a strong positive impact on agronomic productivity and world food security. An increase in SOC pool within the root zone by 1 t C ha^{-1}

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year^{-1} can enhance food production in developing countries by 30 to 50 Mt year^{-1} including 24 to 40 Mt year^{-1} of cereal and legumes, and 6 to 10 Mt year^{-1}of roots and tubers. Despite the enormous challenge of SOC sequestration, especially in regions of warm and arid climates and predominantly resource-poor farmers, it is a truly a win-win strategy. While improving ecosystem services and ensuring sustainable use of soil resources, SOC sequestration also mitigates global warming by offsetting fossil fuel emissions and improving water quality by reducing nonpoint source pollution (Lal *et al.,* 2007).

Atmospheric carbon dioxide and other greenhouse gases act to trap heat that is reflected from the earth's surface. This buildup of heat could lead to global warming. Through terrestrial carbon sequestration, atmospheric carbon dioxide levels are reduced as soil organic carbon levels increase. If the soil organic carbon is undisturbed, then it can remain in the soil for many years as stable organic matter. This carbon is then sequestered or removed from the pool available to be recycled to the atmosphere. This process reduces CO_2 levels in the atmosphere, reducing the chances of global warming.

Increasing tillage intensity enhances the turnover of soil organic matter (SOM) and decreases soil aggregation. It has been proposed that soil aggregates physically protect certain SOM fractions, resulting in pools with longer turnover times (Adu and Oades, 1978). Reduced tillage is regarded as one of the most effective agricultural strategies for sequestering atmospheric C (Kern and Johnson, 1993; Lal and Kimble, 1997). Tillage accelerates organic C oxidation to CO_2 by improving soil aeration, by increasing contact between soils and crop residues, and by exposing aggregate-protected organic matter to microbial attack (Beare *et al*., 1994).

Conventional tillage is a common tillage practice in Bangladesh which may cause aggregate disruption and rapid carbon emission. The cropping intensity also is high in Bangladesh due to high population density. This may increase organic matter loss from soil. So, the objective of the research work was to determine the state of carbon sequestration retention in soil aggregates.

Materials and Methods

Top soil (0-6 cm) samples were collected from different locations of agricultural fields under different cropping pattern and conventional tillage practices (Table 1) in the Ganges Meander and Ganges Tidal Floodplains of Khulna region. Soil samples were collected on the basis of composite sampling method as suggested by the Soil Survey Staff of the USDA (1951) and then processed for subsequent analyses.

Particle size analysis was carried out by combination of sieving and hydrometer method (Gee and Bauder, 1986). Textural class was determined by Marshall's Triangular co-ordinate system. Soil structure was evaluated by microaggregate analysis of the soils following the method Kachinskii (1965). The state of aggregation, degree of aggregation and dispersion factor was determined by using the following equations (Baver and Rhoades, 1932).

$$\text{State of aggregation} = a - b$$

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

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

Where 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 determination of soil organic carbon (SOC) associated with soil aggregates of 8-2 mm, 2-0.25 mm and 0.25-0.05 mm size ranges were kept submerged with distilled water for 5 minutes and then separated manually by moving the sieve 3 cm up and down under water with 50 repetitions during a period of 2 minutes. Soil samples of these three fractions were then oven dried at 70^{0}C for 24 hours. The carbon content of each size fractions were determined by the method as described by Tyurin (1936).

Table 1. Description of sampling sites

Sample	**GPS**	**Soil Series**	**Physiography**	**Location**	**Land use**	**Land type**
1	22^{0}37′33.1 ″N 90^{0}10′02.4 ″E	Barisal	Ganges Tidal Floodplain	Vill: Chatrakanda Union: Gabkhan Upazilla: Rajapur	Fallow-Fallow-T.aman	Medium High Land
2	22^{0}40′13.9 ″N 90^{0}16′38.0 ″E	Jhalokathi	Ganges Tidal Floodplain	Vill: Dohorpara Union: Maghor Upazilla: Jhalokathi	Mug bean-Fallow-T.aman	Medium High Land
3	22^{0}38′38.8 ″N 89^{0}31′17.3 ″E	Barisal	Ganges Tidal Floodplain	Vill: Gopalkhali Union: Gangarampur Upazilla: Botiaghata	Fallow-Fallow-T.aman	Medium High Land
4	22^{0}41′34.9 ″N 89^{0}31′53.7 ″E	Ramgati	Ganges Tidal Floodplain	Vill: Gagramari Salinity Center Upazilla: Botiaghata	Fallow-Fallow-T.aman	Medium High Land
5	23^{0}03′31.9 ″N 89^{0}22′43.3 ″E	Sara	Ganges Meander Floodplain	Vill: Mohakal Vangagate Union: Noyapara Upazilla: Avoynagar	Til-Fallow-T.aman	High Land
6	23^{0}07′39.9 ″N 89^{0}20′07.0 ″E	Gopalpur	Ganges Meander Floodplain	Vill: Dui rasta Union: Basundiaa Upazilla: Jessore Sadar	Boro-Fallow-T.aman	Medium High Land
7	22^{0}41′02.2 ″N 89^{0}05′55.1 ″E	Darsana	Ganges Meander Floodplain	Vill: Brahmarajpur Satkhira sadar	Boro-Fallow-T.aman	High Land
8	22^{0}38′38.0 ″N 89^{0}07′25.9 ″E	Mirpur	Ganges Meander Floodplain	Vill: Darbaista Union: Dhulirhat Upazilla: Satkhira Sadar	Vegetable	High Land
9	22^{0}34′40.6 ″N 88^{0}59′53.8 ″E	Mirpur	Ganges Meander Floodplain	Vill: Sokhipur Union: Sokhipur Upazilla: Debhata	Aus-Fallow-Vegetable/ Vegetable-Sugarcane	High Land
10	22^{0}33′52.7 ″N 88^{0}57′11.3 ″E	Darsana	Ganges Meander Floodplain	Vill: Sosilgati Union: Town sripur Upazilla: Devhata	Rabi-jute-T. aman	High Land
11	22^{0}46′01.2 ″N 89^{0}08′58.4 ″E	Ishurdi	Ganges Meander Floodplain	Vill: Sakdaha Union: Khorolia Upazilla: Tala	Rabi-Jute-Turmeric	Medium High Land
12	22^{0}49′20.3 ″N 89^{0}20′11.3 ″E	Amjhupi	Ganges Meander Floodplain	Vill: Baratia Union: Aatlia Upazilla: Dumuria	Wheat-Jute-T.aman	Medium High Land

For determination of aggregate stability, soils were divided into 8-2 mm, 2-0.25 mm and 0.25-0.05 mm size fractions by using mechanical shaker. For wet sieving with slaking pretreatment 10 g air dry soil samples from each aggregate size fraction were submerged for 5 minutes and then separated manually by moving the sieve 3 cm up and down under water with 50 repetitions during a period of 2 minutes. For wet sieving with wetted pretreatment the air dried samples were adjusted to field capacity by soaking with water for overnight before submerging in water. The soils were then sieved for 2 minutes by the method as stated before. Soil samples of these three fractions were then oven dried at 105^0C for 24 hours. Primary particles retained on the sieves were determined by sieving and then oven dried at 105^0C for 24 hours. The normalized stability index (NSI) of aggregates was calculated by the following formula (Six *et al.*, 2000).

$$\text{NSI} = 1 - [\text{DL}/\text{DL (max)}]$$

The whole soil disruption level (DL) was calculated as:

$$\text{DL} = 1/n \sum_{i}^{n} [(n+1) - i] \times \text{DLS}_\text{i}$$

Where n = number of aggregate size classes. i = 1 for the smallest size class.

The disruption level of a size class upon slaking (DLSi) was calculated by the following formula:

$$\text{DLSi} = \frac{\begin{bmatrix} \{(P_{io} - S_{io}) - (P_i - S_i)\} + \\ |(P_{io} - S_{io}) - (P_i - S_i)| \end{bmatrix}}{2} \times \frac{1}{[P_{io} - S_{io}]}$$

where DLSi = disruption level for each size class i; *Pio* = proportion of total sample weight in size class i before disruption (i.e., rewetted); *Pi* = proportion of total sample weight in size class i after disruption (i.e., slaked); *Sio* = proportion of sand with size i in aggregates of size i (= aggregate-sized sand) before disruption; *Si* = proportion of sand with size i in aggregates of size i after disruption.

The whole soil DL (max) was calculated by the following formula:

$$\text{DL (max)} = 1/n \sum_{i}^{n} [(n+1) - i] \times \text{DLS}_{\text{i (max)}}$$

The maximum disruption [DLSi (max)] was calculated with the following formula:

$$\text{DLSi (max)} = \frac{\left[(P_{io} - P_p) + |(P_{io} - P_p)|\right]}{2} \times \frac{1}{[P_{io} - S_{io}]}$$

Pp = primary sand particle content with the same size as the aggregates size class after complete disruption of the whole soil.

Results

***Particle size distribution*:** The percentage of silt was the highest under Aus-Fallow-Vegetable/ Vegetable-Sugarcane cropping pattern and was the lowest under Wheat-Jute-T.aman cropping pattern whereas clay was the highest under Fallow-Fallow-T.aman (sampling site 12) and was the lowest under Vegetable cropping pattern. The percentage of silt and clay ranged from 58.08-38.36% and 45.91-8.85%, respectively (Table 2). The percentage of sand was the highest under Til-Fallow-T.aman and Rabi-Jute-Turmeric cropping patterns and the lowest under Fallow-Fallow-T.aman (sampling site 12) cropping pattern.

***Degree of Aggregation*:** The highest degree of aggregation was found 13.04% under Til-Fallow-T.aman pattern and the lowest was 0 under Aus-Fallow-Vegetable/ Vegetable-Sugarcane cropping pattern. The percentage of sand, silt and clay were 42.50, 46.01 and 11.49%, respectively under Til-Fallow-T.aman where as 29.00, 58.08 and 12.92%, respectively under Aus-Fallow-Vegetable/ Vegetable-Sugarcane cropping pattern (Table 2).

State of Aggregation**:** The state of aggregation ranged from 0 to 7.5%. The highest value of 7.5% was found under Til-Fallow-T.aman cropping pattern and the lowest value was 0 under Aus-Fallow-Vegetable/ Vegetable-Sugarcane cropping pattern (Table 2).

Dispersion factor**:** The dispersion factor of soils under different cropping patterns varied from 0 to 28.25%. The dispersion factor was highest under vegetable cropping pattern followed by Aus-Fallow-Vegetable/ Vegetable-Sugarcane and the lowest value was found under different cropping patterns (Table 2).

Table 2. Percent sand, silt, clay, degree of aggregation, state of aggregation and dispersion factor under different cropping patterns in different soils

Sampling site	**Soil series**	**Texture**	**Cropping pattern**	**% Sand**	**% Silt**	**% Clay**	**DA (%)**	**SA (%)**	**DF (%)**
1	Sara	Loam	Til-Fallow-T.aman	42.50	46.01	11.49	13.04	7.5	0
2	Ishurdi		Rabi-Jute-Turmeric	42.50	39.58	17.92	4.35	2.5	0
3	Ramgati	Silt loam	Fallow-Fallow-T.aman	23.88	56.43	19.69	0.16	0.12	0
4	Mirpur		Vegetable	40.00	51.15	8.85	1.67	1.00	28.25
5	Mirpur		Aus-Fallow-Veg/ Veg-Sugarcane	29.00	58.08	12.92	0	0	19.35
6	Darsana		Rabi-jute-T. aman	25.24	58.00	16.76	6.37	4.76	0
7	Jhalokathi	Clay loam	Mug bean-Fallow-T.aman	22.06	46.76	31.18	5.06	3.94	0
8	Barisal		Fallow-Fallow-T.aman	22.31	42.87	34.82	3.46	2.69	0
9	Gopalpur		Boro-Fallow-T.aman	25.86	45.52	28.62	6.93	5.14	0
10	Darsana		Boro-Fallow-T.aman	25.84	46.84	27.32	4.26	3.16	0
11	Amjhupi		Wheat-Jute-T.aman	23.00	38.36	38.64	3.90	3	0
12	Barisal	Silty clay	Fallow-Fallow-T.aman	13.43	40.66	45.91	12.21	10.57	0

Normalized stability index (NSI): The NSI varied from 0.29 to 0.95 under different cropping patterns (Table 3). The highest NSI value was found under Fallow-Fallow-T.aman (sampling site 8) cropping pattern and the lowest value was found under Fallow-Fallow-T.aman (sampling site 12) cropping pattern.

Soil Organic Carbon (SOC) associated with soil aggregates (%)**:** The percentages of SOC associated with different aggregates were the highest under Fallow-Fallow-

T.aman (sampling site 8) pattern and were the lowest under Boro-Fallow-T.aman (Sampling site 9) cropping pattern. Organic carbon content in aggregate size ranges from 8-2 mm, 2-0.25 mm and 0.25-0.05 mm varied from 2.28-0.53, 3.00-0.58 and 2.63-0.51%, respectively (Table 3). The percentages of SOC associated with 2-0.25 mm aggregates were higher than those of 8-2 and 0.25-0.05 mm aggregates with exception under Fallow-Fallow-T.aman, Boro-Fallow-T.aman and Wheat-Jute-T.aman cropping pattern.

Table 3. Normalized stability index and aggregate associated organic carbon under different cropping pattern in different soils.

Sampling site	Soil series	Texture	Cropping pattern	NSI	SOC 1	SOC 2	SOC 3
1	Sara	Loam	Til-Fallow-T.aman	0.41	0.77	1.24	0.52
2	Ishurdi		Rabi-Jute-Turmeric	0.45	0.65	1.43	1.02
3	Ramgati	Silt loam	Fallow-Fallow-T.aman	0.46	1.27	2.38	2.41
4	Mirpur		Vegetable	0.65	0.70	1.24	0.69
5	Mirpur		Aus-Fallow-Veg/ Veg-Sugarcane	0.57	1.14	1.71	1.51
6	Darsana		Rabi-jute-T. aman	0.61	1.22	1.76	1.25
7	Jhalokathi	Clay loam	Mug bean-Fallow-T.aman	0.59	1.55	2.20	2.08
8	Barisal		Fallow-Fallow-T.aman	0.95	2.28	3.00	2.63
9	Gopalpur		Boro-Fallow-T.aman	0.34	0.53	0.58	0.51
10	Darsana		Boro-Fallow-T.aman	0.38	0.79	1.06	1.28
11	Amjhupi		Wheat-Jute-T.aman	0.63	1.31	1.55	1.70
12	Barisal	Silty clay	Fallow-Fallow-T.aman	0.29	1.76	2.46	2.09

***Relationship among soil properties*:** Organic carbon associated with 8-2 mm and 0.25-0.05 mm aggregate was negatively correlated with sand and positively with clay contents. The SOC content in 8-2 mm aggregates was positively correlated with other aggregates, whereas 2-0.25 mm aggregate was positively correlated with 0.25-0.05 mm aggregate (Table 4).

Discussion

The value of NSI can vary between 0 and 1 (Six *et al.* 2000). The NSI of studied soils varied from 0.29 to 0.95 under different cropping patterns. The NSI was higher in clay loam soils and lower in silty clay soils. The lower NSI indicated that the aggregates were not water stable. Earlier investigation by Rabbi *et al.* (2004) indicated that water stability of aggregates of silt loam texture was low. However, in the present investigation the NSI of silt loam soil was higher than silty clay soils. The mineralogy of soils may play important role in aggregate stability (Six *et al.*, 2000). However, in the present study mineral identification was not done. In the present study soils under Fallow-Fallow-T.aman cropping pattern had higher NSI. The percentages of SOC associated with different aggregates were also highest in the soils under Fallow-Fallow-T.aman pattern which indicated the significance of minimum tillage and their ability to conserve OC to soil. The cultivation of rice in boro and Kharif-2 season also decreased NSI of soils. Six *et al.* (1999) reported that conventional tillage with high cropping intensity caused maximum destruction of soil. The cultivation of rice twice a year accelerates the aggregate destruction rate under submerged condition. Adiku *et al.* (2008) concluded that soils under rice base cultivation were more prone to degradation. Soil management systems have pronounced effect on soil organic matter content 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). Soil OM can be physically stabilized or protected from decomposition, through microaggregation, or intimate association with silt and clay particles, and can be biochemically stabilized through the formation of recalcitrant soil organic compounds (Six *et al*., 2002). Hence, soil aggregation is an

Table 4. Correlations among selected soil properties.

	%Sand	%Silt	%Clay	DA(%)	SA(%)	DF(%)	SOC-1	SOC-2	SOC-3
%Silt	0.049 0.881								
%Clay	-0.803 0.002	-0.634 0.027							
DA(%)	-0.037 0.909	-0.431 0.162	0.286 0.368						
SA(%)	-0.266 0.403	-0.447 0.145	0.473 0.121	0.963 0.000					
DF(%)	0.382 0.221	0.422 0.172	-0.547 0.066	-0.459 0.133	-0.467 0.126				
SOC-1	**-0.681** 0.015	-0.128 0.691	**0.604** 0.038	-0.005 0.988	0.137 0.670	-0.252 0.430			
SOC-2	-0.526 0.079	0.007 0.983	0.403 0.194	-0.106 0.743	0.012 0.970	-0.191 0.551	**0.929** 0.000		
SOC-3	**-0.704** 0.011	-0.027 0.934	**0.561** 0.058	-0.276 0.384	-0.120 0.709	-0.285 0.369	**0.888** 0.000	**0.915** 0.000	
NSI	-0.021 0.949	0.080 0.805	-0.032 0.922	-0.468 0.125	-0.469 0.124	0.229 0.473	0.555 0.061	0.493 0.103	0.409 0.187

Cell Contents: Pearson correlation
P-Value

SOC-1= Soil organic carbon associated with 8-2 mm aggregate size range.
SOC-2= Soil organic carbon associated with 2-0.25 mm aggregate size range.
SOC-3= Soil organic carbon associated with 0.25-0.05 mm aggregate size range.

important process of C sequestration (Shrestha *et al.*, 2007). The average SOC associated with 8-2 mm aggregates was lower than those of carbon associated with 2-0.25 and 0.25-0.05 mm aggregates. The fresh organic carbon that was derived from the crops were first incorporated to larger aggregates and then shunted to microaggregates after decomposition by soil microbes and this process was stimulated by disturbance by conventional tillage (Franzluebbers and Arshad, 1997; Elliot, 1986). The percentage of SOC associated with 2-0.25 and 0.25-0.05 mm aggregates increased with increasing clay percentages of soils. Wiseman and Puttmann (2005) described the importance of specific surface of clays rather than percentage of clays in SOC sorption. Wattel-Koekkoek *et al*. (2003) showed that smectites have large sorptive capacity for SOC. The existing reports on clay minerals of Ganges River Floodplain of Bangladesh concluded that illite is the dominant clay mineral of this floodplain (Ahmed *et al.*, 2004). The surface area of illite is about 70-120 m^2 g^{-1} which is about 7-9 times less than montmorillonite (Bohn, 1979). So, the capacity of illite to sorb SOC at 0.25-0.05 mm scale may play an important role and it requires further research to conclude.

Conclusion

Soils under Fallow-Fallow-T.aman cropping pattern had higher NSI and SOC. The cultivation of rice in boro and Kharif-2 season decreased NSI of soils. The percentage of SOC associated with 2-0.25 and 0.25-0.05 mm aggregates increased with increasing clay contents of the investigated soils. Soil organic matter can be physically stabilized or protected from decomposition, through microaggregation, or intimate association with silt and clay particles. Hence, soil aggregation is an important process of C sequestration. Aggregate stability and cropping pattern are strongly correlated with soil carbon sequestration.

References

Adiku, S.G.K.; Narh, S.; Laryea, K.B. and Dowuona, G.N. 2008. Short-term effects of crop rotation, residue management and soil water on carbon mineralization in a tropical cropping system. *Plant and Soil*, Published online in 13 June, 2008. DOI 10.1007/s11104-008-9652-y

Adu, J.K. and Oades, J.M. 1978. Physical factors influencing decomposition of organic materials in soil aggregates. *Soil Biology and Biochemistry*, 10: 109-15

Ahmed, I.U.; Akhter, S. and Ahsan, M. 2004. Mineralogical characterization of clay fraction of some Ganges Floodplain soils. *Bangladesh Journal of Soil Science,* 30(1-2): 71-78

Baver, L.D. and Rhoades, H.F. 1932. Soil aggregate analysis as an aid in the study of soil structure. *Journal American Society of Agronomy*, 24: 920-21

Beare, M.H.; Cabrera, M.L.; Hendrix, P.P. and Coleman, D.C. 1994**.** Aggregate-protected and unprotected organic matter pools in conventional and no-tillage soils. *Soil Science Society of American Journal*, 58: 787-95

Bohn, H.L. 1979. *Soil Chemistry*. 1st edition, John Wiley and Sons, New York

Elliott, E.T. 1986. Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Science Society of American Journal*, 50: 627-33

Franzluebbers, A.J. and Arshad, M.A. 1997. Soil microbial biomass and mineralizable carbon of water-stable aggregates. *Soil Science Society of American Journal*, 61:1090-1097

Gee, G. and Bauder, J.W. 1986**.** Particle-size analysis. pp. 383-411. In: Klute, A. (Ed.). *Methods of Soil Analysis*, Part 1 (2nd ed.), Agron. Monogr., Vol. 9, ASA and SSSA, Madison, WI

Gregorich, E.G.; Kachanoski, R.G. and Voroney, R.P. 1989. Carbon mineralization in soil size fractions after various amounts of aggregate disruption. *Journal of Soil Science*, 40: 649-59

Kachinski, N.K. 1965. *Soil Physics*. Part- 1. Publ. Visshayaskola, Moscow

Kern, J.S. and Johnson, M.G. 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. *Soil Science Society of American Journal*, 57: 200-210

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*, 304: 1623-27

Lal, R. and Kimble, J.M. 1997. Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems*, 49: 243-53.

Lal, R.; Follett, R.F.; Stewart, B.A. and Kimble, J.M. 2007. Soil carbon sequestration to mitigate climate change and advance food sequrity. *Soil Science*, 172(12): 943-956

Rabbi, S.M.F.; Kibria, K.Q.; Rahman, A.; Islam, M.S.; Bhuiyan, M.R. and Ahsan, M. 2004. Aggregate stability of Ganges Tidal Floodplain and its relationship with soil physical and chemical properties. *Bangladesh Journal of Soil Science*, 30 (1-2): 61-9

Shrestha, B.M.; Singh, B.R.; Sitaula, B.K.; Lal, R. and Bajracharya, R.M. 2007. Soil aggregate- and particle-associated organic carbon under different land uses in Nepal. *Soil Science Society of American Journal*, 71:1194-1203

Six J.; Paustian, K.; Elliott, E.T. and Combrink, C. 2000. Soil structure and soil organic matter: I. Distribution of aggregate size classes and aggregate associated carbon. *Soil Science Society of American Journal*, 64: 681- 89

Six, J.; Elliott, E.T. and Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Science Society of American Journal*, 63: 1350-58

Six, J.; Conant, R.T.; Paul, E.A. and Paustian, K. 2002. Stabilization mechanisms for soil organic matter: Implications for C saturation of soils. *Plant Soil*, 141: 155-76

Tyrin, I.V. 1936. *Data on a comparative study of determining soil organic carbon*. Probl. Sovet. Pochvoved. 2

USDA (United States Department of Agriculture). 1951. *Soil Survey Manual by Soil* Survey Staff. Bureau of plant industry, soil and Agriculture Engineering, Handbook No.18: 205

Wattel-Koekkoek, E.J.W.; van Genuchten, P.P.L.; Buurman, P. and van Lagen, B. 2003. Amount and composition of clay-associated soil organic matter in a range of kaolinitic and smectitic soils. *Geoderma*, 99: 27-49

Wiseman, C.L.S. and Puttmann, W. 2005. Soil organic carbon and its sorptive preservation in central Germany. *European Journal of Soil Science*, 56: 65-76