**Relevance of Soil Aggregates on**

**Carbon Sequestration in Mangrove and**

**Rice Ecosystems of Sundarbans Delta.**

**Abstract**

Mangrove ecosystems are net carbon sinks. These have high carbon sequestration potential in soil, sediments, and water column. The soil organic carbon (SOC) which is protected by the aggregates is called the slow pool. In this pool, the organic matter is partially decomposed. Carbon which is present between aggregates is called inter-particulate organic carbon and the carbon which is present within aggregates is called intra-particulate organic carbon. It is also called particulate organic matter carbon (POM-C). Many reports have suggested that macroaggregates (>250μm) provide less protection to carbon in comparison to micro aggregates (<250μm), to decomposition. The present paper depicts the comparative analysis of particulate organic carbon (POC) sequestration and soil aggregate stability in mangrove and rice ecosystem of the Sundarban delta. In our study seven different sites were selected based on the degradation status of mangroves from 1930 to 2013 by National Remote Sensing Agency (NRSA), Hyderabad in Sagar Island, Sundarban, India. In order to estimate the POC sequestration and soil aggregate stability aggregate fractions of different sizes were extracted from the sample with the help of Yoder apparatus. POC in soil aggregates of each class were estimated with the help of C/N analyser. Samples were collected from all the two depths (0-15 cm and 15-30 cm) of all sites. To estimate the aggregate stability Mean weight diameter (MWD) was calculated. In mangrove, The average mean weight diameters (MWD) of soils were in between 0.088 to 0.145 mm whereas in rice it was in between 0.120 to 0.438 mm among the seven different sites. This shows that more aggregate stable soil is under the rice system than that of mangrove system. The soils of the top layer had more aggregate stability than the sub-soil in both the (mangroves and rice) systems. The MWD of soil aggregate under the rice system was higher than in the mangroves system. Macroaggregate are generally formed through the cementation of microaggregates. Earlier studies have suggested that aggregate transformation is strongly regulated by microbial activity. Fungal hyphae physically bind the microaggregate together to form macroaggregate and it also stabilize the contents present in microaggregate. This paper investigates the significant impact of all three factors (i.e. ecology, site and depth) on the aggregate stability and POC sequestration.

*Keywords: Mangrove, particulate organic carbon (POC), macroaggregates, micro aggregates, Mean weight diameter*

**1. Introduction**

Mangrove ecosystems are net carbon sinks. These have high carbon sequestration potential in soil, sediments, and water column. High litter deposition, low organic carbon decomposition rate in anoxic conditions, and significant rhizodeposition facilitate the carbon storage in these systems. One-third of the NPP of the systems accounted for the litter-fall (Alongi *et al.*, 2002). The mean litter-fall rate is around ~38 mol carbon m-2 year-1, globally. Below ground biomass also contributes significantly (10-55%) to carbon sequestration. Therefore, soil carbon dynamics in those systems play an important role in the global carbon cycle and climate change feedback. Further, understanding the carbon pools dynamics their decomposition kinetics and subsequent stabilization in the sedimentation of the system is necessary for climate change studies. The organic carbon enters the system either autochthonously or is imported by water flow in the estuaries. The autochthonous carbon is mostly contributed by mangrove litter and or benthic micro-algae (Shedage and Shrivastava., 2018).

 The soil organic carbon (SOC) which is protected by the aggregates is called the slow pool. In this pool, the organic matter is partially decomposed. Slow carbon pools take about six months to ten years to decompose fully. This pool is relatively stable to microbial decomposition compared to labile pools but less stable than passive pools. The particle size of this pool ranges from 53μm to 2000μm. Carbon which is present between aggregates is called inter-particulate organic carbon and the carbon which is present within aggregates is called intra-particulate organic carbon. It is also called particulate organic matter carbon (POM-C). Many reports have suggested that macroaggregates (>250μm) provide less protection to carbon in comparison to micro aggregates (<250μm), to decomposition.

The ability of the soil aggregates to resist the disintegration when subjected to the pressure of destructive agents is called soil aggregate stability. Aggregate stability act as a soil health indicator. Well aggregated soil reduces soil erodibility and enhance the water holding capacity of the soil. When the rain drops strike the soil aggregates, these break into small particles which clog the soil pores and leads to formation of soil crustation which hinders the water infiltration (Vaezi et al., 2017 ). This increases the surface runoff and soil erosion. Thus, study of soil aggregate stability is important to understand the soil- water relationship. Four factors are identified which accelerates the disintegration of soil aggregates. These are a) swelling and shrinking of soil, b) slaking effect, c) rainfall and d) osmotic stress (Xu et al., 2015). Physical factors i.e. soil inter particle van der Waals attraction forces responsible to promote the soil aggregate formation (Huang et al., 2016). Aggregates act as structural unit in soil and take part in regulating SOC dynamics. Carbon sequestration in different aggregate size luminate the different mechanisms (physical, chemical and biological) that protect the SOC from degradation (Six and Paustian, 2014). SOC sequestration is controlled by macroaggregate stability i.e. aggregate turnover cycle, formation of micro-aggregate and protection of carbon from microbial decomposition by micro- aggregate formation (Six et al., 2000a). POM act as a nucleus for aggregate formation (Gulde et al., 2008). The active decomposer group help in biofilm formation and potentially help to bind the soil particles to the POM (Banwart et al., 2019). The external source of carbon i.e. application of plant residues or farm yard manure provide a cementing agent in cultivated soil for aggregate formation and long term C- storage (Bronick and Lal, 2005).

 The specific objectives of this experiment were: (i) to estimate the impact of ecology in the soil aggregates stability, (ii) to access the POC sequestration in different soil aggregate classes (micro and macroaggregates), and (iii) to explore the relation between POC sequestration and aggregate stability in terms of mean weight diameter (MWD) of aggregates.

**2. Material and methods**

**2.1 Sites description and sample collection**

The location of this study was the Sundarbans is situated at the delta of the Meghna, Padma, and Brahmaputra rivers in India. The location of seven different sites was as follows, Sumatinagar (21°43′26.59′′N, 88°09′48.33′′E), Kayalapara (21°45′23.02′′N, 88°10′12.21′′E), Debigobindapur (21°46′16.40′′N, 88°10′13.96′′E), Gobindapur (21°47′15.06′′N, 88°09′56.42′′E), Fulbari (21°51′57.73′′N, 88°07′21.24′′E), Naraharipur (21°45′49.81′′N, 88°04′25.17′′E) and Benuban (21°40′43.46′′N, 88°08′50.27′′E). The soil samples were collected from seven different sites in winter season (Dec 2021). Samples were collected from the mangrove and rice system with five replications. Soil sampling were done with the help of a soil auger having a diameter of 76 mm. In each site, samples were collected from two locations at two depths (0-15 and 15-30 cm). After the collection of samples, they were allowed for air-dry. After the samples got dried, they were kept in a sealed plastic bag for further analysis.

**2.2 Estimation of aggregate stability and particulate organic carbon (POC)**

100 gm air-dried soil samples having particle sizes greater than 5 mm but less than 8 mm were taken on the 5 mm sieve of the Yoder apparatus. The soil sample was wetted with water and the Yoder apparatus was allowed to run for 10 minutes. Samples were sieved in water with the help of Yoder apparatus. The soil aggregates leftover on each sieve (5, 2, 1, 0.5, 0.25, 0.1 and 0.025 mm) were dried in shade for 24 hrs. After 24 hrs, soil samples were collected in the moisture box from each sieve and allowed to oven-dry at 50°C for 24 hrs. Collected aggregate samples from each sieve were weighed individually to calculate water stable aggregate percentage in the given soil samples by following equation.

$$Stable aggregate percentage=\frac{weight of aggregate in seive}{weight of soil sample}×100$$

Mean weight diameter (MWD) acts as a indicator to measure the soil aggregate stability. It was calculated by following equation.

$$MWD=Σ Wi×Xi$$

where *Wi* is the proportion of aggregates in *ith* class; *Xi* is the mean diameter of *ith* class. For estimating POC in soil aggregates, aggregates of each class were grinded into mortar and pestle and 100 mg of each soil aggregate sample was feeded into a C/N analyser (Model name: Analytikjena Multi-N/C 2100 S) to estimate POC.

**2.3 Statistical Analysis**

The OPSTAT was used for the analysis of variance (ANOVA) and the least significant difference at p ≤ 0.05 levels and the interaction effect of three factors i.e., (i) site (S) (Sumatinagar, Kayalapara, Debigobindapur, Gobindapur, Fulbari, Naraharipur and Benuban), (ii) ecology (E) (mangrove and rice) and (iii) soil depth (D) (0-15, 15-30 cm) was estimated for each parameter.

**3. Results**

The particulate organic carbon (active carbon pool) was estimated in two ecologies (mangrove and adjacent rice) in seven different sites (Debigobindapur, Kayalapara, Gobindapur, Fulbari, Naraharipur, Benuban and Sumatinagar) at two depths (0-15 cm and 15-30 cm) in Sagar Island, Sundarban, India. Results of the water stable aggregate proportion, total carbon percentage (TC%) present in each aggregate and particulate organic carbon percentage are presented in tables 1-5.

**3.1 Aggregates size distribution**

Results show clear distribution of water stable aggregate proportion of each aggregate size fraction. Water stable aggregate proportions were estimated under eight different aggregate size (8-5, 5-2, 2-1, 1-0.5, 0.5-0.25, 0.25-0.1, 0.1-0.053 and < 0.053 mm). All aggregate size were grouped under two aggregate fraction: a) macroaggregate (> 0.25 mm) and b) microaggregate (< 0.25 mm). In mangroves, at depth 0-15 cm, macroaggregate fraction ranged from 4.98 to 13.10 % whereas microaggregates ranged from 86.90 to 95.02 % (Table 1). Macroaggregate fraction was highest in Debi Gobindapur (13.10 % ) and lowest in Kayalapara (4.98%). Likewise microaggregate was highest in Kayalapara (95.02 %) and lowest in Debi Gobindapur (86.90%). Similarly, at depth 15-30 cm, in Fulbari macroaggregate was highest (9.44%) and in Sumatinagar microaggregate was highest (98.79%) (Table 1). However in rice, at both depth macroaggregate was highest in Fulbari (at depth 0-15 cm, 35.53 % and at depth 15- 30 cm, 14.91 %). In both ecology, it was found that in each depth microaggregate fraction was more than macroaggregate fraction. In each depth, for every sites it was found that macroaggregate fraction was higher in rice than mangrove ecology (Table 2). In mangrove ecology, at depth 0-15 cm macroaggregate proportion varied between 4.98 to 13.10% and at 15-30 cm it varied between 1.21to 9.44% (Table 1) whereas in rice ecology, at depth 0-15 cm macroaggregate proportion varied between 5.38 to 35.53% and at 15-30 cm it varied between 0.85 to 14.91%. This shows that rice system has more aggregate stability than mangrove system (Table 2).

**3.2 POC sequestration in different aggregate fraction**

In both ecology, it was found that larger particle size account for more TC% than smaller particle size. In mangrove, at depth 0-15 cm, the highest TC% was found in particle size 2-1 mm in Debigobindapur and Naraharipur, and 5-2 mm in Kayalapara, Gobindapur, Fulbari, Benuban and Sumatinagar whereas at depth 15-30 cm, it was found in particle size 5-2 mm in Fulbari, 1-0.5 mm in Debigobindapur, Gobindapur and Naraharipur, and 2-1 mm in Kayalapara, Benuban and Sumatinagar (Table 3). At depth 0-15 cm POC % ranged between 14.18±0.28 to 21.57±1.18 % and at depth 15-30 cm it varied between 14.08±0.21 to 17.40±0.25 %. Particulate Organic Carbon percentage were significantly higher in Debigobindapur (19.2%) than Kayalapara (16.02%) and Naraharipur (14.13%) (Table 5). Similarly, in rice, at depth 0-15 cm POC % ranged between 15.01±0.62 to 16.71±0.98 % and at depth 15-30 cm it varied between 16.67±0.93 to 20.28±0.17 % (Table 5). In mangrove system, at 0-15 cm among different sites and aggregates particle size POC% varied between 12.82±1.11 to 7.56±0.37% and in 15-30 cm it varied between 12.92±0.59 to 5.89±0.18 (Table 3) whereas in rice system at 0-15 cm it ranged between 13.20±0.28 to 7.18±0.21% and at depth 15-30 cm it varied from 7.72±0.60 to 13.95±0.16% (Table 4). POC% were significantly higher in Fulbari (18.155%) than Benuban (16.840%) and Sumatinagar (15.840%). Among the depth and ecology, variation in POC% were at par. The factor S and the interaction S×E, E×D and S×E×D had a significant effect on POC% (Table 5).

**3.3 Aggregate stability**

There was remarkable impact of factors (ecology, sites and depth) on mean weight diameter of aggregates. In mangrove, The average mean weight diameters (MWD) of soils were in between 0.088 to 0.145 mm among the seven different sites. The average MWD was higher in Fulbari (0.145 mm) followed by Debigobindapur (0.106 mm) (Figure 1). The MWD was higher at the top soil layer (0-15 cm) than the sub-soil layer (15-30 cm) (Figure 1). Likewise, in rice, the average MWD of soil were in between 0.120 to 0.438 mm among the seven different sites. The average MWD was higher in Fulbari (0.438 mm) followed by Gobindapur (0.317 mm) (Figure 2). The MWD was higher at the top soil layer (0-15 cm) than the sub-soil layer (15-30 cm). The average MWD contents were higher in the rice systems as compared to mangrove system (Figure 3).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Depth (cm)** | **Particles size (mm)** | **Debi Gobindapur** | **Kayalapara** | **Gobindapur** | **Fulbari** | **Naraharipur** | **Benuban** | **Sumatinagar** |
| **0-15** | **8-5** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **5-2** | 0.00 | 0.36 | 0.14 | 0.70 | 0.00 | 0.56 | 0.10 |
| **2-1** | 0.50 | 0.22 | 0.34 | 0.84 | 0.41 | 0.14 | 1.39 |
| **1-0.5** | 0.57 | 0.89 | 0.64 | 2.70 | 1.09 | 0.47 | 1.14 |
| **0.5-0.25** | 12.03 | 3.50 | 9.18 | 7.60 | 8.57 | 5.18 | 3.96 |
| **Macroaggregate** | **13.10** | **4.98** | **10.30** | **11.83** | **10.07** | **6.35** | **6.58** |
| **0.25-0.1** | 26.60 | 16.12 | 19.78 | 24.17 | 26.83 | 23.22 | 20.63 |
| **0.1-0.053** | 14.69 | 28.89 | 21.90 | 16.18 | 15.94 | 13.98 | 33.76 |
| **< 0.053** | 45.61 | 50.01 | 48.01 | 47.83 | 47.16 | 56.45 | 39.03 |
| **Microaggregate** | **86.90** | **95.02** | **89.70** | **88.17** | **89.93** | **93.65** | **93.42** |
| **15-30** | **8-5** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **5-2** | 0.00 | 0.00 | 0.00 | 0.43 | 0.00 | 0.00 | 0.00 |
| **2-1** | 0.00 | 0.45 | 0.00 | 0.98 | 0.00 | 0.19 | 0.14 |
| **1-0.5** | 0.38 | 0.40 | 0.07 | 1.80 | 0.43 | 0.60 | 0.38 |
| **0.5-0.25** | 3.39 | 4.42 | 1.58 | 6.24 | 1.56 | 4.24 | 0.69 |
| **Macroaggregate** | **3.77** | **5.27** | **1.65** | **9.44** | **1.99** | **5.03** | **1.21** |
| **0.25-0.1** | 20.05 | 13.04 | 15.73 | 22.52 | 9.98 | 18.49 | 6.95 |
| **0.1-0.053** | 28.66 | 22.53 | 28.77 | 25.82 | 34.94 | 23.92 | 22.06 |
| **< 0.053** | 47.53 | 59.17 | 53.85 | 42.22 | 53.10 | 52.56 | 69.78 |
| **Microaggregate** | **96.23** | **94.73** | **98.35** | **90.56** | **98.01** | **94.97** | **98.79** |

**Table 1:** Water stable aggregate proportion (%) of different particle size in mangroves system.

**Table 2:** Water stable aggregate proportion (%) of different particle size in rice system.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Depth (cm)** | **Particles size (mm)** | **Debi Gobindapur** | **Kayalapara** | **Gobindapur** | **Fulbari** | **Naraharipur** | **Benuban** | **Sumatinagar** |
| **0-15** | **8-5** | 0.00 | 0.40 | 2.58 | 2.86 | 0.00 | 0.00 | 4.65 |
| **5-2** | 2.01 | 0.67 | 0.59 | 6.80 | 0.00 | 1.96 | 1.67 |
| **2-1** | 4.63 | 0.60 | 3.54 | 5.53 | 1.92 | 3.23 | 1.75 |
| **1-0.5** | 4.29 | 0.66 | 5.07 | 5.47 | 3.23 | 4.36 | 2.23 |
| **0.5-0.25** | 14.70 | 3.05 | 18.93 | 14.87 | 11.78 | 14.84 | 7.89 |
| **Macroaggregate** | **25.63** | **5.38** | **30.71** | **35.53** | **16.93** | **24.39** | **18.19** |
| **0.25-0.1** | 21.06 | 37.75 | 22.61 | 26.33 | 25.78 | 24.62 | 8.03 |
| **0.1-0.053** | 16.12 | 21.09 | 15.07 | 13.98 | 17.71 | 14.21 | 12.41 |
| **< 0.053** | 37.19 | 35.78 | 31.61 | 24.16 | 39.59 | 36.78 | 61.37 |
| **Microaggregate** | **74.37** | **94.62** | **69.29** | **64.47** | **83.07** | **75.61** | **81.81** |
| **15-30** | **8-5** | 0.00 | 0.00 | 0.00 | 0.54 | 0.00 | 0.00 | 0.00 |
| **5-2** | 0.29 | 0.00 | 2.40 | 0.38 | 0.00 | 0.08 | 0.00 |
| **2-1** | 2.64 | 0.29 | 2.17 | 2.67 | 0.00 | 0.95 | 0.46 |
| **1-0.5** | 2.63 | 0.86 | 2.35 | 2.61 | 0.07 | 3.30 | 0.84 |
| **0.5-0.25** | 8.96 | 5.42 | 6.20 | 8.70 | 0.78 | 6.54 | 3.54 |
| **Macroaggregate** | **14.52** | **6.57** | **13.11** | **14.91** | **0.85** | **10.87** | **4.84** |
| **0.25-0.1** | 22.32 | 17.93 | 22.06 | 21.12 | 16.45 | 17.93 | 16.96 |
| **0.1-0.053** | 26.33 | 33.93 | 21.69 | 28.00 | 40.28 | 28.53 | 36.01 |
| **< 0.053** | 36.83 | 41.58 | 43.13 | 35.97 | 42.42 | 42.67 | 42.19 |
| **Microaggregate** | **85.48** | **93.43** | **86.89** | **85.09** | **99.15** | **89.13** | **95.16** |

**Table 3:** Total carbon percentage in different aggregate size in mangroves system.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Depth (cm)** | **Particles size (mm)** | **Debigobindapur** | **Kayalapara** | **Gobindapur** | **Fulbari** | **Naraharipur** | **Benuban** | **Sumatinagar** |
| **0-15** | **8-5** | - | - | - | - | - | - | - |
| **5-2** | - | 11.05±1.34 | 11.40±0.57 | 13.15±0.92 | - | 12.79±0.45 | 10.90±0.42 |
| **2-1** | 12.82±1.11 | 10.50±0.99 | 11.35±0.35 | 11.95±0.49 | 12.13±0.47 | 12.75±0.49 | 10.16±1.05 |
| **1-0.5** | 12.12±0.12 | 9.71±0.55 | 11.20±0.71 | 11.85±0.92 | 11.35±1.06 | 12.75±0.92 | 9.57±0.66 |
| **0.5-0.25** | 12.00±0.99 | 9.20±0.85 | 10.00±0.16 | 10.93±0.18 | 9.53±0.41 | 10.25±0.78 | 9.44±0.59 |
| **0.25-0.1** | 11.57±0.76 | 9.03±0.24 | 9.80±0.42 | 10.12±1.01 | 7.64±0.79 | 8.88±0.58 | 8.83±0.12 |
| **0.1-0.053** | 10.00±0.42 | 7.89±0.18 | 8.93±0.81 | 9.98±0.40 | 6.54±0.52 | 7.56±0.37 | 8.70±0.85 |
| **< 0.053** | - | - | - | - | - | - | - |
| **15-30** | **8-5** | - | - | - | - | - | - | - |
| **5-2** | - | - | - | 9.75±0.49 | - | - | - |
| **2-1** | - | 9.78±0.32 | - | 9.22±0.02 | - | 11.95±1.06 | 12.92±0.59 |
| **1-0.5** | 11.55±0.21 | 9.65±0.94 | 12.05±0.92 | 8.86±0.65 | 11.10±0.28 | 9.58±0.53 | 11.96±0.48 |
| **0.5-0.25** | 10.23±0.56 | 8.85±0.37 | 10.27±0.47 | 8.70±0.04 | 9.11±0.30 | 9.47±0.37 | 10.06±0.91 |
| **0.25-0.1** | 9.45±0.59 | 7.86±0.48 | 10.12±0.26 | 8.65±0.31 | 8.19±0.40 | 8.25±0.60 | 8.78±0.86 |
| **0.1-0.053** | 7.39±0.73 | 7.26±0.21 | 7.28±0.51 | 7.31±0.41 | 5.89±0.18 | 8.22±0.55 | 8.03±0.70 |
| **< 0.053** | - | - | - | - | - | - | - |

**Table 4:** Total carbon percentage in different aggregate size in rice system.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Depth (cm)** | **Particles size (mm)** | **Debigobindapur** | **Kayalapara** | **Gobindapur** | **Fulbari** | **Naraharipur** | **Benuban** | **Sumatinagar** |
| **0-15** | **8-5** | - | 10.92±1.01 | 12.25±0.78 | 12.67±0.66 | - | - | 12.01±0.43 |
| **5-2** | 11.81±0.86 | 10.35±0.78 | 10.90±0.14 | 11.72±1.25 | - | 11.95±0.18 | 10.70±0.28 |
| **2-1** | 11.71±0.30 | 9.57±0.75 | 10.42±0.82 | 11.00±0.42 | 13.20±0.28 | 11.17±0.61 | 9.77±0.47 |
| **1-0.5** | 10.44±1.08 | 8.60±0.71 | 10.10±0.23 | 9.67±0.36 | 11.75±0.64 | 9.81±0.57 | 9.20±0.57 |
| **0.5-0.25** | 10.22±0.86 | 8.34±0.11 | 8.69±0.37 | 8.86±0.48 | 10.50±0.57 | 9.38±0.36 | 8.06±0.75 |
| **0.25-0.1** | 9.20±0.32 | 7.84±0.13 | 8.35±0.74 | 8.62±0.40 | 8.65±0.88 | 8.95±0.49 | 7.83±0.41 |
| **0.1-0.053** | 7.45±0.33 | 7.25±0.05 | 7.46±0.25 | 7.41±0.30 | 8.05±0.59 | 7.76±0.48 | 7.18±0.21 |
| **< 0.053** | - | - | - | - | - | - | - |
| **15-30** | **8-5** | - | - | - | 13.95±0.16 | - | - | - |
| **5-2** | 12.70±0.14 | - | 13.05±0.49 | 13.47±0.64 | - | 12.71±0.56 | - |
| **2-1** | 10.35±0.92 | 11.70±0.57 | 10.95±0.07 | 12.45±0.58 | - | 11.89±1.17 | 12.75±0.92 |
| **1-0.5** | 9.91±0.83 | 11.20±0.42 | 10.07±0.19 | 12.05±1.20 | 11.91±1.16 | 10.32±0.59 | 10.44±0.86 |
| **0.5-0.25** | 9.70±0.62 | 10.08±0.74 | 9.50±0.60 | 11.15±1.06 | 10.00±0.15 | 9.52±0.47 | 9.85±0.35 |
| **0.25-0.1** | 9.03±0.10 | 9.80±0.85 | 9.43±0.81 | 10.85±0.07 | 9.16±0.04 | 8.83±0.81 | 8.42±0.44 |
| **0.1-0.053** | 8.48±0.69 | 9.05±0.45 | 7.72±0.60 | 9.43±0.10 | 8.42±0.75 | 8.14±0.34 | 8.25±0.49 |
| **< 0.053** | - | - | - | - | - | - | - |

**Table 5:** Particulate Organic Carbon (%) in different sites of mangrove-rice system of Sagar Island, Sundarban, India. [S= Sites (Debigobindapur, Kayalapara, Gobindapur, Fulbari, Naraharipur, Benuban and Sumatinagar); E= Ecology (Mangrove and rice); D= Soil depth (0-15, 15-30, 30-45cm)].

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ecology** | **Depth (cm)** | **Debigobindapur** | **Kayalapara** | **Gobindapur** | **Fulbari** | **Naraharipur** | **Benuban** | **Sumatinagar** | **Mean of sites** |
| **Mangrove** | 0-15 | 21.57±1.18 | 16.92±0.06 | 18.73±1.23 | 20.10±1.41 | 14.18±0.28 | 16.44±0.95 | 17.53±0.97 | 17.924 |
|  | 15-30 | 16.83±0.14 | 15.12±0.69 | 17.40±0.25 | 15.96±0.72 | 14.08±0.21 | 16.47±0.05 | 16.80±1.56 | 16.094 |
|  | **Mean**  | **19.2** | **16.02** | **18.065** | **18.03** | **14.13** | **16.455** | **17.165** |  **17.009** |
| **Rice** | 0-15 | 16.65±0.64 | 15.09±0.18 | 15.81±0.49 | 16.03±0.11 | 16.70±1.47 | 16.71±0.98 | 15.01±0.62 | 16.000 |
|  | 15-30 | 17.51±0.78 | 18.85±1.30 | 17.15±0.21 | 20.28±0.17 | 17.58±0.71 | 16.97±0.47 | 16.67±0.93 | 17.859 |
|  | **Mean**  | **17.080** | **16.970** | **16.480** | **18.155** | **17.140** | **16.840** | **15.840** |  **16.929** |
|  | **Mean of depth (0-15)** | **19.11** | **16.00** | **17.27** | **18.06** | **15.44** | **16.58** | **16.27** | **16.96** |
|  | **Mean of depth (15-30)** | **17.17** | **16.98** | **17.27** | **18.12** | **17.17** | **17.17** | **17.17** | **17.29** |
|  | **Grand mean** | **18.14** | **16.49** | **17.27** | **18.09** | **15.63** | **16.65** | **16.50** |  |
| **ANOVA Statistics (p ≤ 0.05)** |
| **Factors** | **S** | **E** | **S×E** | **D** | **S×D** | **E×D** | **S×E×D** |
| **C.D.** | 0.836 | NS | 1.182 | NS | 1.182 | 0.632 | 1.672 |
| **SE (m)** | 0.288 | 0.154 | 0.407 | 0.154 | 0.407 | 0.218 | 0.576 |

**Figure 1:** Mean weight diameter of soil aggregates of mangroves sediment at seven different sites of Sagar Island, Sundarban, India.

**Figure 2:** Mean weight diameter of soil aggregates of rice soil at seven different sites of Sagar Island, Sundarban, India.

 **Figure 3:** Average Mean weight diameter of soil aggregates of mangrove and rice ecology at seven different sites of Sagar Island, Sundarban, India.

**4. Discussion**

Particulate organic carbon (POC) mainly include the soil organic carbon which is protected by the soil aggregates. This carbon comes under the active carbon pool. This pool is relatively stable to microbial decomposition compared to labile pools but less stable than passive pools. The particle size of aggregates range from 53µm to 2000µm. We found that the more aggregate stable soil is under the rice system than that of mangrove system. The soils of the top layer had more aggregate stability than the sub-soil in both the (mangroves and rice) systems. The MWD of soil aggregate under the rice system was higher than in the mangroves system. The MWD of the top soil layer was higher than that of sub-soils. It was also found that larger soil aggregates contain more total carbon contents (TC%) than smaller soil aggregates. Earlier researches stated that not only the proportion of aggregate but the size of aggregates also regulated the protection of soil carbon decomposition (Six *et al.,* 2000; Trivedi *et al.,* 2015). The amount of carbon present in macroaggregate (>0.25 mm) is more than in microaggregate (<0.25 mm) (Six and Paustian, 2014; Ghosh *et al.,* 2018). Macroaggregates contain a larger amount of soil organic carbon, mineralizable nutrients then microaggregates (Six *et al.,* 2000b; Ashman *et al.,* 2003). Macroaggregate are generally formed through the cementation of microaggregates. These microaggregates could be cemented by organic matter (Haynes, 2000; Huang *et al.,* 2010). With the increase in the amount and stability of larger aggregates, the MWD of soil aggregates also increases (Aksakal *et al.,* 2020). Mangroves are adapted to harsh climatic conditions and various abiotic and biotic stresses like high salinity, high temperature, high tides, strong winds, etc. These climatic conditions have an adverse effect on microbial growth (Padhy *et al.,* 2021). Soil microbial population and their activities are primarily regulated by salinity, pH, temperature and dissolved oxygen concentration in both mangroves and rice system (Lv *et al.,* 2016; Padhy *et al.,* 2020). In earlier research, it has been found that in mangrove system microbial activity is less then rice system. Soil aggregates provide habitat and activity sites for microorganisms. Aggregate formation, stability and its disaggregation depend upon interaction between soil constituent and environmental factors (i.e. climate and environment) (Kiem and Kandeler 1997; Six et al. 2004). Aggregate hierarchy model, Oades (1984) suggested that organic matters present within macroaggregates is decomposed by microorganisms which in future time get covered with minerals and microbial residues to form microaggregates within macroaggregates. Hence, aggregate transformation is strongly regulated by microbial activity. Fungal hyphae physically bind the microaggregate together to form macroaggregate and it also stabilize the contents present in microaggregate (Six et al. 2004). Earlier experiment has stated the presence of fungal phospholipid fatty acid in water stable aggregates (Helfrich et al. 2015). Not only microbial population but microbial activity also play important role in the formation of macroaggregates.

**5. Conclusion**

In the executed experiment we estimated the Soil aggregate fraction, their stability and POC sequestration in them in Sagar Island, Sundarban of India in mangrove and rice ecosystem. Estimation of POC in soil aggregates and soil aggregate distribution showed that POC were more sequestered in the aggregates present in top soil layer (0-15 cm) than the lower layer (15- 30 cm). However, it was found that aggregates stability was higher at top soil layer than the lower most. Among the ecology, rice system had the higher aggregate stability than mangrove system. In macroaggregate (>250 𝜇m) sequestration of POC was higher and decreased as the particle size of aggregates became finer. It was also shown that microbial activity plays important role in POC sequestration and in formation of aggregates and enhancing their stability. Statistical analysis further suggested that ecology, site and depth had significant effect on the POC sequestration. Future study should be performed with respect to explore the possible scope for protection of soil aggregates and enhancement of POC sequestration.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Details of the AI usage are given below:

1.

2.

3.

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