Chapter 4
Pedological Assessment of Soil Organic Carbon and Total Nitrogen Contents in Wetland Rice Ecosystems of Majuli River Island, Assam, India

B. P. Bhaskar, V. Ramamurthy, and Sunil Maske

Abstract The study of soil organic carbon and total nitrogen in relation to texture, landforms, and soil pH in riverine rice growing wetlands is very important for both agrarian economy and land use related issues in Majuli island of Upper Brahmaputra valley, Assam. Thus, thirteen soil series classified under the subgroups of Inceptisols and Entisols under different alluvial landforms in Majuli river island were selected to investigate the distribution of organic carbon (OC) and Total nitrogen (Total N) in pedological point of view. Our results showed an enrichment in OC and Total N on superficial Ap horizons (silt loam to silty clay loam) to the detriment of the deep sandy C horizons. Nevertheless, the irregular distribution of OC and total N contents with depth in stratified soils of the Island showed differential rates of leaching and its subsequent accumulations due to depositional episodes during seasonal floods in the region. These soils are slightly acid to neutral with mean densities of 30.49 Mg/ha of OC in Majuli series (P5) to 196.78 Mg/ha in Dakshinpat series (P7) with significant variations between the horizons ($F = 5.904$). The data further shows that silty clay texture have mean SOC of 25.24 ± 10.48 Mg/ha but low with value of 6.26 ± 2.81 Mg/ha for sand texture whereas total N stocks were high for sand (mean 4.71 ± 3.45 Mg/ha). The stratification of Total N and its stocks are highly variable having positive relation with cation exchange capacity ($R^2 = 0.57^{**}$) and Clay ($R^2 = 0.35^{*}$). The mean C/N ratio of soils was 8.3 ± 10.33 but highly variable (Cv of 124%). The regional study shows that geographically explicit information on soil carbon and total N pools must be combined with seasonal flooding history and depositional episodes for better rice management factors in the island.

Keywords Assam · Brahmaputra valley · Bulk density · Flood deposits · Organic carbon · Rice ecosystems · Soil series · Total Nitrogen

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B. P. Bhaskar (✉) · V. Ramamurthy · S. Maske
Hebbal, Bangalore, Karnataka, India

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4.1 Introduction

The agricultural ecosystems are designed mostly to produce food and other valuable products such as fiber and fuel to the environment (Costanza et al. 1997; Millennium Ecosystem Assessment (MEA) 2005; de Groot et al. 2012). The ecosystem services (ES) from arable lands are largely depended on the inputs used for cultivation and the crop management practices (Wossink and Swinton 2007; Ma et al. 2012). In India, rice is cultivated in 43.4 million hectares (GOI 2016) and is widely grown in eastern parts of India with consumption of 32% fertilizer (FAO 2005), 22% of pesticide (Krishna et al. 2003), and about 60% of water (Raju et al. 2005). Rice-based systems lead to soil loss, nutrient depletion, the hosting of pests and diseases, and greenhouse gas (GHG) emissions (Barrios 2007; Stallman 2011).

In this chapter, we present current knowledge on the soil nitrogen, in rice ecosystems due to low productivity per unit of land and often pay compensation in the form of subsidies to the farmers and policy agendas of local government (Dahal and Bajracharya 2013). Soil nitrogen (N) stocks, soil pH, and carbon-nitrogen ratio (C/N ratio) are important indicators of carbon sequestration potentials and also soil microbial structure and activities (Rousk et al. 2010). The soil carbon and nitrogen data sets are important in attaining target yields and to conserve SOC in rice ecosystems. Generally, the vertical patterns of SOC (soil organic carbon) in relation to total nitrogen, other physico chemical properties were examined to assess the response of the ecosystems to global change (Mi et al. 2008). Most of the soil nitrogen studies in rice ecosystems (Nayak et al. 2019) primarily focused on the top soil but poorly understood nitrogen dynamics in deeper soil layers (Liu and Greaver 2010). It is therefore needed to assess the carbon and nitrogen status in the unique rice ecosystem of riverine floodplain wetlands of Majuli island. The vertical distribution of soil organic carbon and nitrogen information in relation to soil pedological properties of rice are scanty and are useful for understanding the pedogenic behavior of the paddy soils for increasing crop productivity (Singaravel et al. 1996; Vijayakumar et al. 2013). The major challenge to enhance the productivity of rice and rice-based systems requires better crop management and crop care techniques (Barah and Pandey 2005). The soil resource data base generated in riverine wetlands of Majuli island was chosen for pedological assessment of the vertical distribution of SOC and nitrogen across different soil depths in alluvial landforms and worked out its relation with texture and chemical properties.

4.2 Materials and Methods

4.2.1 Study Area

The Majuli island (93°30′–94°35′E and 26°50′–27°10′N) is located in the north of Jorhat district in Assam state of India. The elevation varies from 60 to 85 meters above mean sea level. The island is bounded by Kherkutia Suti, Subansiri, and Brahmaputra rivers. The island is marked by 70 *bils* (local name for small ponds and *oxbow* lakes). The climate is subtropical with warm humid summer and cool dry winter with mean annual rainfall of 1900 mm. Barthakur (2004) defined the climate of island as humid mesothermal gangetic type (CWg) in accordance with Kopper. It is further reported that south west monsoon contributes 62–65% of annual rainfall during April through October (Bhaskar et al. 2010) The island has maximum temperature of 23.6–31.7 °C and minimum temperature of 10 °C but drops to as low as 6.0 °C in some years. On an average, the relative humidity is more than 80% throughout the year.

4.2.2 Rice System in Majuli

The rice growing seasons (Ahmed et al. 2011) along with varieties and general package of practices were presented (Table 4.1). The rice is the principle crop grown to an extent in three seasons of 787 ha in Ahu, 15,857 ha in Sali, and 7857 ha in Boro but area under Bao rice approximately accounts to 1197 ha. The island has 142 villages with total geographical area of 924.6 km^2. This island has 42 chapori's covering an area of 26315.97 ha supporting population of 21,650.The chronically flood prone areas in three circles (Garmura, Kamalabari, and Jenjari) of Majuli are recorded as 39,298 ha with total cropped area of 47,348 ha. The major rice-based cropping systems are mustard, wheat, with black gram. The general fertilizer dose for rice is 40 N:20P_2O_5:K_2Okg/hectare. The commonly grown rice varieties include: semi dwarf:-Govind, IR-50, IR-36, Luit, Kopilee, Disang and Jaya, where tall varieties include Rangdoria, Banglami, Dubaichang, Fapori, Guni, and Ihajit.

4.2.3 Soil Data Base

A reconnaissance soil survey was carried out using 1:50,000 scale topsheets in combination with geocoded Indian Remote Sensing Satellite (IRS)-1D images (taken on 18th January, 2003). Thirteen soil series were identified and described as per Schoeneberger et al. (2012). The soil database from soil survey report of Majuli was used in the present study (Bhaskar et al. 2008).

4.2.4 Laboratory Analysis

The horizon-wise soil samples were collected for laboratory analysis. The samples were air dried, ground, and passed through a 2 mm sieve for laboratory analysis. The international pipette method was used to estimate particle size as per procedure

Table 4.1 Distribution and estimation of total N, organic carbon stocks, and C/N ratio in paddy soils of Majuli island

Soil series	Depth (cm)	Horizon	Total		Stock estimation (Mg/ha)		C/N	Clay (%)	pH	CEC (cmol/kg)
			N	OC	OC	Total N (TN)				
			g/kg							
P1.Boritika series—Fluvaquentic Endoaquepts	0–26	Ap	0.81	12.3	39.45	2.60	15.19	24.0	7.0	17.9
	26–52	C1	1.46	1.6	5.67	5.17	1.10	6.0	7.5	11.9
	52–64	2Bw1	0.81	11.0	15.70	1.16	13.58	34.5	7.2	19.6
	64–79	2Bw2	1.46	4.3	8.01	2.72	2.95	29.5	7.3	20.0
	79–113	C2	0.49	0.6	2.78	2.27	1.22	6.5	7.6	8.9
P2.Puranibari series—Fluvaquentic Endoaquepts	0–14	Ap	1.14	6.1	11.14	2.08	5.35	14.5	6.1	14
	14–27	A/B	0.81	4.9	8.28	1.37	6.05	16.5	6.6	15.9
	27–46	C1	0.65	1.2	3.11	1.68	1.85	6.5	6.4	9.57
	46–71	C2	0.65	2.9	9.60	2.15	4.46	13	6.5	13.2
	71–86	2Bw1	2.44	5.3	9.98	4.60	2.17	25.5	6.4	18.9
	86–105	2Bw2	1.3	6.3	14.48	2.99	4.85	34.5	6.5	20.6
	105–175	2Bw3	0.97	1.8	15.77	8.50	1.86	29.5	6.5	20.1
P3.Adi elengi series—Typic Endoaquepts	0–13	Ap	0.16	9.7	16.46	0.27	60.63	11	7.1	11.1
	13–34	Bw1	1.79	16.7	41.13	4.41	9.33	33	6.8	14.1
	34–60	Bw2	0.97	5.8	19.23	3.22	5.98	21	7	12.5
	60–98	C1	1.14	1.4	7.18	5.85	1.23	9	7.2	7.89
	98–225	C2	0.81	1.4	24.33	14.08	1.73	5	7.2	3.48
P4.Chilakala series—Typic Endoaquepts	0–16	Ap	1.62	13.8	25.59	3.00	8.52	38.5	5.5	11.6
	16–35	Bw1	1.46	10.5	22.60	3.14	7.19	47	6.4	11
	35–59	Bw2	1.14	8.1	23.14	3.26	7.11	37	6.8	11.5
	59–170	C1	0.65	0.6	9.18	9.95	0.92	3.5	7.2	4.78
P5.Majuli series—Typic Psammaquents	0–33	Ap	0.65	1.5	6.78	2.94	2.31	4.5	7.5	5.54
	33–57	AC1	1.3	3.8	12.24	4.19	2.92	8.5	7.2	9.02
	57–82	AC2	0.81	3.4	11.46	2.73	4.20	7.5	7.2	7.28

P6.Bangaon series—Typic Fluvaquents	0–13	Ap	1.3	8.3	14.33	2.24	6.38	7.5	7.7	9.78
	13–38	Ac	0.81	5.0	16.86	2.73	6.17	6	7.8	8.8
	38–68	C1	0.65	3.5	14.11	2.62	5.38	8.5	7.8	7.17
	68–80	C2	0.49	3.3	5.36	0.80	6.73	6.5	7.9	6.41
	80–105	C3	0.49	2.3	7.79	1.66	4.69	7	7.7	5.54
	105–170	C4	0.49	1.2	10.76	4.39	2.45	3	7.7	1.41
P7.Dakhinpath series—humic Endoaquepts	0–13	Ap	4.87	57	73.49	6.28	11.70	35.5	5.5	25.6
	13–34	Bw1	1.79	19.3	45.09	4.18	10.78	43.5	6.3	19.7
	34–55	Bw2	0.97	7.3	19.20	2.55	7.53	24.5	6.9	14.5
	55–105	Bw3	0.49	5	32.37	3.17	10.20	17.5	7	15.7
	105–200	BC	0.49	2.1	26.64	6.22	4.29	11.5	7.2	10
P8.Kamalabari series—Humaqueptic Fluvaquents	0–19	Ap	1.62	12.2	29.15	3.87	7.53	19	5.9	12.6
	19–39	AC	0.97	4.8	12.48	2.52	4.95	16.5	6.8	12.3
	39–61	C1	0.81	1.9	5.67	2.42	2.35	7	7	10.2
	61–89	C2	0.49	2.5	9.43	1.85	5.10	8.5	7.1	11.2
	89–130	C3	0.32	0.8	4.51	1.80	2.50	4.5	7.2	7.61
P9.Garumara series—Fluvaquentic Endoaquepts	0–14	Ap	0.97	9.6	17.17	1.74	9.90	17	4.8	10.6
	14–43	Bw1	0.65	7.7	28.40	2.40	11.85	20	5.8	13.5
	43–64	Bw2	0.65	3.9	10.78	1.80	6.00	14.0	6.3	12.2
	64–75	BC	0.32	1.4	2.10	0.48	4.38	6.0	6.3	8.7
	75–160	C	0.65	0.6	7.10	7.70	0.92	0.5	6.7	4.35
P10.Gayangaon series—Typic Endoaquepts	0–13	Ap	1.3	10	16.10	2.09	7.69	25.0	6.0	17.1
	13–39	Bw1	0.39	5.1	17.26	1.32	13.08	16.0	7.2	14.4
	39–54	Bw2	0.97	6.1	11.61	1.85	6.29	22	7.3	16.5
	54–72	Bw3	1.14	10.9	24.09	2.52	9.56	26.5	6.9	14.7
	72–94	Bw4	0.81	7.4	20.61	2.26	9.14	21.5	6.9	10.7
	94–169	C	0.32	0.8	10.66	4.26	2.50	4.5	7.1	4.78

(continued)

Table 4.1 (continued)

Soil series	Depth (cm)	Horizon	Total *N*	Total OC	Stock estimation (Mg/ha) OC	Stock estimation (Mg/ha) Total N (TN)	C/N	Clay (%)	pH	CEC (cmol/ kg)
			g/kg							
P11.Sonaribari series—Typic Endoaquepts	0–13	Ap	0.33	19.5	29.25	0.49	60.00	34.5	6.7	17.5
	13–31	B/A	0.97	10.2	23.11	2.20	10.52	20.5	7.7	14.2
	31–38	Bw1	0.16	5.0	4.60	0.15	31.25	13.5	7.7	11.7
	38–47	Bw2	0.49	3.9	4.69	0.58	8.02	9.5	7.9	10.9
	47–56	Bw3	0.49	4.2	5.02	0.58	8.64	11	7.7	11.5
	56–66	Bw4	0.65	6.2	8.03	0.84	9.57	16.5	7.8	12.6
	66–90	C	0.65	6.4	20.19	2.04	9.88	12	7.6	10.2
P12.Bharaki series—Fluvaquventic Endoaquepts	0–20	Ap	1.46	12	30.20	3.67	8.23	19.0	6.6	14.8
	20–30	C1	0.65	3.9	5.17	0.86	6.02	12.0	7.3	11.2
	30–48	2Bw1	0.65	5.8	13.14	1.47	8.95	24.5	7.2	12.6
	48–68	2Bw2	0.65	2.5	6.62	1.72	3.86	13.5	7.4	13.5
	68–99	2Bw3	0.16	3.1	12.63	0.65	19.38	15	7.5	14.4
	99–140	2Bw4	1.46	3.9	20.03	7.50	2.67	27.5	7.4	12.4
P13.Bhakat series—Typic Fluvaquents	0–27	Ap	0.33	4.9	17.45	1.16	15.08	12.5	7.7	11
	27–46	AC	0.49	1.5	3.83	1.25	3.06	10.0	7.6	9.54
	46–85	C1	0.49	1.3	6.87	2.59	2.65	8.0	7.9	9.57
	85–98	C2	0.16	1.9	3.31	0.28	11.88	10.5	8.1	9.7
	98–180	C3	0.97	0.4	4.53	10.98	0.41	3.5	8.1	3.96

described by Gee and Bauder (1986). The pH of the soil samples was determined in 1:2.5 soil:water ratio. The quantity of organic carbon in the soil was estimated by using Walkey Black method (Walkley and Black 1934; Jackson 1973). The exchangeable K and Na were determined by flame photometer while Ca and Mg were determined using atomic absorption spectrometer. The cation exchange capacity (CEC) was determined by distillation method as described by Jackson (1979). Soil bulk density was determined using the soil core sampler having a diameter of 5.7 cm (Blake and Harte 1986). Total nitrogen (TN) was determined by the Kjeldahl digestion-distillation method (Bremner and Mulvaney 1982).

4.2.5 Calculation of Stocks of Total Nitrogen and Organic Carbon in Soil

1. Soil organic carbon in ton per hectare (SOC, Mg/ha) = organic carbon content (%) × soil bulk density × depth of soil layer,
2. Total nitrogen in ton per hectare (TN, Mg/ha) = nitrogen content (%) × soil bulk density (Mgm^{-3}) × depth of soil layer (cm).

4.2.6 Statistical Analysis

The correlation test was applied to find out relationship between the variables of soils. The ANOVA, multiple and bivariate correlation were out using SPSS software. The depth distribution functions were constructed for soil parameters under study using Microsoft excel and picture manager.

4.3 Soil Organic and Total N in Relation to Soil Types and Soil Properties

4.3.1 Depth Distribution Function of Organic Carbon (OC) and Total Nitrogen (TN)

The depth wise distribution of the TC and TN contents in rice growing soils of majuli island, respectively, is presented in Table 4.1. The Fluvaquentic Endoaquepts (P1, P2, P9, and P12) have recorded irregular distribution with the contents in Ap horizons of 6.1 g/kg (P2) to 12.3 g/kg in Boritika profile (P1) but decreases to 0.6 g/kg in C horizons of Boritika (P1). In Typic Endoaquepts (P3-Adi Elengi series; P4-Chilkala series, P11-Sonaribari series), the Ap horizons have 9.7 g/kg in P3 to 19.5 g/kg in P11. In P3, the OC shows increase in cambic B horizon (16.7 g/kg) but

Table 4.2 Relation of geomorphic units on stocks of SOC, TN, and C/N

Source	Degrees of freedom (df)	Sum of squares	Mean sum of squares	*F* statistics	*P* value	Critical value of Turkey test (HSD at 0.05 level)
OC stock (mg/ha)						
Soils	3	567.02	189.21	1.72	0.1793	9.97
Geomorphic units	2	1245.26	622.63	5.66	0.006	7.77
Soils X geomorphic units	6	1769.02	294.84	2.68	0.0242	22.66
Error	52	5725.24	110.1			
Total	63					
TN (mg/ha)						
Soils	3	35.27	11.76	2.13	0.107	2.23
Geomorphic units	2	14.83	7.42	1.35	0.268	1.74
Soils X geomorphic units	6	43.52	7.25	1.21	0.265	5.07
Error	52	286.67	5.51			
Total	63	380.29				
C/N ratio						
Soils	3	497.38	165.79	1.57	0.2077	9.77
Geomorphic units	2	24.17	12.09	0.11	0.896	7.61
Soils X geomorphic units	6	1064.73	177.46	1.68	0.145	22.2
Error	52	5494.07	105.66			
Total	63	7080.35				

gradually decreases to 1.4 g/kg in C horizons. In P4 and P11, the gradational decrease of OC is visible but C horizons have 0.6 g/kg in P4 and of 6.2 g/kg in C horizons of P11. The OC in Typic Fluvaquents (P6-Bangaon series and P13-Bhakat series) shows a slight infliction with depth and have values of 8.3–4.3 g/kg in A horizons but decreased to less than 1.5 g/kg in C horizons. The profile distribution of TN in Fluvaquentic Endoaquepts (Table 4.1) have shown irregular with its contents more than 2 g/kg in Bw horizon s (P2, P12) and of 0.49 g/kg in C horizons (P1). In case of Typic Endoaquepts show variable patterns with depth except Chilkala series (P4) where TN shows gradational decrease. In case of Sonaribari series (P11) the TN is 0.97 g/kg in transitional B/A horizon (0.97 g/kg) but decreased to less than 0.5 g/kg in other B horizons. In AdiElengi series (P3), the TN values are low but varied from 1.79 g/kg in Bw horizon to 0.89 in C horizons but Ap horizons have 0.16 g/kg due to recent flood deposit on the top layers.

4.3.2 Vertical Distribution of Organic Carbon and Total N Stocks

The depth functions of total organic carbon stock of paddy growing soils in Majuli island show irregular trends with value of 30.49 Mg/ha in Majuli series (P5, Typic Psammaquents) to 196.78 Mg/ha in Dakshinpat series (P7, Humic Endoaqupets, Table 4.1). The reported values are in agreement with the values reported in depositional riverine soils of Wisconsin (Adhikari et al. 2019). The results showed that the mean carbon stock is only 15.58 ± 12.01 Mg/ha and its distribution is highly variable (Cv of 77.14%). The distribution pattern of SOC stock in wetlands of majuli was highly variable due to seasonal erosion/depositional processes operating in the island. Out of thirteen, nine soil series were classified in the subgroups of Inceptisols (Typic Endoaqupets-P3,P4, P10, and P11), Fluvaquentic Endoaquepts (P1, P2, P9, and P12), and Humic Endoaquepts (P7) whereas other soils were placed in the subgroups of Entisols, viz., Typic Psammaquents (P5), Typic Fluvaquents (P6, P13), and Humaquentic Fluvaquents (P8). The mean carbon stock is 21.25 ± 6.61 Mg/ha for Typic Endoaquepts (P3, P4, P10, P11) with moderate variability (Cv of 30.22%) whereas Fluvaquentic Endoaquepts have mean of 21.25 ± 3.2 Mg/ha with high Cv of 62.18%. The anova analysis shows that Fluvaquentic Endoaquepts have a significant variation in carbon stocks between the horizons with calculated F value of 5.904 (p value of 0.0069 at 2, 30 degrees of freedom) but not significant in case of Typic Endoaqupets ($F = 0.722$ at 2, 19 degrees of freedom).

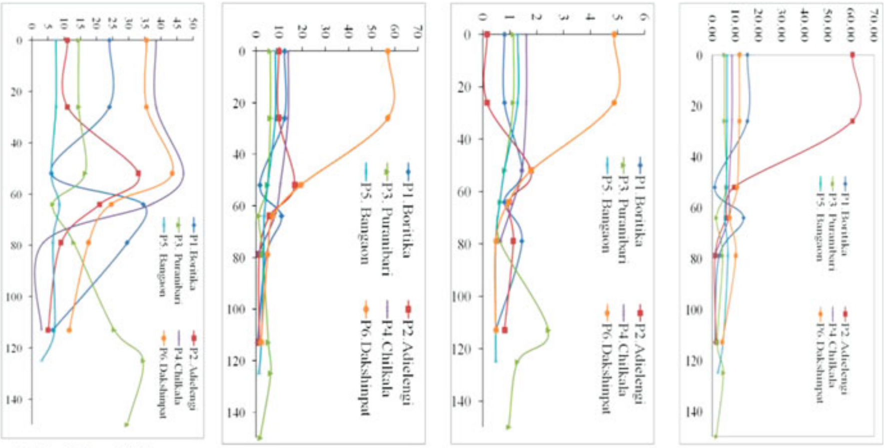
With respect to the depth distribution of total N stock in these soils, the mean for Total N stock in C horizons is 14.31 ± 7.51 Mg/ha and Cv of 52.47% in Typic Endoaquepts whereas B horizons have a mean of 3.23 ± 2.59 TN Mg/ha but highly variable (Cv of 84%). The depth distribution pattern of total N stock in studied soils is similar to that of SOC but with low contents (range from 0.27 in Ap horizon to 14.8 Mg/ha in C horizons of P3, Table 4.1). The Ap horizons have low TN stock as compared to cambic B and C horizons. The distribution of TN stock between the horizons is not significant with F value less than unit value in both soils types under study. The C/N ratio follows similar pattern with depth to that of SOC and TN stocks with a mean of 8.3 ± 0.33 and Cv of 124.48%. The values C/N ratio in submerged rice soils of Majuli is in agreement with values reported for paddy soils of India (Sahrawat et al. 2005). The wide C/N ratio's within these soils is due to recurring seasonal floods and also due to triple rice crop systems in the region (Olk et al. 1996).

4.3.3 Relation of Geomorphic Units on Stocks of SOC, TN, and C/N

The results of anova analysis shows that to findout variation in stocks of OC, Total N and C/N ratio between horizons and within geomorphic units and interaction between horizons and the estimation of stocks. The results showed significant relation of OC stocks with respect to geomorphic units (*F* value of 5.66, *p* value of 0.006) but nonsignificant for Total N and C/N ratio in these soils (Table 4.2).

4.3.4 *Stratification of Clay, Organic Carbon, Total Nitrogen and Carbon to Nitrogen Ratio in Paddy Growing Soils*

The distribution clay in soil profiles from rice ecosystems is presented in Fig. 4.1. The distribution of clay is duplex positive in Boritika (P1), bulged in Adielengi (P2), Chilkala (P4) and Dakshinpat (P6), variable in Puranibari (P2) and Bangaon (P5). Similar kind of observations were reported in paddy soils of Thailand (Kyuma and Kawaguchi 1977) and in poorly drained soils of Ohio (Smeck et al. 1981). The organic carbon at Ap horizons is more than 10 g/kg in P1, P4, and P6 but low organic carbon in other soils. All soils show decreasing trend of organic carbon with depth. It is further reported here that there is irregular distribution of organic carbon in Puranibari soils (P3) but a perceptible increase of carbon below 50 cm in Boritika (P1) and Adielengi (P3). The high content of organic carbon in A horizons of rice soils in Majuli is ascribed to application of manure in top layer, its slow translocation process and lack of incorporation into the deeper layer (Anshori et al. 2020). The variable distribution of total nitrogen in the soil profiles of paddy soils is in the similar pattern of organic carbon. The stratification of Total N shows an increase of its content below 1 m depth indicating leaching of residual nitrogen and its subsequent accumulation in deeper layers (Zhao et al. 2015). The regression equations



(A).Clay(%) (B).Organic carbon(g/kg) (C).Total nitrogen (g/kg) (D) C/N ratio

Fig. 4.1 Depth distribution of clay, organic carbon, total nitrogen, and Carbon to Nitrogen in paddy soils were constructed between total N versus organic carbon ($R^2 = 0.62^{**}$) and cation exchange capacity ($R^2 = 0.571^{**}$) as given under:

$$\text{Total N(g/kg)} = 0.604 + 0.036(\text{organic carbon, g/kg}) \tag{4.1}$$

$$\begin{aligned}\text{Total N(g/kg)} = {} & 0.166 + 0.001(\text{CEC, cmol/kg}) + 0.306(\text{CEC})) \\ & - 0.031(\text{CEC})^2\end{aligned} \tag{4.2}$$

Over all, the mean C/N ratio is 8.33 ± 10.33 with variation of 124 per cent. The Ap horizons have mean C/N ratio of 9.41 ± 12.11 but varies to mean of 7.025 ± 7.66 in B horizons and of 3.00 ± 5.02 in C horizons. In all soils, the C/N ratio in surface layer ranges from 5.63(Puranibari P3) to 60.63(Adielengi P2) and the reported values are in agreement with rice soils of riverine floodplains with less than 25% of clay and of variable proportions of sand and silt (Yang et al. 2010; Zhou et al. 2019).The C/N ratio has yielded significant positive relation with clay and silt and its relation is expressed in regression equation as under:

$$\begin{aligned}\text{C/N} = {} & -0.195 + 0.001(\text{clay, \%}) \\ & + .198(\text{silt, \%}) \text{ with } F \text{ value of 8.079 at 2 and 66 degrees of freedom.}\end{aligned} \tag{4.3}$$

4.4 Pedogenic Assessment of SOC, TN, and C/N in Paddy Soils

The dominant pedogenic process was “gleyzation” with mottle formation (P1, P2, P4, P8, P9, P11, P12, & P13). These soils have horizon sequence of gleyed plowed layer (Apg) and gley cambic horizon (Bwg*, in P1, P4, P5, P6, P7, P8, P9, P12, & P13). These soils are “saturated and flooded” resulted in characteristic morphologies with stratified layers starting with in 15 cm of soil surface (Bharaki series, P4 with value 3 and chroma of 1 and ochric horizon was depleted in all soil profiles with matrix value of 5 or more and chroma of 1 (Bhaskar and Sarkar 2013). Occurrence of distinct brown mottles (10YR4/4 to 4/3) below 30–150 cm depth are the indicators of translocation of Fe, Mn oxides (Mokma and Sprecher 1994) and also due to diffusion of oxygen into the soil aggregates (Ponnamperuma 1972). The soil profile has silty loam /clay loam to silty clay textures with underlying sandy horizons. The distribution of silt and clay is irregular with depth in all the pedons. The silt content varies from 26.1% (P12) to 74.3% in Ap horizons of P1 and 42.8% in P4 to 75.4% in Bwg horizons of P13. The particle size classes of P1, P7, P9, and P13 are fine silty as the silt content exceeds 50 per cent in soil control section. The infliction in sand to silt ratio is useful to identify lithological discontinuities. The illuvial process is evident in the cambic B horizons with an increase in clay content (33% clay in

Bwg1 horizon in P1, 47% in P6, 43.5% in P7, 34.5% in 2Bwg2 horizon of P12). The distribution of clay is duplex positive in P5 and P12, bulged in P1 and P6, variable in P2, P3, P4, gradationally negative in P7 and P10 and duplex negative in P9 and P13. The downward increase of clay was recorded in cambic Bw horizons of Adielengi (P1), Chilkala (P6), and Dakshinapat series (P7). Similar kind of observations were reported in paddy soils of Thailand (Kyuma and Kawaguchi 1977) and in poorly drained soils of Ohio (Smeck et al. 1981). The Chilkala (P6) and Dakshinpat (P7) soils have strongly acid Ap horizons but moderately acid to neutral subsoils in Garumara (P9), Gayangaon (P10), and Kamalabari (P8). The mean organic carbon in Ap horizons is 12.66 g/kg with coefficient of variation of 113.5 per cent but organic carbon decreases to 6.57 g/kg in Bw horizon and then to 2.07 g/kg in C horizons (Table 4.1). These soils have 14.9 cmol/kg of CEC for cambic B horizons but have 11 cmol/kg for Ap horizon and 7.8 cmol/kg in C horizons. Similar pattern of CEC, organic carbon, total Fe and Mn in soils were reported from Brahmaputra valley (Karmakar 1985; Chakravarthy et al. 1984; Bhaskar et al. 2009).

Generally, these soils undergo "ferrolysis" (Brinkman 1970; Bhaskar et al. 2005) that has resulted in low cation exchange capacity (1.41 cmol$^{(+)}$/kg in C4 horizon of Bangaon series (P2) to 25. cmol$^{(+)}$/kg in Apg horizon of Dakshinpat series (P7). Earlier, soils under paddy cultivation can be separated at lower subgroup level as "Aquorizem" (Kawaguchi and Kyuma 1969) and the movement of iron in hydra-agric horizon, is reported in paddy soils of China (Zhang 1985). The Bw horizon is an illuvial horizon, where ferrous iron is formed and absorbed on the exchange sites. The absorbed iron is oxidized and form iron illuvial horizon by which a typical paddy soil is characterized and eluviation of organic matter had resulted in grayization (Mitsuchi 1974).

Most of the rice soils classified under subgroups of inceptisols and Entisols are rich in silt and sand with clay content less than 25% and moderate CEC less than 25 cmol/kg. The Majuli island has a complex mosaic of soils belonging to subgroups of "Inceptisols and Entisols" with young and intermediate pedogenetic development levels (Bhaskar et al. 2008). Most of these soils are less weathered and were influenced by the uprising of Brahmaputra valley (Sarma and Phukan 2004), thus having much younger geological ages. The very low nutrient content of these soils, often associated with high groundwater levels, results in the formation of thick root mats in the soil surface (Herrera et al. 1978) which then strongly influences the amount and vertical distribution of their SOC stocks. The soil mats close to surface layers in bil environs may reasonably be expected to exert a strong influence on soil SOC concentrations, in seasonally waterlogged soils (Dakshin part series, P7, AdiElengi-P3). It is therefore not a surprise that we observed some of the highest carbon in this soil.

All soils show irregular distribution of organic carbon in Puranibari soils (P2) but a perceptible increase of carbon below 50 cm in Boritika (P1) and Adielengi (P3). The high content of organic carbon in A horizons of paddy soils in Majuli is ascribed to application of manure in top layer, its slow translocation process and lack of incorporation into the deeper layer lowered its concentration in the deeper layer (Anshori et al. 2020). The variable depth distribution of total nitrogen in profiles of paddy soils is similar pattern to that of organic carbon distribution. The stratification of Total N shows an increase of its content below 1 m indicating leaching of residual nitrogen and its subsequent accumulation in deeper layers (Zhao et al. 2015). The polynominal equations derived from the regression analysis clearly shows that TN has a significant positive relation with CEC ($R^2 = 0.571^{**}$ significant at 1% level) and also with clay ($R^2 = 0.352^{*}$ significant at 5% level). The results are in agreement with the findings of Hassink (1994) who reported that TOC contents were positively correlated with clay and silt contents and also help to stabilize soil organic matter (Baldock and Skjemstad 2000; Quesada et al. 2020).

Mean soil organic carbon content in each soil subgroup of inceptisols and Entisols of paddy growing soils (Table 4.1) shows that the high values recorded for Humic Endoaquepts in bil environs is due to periodical addition of aquatic weeds (Water hycianth, P7, Dakshinpat series, 196.78 Mg/ha) and also reflects a lower degree of decomposition of the organic materials present in poorly drained environments. This region experiences air temperature below 4 °C and foggy days during winter. The mean carbon density is 15.58 ± 12.01 with high coefficient of variation (74.14%). These soils have nitrogen density of 27.82 Mg/ha for Typic Endoaquepts (P3, Table 4.3) to 9.8 Mg/ha in Typic Psammaquents (P5) Typically the mean C/N ratios is varied from 8.3 ± 10.33 with high coefficient of variation (120%). The C/N ratio above 12–14 often is considered indicative for a shortage of nitrogen in the soil (Batjes and Dijkshoonn 1999). The C/N ratio of these soils is below to that of reported value and reflected the continuous rice–rice–rice cultivation in the region.

The results from two-way ANOVA analysis show a significant influence of geomorphic units on SOC stocks of each soil types (F value of 5.66) but non-significant for Total N and C/N ratio. These soils are slightly acid to slightly alkaline but have insignificant influence on SOC and Total N. This finding is in agreement with findings of Zhou et al. (2019). These paddy soils of Majuli were grouped into 8 textural classes and worked out the influence of texture on stocks of SOC and TN. The results showed that the stocks of SOC and Total N have significant relation with texture and yielded an F value of 2.89 for SOC and 2.237 for total N but significant at 0.05% probability level. The data further shows that silty clay texture has mean SOC of 25.24 ± 10.48 Mg/ha but low with value of 6.26 ± 2.81 Mg/ha for sand texture. The moderate coefficient of variation for loamy sand is recorded with value of 25.37 but rated as high in other textures. Similarily, the total N stocks are high for sand (mean 4.71 ± 3.45 Mg/ha) and low in silt loam texture (1.4 ± 1.02 Mg/ha). This region receives mean annual rainfall of 1900 mm and subjected to serious losses of calcium and magnesium ions (Bhaskar 2019) but also have sandy flood deposits in C horizons. In general, these soils are neutral with rich in organic matter in bil environs but low in sand deposit zones of active and old floodplains. The soils in bil environs have shown lowering of top soil pH (Hong et al. 2019). These soils have mottles and also iron manganese nodules (Bhaskar et al. 2008) with increase of pH values in the middle section of soil profiles. In interpreting the use of soil C / N ratios as an indicator for litter quality, the whole part correlation such as $\log(\mathrm{C{:}N}) = \log[\mathrm{C}] - \log[\mathrm{N}]$, (Chayes 1971). The logarithamic expression of C:N was used to estimate the extent to which slopes and correlation coefficients are biased by the presence of the same terms on both sides (Lloyd et al. 2013). In the present study, the whole part correlation yielded significant correlation ($R^2 = 0.652$ $n = 67$, Fig. 4.1) but, cautious in using this equation in any sort of predictive framework specially in riverine floodplains.

4.5 Conclusion

The wet land rice growing soil data base for Majuli island on was made with thirteen soil series and twenty five soil mapping units designated as soil series association. This soil data base was used to workout the stocks of organic cabon (OC) and total N (TN) for each soil subgroup. These soils are endosaturated throughout the year with continuous rice cultivation and eight textural groups were identified. The study showed the strong influence of textural class on stocks of OC and TN but not soil pH. The vertical variation in stock of C and N in each soil subgroups and its horizons suggests that rice management factors practices would be a major factor influencing the degree of soil organic matter and total N storage. The profile distribution of C and N stocks showed irregular depth trends indicating periodic depositional episodes occurred in the Island. Our study using remote sensing and GIS techniques allows to put reasonable hurdles on soil organic and total N stocks for Majuli region (1.2 lakh hectares) with a suitable baseline data base for further studies of pedogenic changes in rice ecosystems. Understanding regional characteristics of SOC and Total N are of great importance for designing best management practices for rice. The study suggested that modeling approaches to estimate SOC changes with respect to land use, flooding events, depositional layering and spatial heterogeneity of soil properties are to taken up on priority in future for upgrading and monitoring pedogenic changes using soil base line data as reference and to improve management strategies of rice ecosystems with long-term field measurements in the region.

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