Influence of anthropogenic and natural factors on the mangrove soil of Indian Sundarbans wetland

Kakoli Banerjee[1]*, Mahua Roy Chowdhury[2], Kasturi Sengupta[2], Saurov Sett[2], Abhijit Mitra[2]
[1]*School of Biodiversity & Conservation of Natural Resources, Central University of Orissa, Landiguda, Koraput, Pincode – 764020, India*
[2]*Department of Marine Science, University of Calcutta, 35, B.C. Road, Kolkata 700019, India*
**To whom correspondences should be addressed*
E-mail: banerjee.kakoli@yahoo.com

Received January 28, 2012, Revised manuscript received August 12, 2012, Accepted 14 August, 2012

Abstract

Soil organic carbon, pH and salinity were monitored in mangrove ecosystem of Indian Sundarbans in five successive years (2006–2010). Samplings were carried out at 14 stations in four different depths (0.01-0.10, 0.10-0.20, 0.20-0.30 and 0.30-0.40 m) during premonsoon period. High organic carbon load is observed in the stations of western Indian Sundarbans (mean = 1.02 Wt %) which are near to the highly urbanized city of Kolkata. The central and eastern sectors under the protected forest area show comparatively less soil organic carbon (mean = 0.64 Wt %). A unique spatial variability in soil salinity and pH was observed with lower values in the western and eastern sectors compared to central sector. Soil pH exhibited a lower value (7.47 ± 0.071) in reserve forest zone (central and eastern sectors) compared to western sector (7.57 ± 0.067). The soil salinity increased with depth, while organic carbon and pH decreased with depth in all the stations. The paper depicts the increase of soil organic carbon and pH due to anthropogenic activities in western Indian Sundarbans, which if continued may decrease the potential of Sundarban soil as carbon sink and make the soil highly saline. Hence curbing of anthropogenic activities may keep the soil characteristics ecologically safe.

Keywords: Indian Sundarbans, Soil Organic Carbon, Soil pH, Soil Salinity

1. Introduction

In mangrove ecosystem, organic carbon usually originates *via* the riverine introduction of pollutants, including industrial and domestic wastes, agricultural, aquacultural and mining runoff, accidental spillages and decomposition of debris from marine organisms. However, different factors may control the partitioning and also the bioavailability of the organic compounds within the benthic ecosystem. These factors include sediment characteristics, such as grain size distribution, mineral composition and organic content [1-3]. Surface sediments may be resuspended and redistributed by the action of waves and currents [4]. As these phenomena trigger the process of erosion and accretion, therefore the top most layers of the sediments contain recently deposited organic matter. Total organic carbon has a major influence on both chemical and biological processes that take place in sediments [5]. The amount of organic carbon has a direct role in determining the redox potential and pH in sediment, thus regulating the behavior of other chemical species such as metals [6,7]. Natural processes and human activities have resulted in elevated content of total organic carbon in mangrove soils and adjacent estuaries and creeks. These include diverse input through fall, stream flow, inappropriate animal waste applications and disposals, forest clearance, agricultural practices, and changes in land uses [8]. Also mangrove litter fall and decomposition of organisms regulate the organic carbon budget in the intertidal mudflats [9].

The mangrove ecosystem of Indian Sundarbans, at the apex of Bay of Bengal covers an area of about 4266.6 sq. km. On the basis of satellite imagery, the Forest Survey of India [10] estimated the area of Indian Sundarbans as 2125 sq. km, excluding the network of creeks and backwaters, which are the vital matrix of mangrove ecosystem. Mangrove communities often exhibit distinct patterns of species distribution [11-13] that contribute to the organic carbon level in the intertidal soil through decomposition of litter and organisms. Since the mangrove habitat is basically saline, several studies have attempted to correlate salinity with the standing crop of vegetation and productivity [14-19]. Sundarbans shelters one of the most important mangrove communities of the world. A few published works deal with the community structure of this forest [20]. However, very few reports are available on the organic carbon profile of mangrove soil [9] that can reflect the status of this unique ecosystem in terms of natural [21] or anthropogenic influences [22-24]. The aim of this paper is to determine what role the anthropogenic and natural factors have on mangrove soil and how the soil characteristics change over time.

2. Materials and Methods

2.1. The Study Area

The Indian Sundarbans (between 21°13’N and 22°40’N latitude and 88°03’E and 89°07’E longitude) is bordered by Bangladesh in the east, the Hooghly River (a continuation of the River Ganga) in the west, the Dampier and Hodges line in the north, and the Bay of Bengal in the south. The temperature is moderate due to its proximity to the Bay of Bengal in the south. Average annual maximum temperature is around 35°C. The summer (premonsoon) extends from the middle of March to mid-June, and the winter (post-monsoon) from mid-November to February. The monsoon usually sets in around the middle of June and lasts up to the middle of October. Rough weather with frequent cyclonic depressions occurs during mid-March to mid-September. Average annual rainfall is 1920 mm. Average humidity is about 82% and is more or less uniform throughout the year. Thirty four true mangrove species and some 62 mangrove associate species have been documented in Indian Sundarbans [23]. The ecosystem is extremely prone to erosion, accretion, tidal surges and several natural disasters [21], which directly affect the top soil of the intertidal mudflats encircling the islands. The average tidal amplitude is around 3.0 m. Some sea facing islands experience high tidal amplitude (~5.0 m).

We conducted survey at 14 stations in the Indian Sundarbans region during premonsoon (May) from 2006 to 2010. Station selection was primarily based on anthropogenic activities, salinity, mangrove floral richness. The western Indian Sundarbans is a stressed zone (stations 1 to 7). On the contrary stations 8 to 14 are within the reserve forest areas with luxuriant mangrove vegetation and diversity and have been considered as control zone in this study. The major activities influencing the nature of soil in the selected stations are highlighted in Table 1.

2.2. Sampling and Analysis

Table 1 and Fig. 1 represent the study site in which sampling plots of 10 m × 5 m were considered for each station. Care was taken to collect the samples within the same distance from the estuarine edge, tidal creeks and the same micro-topography. Under such conditions, spatial variability of external parameters such as tidal amplitude and frequency of inundation [25], inputs of material from the adjacent bay/estuary and soil granulometry and salinity [26] are minimal.

Ten cores were collected from the selected plots in each station by inserting PVC core of known volume into the soil to a maximum depth of 0.40 m during low tide condition. Each core was sliced into four equal parts, placed in aluminium foil and packed in ice for transport. In the laboratory, the collected samples were carefully sieved and homogenized to remove roots and other plant and animal debris prior to oven-drying to constant weight at 105°C. Total organic carbon was analyzed by rapid dichromate oxidation method of Walkley and Black [27].

Measurement of soil pH was done with fresh samples in the field with a Systronics pH meter with glass – calomel electrode (sensitivity ± 0.01) and standardized with buffer 7.0 to avoid oxidation of iron pyrites (a common constituent of mangrove soils) to sulphuric acid [28]. Soil salinity was determined in supernatant of 1:5 soil-water mixtures using a refractometer.

3. Results

3.1. Soil Organic Carbon

The soil organic carbon differs significantly between stations and years considering the mean values (0.99 ± 0.07) of all four depths (Fig. 2). We observe relatively higher values of organic carbon in the stations of anthropogenically stressed western sector (Stn. 1 to 7) compared to those in the central (Stn. 8 to 11) and eastern sectors (Stn. 12 to 14) of

Indian Sundarbans that encompass mainly the reserve forest with almost no human intrusion. The mean value of soil organic carbon in the western sector (stressed zone) is 1.02 Wt %. In the central and eastern sectors (control zone) the value is 0.64 Wt %. In all the selected stations, the soil organic carbon content decrease with depth (Fig. 3). The gradual increase of organic carbon (composite figure of four depths) through years in all the stations clearly reflects the efficacy of Sundarban mangrove as potential sink of carbon. In western Indian Sundarbans the rate of increase is 0.031% yr^{-1}, whereas in the stations of central and eastern sectors that are mostly within the reserve forest, the value is 0.026% yr^{-1}.

3.2. Soil pH

Soil pH decreases significantly at those sites which fringe the salt marsh grass (*Porteresia coarctata*) bed and sustain rich mangrove vegetation particularly in the reserved forest area (Stn. 8 to 14). The average soil pH in this zone (considering all depths and years) is 7.47 ± 0.071. In western sector of Indian Sundarbans (Stn. 1 to 7) comparatively higher soil pH is observed (average pH value of all four depths considering five successive years = 7.57 ± 0.067). We also observe a decreasing trend in soil pH with depth in all the stations (Fig. 4). The uppermost layers are alkaline and slightly acidic soil is observed within the depth of 0.20 to 0.40 m mainly in the stations 8 to 14. Significant yearly variations of soil pH are observed in the present study area (Fig. 5). In stations 1 to 7 the mean values (of all depths) are 7.67 ± 0.23, 7.60 ± 0.21, 7.55 ± 0.21, 7.53 ± 0.21, and 7.49 ± 0.19 in 2006, 2007, 2008, 2009, and 2010 respectively. In stations 8 to 14 the values are 7.57 ± 0.23, 7.51 ± 0.21, 7.43 ± 0.16, 7.44 ± 0.21, and 7.40 ± 0.19 in 2006, 2007, 2008, 2009, and 2010 respectively.

3.3. Soil Salinity

The soil salinity exhibits a unique spatial and temporal trend (Fig. 6). In western Indian Sundarbans (Stn. 1 to 7), the values are relatively lower (mean value of all depths and years = 9.75 psu), while in stations 8 to 11 adjacent to Matla River in the central sector of Indian Sundarbans, the values are relatively higher (mean value of all depths and years = 13.85 psu). Interestingly, in the eastern Indian Sundarbans encompassing stations 12 to 14 (adjacent to Bangladesh Sundarbans), the soil salinity again decreases significantly (mean value considering all depths and years = 6.98 psu). An apparent increase in soil salinity with depth is observed in all the stations (Fig. 7). It is observed that the soil salinity exhibits a decreasing trend with years in stations 1 to 7 (10.92 psu, 10.14 psu, 9.80 psu, 9.16 psu, and 8.71 psu in 2006, 2007, 2008, 2009, and 2010 respectively) and stations 12 to 14 (7.70 psu, 7.35 psu, 7.04 psu, 6.64 psu, and 6.18 psu in 2006, 2007, 2008, 2009, and 2010 respectively), but the values increase in stations 8 to 11 (13.32 psu, 13.52 psu, 13.64 psu, 14.26 psu, and 14.49 psu in 2006, 2007, 2008, 2009, and 2010 respectively).

4. Discussion

4.1. Soil Organic Carbon

The significant variation ($p < 0.0001$) of soil organic carbon between anthropogenically stressed western zone and non-disturbed central and eastern zones may be attributed to a large extent by human activities, mangrove floral richness, and physical factors like accretion and erosion. Anthropogenic activities like fish landing, tourism and unplanned urban development and shrimp farms contribute appreciable amount of organic load in stations like Kachuberia (Stn. 1) and Frazergaunge (Stn. 5). The presence of shrimp farms at Chemaguri (Stn. 6) along with 12 years old mangrove vegetation (17 species) may be attributed to highest organic carbon level in the soil core. The western Indian Sundarbans (encompassing stations 1 to 7) is under severe stress due to intense industrialization, rapid urbanization and unplanned tourism and aquaculture activities [22,29] which contribute appreciable organic carbon in the soil. The relatively low organic carbon at Sagar South (Stn. 3) is due to its location at sea front where wave action and tidal amplitude is maximum (range 3.0 m to 5.0 m and mean = 3.5 m). Continuous erosion of this island may be the reason behind minimum retention of organic matter in the intertidal zone. The low organic carbon at stations 8 to 14 confirms the anthropogenic origin of organic load, which is almost absent in these stations (control zone). Being located within the reserve forest area, stations 8 to 14 receive complete legal protection and hence the major source of organic carbon in this zone is primarily the mangrove detritus. The variation of organic carbon in the Indian Sundarbans is thus regulated through an intricate interaction of biological, physical and anthropogenic activities (Table 1).

The decrease in soil organic carbon with increased depth ($p < 0.0001$) is in accordance with the findings of Lacerda et al. [30], where the organic carbon levels under *Rhizophora mangle* soil were 2.80%, 2.70% and 2.70% in the 0.01-0.05 m, 0.05-0.10 m and 0.10-0.15 m depth respectively. Similar trend was also observed under *Avicennia* soil [30]. Report of decreasing mangrove soil organic carbon below 1 m is presented by Donato et al. [31]. The factors governing variation of below-ground carbon storage in mangrove soils is difficult to pinpoint [32,33] as it is not a simple function of measured flux rates, but also integrates thousands of years of variable deposition, transformation, and erosion dynamics associated with fluctuating sea levels and episodic disturbances [34].

The present study is significant from the point that the area has not yet witnessed the light of documentation of soil carbon content although AGMB and carbon storage have been studied by several workers [19]. Donato et. al. [31] quantified whole-ecosystem C storage in mangroves across a broad tract of the Indo-Pacific region, which includes the Bangladesh Sundarbans. The study however did not cover the lower Gangetic soil sustaining 38% of the total Sundarbans in the Indian part. The present approach is thus an attempt to fill this gap area and establish a continuous five year baseline data of soil carbon in the mangrove dominated Indian part of Sundarbans.

4.2. Soil pH

The acidity of the soil influences the chemical transformation of most nutrients and their availability to plants. Most mangrove soils are well buffered, having a pH in the range of 6 to 7, but some have a pH as low as 5 [35]. In this study, soil pH (7.47 ± 0.071) is lower in the reserved forest area (Stn. 8 to 14) that sustains rich mangrove and several associate floral species. The organic acids released from these vegetations may drive the pH of soil to lower value. In anthropogenically stressed western Indian Sundarbans, the soil pH is comparatively higher (7.57 ± 0.067). The spatial variation of soil pH is highly significant ($p < 0.0001$). The spatial variation of soil pH is highly significant ($p < 0.0001$).

A significant decrease in soil pH with depth at all locations ($p < 0.0001$) may indicate the production of organic acids and carbon dioxide by actively metabolizing mangrove roots. The surface soils are usually neutral to slightly acid in mangrove ecosystem due to the influence of alkaline estuary water [35] and in the present system the value ranges from 7.90 to 8.30 depending on season [24]. Soil pH in all the stations exhibit significant yearly variations ($p < 0.0001$), which may be attributed to climatic factors that regulate the ambient aquatic pH through precipitation, run-off and biological phenomenon like mangrove litter fall and their subsequent decomposition in the soil of intertidal mudflats.

4.3. Soil Salinity

Soil salinity reflects the geophysical features of the ecosystem. It is also an indicator of dilution caused by run-off, stream discharge, barrage discharge and other anthropogenic activities. The relatively low soil salinity in the stations at western sector (stations 1 to 7) is the effect of Farakka barrage discharge that release fresh water through the main Hooghly channel. The Hooghly estuary in the western Indian Sundarbans marked by the outer drainage of Ganga River system receives high volume of freshwater discharge all round the year. The annual fresh water discharge through the estuary accounts for 67200, 16200, and 62100 million ft^3 from the main channel of the River Ganga, Damodar and Roopnarayan covering an aggregate of about 11900 km^2 of catchment area. The siltation of the Bidyadhari River since the late 15^{th} century blocked the flow of fresh water in the central and eastern Indian Sundarbans. Interestingly stations 12, 13, and 14 in the eastern Indian Sundarbans exhibit low soil salinity profile and also a decreasing trend with time. This is due to proximity of these stations to Bangladesh Sundarbans that receive the maximum fresh water flow from the Himalayan glacier through the River Padma. The presence of numerous creeks and channels in the eastern most part of Indian Sundarbans may act as conveyer belt of fresh water from the Bangladesh part to the eastern Indian Sundarbans. The increase of soil salinity with depth ($p < 0.0001$) is the effect of percolation during tidal inundation of the intertidal mudflats (twice daily). The bottom layer is not washed away unlike the top soil layer by daily tidal action which results in accumulation of salts in the bottom layer.

It is to be noted that increase of salinity in the stations adjacent to the Matla River (Stn. 8 to 11 in the central sector) may pose serious threat to certain mangrove species like *Heritiera fomes* (locally known as Sundari, from which the name Sundarbans has originated). Symptoms of excess chloride include burning and firing of leaf tips or margins, bronzing, premature yellowing, abscission of leaves and, less frequently chlorosis. Smaller leaves and slower growth also are typical. Symptoms of excess sodium also include necrotic areas on the tips, margins, or inter-veinal areas. High salinity also results in the stunted growth of mangroves [19,36,37]. This may have far reaching impact on the aquatic sub-system of central Indian Sundarbans as mangrove litter and detritus, which are the primary source of soil organic carbon may reduce in quantum. This may eventually lead to poor productivity of the adjacent water bodies. Therefore, efforts should be made to develop better understanding of the problem so that appropriate management strategy could be adopted for improved and sustainable ecological management of the central sector of Indian Sundarbans with particular reference to siltation problem that has cut off the fresh water supply in the region.

5. Conclusions

Few core findings are listed below:

The estimated mean soil organic carbon in the western Indian Sundarbans is 1.02 Wt.%, where the soil salinity is low due to dilution of the system with Farakka barrage discharge and run off from highly urbanized townships and agricultural fields around the area. The average pH is (7.57 ± 0.067) is relatively higher in this sector.

The stations in the central and eastern part of Indian Sundarbans are free from anthropogenic influences due to their locations within the reserve forest area. The luxuriant mangrove vegetation in these areas associated with salt marsh grass (*Porteresia coarctata*) has caused low pH in the soils of intertidal mudflats (7.47 ± 0.071). The organic carbon is comparatively low (0.64 Wt. %) in the absence of any human activities like aquaculture, agriculture, sewage disposal etc.

It can be concluded from the soil organic carbon data that the carbon budget in the soil is mostly influenced by physical (waves, tides, erosion, accretion etc), biological (vegetation type and density) and anthropogenic (urbanization, barrage discharge and nature of livelihood etc) factors.

The gradual increase of soil organic carbon with time in the western Indiian Sundarbans is a clear signature of anthropogenic role in regulating soil organic carbon in the present geographical locale.

Acknowledgments

The financial assistance from the National Remote Sensing Centre, Govt. of India under the programme ISRO-GBP/NCP/SVF is gratefully acknowledged. Infrastructural facilities of Forest Department, Government of West Bengal is also duly acknowledged.

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Table 1. Major activities influencing the organic carbon pool in Indian Sundarbans

Station name and Stn. No. (as in map)	Geographical location		Major activity	Magnitude
	Longitude (°E)	Latitude (°N)		
Kachuberia (1)	88°08’04.43’’	21°52’26.50’’	Navigational channel	+++
			Passenger vessel jetties	+++
			Shrimp culture farms	+
			Market place	++
Harinbari (2)	88°04’52.98’’	21°47’01.36’’	Mangrove patches (n = 7; AGMB = 89t/ha)	++
			Unorganized fishing activities	+
Sagar South (3)	88°03’06.17’’	21°38’54.37’’	Pilgrims	+++
			Tourism	+++
			Navigational channel	+++
			Erosion (sea facing)	+++
			Mangrove patches (n = 11; AGMB = 94t/ha)	++
Chemaguri (4)	88°10’07.03’’	21°39’58.15’’	Fish landing stations	+++
			Tourism	+++
			Mangrove patches (n = 17; AGMB = 71 t/ha)	++
			Shrimp culture farms	++
Frazergaunge (5)	88°15’15.63’’	21°33’11.84’’	Shrimp culture farms	++
			Mangrove forest (n = 17; AGMB = 124 t/ha)	+++
			Fish landing stations	+
			Market place	++
Prentice Island (6)	88°17’10.04’’	21°42’40.97’’	Mangrove patches (n = 18; AGMB = 108 t/ha)	+++
Lothian island (7)	88°22’13.99’’	21°39’01.58’’	Mangrove forest (protected area; n = 31; AGMB = 136 t/ha)	+++
			Navigational channel	+++
			Erosion	+++
			Wave action	+++
Sajnekhali (8)	88°46’10.08’’	22°05’13.04’’	Mangrove forest (protected area; n = 31; AGMB = 136 t/ha)	+++
			Tourism	++
Amlamethi (9)	88°44’26.07’’	22°03’54.02’’	Mangrove forest (n = 17; AGMB = 148 t/ha)	+++
			Tourism (occasional)	+
			Shrimp and prawn culture farms.	+
Jharkhali (10)	88°41’47.25’’	22°05’52.82’’	Mangrove forest (protected; n = 13; AGMB = 141 t/ha)	+++

Dobanki (11)	88°45’20.06’’	21°59’24.04’’	Accretion zone	++
			Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Netidhopani (12)	88°44’39.4’’	21°55’14.9’’	Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Haldibari (13)	88°46’44.9’’	21°43’01.4’’	Accretion zone	++
			Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Burirdabri (14)	89°01’43.6’’	22°04’39.2’’	Mangrove forest (protected area; n = 21; AGMB = 136 t/ha)	+++

+, ++, and +++ indicate low, medium and high magnitude respectively for the major activities in the selected stations; n and AGMB represent number of mangrove species and above ground mangrove biomass (t ha^{-1}) of three dominant species respectively.
Data sources: Chaudhuri and Choudhury (1994), Mitra et al. (2010), and Mitra et al. (2011).

Figure 1. Map of the study region showing the sampling stations. R1 to R7 are the seven rivers of Sundarbans starting from west to east, namely Hooghly, Mooriganga, Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga

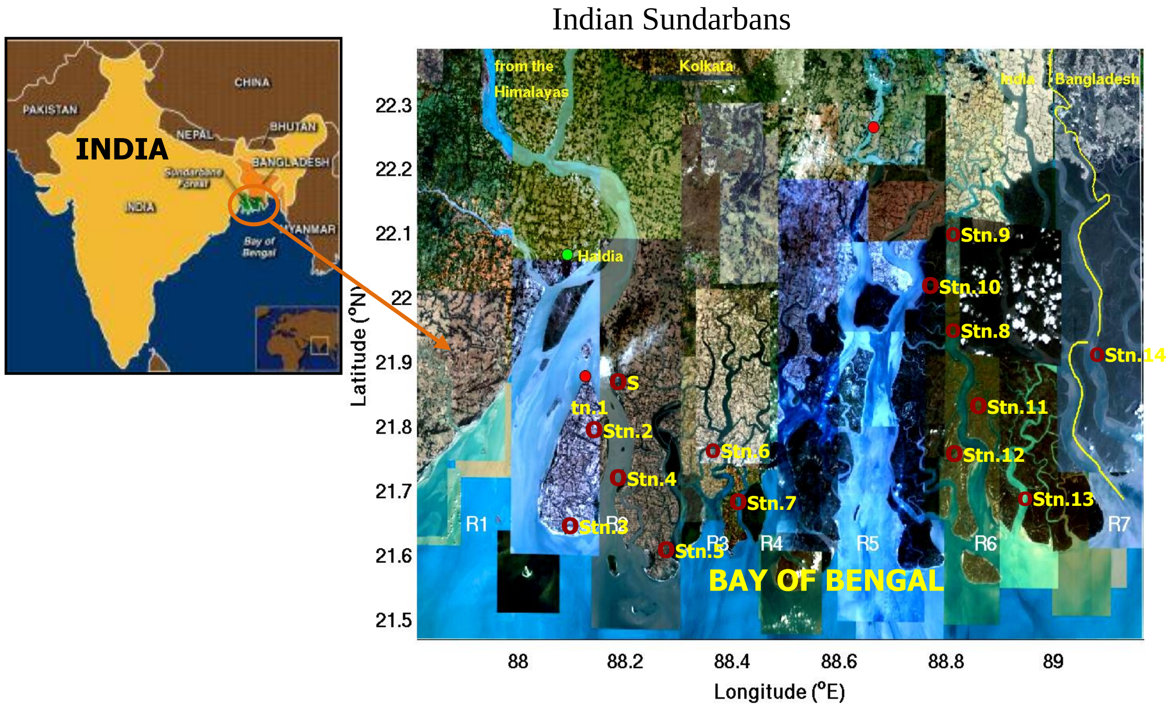


Figure 2. Spatial and temporal variations of soil organic carbon (Wt. %) during premonsoon 2006-2010 (composite value of the depths)

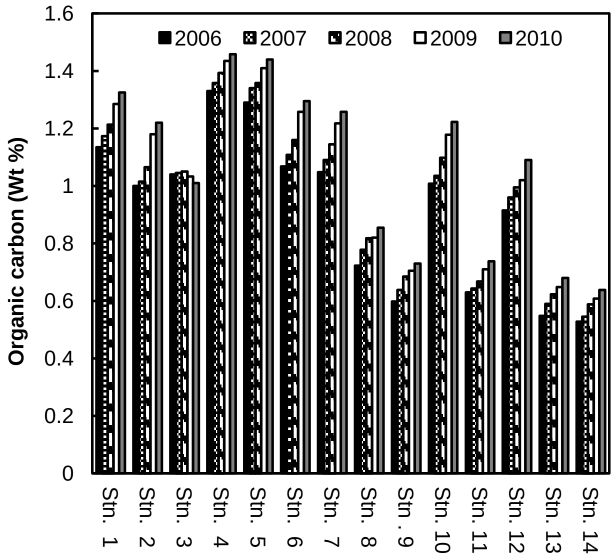
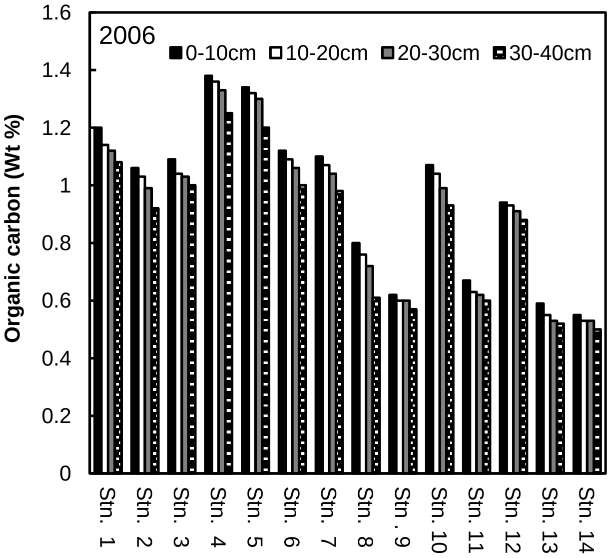
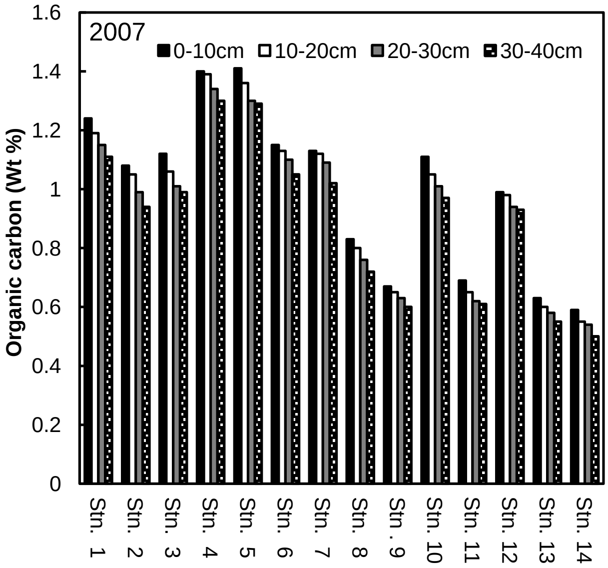
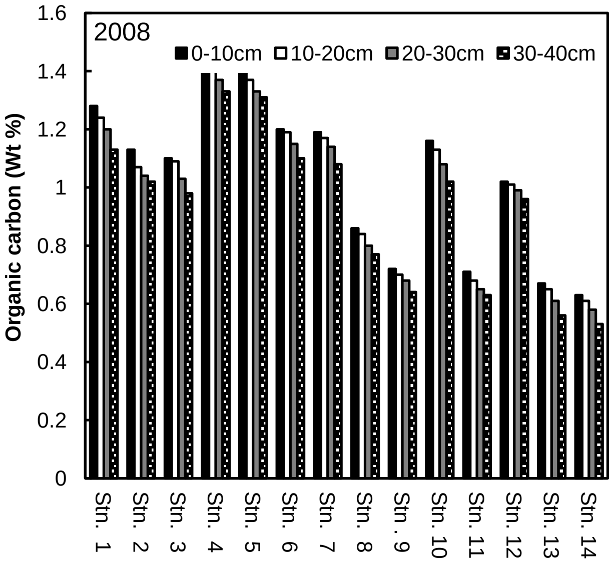
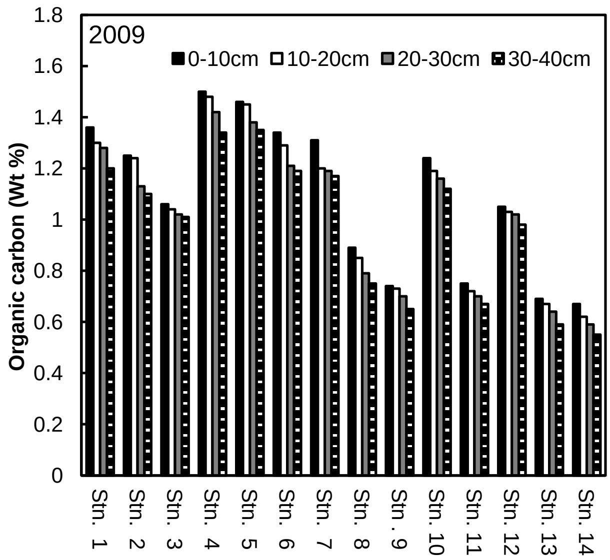


Figure 3. Yearly variations of soil organic carbon (Wt. %) with depth in the selected stations









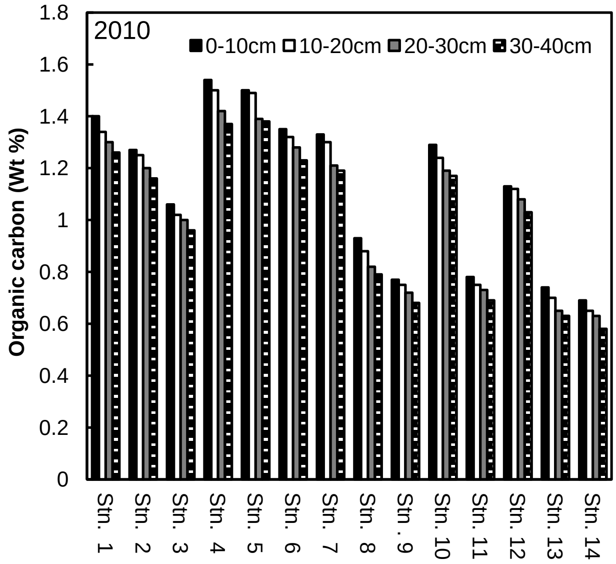


Figure 4. Spatial and temporal variations of soil pH during premonsoon 2006-2010 (composite value of the depths)

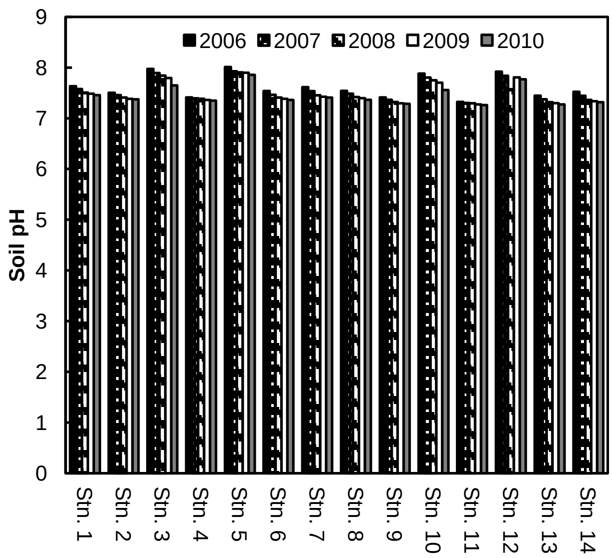
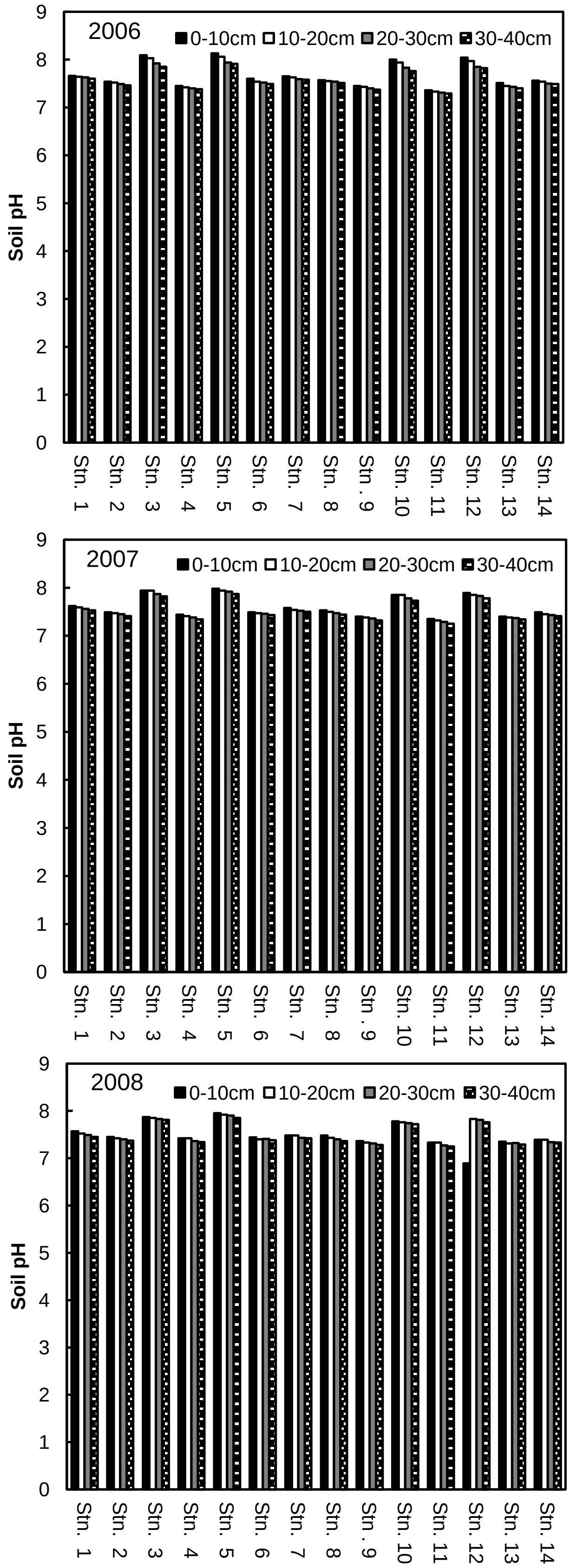


Figure 5. Temporal variations of soil pH with depth in the selected stations



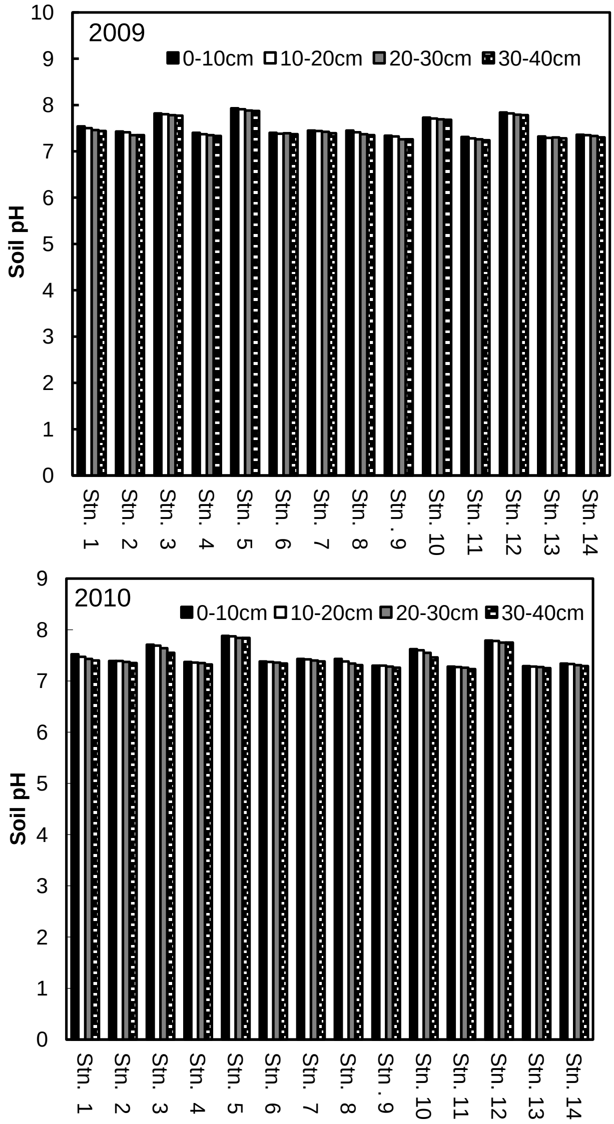


Figure 6. Spatial and temporal variations of soil salinity (psu) during premonsoon 2006-2010 (composite value of the depths)

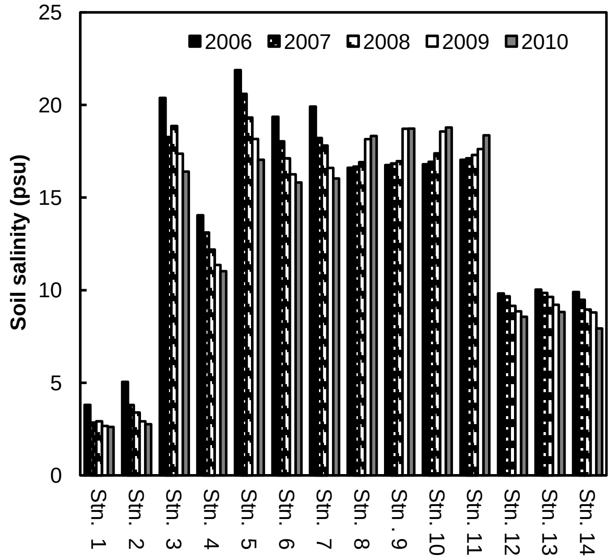


Figure 7. Yearly variations of soil salinity (psu) with depth in the selected stations