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IMPROVING ESTIMATES OF MANGROVE SOIL ORGANIC CARBON STOCKS BY CONSIDERING SOIL PHYSICOCHEMICAL PROPERTIES

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The organic carbon sequestered by the world's mangrove forests plays a key role in the global carbon cycle and may be central to climate change mitigation. This is because mangroves typically exhibit high rates of net primary production and greater carbon sequestration capacity compared to terrestrial ecosystems. This study investigated the influence of selected soil physicochemical properties on the soil organic carbon (SOC) content of Rekawa mangrove forest, Sri Lanka. The effect of soil pH, salinity, conductivity, moisture content (%), bulk density, porosity, phosphate, and nitrate content on SOC was examined along an intertidal gradient. Results showed, SOC was positively correlated with salinity (r^2= 0.74), conductivity (r^2= 0.76), moisture content (r^2= 0.76), porosity (r^2= 0.92), and phosphate content (r^2= 0.74) while SOC was negatively correlated with bulk density (r^2= -0.92) across the entire intertidal zone. Generalised Linear Model (GLM) resolved SOC to be best predicted as a function of soil porosity and soil moisture content [Akaike Information Criterion (AIC): 142.04], with other soil properties modulating the results within some zones. Overall, the present study shows that specific consideration of soil physicochemical properties could allow improved estimates of total carbon stocks which are becoming increasingly important for carbon accounting and national inventories

Keywords: blue carbon, correlation, intertidal zone, soil factors, Sri Lanka

INTRODUCTION

The mangrove forests which dominate the coastlines of south and southeast Asia continue to be degraded and disappear as a result of climate change and human intervention (Friess et al. 2022). Tropical, subtropical, and warm temperate (30°N to 37°S) coastal wetlands make up the majority of mangrove ecosystems, spanning 123 countries (Spalding et al. 2010) and providing an array of ecosystem services such as coastal defence against storms and tidal waves, sediment stabilization, reduced shoreline and riverbank erosion, regulating flooding, recycling nutrients and providing habitat for birds and other animals (Ransara et al. 2012, Jayatissa et al. 2016, Satyanarayana et al. 2017, Koh et al. 2018, Okello et al. 2019, Zimmer et al. 2022). Furthermore, tremendous economic benefits are derived through fishing, shrimp and prawn culture, salt production, and farming (Ofori et al. 2021, 2023). Despite all the ecological services and economic benefits, mangrove forests are largely disturbed due to anthropogenic activities such as development projects, deforestation, aquaculture, pollution and invasive plant species, (Madarasinghe et al. 2020a, 2020b, Ofori et al. 2021, 2023, Kodikara et al. 2022).

Mangroves are adapted to cope with harsh environmental conditions such as high salinity, extreme tides, strong winds, high temperatures, and muddy and anaerobic soils that occur at the land-sea interface (Priyashantha &

Taufikurahman 2020). Because of their deep and anoxic soils, mangrove forests have been increasingly recognized as one of the most important carbon storage ecosystems on the planet, trapping 4 – 8 times the carbon of terrestrial forests (Cooray et al. 2021). The carbon stored and sequestered in marine and coastal ecosystems including mangroves, saltmarshes and seagrass meadows has recently been termed as "Blue Carbon" (Qu et al. 2019, Gorman et al. 2022) and can be generally separated into four carbon pools: aboveground living biomass, aboveground dead biomass, belowground living biomass, and soil carbon in mangrove ecosystems (Howard et al. 2014). The blue carbon in marine ecosystems can accumulate significantly and be stored for centuries due to the low degradation rate of organic matter under anaerobic (waterlogged) conditions. Mangrove ecosystems can store more carbon than other coastal and marine ecosystems, with much of it being sequestered in several meters deep sediment layers (Yong et al. 2011, Donato et al. 2012, Huang et al. 2018).

The distribution of mangroves in Sri Lanka is patchy, with isolated stands along estuaries and lagoons (Dayarathne & Kumara 2015) and the conservation of forests has been linked with actions on climate change mitigation and the maintenance of global carbon cycle i.e. with global estimates of 102,300 Mg C km^{-2} (Chambers et al. 2014, Gunathilaka et al. 2022). Therefore, when mangroves are disturbed by human activities, large volumes of greenhouse gases can be released, transitioning these ecosystems from a carbon sink to a carbon source, with estimates indicating that between 2000 and 2012, approximately 316,996,250 Mg of CO_2 was released into the atmosphere as a result of the global mangrove deforestation (Cooray et al. 2021).

A variety of organic carbon processes underpin the function of natural mangrove ecosystems, with the amount of organic carbon in their soils being affected by factors such as soil texture, vegetation type, climate, and historical and current land use (Howard et al. 2014, Hinson et al. 2017, Rogers et al. 2019, Wijeratne et al. 2022). When considering the sequestered blue carbon in mangrove soils, several authors have studied the physical and chemical characteristics of mangrove soil and mangrove soil water relations (Huang et al. 2018, Rajal et al. 2019). Further, according to Huang et al. (2018), plant types, soil depths, phenolic material concentration, soil physical factors and chemical factors such as nitrogen, phosphorus, the carbon-to-nitrogen (C/N) ratio, potassium, pH, bulk density, and water content influence mangrove SOC. Further, the study of Pazi et al. (2016) suggest pronounced differences in the carbon storage potential between different zones: seaward, middle, and landward at two different soil depths (0–20 cm and 20–40 cm) in Sarawak, Malaysia. Howard et al. (2014) pointed to the apparent knowledge gap and limited scientific literature about the carbon sequestration and storage rates of blue carbon ecosystems in Africa, South America and Southeast Asia.

In Sri Lanka, only a few studies have focused on the soil organic carbon of mangrove forests. A study conducted by Perera and Amarasinghe (2019) assessed the soil carbon content of seven mangrove sites; Negombo, Kala Oya (river) estuary, Malwathu Oya estuary, Chilaw lagoon, Rekawa lagoon, Batticaloa lagoon and Uppar lagoons which represent wet, intermediate and dry zones in Sri Lanka. Another study reported on the vegetation structure and estimated variation in the carbon pool in relation to plant biomass on the northeast coast of Sri Lanka (Perera & Amarasinghe 2021). Only a few studies have quantified above-ground carbon and below-ground root carbon pools using allometric models for biomass estimation, thus, sparse information on the total carbon storage of mangroves is available (Cooray et al. 2021). Indeed, Cooray et al. (2021) appears one of the only studies to attempt to specifically report variation in total carbon stocks between dry, intermediate, and wet zones. However, the effect of different soil parameters on SOC has not yet been studied in detail within Sri Lanka, despite its likely profound influence on soil organic carbon stocks.

The aim of this study was to investigate the influence of some of the most important soil physicochemical properties on the soil organic carbon stocks along an intertidal gradient (i.e., comprising of three distinct intertidal zones). This will be one of the crucial topics which should be discussed at present as a timely necessity. And the information will give a better understanding of the variability expected in soil carbon stocks in Sri Lanka and will be vital to move towards national inventories. Ultimately it will be able to facilitate carbon conserving mechanisms in mangrove soil based on the outcomes of this study thereby conducting future studies.

MATERIALS AND METHODS

Study site

Sri Lanka is an island in the Indian Ocean, located in the southwestern part of the Bay of Bengal, with latitudes ranging from 5.55° to 9.51° N and longitudes ranging from 079.41° to 081.54°E. The coastline stretches for 1738 km and covers a total area of 65,610 km^2 of the island (Kodikara et al. 2017a). Mangrove ecosystems in Sri Lanka occur in 14 out of 25 administrative districts that span the coastal belt (Priyashantha & Taufikurahman 2020). Moreover, 21 true mangrove species and 24 mangrove associates have been identified along the southwestern coast (Priyashantha & Taufikurahman 2020).The southern region of Sri Lanka has a healthy mangrove ecosystem, particularly around Rekawa lagoon, which is located in Hambantota district in the southern coast (coordinates 6°03'N 80°50E) (Figure 1).

The study was done at replicate sites within the Rekawa lagoon system (Figure 1). Randomly selected transects represent the whole mangrove vegetation around the Rekawa lagoon including monospecific and mixed mangrove vegetations. The surface area of the lagoon is 250 ha and it has wide basin of 3.3 km in length, 0.9 km in width and 1.4 m in depth. The lagoon's long axis is running parallel to the ocean. There is inflow of several small fresh water sources that significantly account to change the salinity of the lagoon. The discharge of the lagoon is blocked by a sand bar that is frequently removed by local inhabitants facilitating the discharging. The salinity ranges from 0 to 35 psu (annual average of 15 psu) at the lagoon mouth, and from 5 to 16 psu in the middle and upper parts of the lagoon (annual average of 7.5 psu). The fringe mangrove forest is composed of true mangrove species such as *Avicennia marina, A. officinalis, Rhizophora mucronata, R. apiculata, Ceriops tagal, Lumnitzera racemosa* and mangrove associates such as *Nypa fruticans* and *Acrosticum* sp. Moreover, almost all the species that are

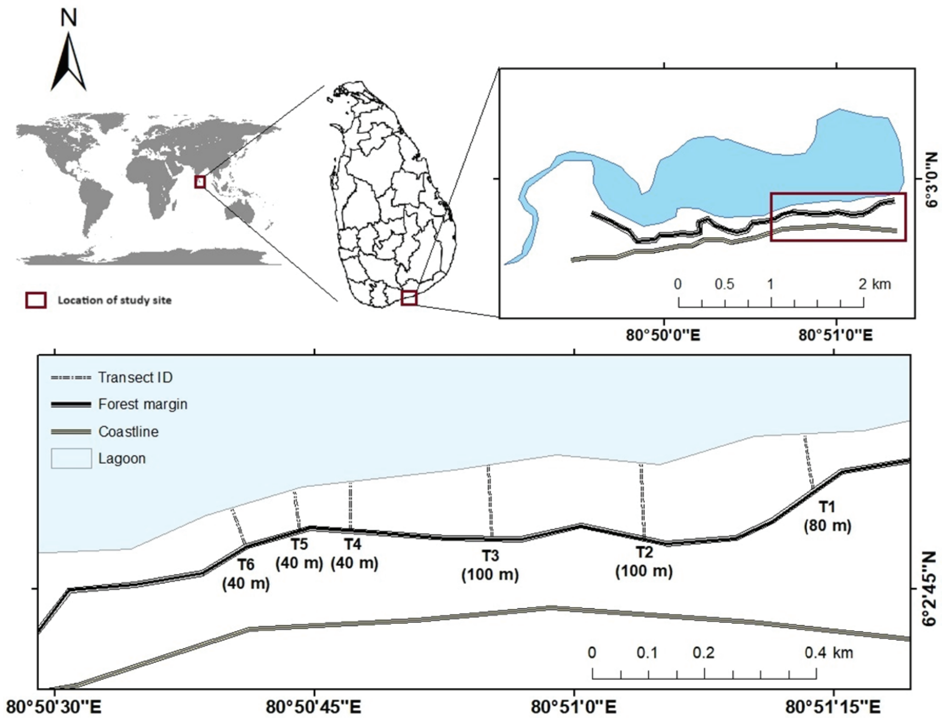

Figure 1 Map of the study site in Rekawa lagoon (According to the legend, blue color area represents the Rekawa lagoon, and each line represents the line transects, forest margin and coastline respectively)

reported as common mangrove species in Sri Lanka occur in Rekawa.

Sample collection

Soil samples were collected along six line transects which were randomly placed between the landward and water edge margins of the mangrove belt of the Rekawa lagoon (Figure 1). Soil samples from the topsoil layer (0–30 cm) were obtained every 20 m, along the selected line transect from the landward zone, middle zone to water edge zone by using hand shovel. Even though the length of random transects varied from each other, their zonation pattern remains same. Based on that fact, landward, middle and water edge zones were demarcated. Collected soil samples were packed and sealed in zip-lock™ bags (Gao et al. 2019) and transported to the laboratory. A portion of each soil sample was air-dried and sieved to a particle size <2 mm for homogenization (Qu et al. 2019). Fresh soil samples (portion A) were used to measure soil pH, salinity and conductivity, while 4°C refrigerated soil samples (portion B) were used for other soil analyses i.e., soil moisture content, soil organic matter, soil bulk density, phosphate and nitrate content (Gao et al. 2019, Qu et al. 2019).

Sample preparation and analysis

Fresh soil samples were used to measure pH, salinity and electrical conductivity. A 5 g soil portion was dissolved in 20 mL of deionized water to make soil slurry of 1:4 w/v ratio. Soil pH was measured using a HP9010 pH/ ORP/Temperature meter (Trans, Singapore). Electrical conductivity and salinity were measured using an EC 8500 Cond/ Sal/ TDS meter (APERA EC8500/China). Soil moisture content (Equation 1), soil organic matter (Equation 2,3), phosphate and nitrate content were analyzed using air dried portions of soil. Soil moisture content was analyzed using an oven drying method at 105 °C maintained overnight (Huang et al. 2018) and soil organic matter was calculated using the loss on ignition method at 550 °C for 5 hours (Chambers et al. 2014). This value was converted to soil organic carbon by using conversion factor. Soil bulk density was analyzed using the ring drive method (Weston et al. 2006) (Equation 4) and soil porosity was assessed using the reciprocal of the soil bulk density values (Equation 5). Soil phosphate concentration was quantified by ammonium molybdate colorimetric method (Luo et al. 2014) and soil nitrate content was analyzed by Na- salicylate colorimetric method (Monteiro et al. 2003).

$$\text{Soil moisture content} = \frac{\text{Initial weight-Final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

$$\text{Soil organic matter} = \frac{\text{Oven dried weight-Final weight}}{\text{Oven dried weight}} \times 100 \quad (2)$$

$$\text{Soil organic matter} = 1.72 \times \text{Soil Organic Carbon} \quad (3)$$

$$\text{Soil bulk density} = \frac{V1}{W1} \quad (4)$$

$$\text{Soil porosity} = \frac{1}{\text{Soil bulk density}} \quad (5)$$

W_1= Dry soil weight
V_1= Volume of the original soil sample

Statistical analysis

All data were expressed as mean ± standard error (SE). All derived raw data for each parameter were checked for parametric assumptions, including normality (Shapiro-Wilk normality test) and transformed to log values, square root values and arc-sin values where necessary. As the data were not normally distributed even under such transformations, nonparametric analysis was selected. Kruskal Wallis H-test was performed to check the significant variation of pH, salinity, conductivity, soil moisture content, soil bulk density, soil porosity, soil phosphate content and soil nitrate among all transects. To check pairwise correlation, the Spearman rank correlation test was performed between SOC and soil physicochemical properties in all three zones, landward, middle and water edge. A Generalised Linear Model (GLM) was used to test the best fit model describing the SOC content of mangrove soils in each zone. Owing to the multico-linearity, conductivity values were omitted, but all other parameters were included in the full model formulation. However, due to the performing of backward elimination, some parameters had been eliminated. Models were formulated for all three zones. Among those models the models which have the lowest AIC values were taken as best-fit models in each zone. The statistical significance in all analyses was considered at 95% confidence interval and $p<0.05$. All the statistical analyses were performed using R- 4.1.0 statistical software.

RESULTS

Soil pH, conductivity and salinity showed significant variations among the three zones of transects (Table 1 and 2). Considering the three zones of each transect, landward, middle zone and water edge, the highest pH was recorded at the water-edge while the lowest was observed in the middle zone. With respect to salinity and conductivity, the highest and lowest values were recorded in the middle zone. Considering soil moisture content, the water edge showed the highest value whereas the middle zone showed the lowest value. The highest and lowest SOC values were observed in the water edge. Considering soil bulk density, the highest value was recorded in the water edge while the lowest was recorded in the middle zone. Water edge has also recorded the lowest and highest values for soil porosity and soil phosphate contents. When considering soil nitrate content, the highest value was recorded in the water edge and the lowest value was recorded in the middle zone (Figure 2).

According to the Spearman Rank Correlation test, SOC was positively correlated with salinity, conductivity, soil moisture content, soil porosity and soil phosphate content, while negatively correlated with soil bulk density in all three zones (Table 2). However, the weak positive correlation between pH and SOC was significant only in the middle zone. With the exception of the landward zone, positive correlations between nitrate content and SOC were significant for the other two zones (Figure 3).

A Generalised Linear model (GLM) was used to reveal the best-fit model for the Soil Organic Carbon in the landward, middle and water edge zones. Owing to the multico-linearity, conductivity values were omitted from all three zones, with the other parameters included in the initial model formulation (Table 3).

DISCUSSION

Understanding the environmental factors that influence carbon pools within mangrove forests is vital to promote conservation by recognizing their importance for climate change mitigation, the provision of ecosystem services and support of livelihoods (e.g., fisheries). Rekawa lagoon is broadly considered to be one of the most undisturbed mangrove forests in southern Sri Lanka, given it experiences minimum anthropogenic influence. According to Jayatissa et al. (2006), the Rekawa lagoon has the highest true mangrove diversity in southern Sri Lanka. Thus, studying the influence of soil attributes factors that underpin the carbon stocks of mangroves along an intertidal gradient within the Rekawa lagoon is thus an important research focus.

The study conducted by Chambers et al. (2014), shows that approximately 60% of organic carbon inputs to mangroves are retained in the sediments but an increase in salinity and inundation caused by sea level rise have the potential to change both carbon inputs and losses. Yong et al. (2011) reported that, in addition to the contents, activities and size of organic matter, mineralization rates of organic carbon in mangrove sediments are influenced by factors such as forest age, physiological activities of the roots, extent of waterlogging, and intensity of faunal burrowing activities.

Soil pH defines the acidity or alkalinity and depends on the existing H^+ concentration in the soil. Our data suggests that soil pH could be an important factor influencing SOC within the landward and water edge zones. Rainwater plays an important role in the pH values of coastal soil (Rajal et al. 2019). Considering the outcomes of this study, since there is a weak positive correlation between pH and SOC in landward and water edge zones, we cannot exactly predict about SOC dependency on pH value. This outcome matches the study by Huang et al. (2018) who found no significant correlation between SOC and pH. In Sri Lanka, previous studies have suggested that the pH value range of mangrove soils can range from 6.8 (minimum) to 8.45 (maximum) from June to November in the Jaffna Peninsula (Saruga et al. 2018). Even though the study periods are slightly different, this study confirmed similar pH

Table 1 Soil properties of the mangrove soil in Rekawa lagoon

	pH	Salinity/ppt	Conductivity /mS	SMC/ %	SOC/ %	SBD/ g cm^{-3}	SP/ g^{-1} cm^{3}	Phosphate content/ mg L^{-1}	Nitrate content/ mg L^{-1}
Highest value	7.80±0.04	4.45 ±0.02	8.88± 0.01	69.30±0.42	35.91±0.06	1.66± 0.01	8.57± 0.11	0.81± 0.07	8.69±0.04
Lowest value	6.35± 0.18	0.59	1.18± 0.01	0.90± 0.41	1.30± 0	0.12± 0.01	0.60±0.004	0.03± 0.01	0.01± 0.04

Table 2 Correlation coefficient values and p- values of the Spearman rank correlation tests

Parameters	Landward		Middle zone		Water edge	
	p value	rho	p value	rho	p value	rho
SOC with pH	0.6032	0.1314	0.0449	0.3891	0.4580	0.1277
SOC with salinity	0.0007	0.7176	4.654e-08	0.8388	0.0007	0.5354
SOC with conductivity	0.0009	0.7087	1.675e-08	0.8358	0.0007	0.5381
SOC with SMC	0.0030	0.6574	4.413e-08	0.8395	0.0022	0.4926
SOC with SBD	0.0008	-0.7317	8.195e-12	-0.9222	2.184e-07	-0.7423
SOC with SP	0.0005	0.7331	7.552e-08	0.8319	2.184e-07	0.7423
SOC with phosphate content	0.0168	0.5549	0.0067	0.5083	1.772e-08	0.7821
SOC with nitrate content	0.2199	0.3041	0.0002	0.6547	0.0014	0.5122

(rho = correlation co-efficient, SOC = soil organic carbon, SMC = soil moisture content, SBD = soil bulk density, SP = soil porosity)

Table 3 Best models evaluated using AIC values for SOC in three zones of transects

Zone	Model	AIC value
Landward	SOC ~ pH*+ Sal +SMC +SBD. + SP ***+[Phos]. + [Nitra]**	44.69
	SOC ~ pH** + SMC*+ SBD* +SP***+ [Phos]*** + [Nitra] ***	42.27
Middle zone	SOC ~ pH + Sal +SMC + SBD + SP + [Phos] + [Nitra]	132.91
	SOC ~ SMC*** + SP***	126.00
Water edge	SOC ~ pH*** + Sal + SMC* + SBD* + SP*** + [Phos]*** + [Nitra]***	190.68
	SOC ~ pH*** + Sal + SMC* + SBD* + SP*** + [Phos]*** + [Nitra]***	190.68

(SOC = soil organic carbon, SMC= soil moisture content, SBD = soil bulk density, SP = soil porosity, AIC = Akaike Information Criterion, Sal = salinity, [Phos] = phosphate concentration, [Nitra] = nitrate concentration, accepted models are in Italics. Significant codes - 0 '***' , 0.01 '**', 0.01'*', 0.05 '.', 0. 1 ' ', 1)

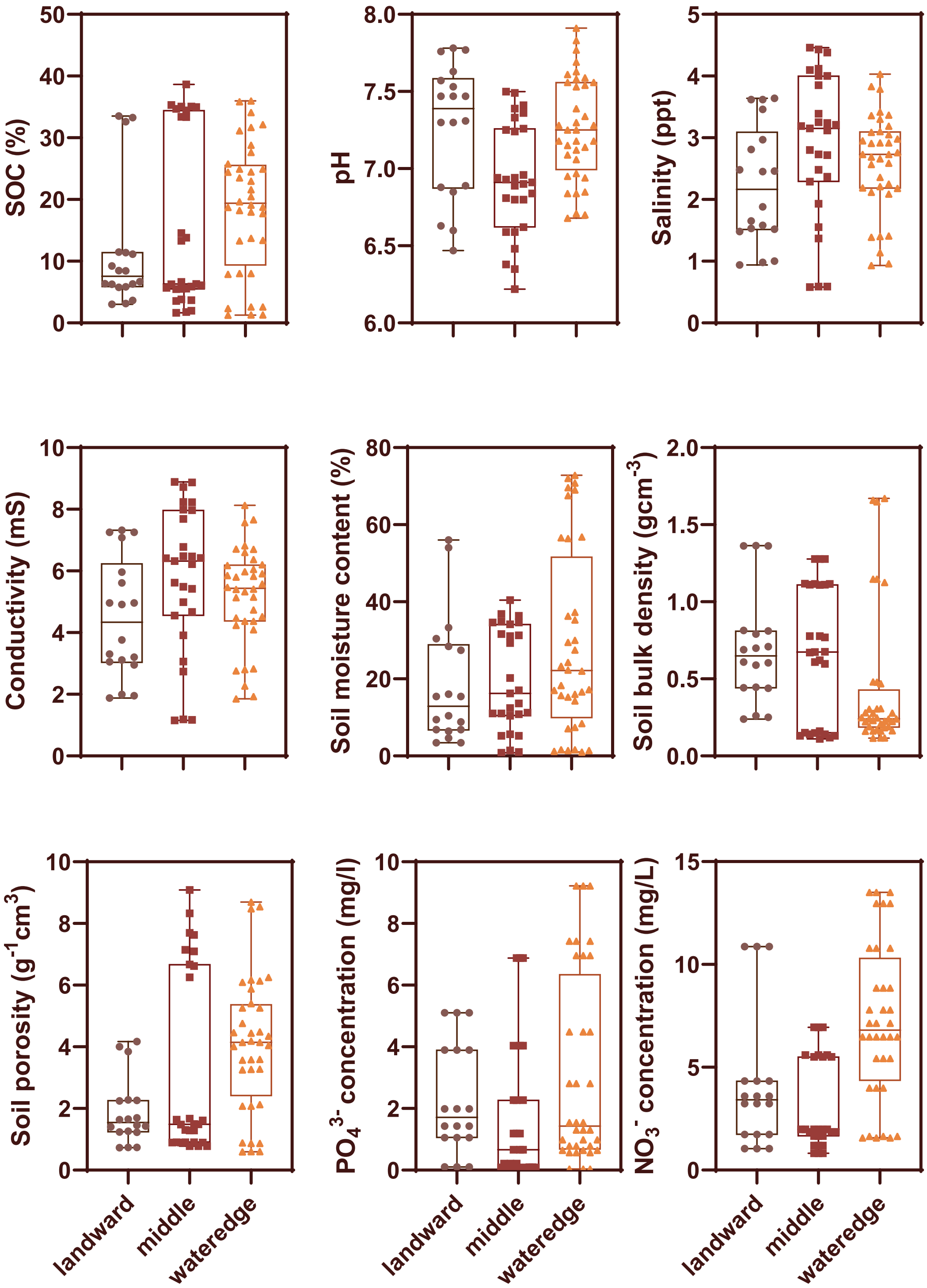

Figure 2 Box and whisker plots showing the variation in each measured parameter among landward, middle and water edge zones among transects

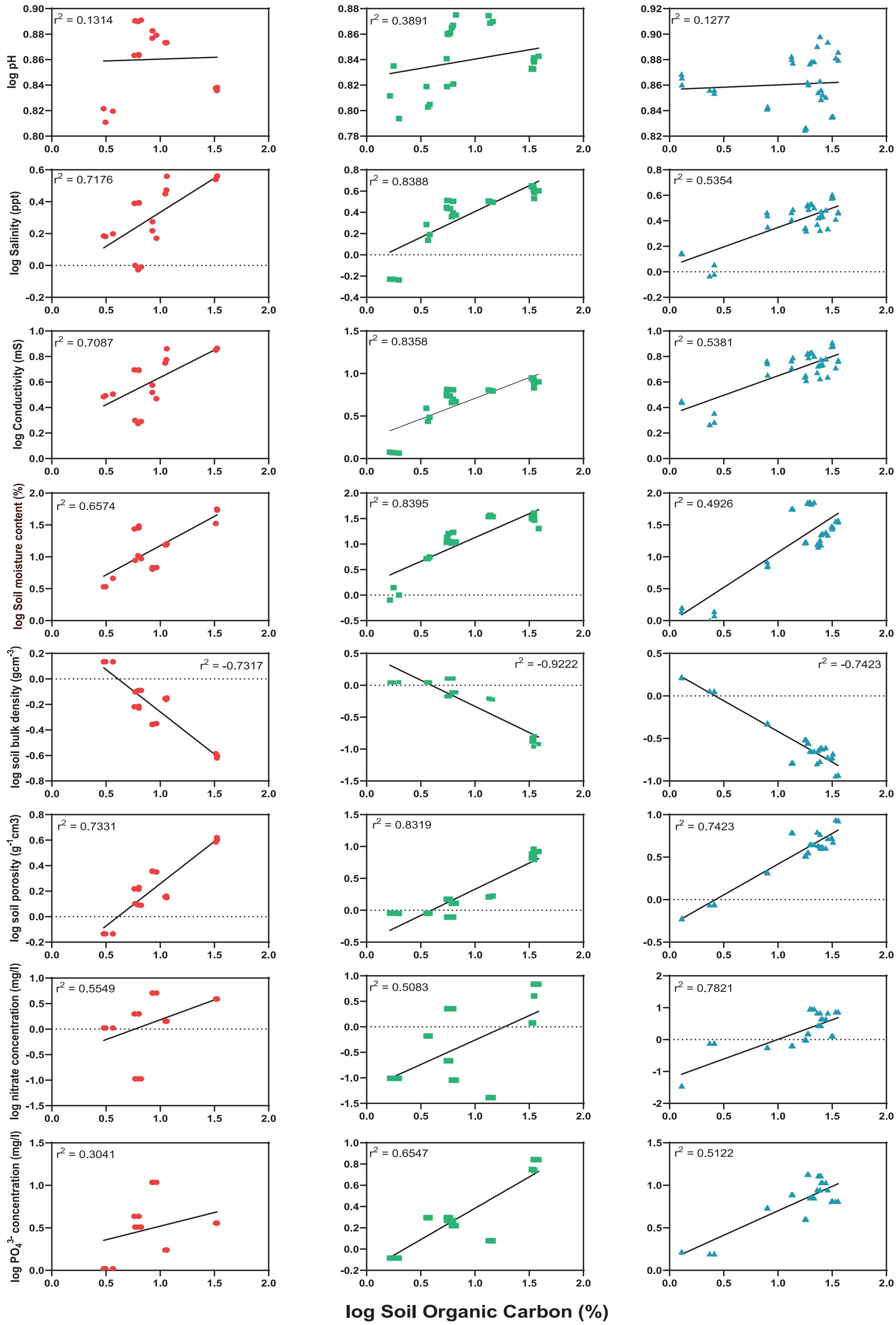

Figure 3 Scatter plots showing the relationship between estimates of soil organic carbon (SOC) and soil properties within intertidal zones (red = landward, green = middle zone and blue = water edge zone.

values to those mentioned above. Confirming the above statement, Rajal et al. (2019) showed that pH changes in mangrove soils can be due to seasonal variation in rainfall (precipitation pattern). Therefore, it is encouraged to carry out the study in other seasons to see how this factor may change at the whole lagoon scale, and within specific zones.

Our results show that soil salinity was positively correlated with SOC in all three zones. This possibly have implications for coastal vegetated systems, especially where this can influence the plant communities that occur within certain and are likely to change as a result of climate change (Mathiventhan et al. 2022). Additionally, high soil salinity can cause the flocculation or dispersion of soil particles and influences the solubility of soil organic matter (Qu et al. 2019), and excessive salinity in mangrove wetlands could cause inhibition of growth and biomass production, slowing down the rate of organic carbon decomposition (Huang et al. 2018, Qu et al. 2019).

Although we observe a significant positive correlation between conductivity and SOC, this was not reported in the study by Huang et al. (2018). Permeation of seawater through tides, evaporation of water and capillary rise of ground water during low tides are reported reasons for high conductivity values (Kumar & Kumara 2020).

In all three zones, soil moisture content was positively correlated with SOC. Confirming the results of this study, Gao et al. (2019) have resulted in a positive correlation between soil moisture content and SOC in four different study sites in China. According to Singh et al. (2017), soil moisture has a significant effect on the capacity of soil to sequester carbon. This is likely due to the fact that waterlogged soils do not contain a lot of oxygen (indeed some are even anoxic), slowing down bacterial decomposition. Changes in moisture content are likely to have variable impacts on the carbon sequestration capacity of soils, particularly in a cold climate or in temperate soils. The bacterial degradation of organic carbon may be reduced due to the lower efficacy of bacteria to degrade the organic matter as the temperature may not be optimal hence the carbon sequestration in colder climate may increase. It means high soil moisture facilitates anaerobic conditions in which organic matter is only partially degraded, leading to the accumulation of various organic compounds throughout the soil profile. A greater comparison of mangroves soils in Sri Lanka from different climate zones (e.g., cool southern vs. arid or tropical), might provide a useful test of this and help predictions.

Soil bulk density is one of the most important parameters for predicting soil organic matter or SOC. A study by Rajal et al. (2019), evaluated soils with a higher organic matter content and a lower bulk density, whereas compaction increases the bulk density, which is highly dependent on the mineral make-up of the soil and the degree of compaction. The decrease in soil bulk density indicates (an increase in soil porosity) in which the soil becomes much looser, improving permeability, water holding capacity, and storage capacity. This was shown to favor nutrient element accumulation as well as increase in soil organic carbon and dissolved organic carbon accumulation (Luo et al. 2014).

The number and size of soil pores which are described by soil porosity have a significant impact on the availability and movement of air and water within the soil environment, which has the potential to affect SOC decomposition (Singh et al. 2017). The prevalence of macro and mesopores, combined with the absence of micropores in sandy soils provides well-aerated (aerobic) conditions compared to texture-heavier waterlogged soils, leading to enhanced microbial degradation of SOC and its depletion.

Because of their estuarine occurrence mangroves are frequently limited by nitrogen and phosphorus rather than the relatively large quantities of sulfur, boron, potassium, magnesium, and sodium in seawater (Alongi 2018). Considering phosphate in pore water, a study by Chambers et al. (2014) reported that, for an elevated salinity treatment, soluble reactive phosphate was greater than ambient salinity. However, our results did not conform to this finding, as there was no significant correlation between phosphate and SOC. Therefore, we can assume that there could be other more important factor/s that influences the activity of soluble reactive phosphorus (ortho-phosphate) rather than salinity.

The correlation between nitrate concentrations and SOC was not significant in the landward edge. In the middle zone and water edge zone (seaward edge) soil nitrate was positively correlated with SOC. Related to nitrate, NH_4^+ accumulation during inundation prevents nitrification. Even so, high chloride concentrations which associate with salinity can reduce (interrupt) denitrification (Chambers et al. 2014), stimulating the nitrification. Therefore, this may be possible for the positive relationship between SOC and nitrate concentration.

Modelling showed that, in water edge zone (seaward zone) full model and the accepted model both are same. It means the SOC in water edge is affected by all the parameters collectively. There is no any parameter to neglect. However, in middle intermediate zone most suitable model only includes soil moisture content and soil porosity. All the other parameters have neglected. According to the results we have obtained, the interesting fact is, in middle intermediate zone SOC is affected by moisture content and porosity of the soil. Considering the landward zone, in best fit model includes all the other parameters except salinity.

According to the outcomes of the GLM analysis, the best fit models of SOC content for all three zones included soil moisture content and soil porosity. Therefore, we propose that these factors play an important role in SOC accumulation in mangrove soils irrespective of an intertidal gradient. Hinson et al. (2017) reported that organic carbon density is the product of organic matter fraction and bulk density. It possibly be due to organic carbon is a measurable component of soil organic matter which makes up from approximately 60% of soil organic matter. As soil porosity, which is inversely proportional to the soil bulk density, influences the latter, it also affects the density of organic carbon in a contrary manner.

Accordingly, soil pH, soil salinity, soil moisture content, soil bulk density and soil porosity, soil phosphate and nitrate content are significant factors that can help to predict the soil organic carbon content of landward, middle zone and water edge zones of mangrove forests.

Considering the importance of mangrove forests to maintain natural carbon sinks and lowering carbon emissions, the high tree biomass of mangrove forests is important (Perera and Amarasinghe 2021). Land use changes in alluvial and riverine mangrove ecosystems may rapidly affect soil properties, including carbon stocks, even at depths below 100 cm (Cooray et al. 2021). Between the years 2000 and 2012, more than 100,000 ha of mangroves were lost throughout South-East Asia. During the same period, net mangrove coverage in Bangladesh, India, Pakistan, and Sri Lanka have declined by 11,673 ha due to natural causes and anthropogenic activities (Cooray et al. 2021). Sri Lanka currently has approximately 8000 ha of mangrove forest, which has the potential to release ~ 12.72×10^6Mg CO_2 if disturbed (Kodikara et al. 2017a). According to Cooray et al. (2021), Rekawa lagoon has the highest mean total soil carbon stock compared to four other selected mangrove forests in their study (1253.57 ± 81.24 Mg C ha^{-1}) which highlights the national importance of conserving this area.

Apparently, the ability of mangrove ecosystems to mitigate the climate change depends on their potential of storing a large amount of organic carbon. Nevertheless, mangroves are yet to be disturbed as a result of natural disasters, shrimp farming, and anthropogenic activities such as coastal development and urbanization (Ofori et al. 2022), which are resulting in the exposure and release of carbon dioxide to the atmosphere. This is where communicating the importance of blue carbon ecosystems is paramount (Gorman et al. 2023) and effective governance and management vitally important (Dahdouh-Guebas et al. 2021, 2022, Nijamdeen et al. 2022, 2023). Therefore, keeping good carbon stabilization of mangrove soil to a maximum level is as important as carbon sequestration due to its importance in mitigating climate change and global warming like environmental crisis conditions.

Our study emphasizes the importance of physicochemical factors as determinants of SOC content within landward, middle zone and water edge zones of mangrove forests occurring in Rekawa lagoon. Soil salinity, conductivity, moisture content, porosity and soil phosphate concentrations were positively correlated with soil organic carbon in all intertidal zones, while there was a strong negative correlation between soil bulk density and SOC. The positive correlation between soil pH and SOC was only significant in the middle zone and nitrate content and SOC were correlated positively only in the middle and seaward zone (water edge zone). Even though, other parameters influence SOC in each zone, soil porosity and soil moisture content play a decisive role in all three zones on SOC content as they include in all best fit models. In conclusion, we highlight the need to consider certain physicochemical soil properties and indeed report intertidal zonation when collecting data for blue carbon stock assessment surveys for local and national needs. These results can contribute to a better understanding of the variability of SOC in mangrove ecosystems and support more sustainable conservation and management of these important carbon sink ecosystems. Finally, the results highlight the need for comprehensive and interdisciplinary approaches to blue carbon research that can support efforts to mitigate and adapt to the impacts of climate change.

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