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NUTRIENT DYNAMICS IN MANGROVE ECOSYSTEM IS A FUNCTION OF LITTER PRODUCTION AND DECOMPOSITION AT SANDSPIT BACKWATER KARACHI, PAKISTAN

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Abstract

The importance of mangrove litter for food of a variety of organisms is well established. Litter production and decomposition has been studied previously from two locations in Pakistan. This communication presents release of dissolved nutrients in mangrove channel water at Sandspit. Overall concentration of nutrient ions was high during post-monsoon season. Highest values of all nutrients (NH4 15.41µg. l^{-1}, NO3 8.26 µg. l^{-1} and NO2 6.58 µg. l^{-1}), except for phosphates, were recorded in November. Phosphate had highest value (14.78 µg. l^{-1}) in December. The levels of all nutrients showed sharp decreases and attained lowest values in summer. The *in situ* seasonal values of nutrient ions had significant correlation with the litter production in the area. The litter trap data reveals high production of litter during dry post-monsoon season (1.93±1.15 $g.m^{-2}.d^{-1}$) which is largely constituted of leaf litter (52%). Similarly, the in vitro leaf decomposition experiment clearly demonstrate release of particulate and dissolved matter during decomposition and 50% weight loss was noted in 48 and 50 days under aerobic and micro-aerobic conditions, respectively. Rate of release of all nutrient ions was slightly slower under micro-aerobic condition. Seasonal variability observed in water parameters and dissolved nutrients showed significant correlation with the litter production and decomposition. It is evident from the data that nutrient concentration in mangrove ecosystem (Manora Channel) is regulated through mangrove detrital system, though some influence of Layari River may exist. The organic detritus and nutrients could potentially enrich the coastal waters and ultimately support primary and secondary productivity.

Key words: *Avicennia marina*, Nutrient release, Mangrove, Seasonal variation, Detritus.

Introduction

Litter produced in the mangrove ecosystem provides food for a wide variety of organisms, including commercially important detritus feeding organisms (Husain, 2020, Muro-Torres *et al.,* 2020, Friis & Killilea, 2023). Freshly fallen litter in water or on the sediment surface is either transferred through tidal currents to the adjacent water bodies or accumulated as peat and buried under forest sediments (Naidoo, 2023; Shanij *et al.,* 2023). Litter degradation starts with rapid leaching of dissolved organic (carbon, nitrogen, phosphorus, and tannin) and inorganic matter (Howard *et al.,* 2020; Mamidala *et al.,* 2022, 2023). Litter decomposition involves detritus feeding, microbial degradation and leaching of nutrients **(**Jessen *et al.,* 2020, Shanij *et al.,* 2023). During decomposition the chemistry of detritus changes completely (Van Vinh *et al.,* 2020, Mamidala *et al.,* 2023).

Particulate organic detritus is one of the major components in the movement of organic matter from mangroves to the adjacent coastal waters (Tue *et al.,* 2012; Saavedra-Hortua *et al.,* 2020; Mamidala *et al.,* 2023). However, it depends on flushing rate, tidal amplitude, geomorphology, and structural characteristic of the plants (Signa *et al.,* 2017; Sanyal *et al.,* 2020; Alongi, 2020). Contribution of mangrove forest to the near-shore food chain, nutrient supply, and net export of detritus from mangrove forests have been appreciated (Yan *et al.,* 2022). The relationship between biodiversity and ecosystem properties is a function of litter decomposition (Carugati *et al.,* 2018, Wintah *et al.,* 2023). High nutrient production in mangrove ecosystem has profound effect on the biodiversity and abundance of organisms. From fisheries point of view, the mangrove ecosystem has significant importance owing to its role as feeding and breeding grounds for juveniles of many economically important finfish and shellfish has been well documented (Kathiresan, 2021; Priya *et al.,* 2023).

Exchange of nutrients between mangrove and coastal water is difficult to measure and hence the process is poorly understood. A few reports on the release of nutrients in mangrove swamps are available from various parts of the world (Taillardat *et al.,* 2019; Twilley, 2019; Mamidala *et al.,* 2022, 2023).

Pakistan has significant mangrove cover along the Sindh and Baluchistan coasts (Siddiqui *et al.,* 2008, Ahmed *et al.,* 2020). Release of substantial amount of organic matter from *Avicennia marina* forest into the coastal water has been reported earlier (Siddiqui & Qasim, 1988; Farooqui *et al.,* 2012; Sahar *et al.,* 2023). Despite the importance of dissolved nutrient flux, the release of nutrient from decomposing leaves of *A. marina* has not been studied. To understand the importance and function of these forests it is inevitable to undertake studies on nutrient available and its release from decomposing mangrove litter in this ecosystem. Present study involves assessment of litter production, litter decomposition, dissolved nutrients release during leaf litter decomposition and its seasonal variation in mangrove channels at Sandspit backwaters.

Material and Methods

Study site: The Sandspit mangrove area (24°82'84"N 66°94'34"E) is connected to the Arabian Sea through Manora channel. Ships and boats frequently use this channel to access Karachi Port and Fish harbour. The Manora channel is flushed twice every day through tidal currents and receives discharge from the Lyari River, a continuous source of fresh water but also carrying domestic and industrial effluents (Fig. 1).

Fig. 1. Map showing study site in mangrove forest located at Sandspit backwaters.

Field experiments

Litter production: Seasonal litter production was estimated at Sandspit backwater mangroves by fixing nine litter-traps (25x25 cm) under the plant canopy (for details see Farooqui *et al.*, 2012). The litter collected in the traps was recovered bimonthly, carefully sorted into different component (i.e., leaves, twigs, flower, fruits and other miscellaneous) and weighed after drying at 70°C for 48hrs. Data from Farooqui *et al.*, (2012) was used to compare it with the seasonal dissolved nutrients in the adjoining channel water.

Seasonal analysis of channel water (dissolved nutrients and other parameters): Water samples (from 1 m below the surface) were collected from mangrove channels every month during high tides in acid-washed polyethylene screw capped bottles and brought to the laboratory on ice. Samples were filtered immediately (Whatman GF/F) and analyzed within12 hrs. for dissolved nutrients (ammonia, nitrate, nitrite, and phosphate) according to previously describe methods (Parsons *et al*.,1984).

Other water parameters, such as, temperature (mercury thermometer), salinity (refractometer 0161633ATAGO, Japan) and pH (ELEMETRON CP-401 pH meter) were also analyzed at the same site. Water samples were also fixed on site for the analysis of dissolved oxygen as per Winkler's method (Parsons *et al.*, 1984).

Laboratory experiment

Decomposition and nutrient release: Fresh yellow leaves of *A. marina* were picked from mangrove trees, washed with tap water and blot dried. Known quantities (15 g) of leaves were placed in 30 beakers (100 ml) capacity containing well aerated filtered (Whatman GF/F) seawater. Fifteen sets of beakers incubated in well aerated seawater providing aerobic condition and (ii) another set of 15 beakers was incubated in seawater under micro-aerobic condition in anaerobic jars. Triplicate bags were randomly selected and recovered at the incubation period of 0, 7, 14, 30 and 60 days. Content from each beaker was filtered (Whatman GF/F), leaf material on the filter was air dried briefly and weighed to obtain weight remaining. The samples from filtrate (50 ml) were analyzed for dissolved nutrients (ammonia, nitrate, nitrite, and phosphate) according to previously described methods (Parsons *et al.*, 1984).

Data analysis

Pearson Correlation coefficient and nMDS plots were used to determine the relationship between physico-chemical parameters and dissolved nutrients in channel waters by using PAST version 2.13 (Hammer *et al.*, 2001) and PRIMER software package version 7.0 (Clarke & Gorely, 2006; Clarke & Gorely, 2015). Linear regression was used to determine the relationship between concentration of nutrients and weight loss during incubation period. The statistical software Minitab-17.0 was used for statistical analysis.

Results

Litter production: A seasonal variability in litter production and nutrient leaching (Table 1) were recorded in Sandspit backwaters mangroves depicting low value of litter production during pre-monsoon (0.58±0.15 $g.m^{-2}.d^{-1}$) followed in ascending order by monsoon season (1.10±0.43 $g.m^{-2}.d^{-1}$) and post-monsoon season (1.93±1.15 $g.m^{-2}.d^{-1}$). Leaf-litter constituted 52% of the total litter fall. Low contribution of fruits (19%), flower (17%) and twigs (4%) were recorded including 8% of other miscellaneous component (Fig. 2).

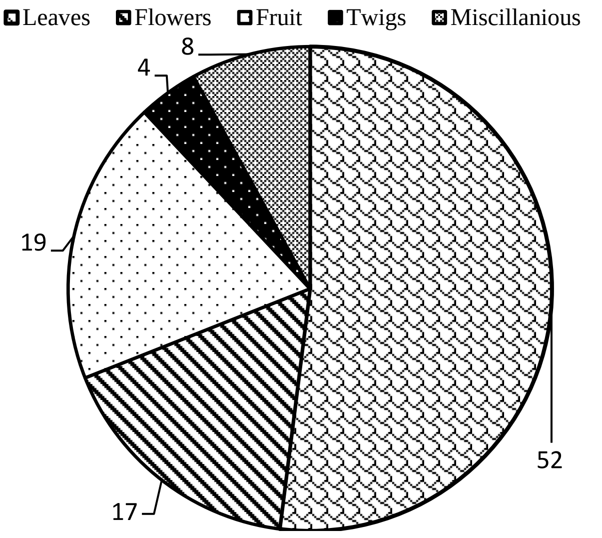

Fig. 2. Percent litter fall in *A. marina* mangrove stands at Sandspit backwater during study period (modified from Farooqui *et al.*, 2012).

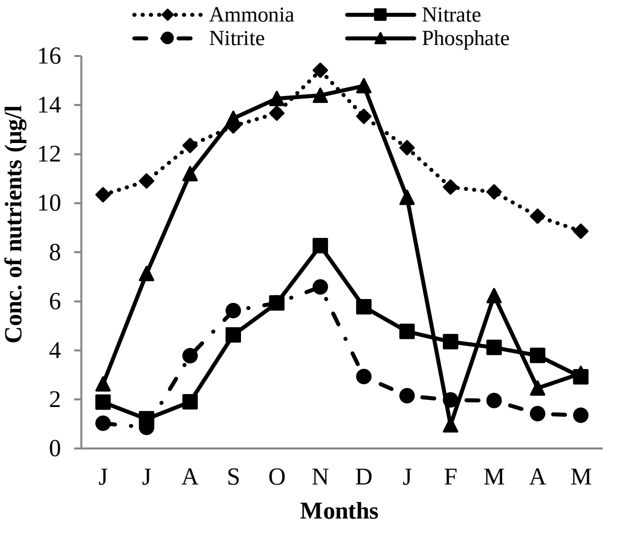

Fig. 3. Seasonal variation in the concentration of nutrients (ammonia, nitrate, nitrite and phosphate in channel water at Sandspit during study period.

Table 1. Seasonal variation in concentration of nutrient ion (µg/l) in channel water and rate of litter fall (gm.m^{-2}.d^{-1})) at Sandspit mangrove area.

Seasons	Total litter fall (gm.m^{-2}.d^{-1})	Concentration of nutrient ions (µg/l)			
		Ammonia	Nitrate	Nitrite	Phosphate
Pre-monsoon	0.58 ± 0.15	10.64 ± 1.34	4.19 ± 0.37	1.84 ± 0.31	4.89 ± 4.11
Monsoon	1.10 ± 0.43	10.42 ± 1.43	1.91 ± 0.75	1.72 ± 1.35	5.93 ± 3.96
Post-monsoon	1.93 ± 1.15	13.81 ± 0.97	6.01 ± 1.46	5.14 ± 1.54	14.07 ± 0.54

Table 2. Two-way ANOVA showing individual effect of seasons on nutrient ion (NO_2^-; NO_3^-; NH_4^+; and PO_4^{3-}) concentrations.

Factor	F-value
Nutrients	9.4***
Seasons	16.25***

Where, *** = p<0.001

Analysis of channel water

Dissolved nutrients: In general, variable nutrient concentrations were observed in channel water with a clear seasonal pattern (Fig. 3). Overall concentration of nutrient ions were high during post-monsoon season (Tables 1 and 2). Highest values of all nutrients (NH_4: 15.41µg. l^{-1}, NO_3: 8.26 µg. l^{-1} and NO_2: 6.58 µg. l^{-1}), except for phosphates, were recorded in November. Phosphate had highest value (14.78 µg. l^{-1}) in December. The levels of all nutrients showed sharp decreases and attained lowest values in summer. Lowest values were recorded for ammonia (8.85 µg. l^{-1}) in May, nitrate, and nitrite in June (1.2 µg. l^{-1} and0.86 µg. l^{-1}), and phosphate (0.96 µg. l^{-1}) in February (Fig. 3). The Pearson correlation analyses showed (Table 3) that ammonia had significant correlation with nitrate (r^2 = 0.72), nitrite (r^2= 0.86) and phosphate (r^2=0.912), respectively. Water temperature was significantly correlated with salinity (r^2= 0.77), pH (r^2= 0.729 and nitrate (r^2= 0.616). The relationship between the seasonal litter production and dissolved nutrient concentration in the adjacent channel was also assessed. Ammonia, nitrite and phosphate concentrations in the channel water had significant positive correlation with the litter production except for phosphate concentrations (Fig. 4).

Table 3. Pearson correlation coefficient matrix showing relationship between concentration of nutrients (nitrate, nitrite, ammonia and phosphate) and hydrographic parameters (air temperature, water temperature, mud temperature, salinity, pH and dissolved oxygen) observed in channel water at Sandspit.

Water variables	AT (°C)	WT (°C)	ST (°C)	Salinity (PSU)	DO (mg/l)	Ammonia (µg/l)	Nitrate (µg/l)	Nitrite (µg/l)
W T (°C)	0.904*	-	-	-	-	-	-	-
ST (°C)	0.9*	0.99*	-	-	-	-	-	-
Salinity (PSU)	0.879*	0.77*	0.769*	-	-	-	-	-
pH	0.84*	0.729*	0.721*	0.859*	-	-	-	-
DO (mg/l)	-	-	-	-	-	-	-	-
Ammonia (µg/l)	-	-	-	-	0.518*	-	-	-
Nitrate (µg/l)	0.652*	0.616*	0.514*	-		0.411±	-	-
Nitrite (µg/l)	-	0.169	-	-		0.791*	0.651*	-
Phosphate (µg/l)	-	-	-	0.231		0629*	0.845*	0.837*

AT (air temperature), WT (water temperature), ST (mud temperature), DO (dissolved oxygen) * = Highly significant at probability 0.05

Table 4. Seasonal variation of physico-chemical variables in channel water at Sandspit mangrove.

Seasons	Temperature (°C)		Salinity (PSU)	pH	DO (mg/l)
	Water	Mud			
Pre-monsoon	23.44 ± 3.31	23.30 ± 3.32	40.08 ± 2.45	6.80 ± 0.09	1.92 ± 0.22
Monsoon	29.77 ± 3.71	30.10 ± 3.54	46.11 ± 1.18	7.44 ± 0.38	0.96 ± 0.20
Post-monsoon	23.73 ± 2.46	22.81 ± 1.55	41.98 ± 3.37	6.96 ± 0.39	1.61 ± 0.45

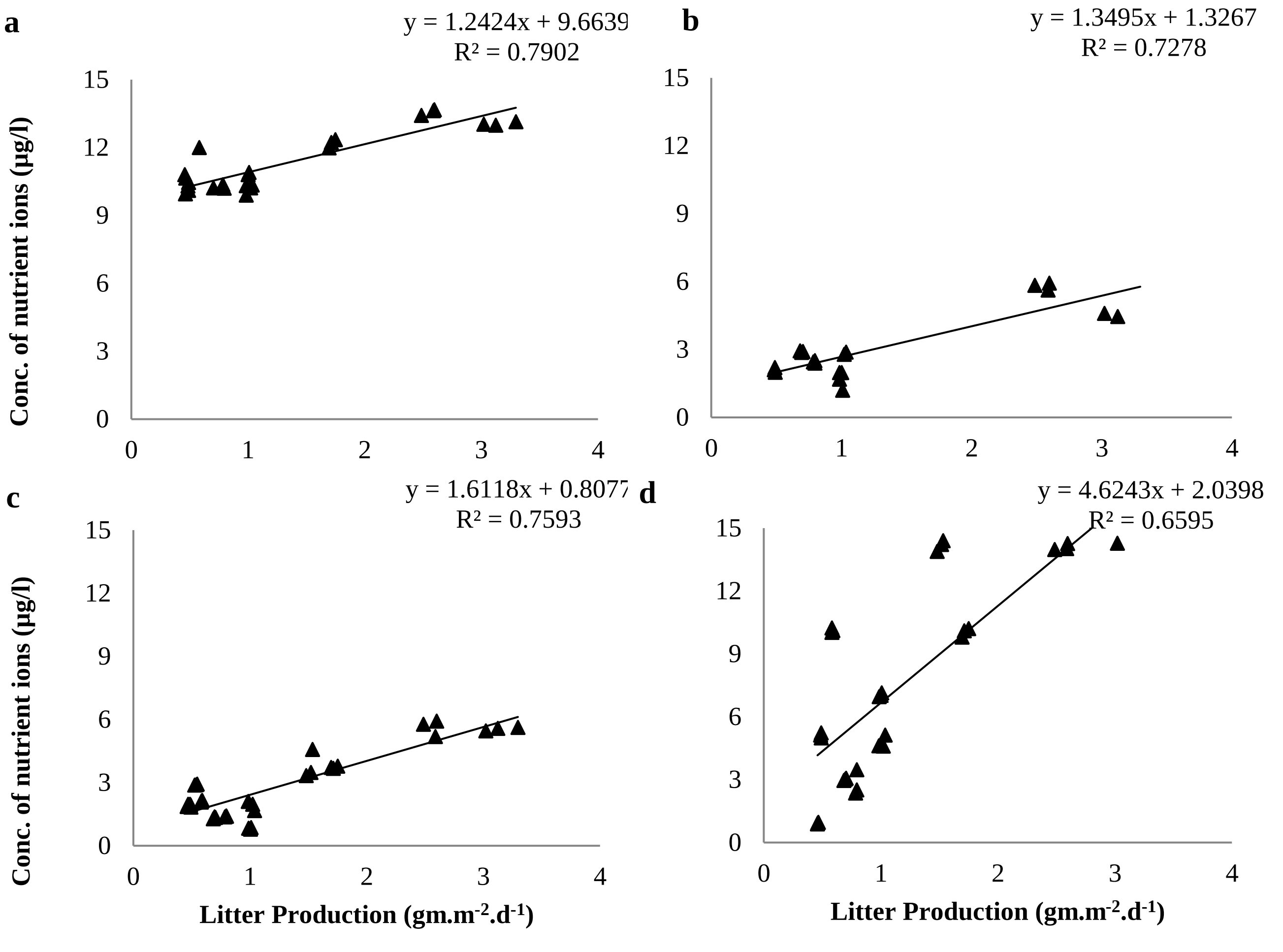

Fig. 4. Concentration of nutrient ions (a) ammonia, (b) nitrate, (c) nitrite and (d) phosphate (µg/l) in channel water with respect to letter production (gm.m^{-2}.d^{-1}) at Sandspit mangrove area.

Other parameters: Water parameters recorded for samples collected from mangrove channel through a year are shown in Table 4. Seasonal variability in the water (23.44-29.77ºC) and sediment (22.81-30.10ºC) temperatures were noted and the highest temperature values were recorded in monsoon and lowest during pre-monsoon in water and post-monsoon in sediment (Table 4). Salinity of channel water ranged from 40.08-46.11 PSU with highest value in monsoon and lowest pre-monsoon seasons (Table IV). Channel water remained slightly acidic during pre- and post-monsoon with a minimum pH value of 6.8 observed in post-monsoon. Alkaline pH condition was recorded during monsoon season (Table 3). Concentration of dissolved oxygen in channel water varied from 0.96 to 1.92 µg. l^{-1} and the minimum values were recorded in post-monsoon. Water and sediment and water temperature and salinity were significantly correlated (Pearson correlation; Table 3).

A relationship was made by using non-metric MDS (nMDS) assessment for seasonal variation in physicochemical variable of channel water and nutrient leaching with respect to % weight loss (Fig. 5). The Figure 5a Shown clearly 60% similarity between DO (dissolved oxygen), N2 (nitrite) and N3 (nitrate), 80% between pH, AM (ammonia) and P (phosphate) as well as 80% between WT (water temperature), MT (mud temperature) and S (salinity). Whereas, leaching of nutrients with respect to weight loss showing 20% similarity (Fig. 5bi-ii).

Laboratory experiment

Decomposition and nutrient release: The laboratory experiment clearly indicates that particulate and dissolved materials were released during decomposition of mangrove leaf litter during both aerobic (AC) and micro-aerobic (MAC) incubation. Hence the weight of the decomposing leaves decreases slowly in the initial phase and more rapidly later. It was estimated that 48 and 50 days were required for 50% reduction in weight during aerobic and micro-aerobic incubation, respectively. The dissolved nutrient release also followed the same pattern and the concentration of all nutrients (ammonia, nitrate, nitrite, and phosphate) increased slowly during early incubation period (up to 7 days) and a rapid phase of nutrient release was noted as decomposition proceeds further (Fig. 6). In both aerobic and micro-aerobic condition the rate of ammonia release was highest (AC: 0.221 $\mu g.l^{-1}.d^{-1}$; MAC: 0.194 $\mu g.l^{-1}.d^{-1}$) followed in descending order by nitrate (AC: 0.174 $\mu g.l^{-1}.d^{-1}$; MAC: 0.127 $\mu g.l^{-1}.d^{-1}$), phosphate (AC: 0.141 $\mu g.l^{-1}.d^{-1}$; MAC: 0.113 $\mu g.l^{-1}.d^{-1}$), and nitrite (AC: 0.122 $\mu g.l^{-1}.d^{-1}$; MAC: 0.091 $\mu g.l^{-1}.d^{-1}$), respectively (Fig. 6 A & B). Dissolved nutrients released during incubation appeared to have a significant positive correlation with the weight loss (Figs. 7 and 8).

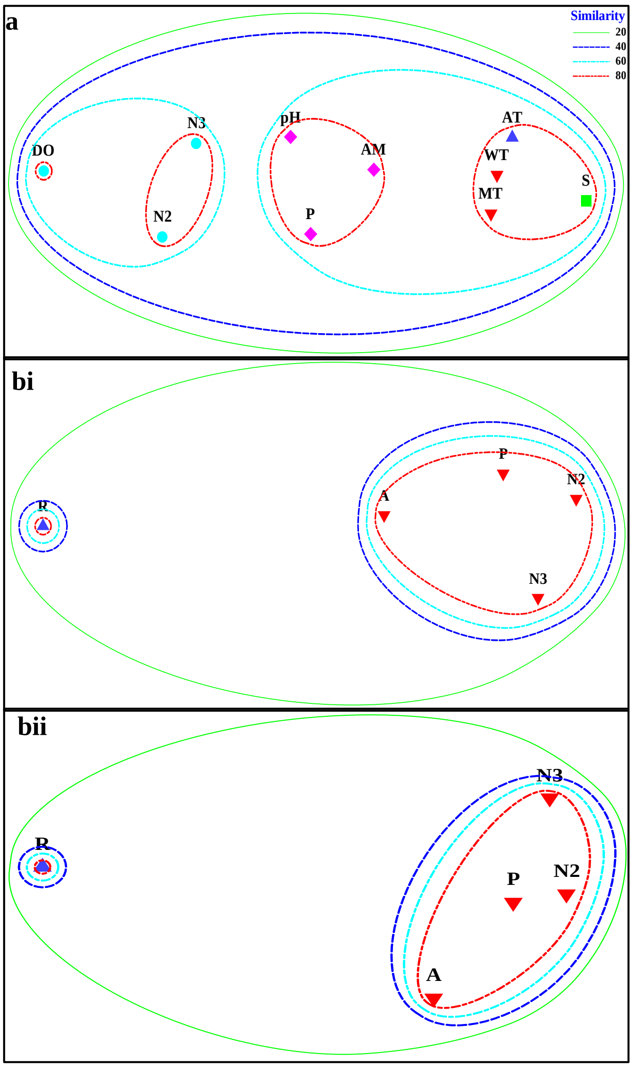

Fig. 5. Seasonal variation in % similarity between (a) water parameters, (bi) % weight loss and nutrient leaching in aerobic condition and (bii) % weight loss and nutrient leaching in micro-aerobic environmental condition at Sandspit along Karachi coast.

Discussion

Here we report on the assessment of dissolved nutrient ions variations in a mangrove stand at Sandspit (Karachi, Pakistan). Seasonal variations in nutrient composition in coastal marine ecosystem is well established (Masoud *et al.*, 2019; Minu *et al.*, 2020; Matos *et al.*, 2022; Kamal *et al.*, 2023). The values observed for the channel water in the present work are in good agreement with the previous studies from Pakistan, for example, Manora channel (Khan & Saleem, 1988, Rizvi *et al.*, 1988; Shoaib *et al.*, 2017; Sahar *et al.*, 2023) and Sonmiani Bay (Farooq, 2006; Hameed-Baloch *et al.*, 2014), and from elsewhere (Zhang *et al.*, 2020; Sun *et al.*, 2022; Anitha Kumari *et al.*, 2023). The major contribution in the dissolved nutrients is apparently through leaf litter production and decomposition involving leaching and microbial degradation (Hutchison *et al.*, 2014; Mamidala *et al.*, 2023). Leaching alone removes considerable substances and can produce high levels of DOM (Saifullah *et al.*, 2016). Environmental conditions, for example, temperature (Sanyal *et al.*, 2020), tidal inundation (Howard *et al.*, 2020; Mamidala *et al.*, 2023), role of microbial community and invertebrates grazing efficiency (Mamidala *et al.*, 2023; Morrison *et al.*, 2023) are known to control the decomposition and release of DOM and POC in the mangrove environment. Mangrove leaves have major contribution in the liter production (Faroqui *et al.*, 2012; Mamidala *et al.*, 2023) and hence appears to regulate nutrient cycle in the mangrove environment. In the present study, the pattern of nutrient variation in the channel water follows the seasonal pattern of litter production.

The peak in the litter production (Faroqui *et al.*, 2012, Siddiqui and Qasim 1988) appears more than a month earlier of the highest nutrient values observed in November (NH4, NO3 and NO2) and December (PO4). The gap in the highest litter production and maximum nutrient concentration in channel water is probably due to the time required for decomposition of litter and release of particulate and dissolved nutrients in the field condition (average t50 = 51.5 d; average decay constant = 0.135 Kd^{-1}; Shafique *et al.*, 2015). Although nutrient loading through Layari River carrying sewage and other wastes also seems to impact nutrient levels in the back waters, but we suggest that the nutrient fluctuation in Manora channel water is a function of rate of litter production and decomposition as expected and the effluents have low impact. All nutrients assessed here except nitrate and phosphate ions in mangrove channel have significant positive correlation with litter production data. However, in the laboratory experiment, all nutrients, including nitrate and phosphate ions, increase concomitantly with decomposition of leaves and show a significant positive correlation. The disparity in the litter production and nitrate/phosphate levels in the channel water could be attributed to its variable nutrient loadings through Layari (effluents), consumption by planktons (Flores, 2022; Mack, 2023), denitrification and/or ammonification; later being the preferred pathway (Mack, 2023); microbial phosphate solubilization known to occur in mangrove sediment (Mack, 2023) and conversion of polyphosphates into orthophosphates (Pandey & Pande, 2023).

We designed the nutrient leaching experiment in laboratory so that it mimics the litter decomposition conditions prevailing in the field (e.g., aerobic and micro-aerobic). The experiment shows that mangrove litter releases both particulate material and dissolved nutrients with slower rates during initial stage of decomposition and much faster during later stage of decomposition (Pradisty *et al.,* 2021). This observation supports the notion, already mentioned above, that increases in the nutrient levels in channel water has a lag period of about a month with the increases observed in the litter production since litter produced in mangrove environment takes time to decompose completely (Roy *et al.,* 2012; Mamidala *et al.,* 2022, 2023).

In the summary, it is evident that dissolved nutrient ions are released from the decomposing litter. Taking into account the total litter production in this area (4.35 tonnes.ha^{-1}.y^{-1}; Faroqui *et al.,* 2012), a considerable amount of nutrients are being into the system through litter decomposition (Kamruzzaman *et al.,* 2019; Shanij *et al.,* 2023). The organic detritus and nutrients could potentially enrich the coastal waters and ultimately support primary and secondary productivity.

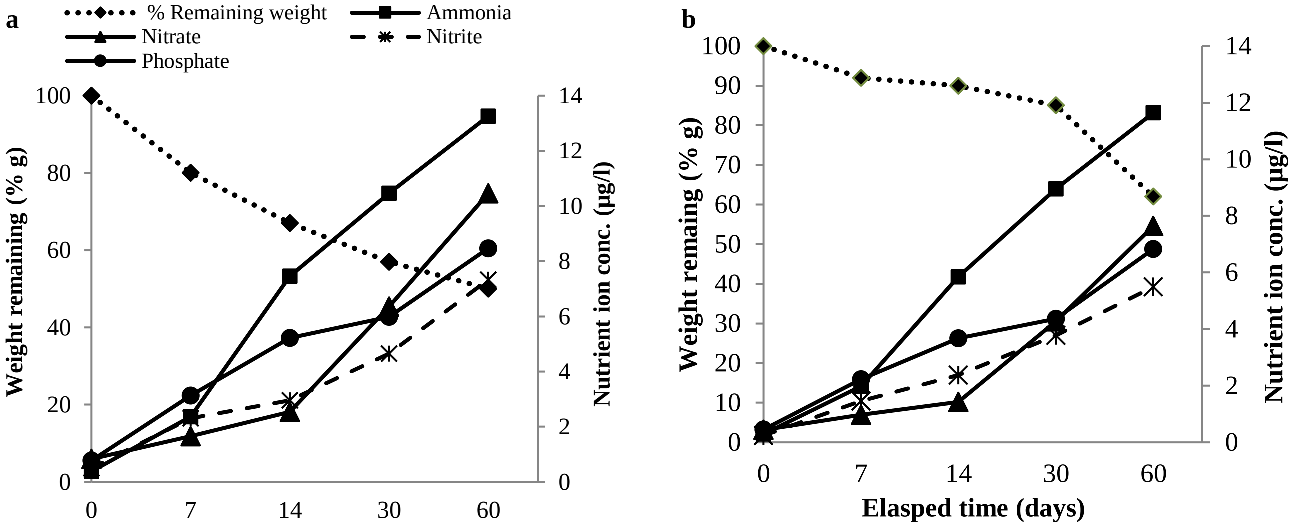

Fig. 6. Variation in the concentration of ammonia, nitrate, nitrite and phosphate observed during decomposition of *A. marina* foliage: a) aerobic condition and b) micro-aerobic condition.

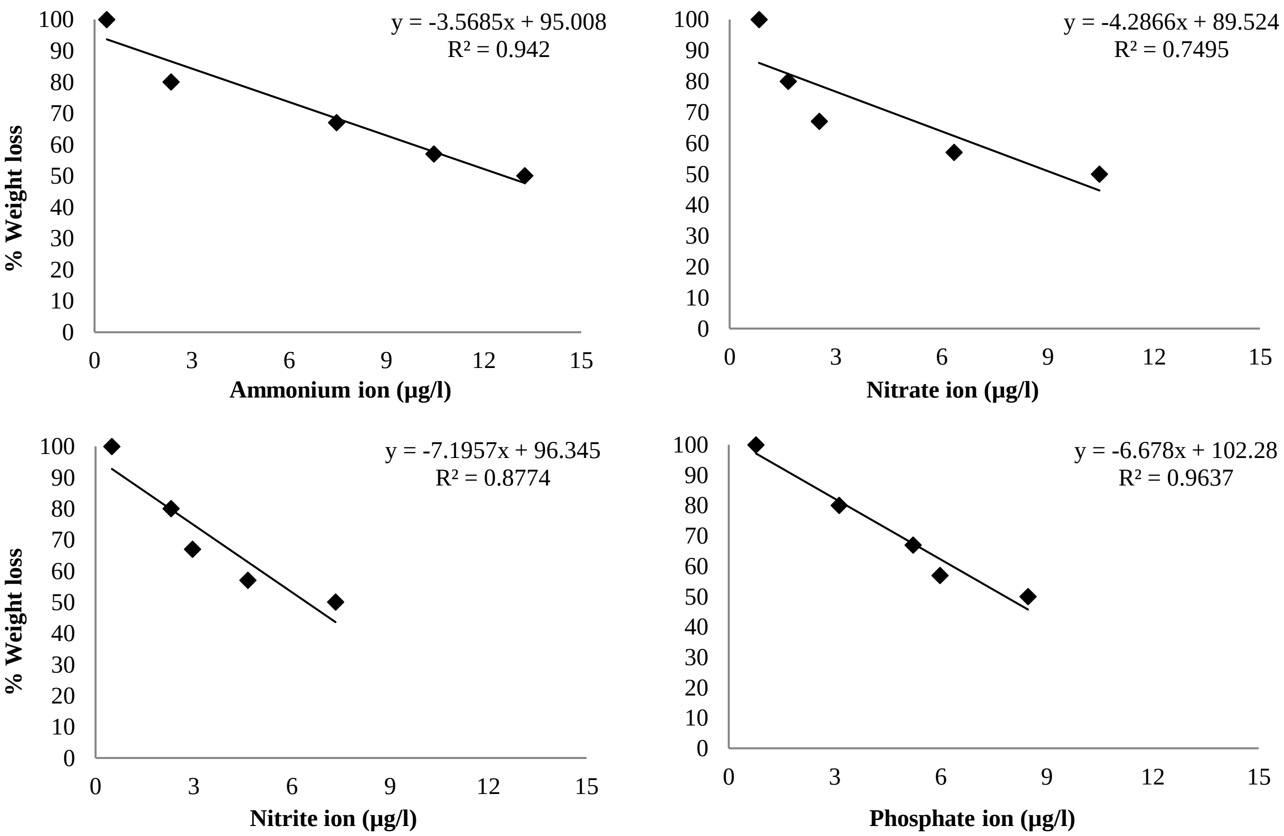

Fig. 7. Concentration of nutrient ions (µg/l) leaching during *Avicennia marina* leave decomposition in lab aerobic condition (LAC).

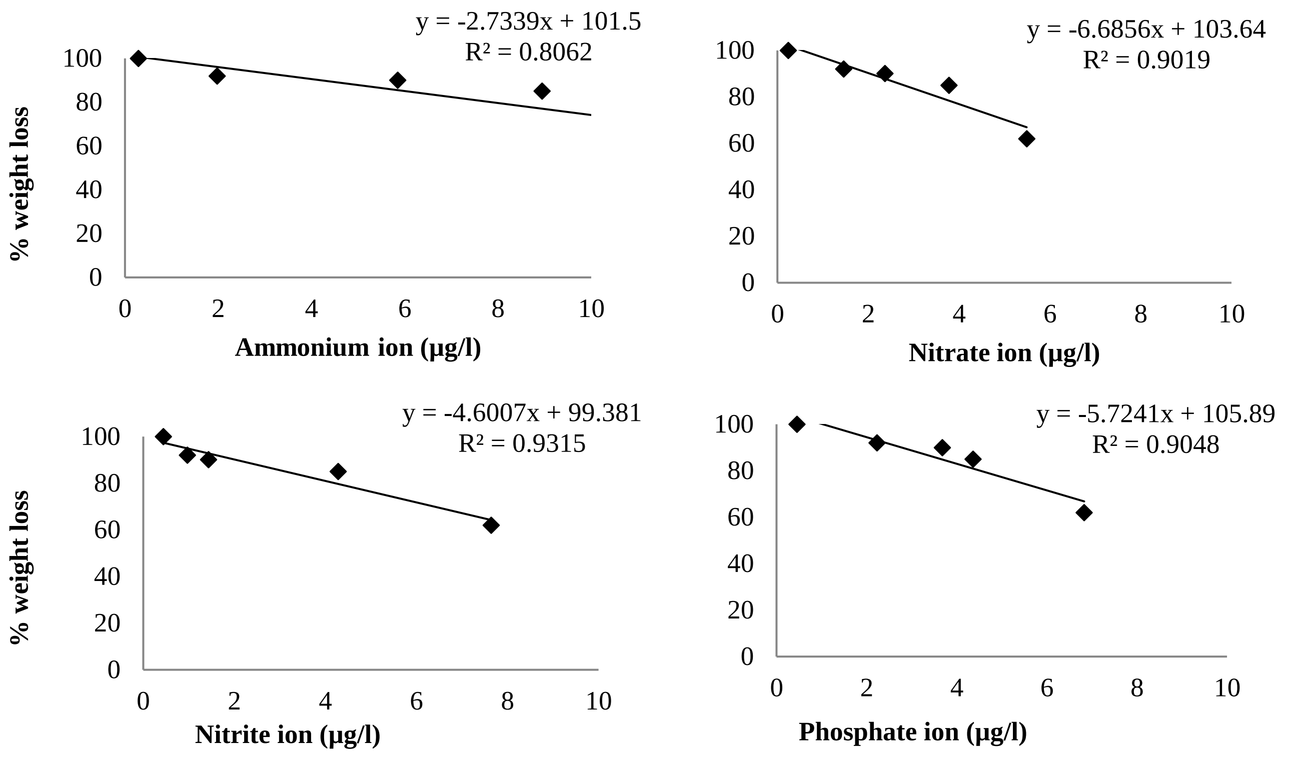

Fig. 8. Concentration of nutrient ions (µg/l) leaching during *Avicennia marina* leave decomposition in lab anaerobic condition (LAAC).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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