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RESEARCH ARTICLE **LIFE SCIENCE**

BIOLOGICAL CYCLING OF MACRO-NUTRIENTS (N, P, K, Ca, Mg, S) IN *BRUGUIERA PARVIFLORA* DOMINATED MANGROVE FOREST AT KUALA SELANGOR NATURE PARK, MALAYSIA

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Abstract: Biological cycling of macro-nutrients (N, P, K, Ca, Mg and S) were studied by synthesizing the previous and new data from *Bruguiera parviflora* dominated mangroves at Kuala Selangor Nature Park, Malaysia. The total stock and annual accumulation of N, P, K, Ca, Mg and S in plant biomass were 60.11 kg ha^{-1}y^{-1}; 11.48 kg ha^{-1}y^{-1}, 36.25 kg ha^{-1}y^{-1}; 72.75 kg ha^{-1}y^{-1}; 31.32 kg ha^{-1}y^{-1} and 82.12 kg ha^{-1}y^{-1} respectively. The annual return of N, P, K, Ca, Mg and S in the form of litter fall were 59.82 kg ha^{-1}, 10.93 kg ha^{-1}, 23.43 kg ha^{-1}, 118.31 kg ha^{-1}, 29.25 kg ha^{-1} and 54.15 kg ha^{-1} respectively, which yield the annual uptake of N, P, K, Ca, Mg and S were 119.92 kg ha^{-1}, 22.41 kg ha^{-1}, 59.69 kg ha^{-1}, 191.07 kg ha^{-1}, 60.57 kg ha^{-1} and 136.26 kg ha^{-1}, respectively. The return/accumulation ratios of N, P, K, Ca, Mg and S showed that accumulation = return for N, return > accumulation for Ca, accumulation > return for P, K, Mg and S. The calculated turnover period of N, P, K, Ca, Mg and S were 10 yr, 10 yr, 15 yr, 6 yr, 10 yr and 14 yr respectively.

Key words: Biomass increment, *Bruguiera parviflora*, litter production, macro-nutrients, mangroves, nutrient cycling

Introduction

Mangroves are ecologically and commercially important and serve as a link between terrestrial and marine ecosystems (Aksornkoae, 1993; Field, 1995). Mangroves are the obvious source of inorganic and organic compounds for estuarine production (Aksornkoae and Khemnark, 1984) and act as an open pathway of nutrient transport to the aquatic ecosystem. These ecological functions make the mangroves most productive ecosystem in the tropical and sub-tropical coastal region (Clough and Attiwill, 1982; Hutchings and Saenger, 1987). Estimation of standing biomass, annual biomass increment, litter production and litter standing crop are the approaches for estimating the productivity and functioning of a mangrove forest (Ong *et al*., 1985; Gong and Ong, 1990). At the same time, measurement of within stand nutrient cycling could be another useful approach of estimating mangrove productivity and functioning.

There are few studies on within stand nutrient cycling in mangroves (Li, 1997; Zheng *et al*., 1997), but they were conducted in subtropical mangroves with *Rhizophora stylosa*, *Aegiceras corniculatum* and *Kandelia candel* dominated stand in Shenzhen of South China. But, no attempt

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has been taken on the study of within stand nutrient cycling in tropical mangroves. *Bruguiera parviflora* is the least studied among the tropical mangrove communities in Malaysia as well as elsewhere and found to occur throughout Southeast Asia to tropical Australia. It serves as a nurse crop by modifying the site condition to suitable for climax species in the process of succession (Watson, 1928; Noakes, 1952; Chapman, 1976). Considering the importance of this species, the present study synthesized the previous and new data and estimates the biological cycling of macro-nutrients (N, P, K, Ca, Mg and S) in *B. parviflora* dominated tropical mangroves.

Materials and Methods

Study site: The study area consists of 100 ha of *B. parviflora* dominated mangrove forest (Latitude 3°20′ N and Longitude 101°14′ E) in the Kuala Selangor Nature Park, Kuala Selangor, Malaysia and categorized under Watson's (1928) tidal inundation class 4. The mean annual rainfall is about 1790 mm and mean minimum and maximum temperatures are 24 and 32 ºC respectively. Wet season is from September to December, which contributes 46% of total annual rainfall. Intermediate season contributes 31% of annual rainfall from January to April and dry season contributes 23% of annual rainfall from May to August.

Standing biomass and annual biomass increment: Standing biomass of *B. parviflora* saplings and trees in the present study were taken from the study of Mahmood *et al.* (2004) (Table 1). Annual biomass increment in different components (leaves, branches, stems, bark and roots) of *B. parviflora* saplings and trees were measured from randomly selected nine saplings and eighteen trees. Diameter at breast height (DBH) of individual sapling and tree were measured and tagged during September 2001, and DBH of the tagged saplings and trees were again measured at yearly interval for successive two years. The biomass of each tagged sapling and tree were estimated by using the allometric equations (Log_{10} Biomass = A + B Log_{10} DBH) (Mahmood *et al.*, 2004). The biomass accumulation in different components of each tagged sapling and tree were computed by subtracting the initial biomass from the final biomass. Finally, biomass accumulation was expressed in t ha^{-1} and calculated from the saplings and trees having mid DBH of respective DBH classes as derived by Mahmood *et al.* (2004).

Sampling of plant, litter and soil: Six saplings (DBH ranged from 1 to <4 cm) were randomly selected and uprooted by low pressured water jet and portable winch. Uprooted saplings were then separated into different components (leaves, buds, branches, bark, stems and roots) and sub-samples (about 100 g) of each component were taken randomly from each sapling. Six trees (DBH ranged 4 to <16 cm) were selected randomly and sub-samples of leaves, buds, and small branches (diameter < 2 cm) were collected randomly. Increment borer was used to collect stem samples. One buttress root was selected randomly from each tree and excavated by using high-pressure water jet and portable winch. Sub-samples (about 100 g) of leaves, buds, small branches (diameter < 2 cm), bark, stems and roots collected from each trees. All sub-samples of plant components were oven-dried at 80 ºC until constant weight. Eighteen litter traps (1 m x 1 m) were suspended under the tree canopy by nylon rope between trees at a height of 1.5 m above the ground level. The trapped litter was collected at monthly interval for 20 months (December 2001 to July 2003). The trapped litter of individual catcher was sorted into leaves, small branches, bracts, flowers and propagules and oven dried at 80 °C to constant weight. Macro-nutrient contents in different components of B. pariflora saplings, trees and litter production were analysed during the intermediate season (March 2002 and 2003), dry season (July 2002 and 2003) and wet season (November 2002). Nine samples of topsoil (up to 30 cm depth) were collected randomly from the study area during the wet season (November 2001 and 2002), intermediate season (March 2002 and 2003), dry season (July 2002 and 2003), by using core sampler of 5 cm diameter. Soil texture and bulk density were measured according to Black (1965).

Nutrient analysis: The different samples of saplings, trees, litter components and soil were processed according to Allen (1974) for the determination of Nitrogen (Weatherburm, 1967), Phosphorus (Timothy *et al*., 1984) and Sulphur (Tandon, 1993). Potassium concentration in the sample extractions was measured by Flame photometer (Jenway PFP, England). Calcium and Magnesium concentration in extraction were measured by Atomic Absorption Spectrophotometer (AAS PERKIN ELMER 4100, USA). Weighted mean and standard error of nutrient concentration were calculated.

Nutrients stock, annual return, accumulation and uptake: Nutrient stock in different components of saplings and trees were calculated from the individual nutrient concentration in each components multiplied by their dry weight. Annual accumulation of nutrients was calculated from the annual biomass increment in each component of saplings and trees multiplying with the concentration of individual nutrient. Annual return is the returned amount of a nutrient in 1 yr and this study only estimated the annual return of nutrients via litter fall. Therefore, the estimated values of nutrient return could be underestimation slightly. The amount of nutrient uptake, turnover rate (yr), absorption coefficient, utilization coefficient and cycling coefficient were calculated from the following equations:

Uptake = Return + Accumulation (Duvigneaud and Smet, 1970)

Turnover rate (yr) = Nutrient stock in biomass/Return of nutrients (Duvigneaud and Smet, 1970)

Absorption coefficient = Uptake of the nutrient/Nutrient in soil pool (Zheng *et al*., 1997)

Utilization coefficient = Uptake amount of nutrient/Stock of nutrient (Zheng *et al*., 1997)

Cycling coefficient = Return of nutrient/Uptake of nutrient (Zheng *et al*., 1997).

Results

Annual biomass increment and litter production: The yearly average biomass increments in saplings and trees were 0.58 t ha^{-1} and 16.51 t ha^{-1} respectively (Table 1). The amount of total litter production, leaf litter, small branches, bracts, flowers and propagules were 10.35 t ha^{-1}yr^{-1}, 7.06 t ha^{-1}yr^{-1}, 0.77 t ha^{-1}yr^{-1}, 1.03 t ha^{-1}yr^{-1}, 0.19 t ha^{-1}yr^{-1}and 1.30 t ha^{-1}yr^{-1} respectively.

Nutrients in plant components and soil: Relatively higher concentration of N, P, K and Mg were found in leaves, buds and flowers. Leaves, buds, flowers and barks contained higher concentration of Ca and roots contained higher concentration of S. Comparatively higher amount of S was stocked in plant biomass followed by Ca, N, K, Mg and P. Above-ground components of saplings and trees contributed to 87%, 85%, 75%, 88%, 45% and 69% stock of N, P, K, Ca, Mg and S respectively (Table 2). In litter components, leaves, flowers and propagules contained comparatively higher concentration of N, P and K. Higher concentration of Ca and Mg were found in leaves, bracts and flowers, but propagules contained comparatively higher concentration of sulphur (Table 3).

The soil texture was clay and the bulk density was 0.63 g cm^{-3} and the weighted mean concentration of N, P, K, Ca, Mg and S were 3.46 ± 0.01 mg g^{-1}, 0.32 ± 0.00 mg g^{-1}, 5.50 ± 0.48 mg g^{-1}, 3.30 ± 0.08 mg g^{-1}, 9.19 ± 0.39 mg g^{-1}, 6.48 ± 1.00 mg g^{-1} respectively.

Table 1. Standing biomass and annual biomass increment (kg ha^{-1}) in different components of *Bruguiera parviflora* saplings and trees (after Mahmood *et al.,* 2004).

Plant components	Standing biomass (t ha^{-1})	Biomass increment (t ha^{-1}yr^{-1})
Saplings:		
Leaves	0.08	0.04
Buds	5.01	--
Branches	0.12	0.06
Stems	0.61	0.38
Bark	0.08	0.05
Roots	0.14	0.05
Subtotal		0.58
Trees:		
Leaves	10.91	1.11
Buds	0.50	0.05
Flowers	0.40	
Branches	38.23	4.11
Stems	81.28	7.99
Bark	11.11	1.09
Roots	18.93	2.16
Subtotal		16.51
Total	162.42	17.09

Cycling of nutrients: The annual return of N, P, K, Ca, Mg and S in the form of litter fall were 59.82 kg ha^{-1}, 10.93 kg ha^{-1}, 23.43 kg ha^{-1}, 118.31 kg ha^{-1}, 29.25 kg ha^{-1} and 54.15 kg ha^{-1} respectively, with the order of Ca>N>S>Mg>K>P (Table 3).

Comparatively higher amount of S was annually accumulated in plant biomass followed by Ca, N, K, Mg and P (Table 4). Leaf fall is the main and quick source of nutrients return to the soil and contributed to 70%, 70%, 65%, 78%, 80% and 68% of the total annual return of N, P, K, Ca, Mg

Table 2. Weighted mean (± SE) concentration (mg g^{-1}) and stock (kg ha^{-1}) of macro-nutrients in different components of *Bruguiera parviflora* saplings and trees from Kuala Selangor nature park, Malaysia.

Plant components	Nutrient concentration (mg g^{-1})						Amount of nutrients in biomass (kg ha^{-1})					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Saplings:												
Leaves	12.07±0.16	1.14±0.07	7.47±1.50	8.98±0.93	8.03±0.99	5.43±1.02	0.97	0.09	0.60	0.72	0.64	0.43
Buds	9.09±0.33	1.38±0.06	5.80±0.78	10.19±0.1	5.64±0.87	3.74±0.45	0.05	0.01	0.01	0.05	0.03	0.02
Branches	5.43±0.34	0.84±0.08	3.68±0.57	6.88±0.35	1.46±0.12	3.55±0.72	0.65	0.10	0.44	0.83	0.18	0.43
Stems	1.52±0.01	0.59±0.09	0.95±0.02	1.55±0.00	0.60±0.01	2.29±0.48	0.92	0.36	0.58	0.95	0.36	1.39
Bark	4.42±0.07	0.79±0.05	1.25±0.02	9.46±0.36	1.14±0.04	4.76±0.56	0.35	0.06	0.10	0.76	0.09	0.38
Roots	3.67±0.07	0.83±0.03	4.74±0.18	3.71±0.20	4.34±0.25	12.55±2.16	0.51	0.12	0.66	0.52	0.61	1.76
Trees:												
Leaves	12.75±0.46	1.21±0.07	7.79±1.23	9.52±0.73	4.01±0.29	14.34±1.31	139.11	13.21	84.96	103.91	43.72	156.46
Buds	10.08±0.05	1.48±0.01	6.06±0.09	10.27±0.24	5.10±0.11	8.89±0.78	5.23	0.77	3.14	5.33	2.64	4.61
Flowers	7.94±0.91	1.47±0.01	8.90±0.43	11.34±0.35	5.58±0.12	14.33±0.98	3.28	0.60	3.67	4.68	2.30	5.92
Branches	4.52±0.27	0.83±0.08	1.83±0.25	6.80±0.44	0.95±0.10	3.77±0.34	172.72	31.81	69.83	259.97	36.18	144.11
Stems	1.53±0.01	0.38±0.03	0.97±0.03	1.10±0.01	0.40±0.01	1.92±0.27	123.95	31.01	79.06	89.68	32.72	155.82
Bark	4.30±0.09	1.35±0.04	1.28±0.03	13.11±1.27	0.80±0.01	5.79±0.94	47.82	14.99	14.22	145.64	8.85	64.30
Roots	4.04±0.12	0.83±0.04	4.52±0.51	4.22±0.57	8.33±0.83	12.46±2.09	76.43	15.70	85.51	79.79	157.66	235.88

Table 3. Weighted mean (± SE) concentration (mg g^{-1}) and annual return (kg ha^{-1}) of macro-nutrients through litter fall.

Litter production	Nutrient concentration (mg g^{-1})						Amount of nutrients in biomass (kg ha^{-1})					
	N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
Leaves	5.89±0.14	1.08±0.10	2.17±0.06	13.03±1.19	3.32±0.20	5.20±0.23	41.60	7.66	15.35	92.01	23.45	36.74
Branch	3.12±0.13	0.74±0.08	0.60±0.04	11.03±0.88	0.67±0.07	2.74±0.13	2.40	0.57	0.46	8.49	0.52	2.11
Bract	4.91±0.20	0.99±0.09	1.19±0.12	12.57±0.60	3.33±0.16	3.31±0.48	5.06	1.02	1.22	12.95	3.43	3.41
Flowers	6.79±0.05	1.60±0.03	4.33±0.13	14.17±1.97	3.36±0.13	4.14±0.09	1.29	0.30	0.82	2.69	0.64	0.79
Propagules	7.28±0.16	1.07±0.02	4.29±0.05	1.67±0.08	0.93±0.01	8.54±0.21	9.47	1.38	5.58	2.17	1.21	11.10

and S respectively (Table 3). The annual uptake of N, P, K, Ca, Mg and S were 119.92 kg ha^{-1}, 22.41 kg ha^{-1}, 59.69 kg ha^{-1}, 191.07 kg ha^{-1}, 60.57 kg ha^{-1} and 136.26 kg ha^{-1} respectively (Table 5). The return/accumulation ratios of micro-nutrients indicated that accumulation = return for N, return > accumulation for Ca, accumulation > return for P, K, Mg and S. The calculated turnover period of N, P, K, Ca, Mg and S were 10 yr, 10 yr, 15 yr, 6 yr, 10 yr and 14 yr respectively. The absorption coefficients for N, P, K, Ca, Mg and S were 0.018, 0.037, 0.006, 0.031, 0.003 and 0.011 respectively (Table 5).

Table 4. Annual accumulation (kg ha^{-1}) of macro-nutrients in different components of *Bruguiera parviflora* saplings and trees at Kuala Selangor nature park in Malaysia.

Plant components	Amount (kg ha^{-1})					
	N	P	K	Ca	Mg	S
Saplings:						
Leaves	0.48	0.05	0.30	0.36	0.32	0.22
Branches	0.33	0.05	0.22	0.41	0.09	0.21
Stems	0.58	0.23	0.36	0.59	0.23	0.87
Bark	0.22	0.04	0.06	0.47	0.06	0.24
Roots	0.18	0.04	0.24	0.19	0.22	0.63
Trees:						
Leaves	14.15	1.34	8.64	10.57	4.45	15.92
Branches	18.57	3.42	7.51	27.95	3.89	15.49
Stems	12.18	3.05	7.77	8.82	3.22	15.32
Bark	4.69	1.47	1.39	14.29	0.87	6.31
Roots	8.72	1.79	9.76	9.10	17.99	26.92

Discussion

Wide ranges of macro-nutrients (N, P, K, Ca, Mg and S) concentrations were observed in saplings, trees and litter components (Tables 2 and 3). Plants uptake available form of nutrients from soil and are translocated to different components to perform different physiological functions, normal growth and development (Jones *et al*., 1991; Marschner, 1995). Nutrient concentration in different components of plants varies with plant species, types of plant components and physiological age of the tissue (Walbridge, 1991). Moreover, the fluctuation in climatic condition (rainfall and temperature), soil edaphic factors, available nutrients in the substrate and concentration of other nutrients can affect the nutrient concentration in plant components considerably (Kabata-Pendias and Pendias, 1984; Walbridge, 1991; Jones, 1998; Mahmood *et al*., 2006) as well as mineral metabolism and uptake of nutrients by the roots (Barber, 1984; Jones *et al*., 1991; Marschner, 1995; Jones, 1998). Green leaves of *B. parviflora* saplings and trees contained relatively higher percentage of N (53-55%), P (9-20%) and K (61-81%) than the leaf litter, but 50% higher calcium concentration was observed in leaf litter compared to the green leaves (Tables 2 and 3). The re-translocation mechanism of N, P and K from senescence leaves and less mobile nature of Ca and its' accumulation in plant tissue compared to N, P and K (Jones, 1998) could result in lower content of N, P and K and higher content of Ca in leaves of litter production.

Relatively higher concentrations of Mg and S in roots of saplings and trees (Table 2) and higher biomass in roots (Table 1) resulted lower percentages of Mg and S stock and accumulation in above-ground biomass of saplings and trees. Among the above-ground components, stems contributed to about 50% of the total standing biomass but contained less amount of N, P, K, Ca, Mg and S stock and accumulation compared to leaves and buds (Tables 2 and 4) due to the very lower concentration of that nutrients in stem tissue of saplings and trees.

Table 5. Macro-nutrients uptake, return/accumulation ratio, turnover period, soil nutrients pool, absorption coefficient, utilization coefficient and cycling coefficient of *Bruguiera parviflora* dominated mangrove forest at Kuala Selangor nature park in Malaysia.

Variables	Macro-nutrients					
	N	P	K	Ca	Mg	S
Uptake (kg ha^{-1})	119.92	22.41	59.69	191.07	60.57	136.26
Return/Accumulation ratios	1.00	0.95	0.65	1.63	0.93	0.66
Stock (kg ha^{-1})	572.00	108.83	342.81	692.81	285.98	771.51
Turnover rate (yr)	10	10	15	6	10	14
Soil (0-30 cm depth) (kg ha^{-1})	6539	607	10395	6243	17369	12244
Absorption coefficient	0.018	0.037	0.006	0.031	0.003	0.011
Utilization coefficient	0.21	0.21	0.17	0.28	0.21	0.18
Cycling coefficient	0.50	0.49	0.39	0.62	0.48	0.40

Higher amount of Mg and S stock and accumulation in plants roots (Tables 2 and 4) and their lower amount in litter components (Table 3) resulted in very low return/accumulation ratio and longer turnover period for Mg and S (Table 5). Conversely, higher amount of K stocked and accumulation was observed in above-ground components of saplings and trees (Tables 2 and 4). But, lower concentration of K in litter components (Table 3) could lead to lower return/ accumulation ratio and longer turnover period (Table 5). Present study showed comparatively lower N, P and K stock, accumulation, return and uptake as compared to that in *Aegiceras corniculatum* and *Kandelia candel* dominated stand in Shenzhen, South China (Li, 1997). However, nutrients stock, accumulation, return and uptake in mangroves vary with standing biomass, annual biomass increment, litter production, plant species, age of stand, element characteristics, nutrients content in different components of plants, nutrient pool and soil physical and chemical characteristics (Jordan, 1985; Gong and Ong, 1990; Li, 1997; Zheng *et al*., 1997).

Nutrients in any forest ecosystem are cycled in a variety of chemical forms and the description of nutrient cycling is the part of that story. Nutrient cycling is never completely efficient. Nutrients released from trees through litter decomposition are rapidly taken up by the roots and retained within the system (Binkley, 1986). Efficient nutrient cycling is characterized by low nutrient losses from the system, as a whole, despite relatively large amounts of nutrient cycling between trees and soil (Vitousek, 1984). The sequences of absorption coefficient and utilization coefficient were P>Ca>N>S>K>Mg and Ca>N>P>Mg>S>K respectively (Table 5). However, the sequence of cycling coefficient was similar with utilization coefficient and suggested that the flow of Ca, Mg, and N were higher and lower flows were associated with K and S, which coincided with the turnover rate.

Conclusion

The general observation suggested that forest stores large mass of chemical elements in the wood of stem, branches and roots that move slowly through the system. On the other side, stored nutrients in leaves, other green parts and litter cycle rapidly between the soil and plants. There are many factors that control the nutrients input, output, storage and cycling in mangrove forest such as frequency of tidal inundation, runoff from surrounding land area, rainfall, canopy drip, stem flow, litter fall, litter decomposition and mineral uptake by plants (Boto, 1982; Alongi *et al*., 1992; Aksornkoae, 1993).

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