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Litter Quality and Nitrogen Mineralization of Dominant Tree Species in the Ratargul Swamp Forests, Bangladesh

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ABSTRACT

The present study aimed to study the relationship between litter quality and nitrogen mineralization rate in relation to the adaptation of the dominant tree species *Pongamia pinnata*, *Barringtonia acutangula* and *Crateva religiosa* of the Ratargul freshwater swamp forest in Bangladesh. Three plots were selected as replicates from the forest to collect soil and plant leaf and stem bark samples in such an way that all three species were present in each plot. Fully expanded youngest leaves and stem barks of the plants were collected for the determination of concentrations of nutrient elements such as N, P, K, Na, Ca, Mg and Fe. Defensive chemicals such as phenolics and tannin contents were also determined in leaf samples. Leaf litter of the three species was incubated with soil collected from the same forest in order to examine the effects of leaf litter on the amount of mineralized N in soil. Significant difference was found in N contents of leaf ($P < 0.05$) and bark ($P < 0.02$) among the three plant species with the highest mean value in bark (0.663%) and leaf (1.263%) of *C. religiosa* and that of the lowest in bark (0.233%) and leaf (0.683%) of *B. acutangula*. Significant difference was also observed in Fe concentration in bark ($P < 0.0001$) among the three plant species with the highest mean value (0.00085%) in bark of *C. religiosa* and the lowest in bark (0.00074%) of *B. acutangula*. Mineralized N in soil incubated with leaf litter decreased significantly compared with that of control soil (without litter) indicating the immobilization of nitrogen in soil. Overall, data of the present study showed interspecific differences in litter quality which could be related with the nitrogen mineralization indicating the implications for the adaptation of the plants of the wetland habitats.

Key Words: Defensive Chemicals; Immobilization; Incubation; Nutrient Elements; Wetlands

INTRODUCTION

Adaptation and distribution of plants are influenced by a number of factors including water, climate and nutrients (Wright et al. 2001, Ordonez et al. 2009). Among these factors, nutrients are one of the most important factors since these are primary requirements for the growth and development of plants (José et al. 2003). It has been reported that species composition and vegetation structure are influenced by the soil nutrient status (Rodrigues et al. 2018). Several studies have also reported inter-specific difference in nutrient uptake by plants (Tanner 1996, McJannet et al. 1995). Chemical composition in plant tissues determines the quality of litter that may explain the decomposition and nutrient mineralization rates (Hobbie 1992, Hossain et al. 2010). Reports are available that high quality of litter (rich in N and P contents) enhances faster decomposition and mineralization rates and poor quality litter (rich in phenolics and tannin contents) slow down those processes (Bardgett 2005). Because, high quality litter is easily decomposed by the soil microbes since enhanced nutrients stimulate microbial growth and causes release of higher amount of nutrients than is consumed by microbes resulting availability of nutrients in soil. On the other hand, poor quality litter is hard to be decomposed by the microbes since these chemicals block the action of the enzymatic reactions by the microbial community. There are some studies that also reported the importance of rations of the defensive chemicals to nutrient chemicals (e.g nitrogen: lignin) on the litter nutrient mineralization (Scott á and Binkley 1997). However, although studies on relationships between litter quality and nutrient release rates are substantially available for terrestrial forest plants (Thomas and Prescott 2000, Scottá and Binkley 1997, Maithani et al. 1998) relatively less is known about the issue for wetland plants (Vymazal 2007, Keddy 2010), nevertheless, such information would help better understand the adaptation mechanisms of the plant communities of swamp forests.

Swamp forests are complex ecosystems characterized by flooding or saturation of the soil creating nutrient poor and oxygen deficient environment favoring special type of plant assemblage (Keddy 2010, Vymazal 2007). Ratargul swamp forest, the only fresh water swamp forest in Bangladesh, is a sub-tropical wetland ecosystem with rich biodiversity (Choudhury et al. 2004). The dominant tree species that form the upper canopy of the forest are *Pongamia pinnata* (L.) Merr., *Barringtonia acutangula* (L.) Gaertn. and *Crateva religiosa* G. Forst. (Hossain et al. 2016). The present study, therefore, attempted to examine the relationship between litter quality and nutrient mineralization by incubating leaf liter of the selected dominant tree species with soil collected from Ratargul swamp forest.

METHODS

Study Sites

Ratargul swamp forest (25.01°N and 91.92°E) is situated on the bank of the river Gowain in the sub-district of Gowainghat under the district of Sylhet, Bangladesh (Figure 1). During the monsoon, the forestland gets flooded by water of the river Gowain because it flows full to the brim and during dry period the water flow reduces to minimum (Choudhury et al. 2004). With the area of about 204 ha, the forest once declared as 'Reserve Forest' in 1953 was later on declared again as 'Reserve Forest of Special Biodiversity' in 2015 by the government of Bangladesh. The area is about 35 feet (10.6 m) above the sea level (Choudhury et al. 2004). With approximately 73 plant species, the forest is dominated mainly by three tree species *P. pinnata, B. acutangula* and *C. religiosa* with associated species including *Clinogyne dichotoma*, *Ficus religiosa*, *Syzygium fruticosum* and *Alstonia scholaris* (Hossain et al. 2016).

Collection of Plant and Soil Samples

In order to determine the nutrient concentrations in soil and plant parts, three plots each with 10 m x10 m in size were selected randomly from the forest in such an way that all the three dominant tree species namely *P. pinnata*, *B. acutangula* and *C. religiosa* were present together in each plot and the minimum distance between two plots was 50 m. Fully expanded youngest leaf and bark from the stem of the plant were collected for the analysis of chemical composition. Composite soil samples were collected at 0-10 cm depth at the centre of the sampling plot. After collection from the field, both plant and soil samples were brought immediately to the Ecology and Environment Laboratory, Department of Botany, University of Dhaka for analysis.

Experimental Design for the Determination of N Release Rate

Fresh leaf collected from the selected plant species was dried at 60°C for 24 h in the oven. Then, the oven-dry

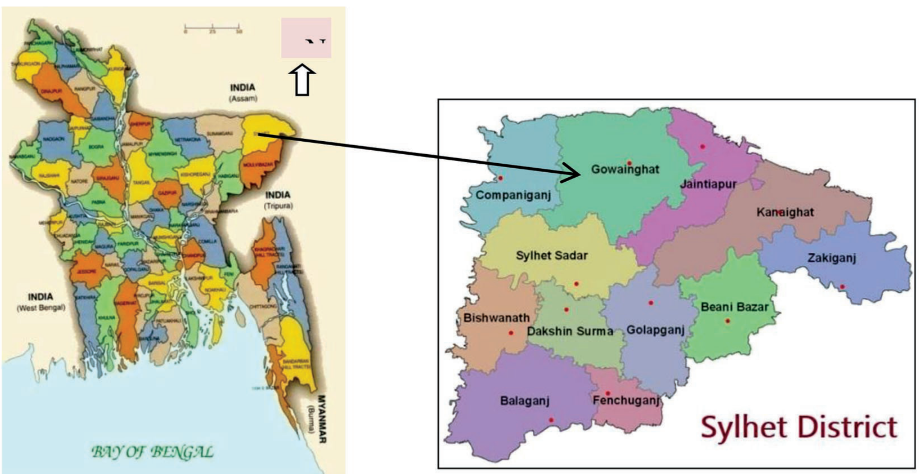

Fig. 1

Figure 1. Map showing the location of Ratargul swamp forest, Sylhet, Bangladesh.

leaves were cut into pieces of 2 cm × 2 cm in size. Dried leaf of 0.2 g in weight was added into each pot (500 ml in volume) filled with soil collected from the forest and mixed thoroughly. Pots were then covered with polythene bags to avoid contamination. Three replicated pots were used for the treatment of each litter species. Pots were kept at room temperature for incubation for 9 months. In order to maintain soil moisture contents stable in the pot, distilled water was added from time to time, when necessary. After completion of incubation, undecomposed leaf litter was removed from the soil to determine soil N content released from the leaf litter.

Chemical Analysis of Soil and Plant Samples

Soil pH and electrical conductivity were determined in suspension made with distilled water with the ratios 2:1 and 5:1 (v:w), respectively. Available N in soil was determined by following extraction with 2N KCl solution using 5 g soil. Total N in soil and plant samples (leaf and stem bark) was determined by using 1 g soil and 0.2 g dry plant samples, respectively. In both cases, N was determined by following the Kjeldahl method (Jackson 1965). Soil P was determined by following the colorimetric method. The digest prepared for the determination of P was also used for the determination of K, Na, Ca, Mg and Fe. Concentrations of K and Na in plant parts were determined from 0.2 g leaf by using flame photometer. Calcium, Mg and Fe were determined by using spectrophotometer. Phenolic compounds and tannins were determined from 0.1 g leaf sample by following methods as described by Graça and Bärlocher (2005).

Statistical Analysis

ANOVA was performed to determine the difference in chemical composition among the three plant species. Tukey's HSD was done to test the level of significance among the means.

RESULTS

Soil Properties of the Selected Plots

The range between maximum and minimum and the average values of the soil properties of the three plots selected from the Ratargul swamp forest were shown in Table 1. Data showed that although soil pH, electrical conductivity and organic C did not vary largely, the other parameters such as soil N, P, Na, K, Ca, Mg and Fe contents showed large variation ranging sometimes more than double among the three plots. A composite soil collected from the three selected plots of the forest for the use in the incubation study showed the values for pH 5.36, electrical conductivity 28.5 µS cm^{-1}, organic C 0.846%, P 0.049%, available N 204.96 (µg g^{-1}), Na 1.49%, K 0.59%, Mg 0.018% and Fe 0.0011%.

Table 1. Soil properties of the three plots selected from the Ratargul swamp forest taken under study.

Soil properties	Range (maximum - minimum)	Average
pH	5.05-5.36	5.25
Electrical conductivity (µS cm^{-1})	27.2-44.1	33.27
Organic C (%)	0.613-0.846	0.77
P (%)	0.049-0.091	0.072
Available N (µg g^{-1})	115.29-204.96	153.72
Total N (%)	0.064-0.141	0.102
Na (%)	0.33-1.49	0.73
K (%)	0.55-0.88	0.67
Ca (%)	0.013-0.213	0.133
Mg (%)	0.006-0.018	0.01
Fe (%)	0.00073-0.00112	0.0009

Nutrient Concentration in Plant Parts

Among the chemical properties, N, P, Fe and relative tannin contents showed significant difference in plant parts among *P. pinnata, B. acutangula* and *C. religiosa* (Figures. 2, 3 and 4). Significant difference was found in N content in leaf ($P < 0.05$) and bark ($P < 0.02$) tissues among the three plant species with the highest content in stem (0.663%) and leaf (1.263%) of *C. religiosa* and the lowest with that in stem (0.233%) and leaf (0.683%) of *B. acutangula*. As shown in Figure 3, the three plant species also showed significant differences in Fe concentration in stem tissue ($P < 0.0001$). The highest Fe concentration (0.00085%) in stem was found in *C. religiosa* while the lowest (0.00074%) was found in *B. acutangula*.

Relative tannin content in leaf differed significantly ($P < 0.05$) among the three plant species with the highest value (0.273%) in *B. acutangula* and the lowest (0.127±0.037%) in *C. religiosa* (Figure 3). Although not statistically significant, leaf phenol concentration showed a trend which was similar to that of relative tannin content.

Nitrogen Release from Leaf Litter

After completion of incubation period, available N content showed significant difference ($P < 0.01$) among the three species. Soil N content decreased in all soils

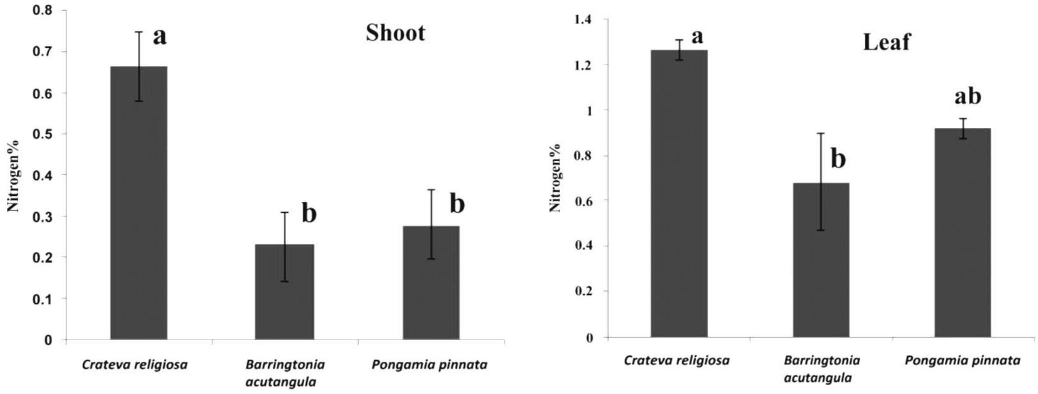

Fig. 2

Figure 2. Total N content (%) in stem and leaf of *Pongamia pinnata, Barringtonia acutangula* and *Crateva religiosa* of the Ratargul swamp forest. Different letters indicate significant difference.

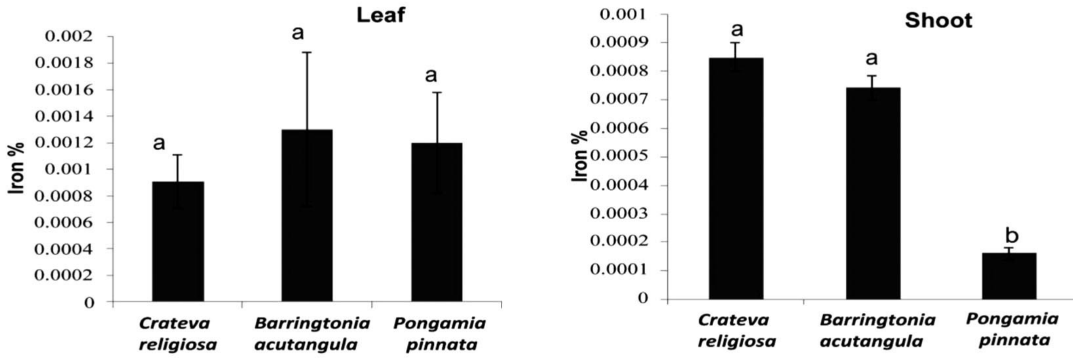

Fig. 3

Figure 3. Total Fe content in the leaf and stem of *Pongamia pinnata, Barringtonia acutangula* and *Crateva religiosa* of the Ratargul swamp forest.

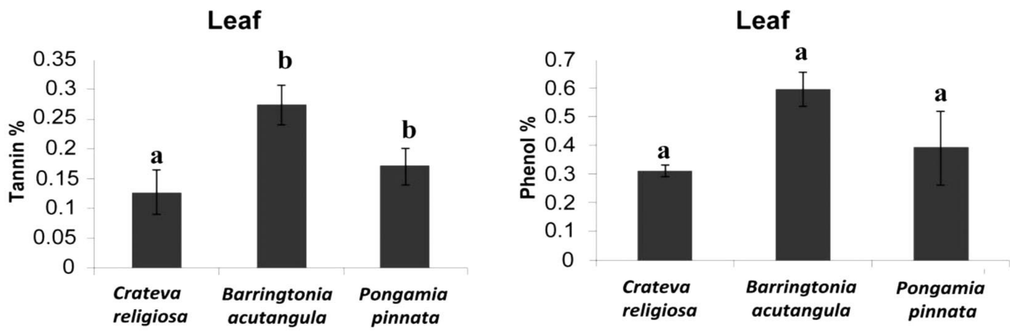

Fig. 4

Figure 4. Relative tannin and phenol content (%) in the leaf of *Pongamia pinnata, Barringtonia acutangula* and *Crateva religiosa* of the Ratargul swamp forest.

treated with the leaf litter compared to that of control soil and the value was significantly lower in soil treated with the leaf litter of *B. acutangula* (Figure 5).

DISCUSSION

Plants uptake nutrients from the soil in order to complete their developmental cycle (Schachtman and Shin 2007, Gojon et al. 2009). Among the nutrients, N is the most important limiting nutrient that largely influences growth and distribution of plant (Hobbie 1992). Therefore, difference in soil nutrient concentrations between habitats is likely to influence vegetation structure (Rodrigues et al. 2018). Plant communities differing in their structure are found to be related with the soil environmental factors. Data of the present study showed that concentration of soil N (0.064%) found in

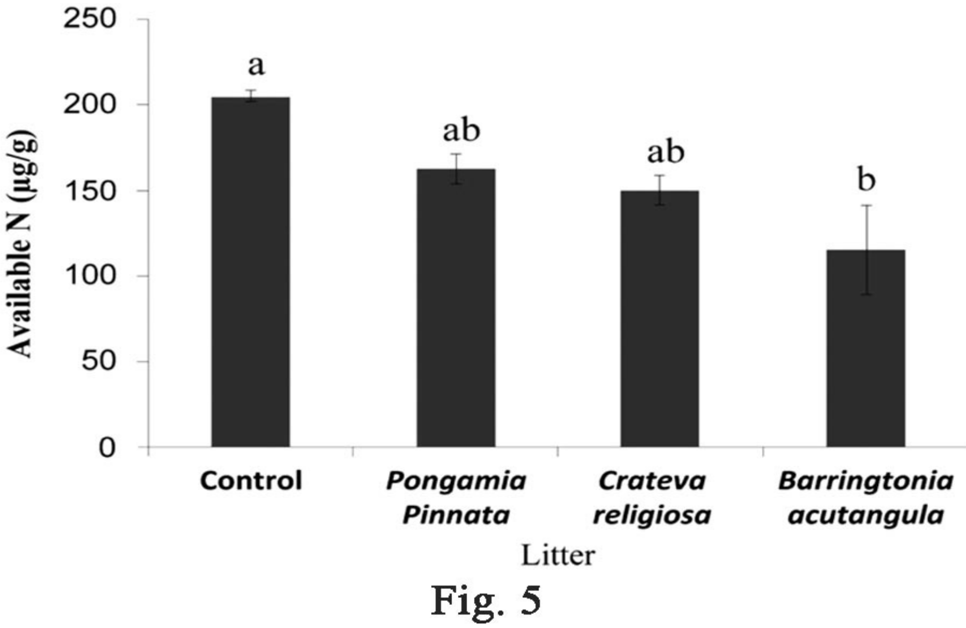

Figure 5. The effects of leaf litter species on N release (µg g^{-1}) in soil of the Ratargul swamp forest.

the Ratargul swamp forest was relatively lower than that in the other forest ecosystems of Bangladesh such as Madhupur deciduous forest (0.094%) (Kashem *et al*. 2015), Chattogram hill forest (0.115%) (Hossain et al. 2014) and the Sundarban mangrove forest (1.72%) (Hossain et al. 2012). Soil P content also showed similar pattern among these forest soils (Kashem et al. 2015, Hossain et al. 2014, 2012). Results obtained in the present study were thus in agreement with the other findings that swamp forests were poor in soil nutrient status (Hossain et al. 2016, Chapin 2002, Rossatto et al. 2015, Vymazal 2007, Keddy 2010). The lower nutrient concentration in the soil of Ratargul swamp forest compared to other forests of Bangladesh might be related to several factors including seasonal inundation due to floods and runoff owing to frequent rainfall which is a common feature of this part of the country.

The difference in nutrient concentrations in plant tissues among the three species although grown in the same location might be related to the inherent genetic makeup of the plant species (Güsewell and Koerselman 2002). As found in the present study, significantly higher concentrations of N in plant parts (leaf and stem bark) of *C. religiosa* compared to that of *B. acutangula* and the higher content of tannin in the leaf of *B. acutangula,* than *C. religiosa* indicated the difference in litter quality among the species. Data thus suggested that among the three species studied, *C. religiosa* should be more decomposable than that of the *B. acutangula.* Although not statistically significant, amount of mineralized N from *B. acutangula* was lower than that from *C. religiosa* indicating a relationship between litter quality and N mineralization rate. Similar result was found by other studies (Thomas and Prescott 2000). Iron plays critical role in metabolic processes such as DNA synthesis, respiration, and photosynthesis (Rout and Sahoo 2015, Khobra et al. 2014). Although Fe concentration showed a significant difference among the three species with the lowest amount in stem tissue of *P. pinnata* it was comparable in leaf tissues and this might occur due to comparatively higher transfer rate of this element from stem to leaf in *P. pinnata.* Difference in tissue nutrient composition among plant species may be an important trait for ecological strategy of a plant species (McJannet et al. 1995).

Nitrogen mineralization is a process by which organic N is converted into plant-available inorganic form of N and this process is mediated by soil microbes. Balance between amount of N mineralized from the leaf litter and the amount of N consumed by microbial communities in soil determines the availability of N in soil. However, if amount of N used by microbes is higher than that of the mineralized N then immobilization of N occurs. The lower amount of available N in soil treated with the leaf litter compared to that of the control soil (without leaf) as observed in the present study indicated the immobilization of N in soil. Immobilization of N by the soil microbial communities was also reported by other studies (Camenzind et al. 2018, Condron et al. 2010 and Qiu et al. 2008). Forest plants select fungi-dominated soil microbial communities for decomposition of litter (Dilly et al. 2004). Thus, fungi-dominating decomposer community is responsible for the slow decomposition of plant litter. Soil of low nutrient status favors slow growing plants that produce low quality litter which in turn produce low quality litter (Craine and Dybzinski 2013). Similar to the soil nutrient status, plant tissues of the selected three species of Ratargul swamp forest of the present study contained relatively lower amount of N but higher amount of tannin compared to some dominant tree species grown in the deciduous forests of Bangladesh (Sultana et al. 2013) indicating a link between relatively poor soil nutrient and litter quality of the Ratargul wetland forests. Microbial communities in the swamp forest might act as mediator in maintaining such feedback relationship between soil nutrient environment and plant communities in this low fertile forestland. Data of the present study also suggested that among the three plant species, *B. acutangula* would get more stability in terms of their adaptation through nutrients condition in the soil of Ratargul swamp forest since it required less amount of N.

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