

Litter-Fall Production, Decomposition and Elemental (Ca, K, Mn, Fe, Zn and Co) Cycling in Deciduous Sal (*Shorea Robusta*) Forest in Bangladesh

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Abstract

The litters in the forest floor are the principal contributor for regulating the cycling of necessary elements, primary productivity and maintain soil fertility within the forest ecosystems. Therefore, this study was conducted in a deciduous forest of Bangladesh to ascertain the leaf-litter production and decomposition along with elemental dynamics (K, Ca, Mn, Fe, Co and Zn). Leaf-litter samples from five deciduous plant species and soil samples were collected from the Madhupur Sal Forest for about six months (July-December) in 2018. Production of leaf-litter during the dry season (December) was found in an order of *Shorea robusta*>*Dipterocarpus indicus*>*Terminalia bellirica*>*Tectona grandis*>*Grewia microcos*. The decomposition rates were higher for the long sampling period (90 days) followed by the intermediate (60 days)> short(30 days) sampling period. The nutrient release pattern from the leaf-litter was similar (Ca>K>Mn>Fe>Zn>Co) for all plant species except for *Terminalia bellirica* and *Tectona grandis*. The Pearson correlation coefficients showed a significant relationship between K and Fe ($r=0.54$; $p<0.05$), Ca and Co ($r=0.59$; $p<0.01$), Fe and Co ($r=0.97$; $p<0.05$) in leaf-litters. Analysis of variance (ANOVA) revealed significant variation in the litter production, decomposition and nutrient content (except Zn; $p>0.05$) among the different plant species ($p<0.05$). There revealed a significant dynamic of necessary elements from soil to trees and vice-versa.

1. Introduction

Leaf-litters are the significant source of nutrient and thereafter transfer of energy between plants and soil. These leaf-litters transfers organic matter, nutrients and energy from the vegetation to the uppermost layers of soils through its decomposition process for enhancing its fertility and by thus litterfall plays a critical role in maintaining the biogeochemical cycling of nutrients within the forest ecosystem (Dutta and Agrawal 2001; Hasanuzzaman and Hossain 2014). Litter decomposition directly affects the dynamics of forest ecosystems as a sink of carbon, by releasing CO₂ and indirectly by improving nutrient availability and consequent changes in net primary production. The rate of litter decomposition is largely a determining factor for the productivity of the forest ecosystems as plant nutrients become available for recycling within the system. By this system, litter decomposition can account for 69–87% of the total annual requirement of essential elements for the forest plants (Ifo 2010). The quantity of above-ground litter-fall is closely linked to the proportion of the senescent foliage biomass, which varies from year to year and between species: the longer the retention of foliage in the canopy, the smaller is the litter-fall mass (Viro 1956; Malkonen 1974; Finer 1996). Litter also aids in soil moisture retention by cooling the ground surface and holding moisture in decaying organic matter. A litter layer of decomposing leaf biomass provides a continuous energy source for macro- and micro-organisms (Mia et al. 2016). Several factors such as latitude, elevation, vegetation density, species composition, seasonal changes and rainfall have a significant influence on the litter-fall and decomposition rate (Williams-Linera and Tolome 1996; Lin et al. 2004). The transfer of nutrients and energy from living biological components to the soil is closely related to litter-fall (Gray and Schlesinger 1981). The tree nutrition, growth patterns and forest production are affected by litter-fall (Newbould 1967). Litter-fall constitutes (together with root turnover) a major portion of nutrient cycling between plants and soils, thus reflecting constraints on internal fluxes of C, N and P in ecosystem-scale (McGroddy et al. 2004; Berg and Laskowski 2006). Primary production related to the functioning of forests is influenced by the availability of nutrients that depends on the pattern and rate of nutrient cycling (Rawat and Singh 1988).

In terrestrial systems, plant litter-fall is a primary pathway for the return of nutrients to the soil. Leaf tissue can account for 70% or more of aboveground litter-fall in forests, with the remainder composed of stems, small twigs, and reproductive structures (Robertson and Paul 1999). Different leaf litters substantially decreased soil acidity and significantly increased the organic matter, total N, available P, exchangeable K, available Ca, Mg contents in the post-

harvest soil. Further, nitrogen (N), phosphorus (P), and calcium (Ca) are released from plant litter during decomposition where they can become available for plant and microbial uptake. Litter on the forest floor affects the moisture status, runoff pattern, and nutritional character of the soil (Bray and Gorham 1964). The rate of forest litter-fall and its gradual decay regulate energy flow, primary productivity, and nutrient cycling in forest ecosystems (Waring and Schlesinger 1985). Litter-fall decomposition, which produces organic matter is an important factor for soil formation as well as nutrient cycling processes (Van Wesemael 1993). Plants uptake these nutrients for their growth and development, and a portion of the nutrients are accumulated in the plant body (Hasanuzzaman et al. 2006; Kamruzzaman et al. 2019). Therefore, litterfall productivity is directly linked with nutrient availability and uptake by the plants (Boto and Wellington 1983).

In this connection, a study on litter production, as well as litter decomposition bears significant importance to assess the function and productivity of forest ecosystems especially deciduous forests. There are several research works available on the litterfall production, decomposition and nutrient analysis for different forest ecosystems in various geographic location (Swarnalatha and Reddy 2011; Liu 2012; Giebelmann et al. 2013; Tu et al. 2014; Hoque et al. 2015; Capellesso et al. 2016; Lanuza et al. 2018; Mishra et al. 2019; Azad et al. 2020; Nonghuloo et al. 2020). However, studies on the litterfall production and nutrient analysis for the deciduous forests in Bangladesh are scarce though it has around 0.20 million hectares of tropical deciduous forest in its central and northwestern regions (Zaman et al. 2011). Hence, this study focused on this particular ecological phenomenon to minimize the knowledge gap for the tropical deciduous forest system. Thus, through this present study, leaf litter production and decomposition rate were estimated along with nutrients content (K, Ca, Mn, Fe, Co and Zn) in leaf litters and soils towards perceiving the nutrient cycling process in the deciduous forest system.

2. Materials And Methods

2.1. Study area

The Sal forest (*Shorea robusta*) is considered one of the richest ecosystems regarding forest diversity in Bangladesh and a very large portion of such forest ecosystem lies in the districts of Mymensingh and Tangail known as Madhupur Sal Forest (MSF). Geographically, this forest is located from 23°50' to 24°50' north latitude and 89°54' to 90°50' east longitudes at a distance of about 96km north from capital Dhaka (Hasan et al. 2020). The total area of the MSF under the Tangail district is about 46,000 acres (186km²) and this forest is a highly diverse and productive ecosystem having some 271 species of which 41 are tree species (Ahmed 2009). Among its four ranges (Madhupur, Aronkhola, Dhokhola, and Madhupur National Park Sadar), the Dokhola range under the MSF was selected as a specific study area with a view for collecting forest leaf litter and soil samples four sampling sites (Figure 1).

2.2. Soil sample collection

Soil samples were collected in triplicate from each four sampling sites of the forest from July to December. Samples were collected from the surface (0 to 10 cm) with the help of an auger. Soil samples were placed in sealed polythene bags and labeled including date of collection, location and code number. The samples were then carried to the laboratory of the Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Bangladesh. From the collected samples, the gravels, pebbles, plant roots, leaves and other foreign particles were picked up and removed. Then the soil samples were dried in air for 2 weeks by spreading on a clean piece of paper and ground to pass through a 2 mm mesh stainless steel sieve. The samples were transported to the laboratory of the Institute of Nuclear Science and Technology, Atomic Energy Research Establishment Savar, Dhaka for soil sample preparation and analysis.

2.3. Leaf-litter collection and possessing

Leaf litter from five tree species (*Shorea robusta*, *Dipterocarpus indicus*, *Terminalia bellirica*, *Grewia microcosom* and *Tectona grandis*) were estimated by randomly fixing 4 traps of 1m² mouths and installed at 2m above the ground in each of the sampling sites for six months (July to December) in 2018. The traps were provided with muslin cotton net in a funnel-shaped manner. The traps were harvested at one-month intervals. The leaf-litters were taken to the laboratory and dried to a constant dry weight at 80°C. The total leaf-litter was weighted to obtain the total dry weight.

2.4. Leaf-litter decomposition

The decomposition was measured by using the litter bag technique. The litter bags (15cm×20cm) were made of muslin cotton net. Standard samples were collected from litter-traps of the study area. After litter samples were oven-dried at 80°C, 5g samples of intact leaves were placed in each bag. Nine bags of each leaf-litter type were pinned to the forest floor. Three bags from each site were collected at monthly intervals. Litter was carefully removed from each litter bag, oven-dried at 80°C and weighted. Percent mass loss was calculated over each period. The decomposition rate constant (k) of leaf litter will be estimated by using the exponential decay model (Olson 1963) as follows:

$$\ln\left(\frac{x_t}{x_0}\right) = -kt \quad (1)$$

Where, x_0 is the original mass of leaf litter, x_t is the amount of leaf litter after a given period t (days) and k is the decay rate constant.

Half-lives (t_{50}) and time required to lose 95% (t_{95}) were estimated from the equation

$$t_{50} = \frac{0.693}{k} \quad (2)$$

$$t_{95} = \frac{3}{k} \quad (3)$$

2.5. Sample preparation for nutrient analysis

After weighing, the soil and leaf samples were made into an individual packet with an individual identification number. The size and shape of packets were kept approximately the same. The packets were then preserved carefully for neutron irradiation. For the soil sample experiment, approximately 0.05g of each dried powder sample was weighted in a polyethylene bag and heat-sealed. For the relative standardization approach, three reference materials (RMs): IAEA-Soil-7(1), Soil-7(2), Soil-7(3), and one standard reference material NIST-1633b (Coal Fly Ash) were used in this study. For the leaf sample, approximately 0.2 g of each dried powder sample was weighted in a polyethylene bag and heat-sealed. For the relative standardization approach, three reference materials (RMs): 1515 (1), 1515(2) and 1515(3) were used. Each of the standards was prepared in the same way as those of samples. Samples and standards were placed in a vial for irradiation. The samples, three standards, and three foils were packed in a vial for irradiation.

2.6. Instrumental neutron activation analysis (INAA) for nutrient content

Two irradiation schemes were performed using a pneumatic transfer (rabbit) system at the 3MW TRIGA Mark-II research reactor of Bangladesh Atomic Energy Commission, Savar: (i) Short irradiation was performed separately for

each sample with the thermal neutron flux of $5.28 \times 10^{12} \text{ cm}^{-2} \cdot \text{s}^{-1}$ for 1 min at 250 kW and (ii) Long irradiation was performed simultaneously with all the samples and standards with the thermal neutron flux of $2.11 \times 10^{13} \text{ cm}^{-2} \cdot \text{s}^{-1}$ for 7 min at 2.4 MW. To determine the neutron flux gradient within the sample stack, three IRMM-530 RAAI-0.1% Au (0.1 mm foil) monitor foils were also irradiated by placing them at the bottom, middle and top of the sample stack for the long irradiation scheme. After long irradiation, samples were turned highly radioactive. For this reason, they usually were not handled immediately. They were in a shielded place for 2 days (Tsoufanidis 1995). Normally, the used irradiation facility is G-ring. After irradiation, gamma-ray counting was performed with high purity germanium (HPGe) detector (CANBERRA, 25% relative efficiency, 1.8 keV resolution at 1332.5 keV of 60 Co) coupled with a digital gamma spectrometer (ORTEC, DSPEC Jr™). For short irradiation, first, counting was performed for 300 s after a decay time of about 300 s and second counting for 600 s after decay time of 2-3 h. For long irradiated samples, first counting was performed for 3600 sec after a decay time of 2-3 days while the second counting was performed for 7200 s after a decay time of 7-10 days and third counting was performed for 8-12 hours after a decay time of 2-3 weeks. Short-lived and long-lived radionuclides were determined from the short and long irradiation separately. The gamma spectrometry of all the irradiated samples and certified reference materials was performed using a PC-based HPGe detector coupled with a digital gamma spectrometry system. The data acquisition was performed using the software Genie-2000 (Canberra) and MAESTRO-32 (ORTEC) and the gamma peak analysis was performed using the software Hypermet PC version 5.12 (Wytttenbach 1971).

2.8. Statistical analysis

Obtained data were analyzed using Microsoft Excel 2013 program for computing mean values, standard errors and to prepare graphs visualization. The mean values of the triplicates of each parameter were calculated with standard deviations. One-way ANOVA was carried out to determine the significant variation of litter production, decomposition rate and nutrient concentration among the tree species. The Pearson correlation coefficient was calculated for displaying significant relationships between investigated parameters while principal component analysis (PCA) was undertaken to determine key nutrients in the leaf litter. The output of the hierarchical cluster analysis was expressed in a dendrogram to classify nutrients in tree species. Above mentioned statistical tests were performed by using Statistical Package for Social Science (IBM SPSS Statistics 20.0).

3. Results And Discussion

3.1. Soil properties of the forest

Investigated soil quality parameters such as pH and EC have been arrayed in Table 1 along with studied macronutrients (K, Ca) and micronutrients (Mn, Fe, Co and Zn). Soil pH in the study area varied between 5.2 to 6.2. Previously, Hoque et al. (2008) reported that the soils of Madhupur Sal Forest (MSF) were strongly acidic to moderately acidic and the values ranged from 4.6 to 6.28. It has been reported that forest soils should be slightly acidic for nutrient supply to be balanced (Leskiw 1998). The EC of the forest soil was found ranging from $70 \mu\text{S cm}^{-1}$ to $110 \mu\text{S cm}^{-1}$ throughout the sampling sites. A similar range of EC was also reported by Hoque et al (2008) for the MSF but present findings were higher than that of Hasan and Mamun (2015). Among the macronutrients, Ca was the most abundant macronutrient with a mean concentration of 18.36 % where K was found ranging from 1.27% to 1.50%. The rest of the micronutrients Mn, Fe, Co and Zn were found with a mean concentration of 915.16 ppm, 2.09 (%), 9.40 and 50.25 ppm respectively. Significant inter-macronutrient relationship was observed for K and Fe ($r=0.745, p < 0.01$), K and Co ($r=0.610, p < 0.05$), Mn and Co ($r=0.772, p < 0.01$) and Fe and Co ($r = 0.804, p < 0.01$)

(Table 2). Present findings for soil macronutrients of MSF are comparable with another deciduous forest of the world (Rossatto et al. 2015; Kleiber et al. 2019; Mishra et al. 2019).

3.2. leaf litter production

The maximum amount (129 g m^{-2}) of leaf litter has been recorded in December for Sal (*Shorea robusta*) while the minimum amount (46 g m^{-2}) of leaf litter has been recorded in August for Datoi (*Grewia microcosom*) (Figure 1). Leaf litter production in different tree species decreased in the order of *Shorea robusta*>*Dipterocarpus indicus*>*Terminalia bellirica*>*Tectona grandis*>*Grewia microcos*. The ANOVA analysis disclosed significant variation for the leaf litter production among species ($d=4$, $F=13.58$, $p < 0.05$). Vyas et al.(1976) and Sanches et al. (2008) also recorded the maximum amount of litter during the dry periods while the minimum amount of litter recorded during the wet period in a deciduous forest of India and semideciduous forest of Brazil respectively, which mostly coincided with the present study. However, the amount of litterfall production was comparatively higher than that of temperate-zone forest (Gonzalez 2012) since the forests in tropical zone produce more litter products rather than temperate zone and polar zone (Bray and Gorham 1964). Usually, the leaf litter production in forest systems is influenced by different climatic factors (temperature, air humidity, wind speed, rainfall etc.) and the higher production rate in the dry season could be due to low air humidity and high wind speed (Triadiati et al. 2011). The tendency of litterfall to be concentrated in the dry season is also linked with declined temperature and lowered soil moisture during this period (Hanpattanakit and Chidthaisong 2012). The wet period is generally characterized by high moisture content in the air and the trees do not need to reduce evaporation which might be a plausible explanation for lower litter production during the wet season.

The fallen leaf litters on the ground of forest soil play a vital role to enrich the forest soil with organic matter content and are naturally decomposed of and released nutrients for forest plants. The forest tree leaf litters contain a higher amount of organic matter, K, Ca and other trace elements which can be applied for the production of crops in the surrounding areas of the forest (Khatun et al. 2010). Hence, the seasonal pattern and amount of litterfall are considerable factors determining the recycling of nutrients and maintenance of soil fertility in terrestrial ecosystems (Facelli and Pickett 1991). Removal or reduction of litter from the forest floor can directly reduce the soil nutrients which ultimately affect forest productivity.

3.3.Decomposition rate

The decomposition rate was found highest for *Grewia microcosom* and lowest for *Dipterocarpus indicus* for initial (30 days), intermediate (60 days) and final (90 days) sampling period (Figure 2). The rate of decomposition decreased in species following the order of *Grewia microcos*>*Shorea robusta*>*Terminalia bellirica*>*Tectona grandis*>*Dipterocarpus indicus*. Significant variation in the decomposition rate of leaf litter among species were observed for initial ($df=4$, $F=69.29$, $p < 0.05$), intermediate ($df=4$, $F=118.93$, $p < 0.05$) and final ($df = 4$, $F = 147.08$, $p < 0.05$) sampling periods through ANOVA analysis. The variations in the decomposition rate of different plant litters may be attributed to differences in substrate quality of different plant species, edaphic characteristics, climatic conditions, litter quality and soil organisms (Dutta and Agrawal 2001). Physical structure of tissues and their proportionate variations in plant parts can also influence decomposition rate (Swift et al. 1979). Decomposition of litter plays a pivotal role in the nutrient budget for a forest ecosystem, where the flora is influenced most significantly by nutrient recycling from plant litter (Vesterdal 1999; Wedderburn and Carter 1999). Fast decomposition rates help to meet plant intake requirements where slow decomposition rates result in the building up of organic matter and nutrient stocks in soil(Isaac and Nair 2005).

The half-lives of different leaf litters during decomposition were varied from species to species. The average highest half-lives were observed for *Dipterocarpus indicus* and the lowest was for *Grewia microcosom* at different time intervals for decomposition (Figure 3). A similar trend was also recorded for the time required to lose 95% during decomposition. The study also revealed that the species which had a low decomposition rate demonstrated higher values t_{50} and t_{95} . The decay pattern under all three conditions was similar, that is rapid early losses followed by a slow and steady decrease in the late decomposition phase which could be due to higher initial content of water-soluble materials, simple substrates and the breakdown of litter by decomposers, especially the microorganisms (Songwe et al. 1995). The relatively slower decay rates at the later stages may be due to the accumulation of more recalcitrant constituents in the residual litter mass (Sundarapandian and Swamy 1999).

3.4. Nutrient release from litter

Nutrients in the litter of investigated tree species have been presented in Table 3. Among the investigated nutrients in leaf litter, Ca was found in higher (10000-23000 ppm) than that of other trace metals detected. The pattern of released nutrients from the litter was similar (Ca > K > Mn > Fe > Zn > Co) for all species except for *Terminalia bellirica* and *Tectona grandis* (Ca > K > Fe > Mn > Zn > Co). The mean concentrations of Fe, Co and Zn were found to be the highest in *Grewia microcosom* with the values of 4082, 2.62 and 66.84 ppm, respectively. The mean concentration of K (4408 ppm) and Mn (2282 ppm) were found to be the highest in *Shorea robusta* where the highest concentration of Ca (23000 ppm) was recorded in *Terminalia bellirica*. Patterns of particular nutrient release from the litter of different tree species were: K- *Shorea robusta* > *Grewia microcosom* > *Tectona grandis* > *Dipterocarpus indicus* > *Terminalia bellirica*; Ca- *Terminalia bellirica* > *Grewia microcosom* > *Tectona grandis* > *Shorea robusta* > *Dipterocarpus indicus*; Mn- *Shorea robusta* > *Dipterocarpus indicus* > *Grewia microcosom* > *Terminalia bellirica* > *Tectona grandis*; Fe and Zn- *Grewia microcosom* > *Tectona grandis* > *Shorea robusta* > *Dipterocarpus indicus* > *Terminalia bellirica*; Co- *Grewia microcosom* > *Tectona grandis* > *Terminalia bellirica* > *Shorea robusta* > *Dipterocarpus indicus*.

The ANOVA analysis confirmed that the release of each of the studied nutrients (except Zn) in leaf litter varied significantly among tree species, and the results are as follows: K (df = 4, F = 59.14, p < 0.05), Ca (df = 4, F = 22.45, p < 0.05), Mn (df = 4, F = 148.80, p < 0.05), Fe (df = 4, F = 635.96, p < 0.05), Co (df = 4, F = 1752.34, p < 0.05) and Zn (df = 4, F = 0.61, p < 0.05). Significant position association has been observed for K and Fe (r = 0.547, p < 0.05), Ca and Co (r = 0.597, p < 0.05), Fe and Co (r = 0.974, p < 0.01) (Table 4). The results of correlation were further supported by multivariate analysis (PCA and Cluster Analysis).

In PCA analysis, two PCs explained 73.43% of the total variance in the dataset having Eigenvalue greater than 1 (Table 5). The PC1 accounted for 39.46% of the total variance with strong positive loading on Ca and Co and moderate loading on Fe. Calcium is a structural component and thus protected from physical leaching (Gosz et al. 1973; Edmonds and Thomas 1995) and the uptake of Fe by plants and its transport in vegetative organs have a dependency on Ca and trace element relationship (Kabata-Pendias and Pendias 2001). The distribution of cobalt in plants is entirely species-dependent and the presence of other metals influences the Co uptake and accumulation process (Dilworth et al. 1979). The PC2 explained 39.46% of the total variance with strong positive loading on K and Mn (Table 5). Potassium is not a structural component of plant litter and is subject to physical removal by leaching (Xu et al. 2004). Besides, K plays a significant role in the regulation of Mn absorption by plants (Ramani and Kannan 1974).

Hierarchical cluster analysis (HCA) was done to classify similar groups of variations for nutrients in the leaf litter from the studied tree species and the results were depicted with a dendrogram. Three main clusters for investigated

nutrients in the dendrogram with the phenom line set to a rescaled distance of about 15 to show statistical similarity for leaf litters in the tree species (Figure 5). Cluster 1 included Ca, Fe and Co which displayed a significant positive association in the correlation analysis (Table 4). The rest of the two clusters were grouped with K and Mn (Cluster 2) and with Zn (Cluster 3).

The pattern of nutrient release from leaf litter has also been previously reported by Xu et al. (2004) in a subtropical forest of Japan and Scheer et al. (2011) in the Atlantic rain forest of Southern Brazil. Released nutrients from the leaf litter are essential for maintaining the fertility of forest soil. The initial leaching of nutrients followed by a nutrient immobilization and finally the release of nutrients into the soil is a well-known general model for nutrient cycling in forest ecosystems (Weerakkody and Parkinson 2006). Along with litter decomposition, the microbial community, soil properties and type, incubation time also influence the release of nutrients by leaf litters (Sangha et al. 2006).

3.5 Transfer of elements from soil to leaf litter

The transfer of studied macronutrients (K, Ca) and micronutrients (Mn, Fe, Co and Zn) from soils to leaf litter was analyzed through the Transfer coefficient (TC) tool. The TC is a ratio between element concentration in an organism and that in soil (Wang et al. 2017). This tool further describes the transfer of nutrients from the soil to the organism in a numerical granularity. The TC was found highest for Mn followed by Zn > K > Co > Ca > Fe (Table 6). The TC value of Mn was highest in *Shorea robusta* while *Grewia microcosom* displayed higher TC values for K, Fe and Zn. The TC value of Ca and Co was found higher in *Terminalia bellirica* and *Tectona grandis*. The range of TC values for K, Ca, Mn, Fe, Co and Zn in the leaf litter of the tree species were 0.16-0.30, 0.05-0.12, 0.12-2.49, 0.01-0.19, 0.04-0.33, 0.04-0.33 and 0.60-1.33 respectively (Table 5). The variation of TC indicates inter-specific differences of nutrients in the leaf litter of studied tree species.

4. Conclusion

Madhupur Sal Forest (MSF) provides significant natural resources and its entity is very much crucial from both national economic and environmental perspectives. Every year there are a sufficient amount of nutrients added to the soil by decomposition and leaching of litter which enhances the nutrients available in soil and plants. This process maintains the nutrient dynamics in the deciduous forest system and helps to circulate a balanced forest ecosystem. This study is the first of its kind to highlight the dynamics of nutrients associated with leaf litter production and decomposition. Leaf litter production was found highest for *Shorea robusta* the dominant tree species followed by *Dipterocarpus indicus* > *Terminalia bellirica* > *Tectona grandis* > *Grewia microcos*. However, the order was reversed in terms of decomposition rate. Nutrient analysis indicated that the Ca and K were prevalently released by leaf litter followed by micronutrients (Mn, Fe, Co, Zn). The information generated by this research would further aid in general to comprehend the ecological significance of seed released by the studied deciduous tree species. Since a forest is required proper management for the survival of plant species and maintenance of biodiversity in the area, this study might also assist policy-makers in forest management, conservation and restoration.

Declarations

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Disclosure statement

No potential conflict of interest was reported by the authors. This paper has nowhere been submitted for publication.

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Tables

Table 1. Descriptive statistics of investigated soil parameter from the sampling sites or MSF

	pH	EC	K	Ca	Mn	Fe	Co	Zn
Range	5.2-6.2	70-110	1.27-1.50	17-23	724-1170	1.55-2.58	6.61-13.14	36-69
Mean	5.6	90	1.43	18.83	915.16	2.09	9.40	50.25
SD	0.31	12.64	0.07	1.90	138.46	0.29	2.16	9.96

*EC in (μScm^{-1}); K, Ca and Fe in percentage (%), Mn, Co and Zn in ppm

Table 2. Pearson correlation matrix among soil parameter

	pH	EC	K	Ca	Mn	Fe	Co	Zn
pH	1							
EC	0.16	1						
K	-0.30	-0.30	1					
Ca	-0.21	0.36	-0.20	1				
Mn	0.11	0.39	0.34	-0.15	1			
Fe	-0.35	0.05	0.74^a	0.24	0.44	1		
Co	-0.07	0.35	0.61^b	0.05	0.77^a	0.80^a	1	
Zn	0.17	-0.16	0.26	-0.43	-0.09	-0.001	-0.05	1
^a Correlation is significant at the 0.01 level (2-tailed)								
^b Correlation is significant at the 0.05 level (2-tailed)								

Table 3. Nutrient content (ppm±SD) in leaf litter of five tree species of MSF

Tree species	K	Ca	Mn	Fe	Co	Zn
<i>Shorea robusta</i>	4408±308	14000±1600	2282±112	959±79	0.47±0.02	41.30±0.6
<i>Dipterocarpus indicus</i>	2727±103	10000±2000	2188±250	577±92	0.40±0.10	36.40±0.70
<i>Terminalia bellirica</i>	2338.33±256.07	23000±3500	149±11	289±27	0.61±0.03	30.40±1.70
<i>Grewia microcosom</i>	4056±109	22000±2300	1853±134	4082±191	2.62±0.07	66.84±0.23
<i>Tectona grandis</i>	3690±157	14200±900	141±6	1138±51	0.69±0.03	43.50±1.40

Table 4. Pearson's correlation matrix among micronutrients in leaf litter of five tree species of MSF

	K	Ca	Mn	Fe	Co	Zn
K	1					
Ca	-0.07	1				
Mn	0.42	-0.36	1			
Fe	0.54^b	0.44	0.28	1		
Co	0.37	0.59^b	0.16	0.97^a	1	
Zn	0.13	-0.32	-0.02	-0.23	-0.30	1
^a Correlation is significant at the 0.01 level (2-tailed)						
^b Correlation is significant at the 0.05 level (2-tailed)						

Table 5. Principal component analysis with screen plot of micronutrients in fivetree species of MSF

Parameters	PC1	PC2
K	0.059	0.844
Ca	0.871	-0.229
Mn	-0.223	0.783
Fe	<u>0.730</u>	0.046
Co	0.847	0.475
Zn	-0.552	0.130
Eigenvalues	2.70	1.69
% total variance	39.46	33.96
Cumulative % variance	39.46	73.43

Bold and underline figures show strong (> 0.75) and moderate (0.50–0.75) loading of variable separately

Table 6. Transfer coefficient values of investigated nutrients in leaf litter of fivetree species from MSF

Tree species	K	Ca	Mn	Fe	Co	Zn
<i>Shorea robusta</i>	0.30	0.07	2.49	0.04	0.05	0.82
<i>Dipterocarpus indicus</i>	0.19	0.05	2.39	0.03	0.04	0.71
<i>Terminalia bellirica</i>	0.16	0.12	0.16	0.01	0.06	0.60
<i>Grewia microcosom</i>	0.28	0.11	2.02	0.19	0.28	1.33
<i>Tectona grandis</i>	0.20	0.09	0.12	0.06	0.33	0.88

Figures

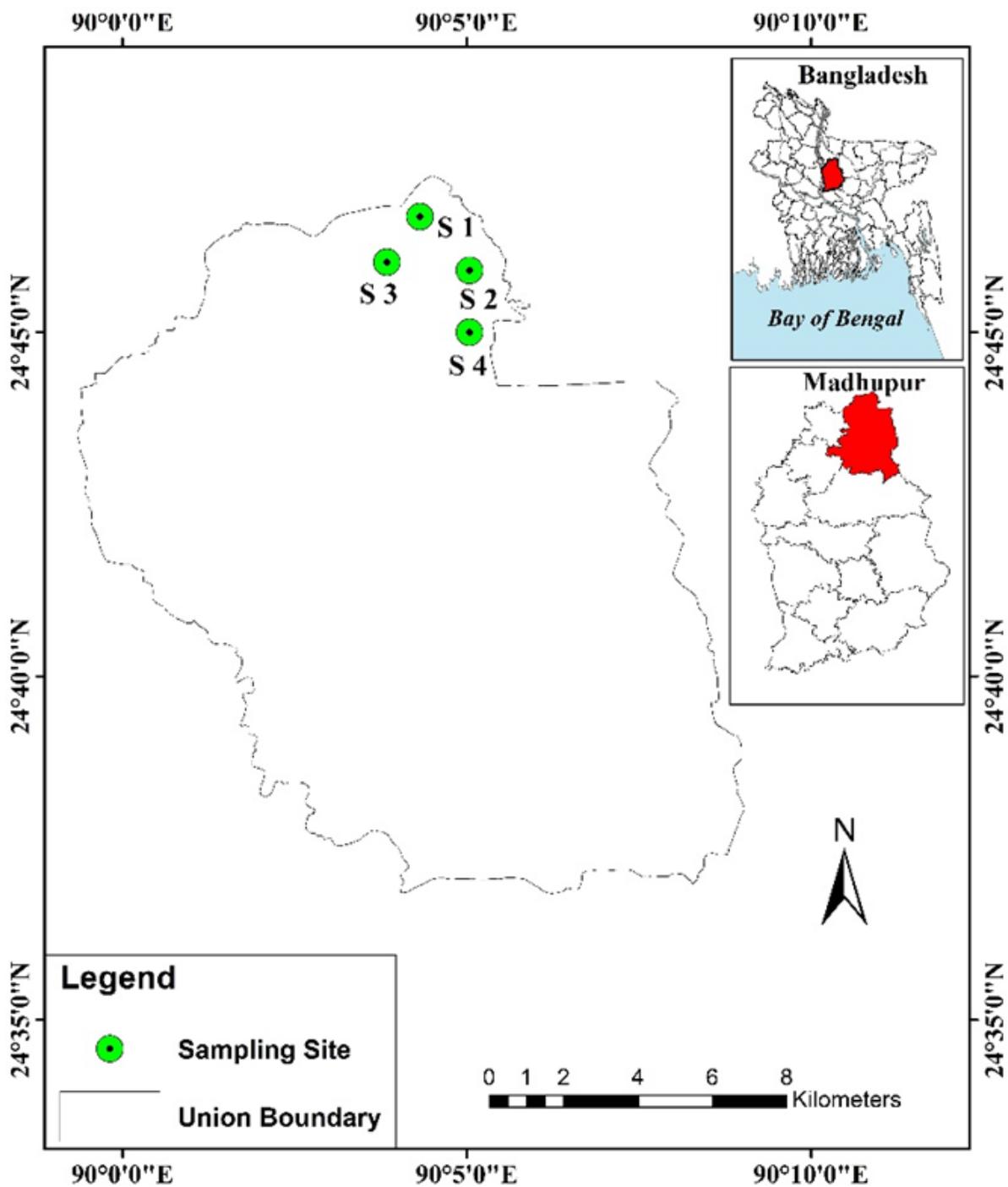


Figure 1

Map of the study area showing samling locations Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

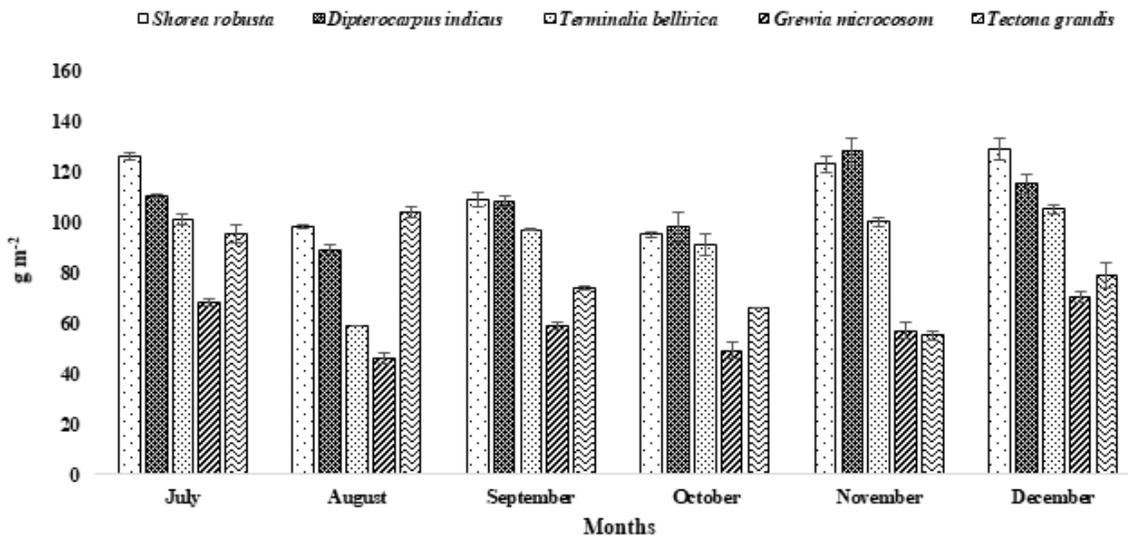


Figure 2

Monthly leaf litter production(±SD) in Madhupur Sal Forest

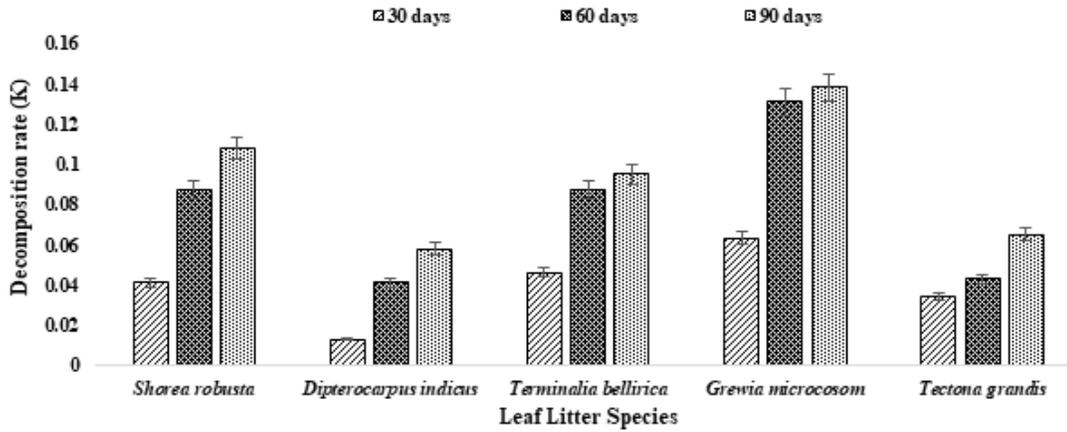


Figure 3

Average decomposition rate (K±SD) of different leaf litter

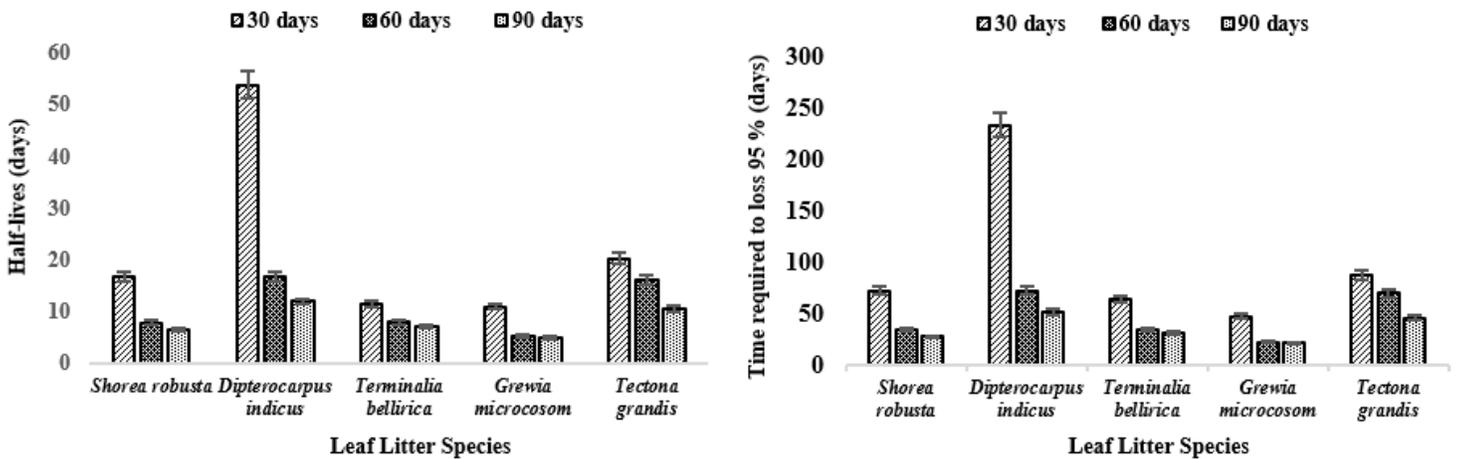


Figure 4

Half-lives($t_{50\pm SD}$) and Time required to loss of 95% ($t_{95\pm SD}$)

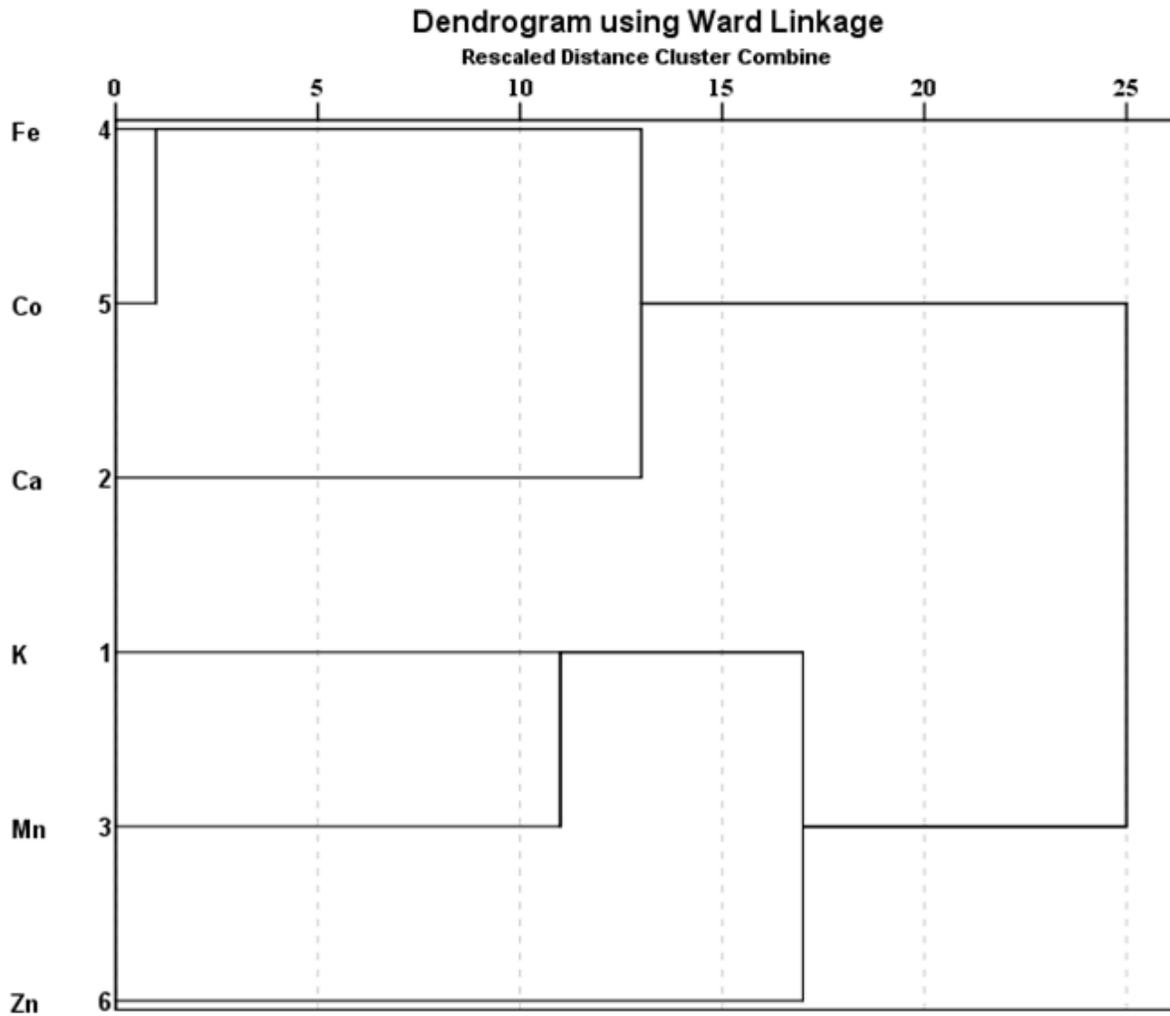


Figure 5

Hierarchical cluster analysis for the investigated nutrients in leaf litter of tree species from MSF