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HABITAT FRAGMENTATION AND NUTRIENT DYNAMICS IN TROPICAL DRY DECIDUOUS FORESTS OF WEST BENGAL, INDIA

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Abstract

Tropical dry deciduous forest of Purulia district known as Matha Protected Forest (MPF) in India is one of the most biodiversity rich area which is fragmented into three plots namely Plot A, Plot B and Plot C. Fragmentation of forest occurred with the advent of urbanization and rapid increase of human population that leads to deforestation for settlements and agricultural practices. This often leads to species loss in the study area. MPF mainly covers Sal (Shorea robusta Roxb.) as dominant species with predominant plant species of piyal (Buchanania latifolia Roxb.), sidha (Lagerstroemia parviflora Roxb.) and kendu (Diospyros melanoxylon Roxb.). The aim of present study is to determine distribution of nutrient content in green leaf, leaf litter and soil to improve the understanding of flow of nutrients and their losses within the ecosystem. From analysis it is revealed that species diversity is more in larger Plot A with improper nutrient cycling at smaller fragmented Plot B. It is found that P use efficiency is enhanced than K, N for Shorea robusta Roxb., while K use efficiency is higher than N, P in piyal (Buchanania latifolia Roxb.), sidha (Lagerstroemia parviflora Roxb.) and kendu (Diospyros melanoxylon Roxb.). We found site-dependent and between-species differences in nutrient content and nutrient remobilization. Particularly plot A shows decreased Nutrient Use Efficiency (NUE) and Nutrient Retranslocation Efficiency (NRE) followed by plot C and plot B which in turn depicts nutrient limitation at smaller plot B.

Keywords: Habitat fragmentation; species diversity; nutrient cycling; Nutrient Use Efficiency (NUE); Nutrient Retranslocation Efficiency (NRE).

INTRODUCTION

One of the major causes for habitat fragmentation as well as the loss of species diversity in the tropical dry deciduous forests is increased disturbance (Biswas and Khan, 2010). Species loss is evident due to fragmentation and smaller patches contain less species diversity than a large forest patch (Game and Peterken, 1984; Dzwonko and Loster, 1989). The dynamics of these forests in terms of their structure and function of ecosystems are governed by certain factors like climate, season, canopy, architecture, timing of canopy gap formation and insect outbreaks (Sukumar et al., 1992; Dorren et al., 2004). Measures of vegetation structure provide information on habitat suitability, ecosystem productivity and help predict successional pathways (Jones et al., 2004; Silver et al., 2004; Wang et al., 2004). Measures of ecosystem processes provide information on biogeochemical cycles and nutrient cycling necessary for the long-term stability of the ecosystems (Herrick, 2000).

The chief functional part of any ecosystem that plays a vital role in regulating nutrient cycling and organic matter content is litterfall. A significant amount of organic matter returns to the

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forest floor through litterfall. Energy transfer in the forest soils are also influenced by litterfall. However, soil physical, chemical and biological characteristics are greatly influenced by litterfall. Litterfall constitutes (together with root turnover) a major portion of nutrient cycling between plants and soils, which reflects the constraints on internal fluxes of C, N and P at ecosystem scale (Berg and Laskowski, 2006; McGroddy et al., 2004).

Functions of ecosystems in most of the tropical forests are constrained by lower degrees of nutrient supply and water limitation (Tanner et al., 1998; Vitousek and Howarth, 1991). Therefore, nutrient cycling in tropical dry forests receive less scientific attention compared to the humid counterpart (Jaramillo and Sanford, 1995). Nutrient restriction plays an important role in plant growth that has been tested across developmental sequences in humid tropical ecosystems of Hawaii (Vitousek and Farrington, 1997). Many studies have been made on litter dynamics in tropical forest ecosystems in India (Biswas and Khan, 2011; Kumar and Deepu, 1992; Pandey et al., 2006; Rai et al., 1986; Tripathi and Singh, 1995; Visalakshi, 1993). But very limited evidence is available for dry deciduous forest. So a study is undertaken on nutrient dynamics in dry deciduous forest of Purulia district, West Bengal. The aim of this study is to assess the nutrients in different fragmented habitats considering soil, green leaves and leaf litter that can form a basis for determining appropriate forest management strategies.

MATERIALS AND METHODS

Study Area

The study area, Matha Protected Forest (MPF) is enclosed within the parallel 23°05'00" N and 23°12'30" N and meridian 86°02'30" E and 86°10'00" E. MPF has three fragmented parts- Plot A, Plot B and Plot C. The area is characterized by undulating topography with highest peak of 665m in Plot A having better vegetative cover while Plot B is smaller with poor vegetative cover. Slope, relative relief, drainage density and road density ranges between <2 - >9°, 6.67 - 184.50m, 0.34 - 1.91km/km^2 and 0.45 – 1.45km/km^2 respectively. The climate is hot and dry with three distinct seasons viz. summer, monsoon and winter. Summer is intense and lasts from middle of March to mid of June. The monsoon starts from mid- June and lasts till end of September. Winter lasts from November to February. Minimum temperature fluctuates from 7°C to 14°C during months of December, January and February. Maximum temperature ranges from 42°C to 45°C during April to June. The average rainfall is 1031 mm while the highest rainfall (1173 mm) and lowest rainfall (767 mm) were recorded in the year 2000 and 1980 respectively. The south-west monsoon is the source of rainfall in Purulia. The soil in the area is laterite, red to brown in color and sandy loam in texture. The study area is covered with sal *(Shorea robusta* Roxb.*)* as a dominant species along with piyal (*Buchanania latifolia* Roxb.), sidha (*Lagerstroemia parviflora* Roxb.) and kendu (*Diospyros melanoxylon* Roxb.).

Vegetation Study and Soil Sampling

Studies on vegetation were done through quadrat method (minimum size of quadrat for each sample plot was 20 × 20 m and minimum number of quadrats was 5). Species diversity was determined by Shanon-Weaver Index (1949). Samples of soil were collected at five points randomly distributed in each plot at depths of 10 - 15 cm. All of the soil samples were oven-dried at 70°C, then grounded and passed through 2 mm sieve.

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Litterfall Collection

Litterfall was measured using five litter traps placed regularly within each plot (Xu et al., 2000), having 1 m^2 area. Litterfall collection took place seasonally (in the month of March, July and November) for four years. Samples was washed thoroughly with water then air dried and finally oven dried at 60°C overnight, then milled for chemical analysis. Fresh mature leaves were collected from the crowns of *Shorea robusta* Roxb., *Buchanania latifolia* Roxb., sidha (*Lagerstroemia parviflora* Roxb.) and kendu (*Diospyros melanoxylon* Roxb.) in the month of March, July and November for four consecutive years. These green leaves were processed in the same way as litterfall.

Chemical Analysis

Soil pH was measured by digital pH-meter (Systronics-121, India) in a 1:5 (w:v) soil water suspension. Organic carbon was estimated by Walkley and Black method (1934). The samples of ground leaf litter and green leaf samples were digested with HNO_3 – $HClO_4$ and analyzed for concentrations of P, K. Subsamples of soil were analyzed for available P following the molybdenum blue method of Jackson (1967), K was extracted from the soil in an ammonium acetate solution (pH=7) and measured with a digital flame photometer (Systronics-121, India). The total Kjeldahl nitrogen was determined by the micro-Kjeldahl procedure (Allen et al., 1974).

Computation and Statistics

The percent nutrient retranslocation efficiency (NRE) was calculated by the following equation (Finzi et al., 2001):

$$\text{NRE \%} = \{(A - B) / A\} \times 100$$

where A is the nutrient in green leaves and B is the nutrient in leaf litter.

Nutrient use efficiency (NUE) was calculated according to Vitousek (1984):

$$\text{NUE} = \text{litterfall mass } (g\ m^{-2}\ year^{-1}) / \text{nutrient content in litterfall } (g\ m^{-2}\ year^{-1}).$$

After generating the data, statistical analysis was done using Statistical Package for Social Sciences (SPSS version 16).

RESULTS AND DISCUSSIONS

Species Diversity

Matha Protected Forest is a gregarious type of forest with single dominating species of *Shorea robusta* (Sal). The other predominating plant species are *Buchanania latifolia* (Piyal), *Lagerstroemia parviflora* (Sidha) and *Diospyros melanoxylon* (Kendu). Species diversity at each habitat patch (plots) was found to be different from each other. Plot A is rich in species diversity (35.69) compared to that of plot B (11.06) and plot C (21.68). Anthropogenic activities are more pronounced in the area and smaller plot is more affected with loss of species diversity. The process is accelerated further by pronounced anthropogenic activities and deforestation of forest (Biswas and Khan, 2010).

Soil Characteristics

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The soil is acidic to neutral in nature which is the characteristic feature of lateritic soil. Nutrient characters of soil at two plots are given in Table 1. Soil organic carbon (SOC) [1.031(0.068)] is higher at plot A compared to plot B [0.755 (0.072)] and plot C [0.888(0.232)]. N% at A, B and C is 0.025(0.006), 0.029(0.007) and 0.028(0.003) respectively. C/N ratio is found to be 42 (in A), 26 (in B) and 32 (in C) which reveals slower rates of decomposition and nutrient immobilization. In case of available P, and exchangeable K the nutrient pattern in soil is similar at 99% level of significance ($p < 0.001$). From Table 1 it is found that SOC is negatively correlated with N as organic carbon is more than the available N. The process of decomposition of litterfall decreases N availability as the carbon–nitrogen ratio of soil organic matter is related to the patterns of nitrogen immobilization and mineralization during organic matter decomposition by microorganisms and its value decreases as decomposition proceeds (Swift et al., 1979). Study by Tsutsumi (1987) indicates that the process is negatively correlated with the rate of nitrogen mineralization in decomposition experiments by soil incubation.

Nutrient Quality of Green Leaves

Litterfall biomass of *Shorea robusta* Roxb. is almost highest about 1273 g m^{-2} $year^{-1}$ (average of three plots where plot A litterfall biomass is 1329 g m^{-2} $year^{-1}$, plot B is 1218 g m^{-2} $year^{-1}$ and plot C is 1272 g m^{-2} $year^{-1}$), whereas it is 850 g m^{-2} $year^{-1}$ for piyal (average of three plots where plot A litterfall biomass is 874 g m^{-2} $year^{-1}$, plot B is 826 g m^{-2} $year^{-1}$ and plot C is 850 g m^{-2} $year^{-1}$); 750 g m^{-2} $year^{-1}$ for *Lagerstroemia parviflora* (average of three plots where plot A litterfall biomass is 774 g m^{-2} $year^{-1}$, plot B is 726 g m^{-2} $year^{-1}$ and plot C is 750 g m^{-2} $year^{-1}$) and 745 g m^{-2} $year^{-1}$ for *Diospyros melanoxylon* Roxb. (average of three plots where plot A litterfall biomass is 768.5 g m^{-2} $year^{-1}$, plot B is 698 g m^{-2} $year^{-1}$ and plot C is 768.5 g m^{-2} $year^{-1}$). There is a positive correlation (Figure 1) between the DBH (diameter at breast height) and AGB (above ground biomass) of all the species at MPF. Nutrient quality of green leaf is given in Table 2. N% in kendu (*Diospyros melanoxylon*) is maximum followed by sal (*Shorea robusta*), piyal (*Buchanania latifolia*) and sidha (*Lagerstroemia parviflora*) in block A which is similar to block C. In block B the N% of four plant species follows the pattern as kendu (*Diospyros melanoxylon*)> piyal (*Buchanania latifolia*)> sidha (*Lagerstroemia parviflora*)> sal (*Shorea robusta*). But between the blocks N% in all the species is higher at block A followed by block C and B ($p< 0.001$) P concentration of *Lagerstroemia parviflora* is greater than *Diospyros melanoxylon* followed by *Buchanania latifolia* and *Shorea robusta* while among the plots, it follows the same trend as for N concentrations ($p< 0.001$). For K concentration, *Shorea robusta* is highest among all the species and considering all the plots, significant variation is found among the plots ($p< 0.001$). However, N, P, K is higher in plot A for all the species except of *Lagerstroemia parviflora* where Plot B K concentration is enhanced than plot A and plot C. Therefore, the mineral component showed site-dependent differences as well as between-species differences.

Nutrient Quality of Leaf Litter

Amount of litterfall was significantly affected by the regional features of the studied sites. The litterfall study was concentrated during three major period e.g. pre-monsoon, monsoon and post-monsoon and was strongly influenced by the high and low range of temperature and soil moisture. A pattern of litterfall in this study was broadly comparable to tropical deciduous forest of Mexico (Martinez-Yrizar and Sarukhan, 1990) and also comparable to the predominating species in the tropical dry deciduous forest (Biswas and Khan, 2011).

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The total nutrient characteristics of the litterfall are summarized in Table 3. Seasonal variations of major nutrient concentration in leaf litter are also analysed. N concentration in *Shorea robusta* Roxb. leaf litter during monsoon is increased than compared to pre-monsoon and post-monsoon ($p<0.05$ at Plot A, $p<0.01$ at Plot B and Plot C). Same trend is found in *Buchanania latifolia* Roxb. ($p<0.01$ at Plot A and Plot C, $p<0.05$ at Plot B); *Lagerstroemia parviflora* Roxb. ($p<0.01$ at both Plot A and B, $p<0.05$ at Plot C) and *Diospyros melanoxylon* Roxb. ($p<0.05$ for Plot A, B and C). Likewise, seasonal variation is found for P concentration among all the species ($p<0.05$- Plot A and B, $p<0.01$- Plot C for *Shorea robusta* Roxb.; $p<0.05$- Plot A, B and $p<0.01$ for *Buchanania latifolia* Roxb.; $p<0.01$- Plot A, B and $p<0.05$- Plot C for *Lagerstroemia parviflora* Roxb.; $p<0.05$- Plot A, B and $p<0.01$-Plot C). But seasonally K concentration in *Shorea robusta* Roxb. varies as $p<0.05$ at Plot A, B and $p<0.01$ at Plot C whereas it is $p<0.01$ at Plot A, B and $p<0.05$ for *Buchanania latifolia* Roxb.; $p<0.01$ at Plot A and $p<0.05$ at Plot B, C for *Lagerstroemia parviflora* Roxb. and $p<0.01$ at Plot A, C and $p<0.05$ at Plot B for *Diospyros melanoxylon* Roxb.

For *Buchanania latifolia* N (%) in litterfall has recorded the highest value at plot A and B while at plot C, N concentration is more for *Shorea robusta.* P concentration is high in *Lagerstroemia parviflora* at plot A and C whereas *Buchanania latifolia* P leaf litter concentration is enhanced at plot B. But K concentration is high in all the plots for *Shorea robusta.*

Nutrient Use Efficiency

Efficient nutrient use is generally characterized by the lower nutrient concentration in the litter fall (Vitousek, 1984) and nutrient use efficiency is influenced by several environmental factors as nutrient uptake from soil, transport and storage. In our study, the litterfall nutrient concentration is less than green leaf, hence, NUE is increased. Nutrient use efficiency of dry deciduous forest of MPF is given in Table 4. In our experiment, K use efficiency is enhanced than N and K for all the species except *Shorea robusta* where P use efficiency is enhanced in all the plots (A, B and C). The forest stand has higher within stand efficiency of P and K at plot B than A and C (Figure 2) which is related to lower availability of P and K at plot B. This can be inferred that NUE in litterfall can be used as an indicator of soil nutrient availability (Vitousek, 1984; Lugo, 1992). But P and K use efficiency is higher in comparison to evergreen broad-leaved forest (Xu et al., 2003) and tropical rain forest (Vitousek, 1984). There is no significant difference in N use efficiency among plot A, B and C. Likewise, P use efficiency of *Shorea robusta* is greater than *Lagerstroemia parviflora, Diospyros melanoxylon, Buchanania latifolia,* and but N use efficiency of *Lagerstroemia parviflora,* K use efficiency of *Buchanania latifolia* is enhanced than other species.

Nutrient Dynamics and Retranslocation

For the production of new leaves during nutrient cycle, translocated N and P supply most of the demand for those nutrients which are required for the process. This translocation allows the forest ecosystem to have certain independence from the soil and the possibility of optimal management of the available elements (Mellilo, 1981). Nutrient concentrations of leaf litter are significantly decreased than green leaf (Table 2, 3) throughout the forest and thus the nutrient retranslocation efficiency is high which suggests nutrient limitation. Nutrient retranslocation efficiency indices are given in Table 4. Throughout the forest N retranslocation efficiency is higher than that of P and K, i.e. N is highly remobilized. Accordingly, within stands total NRE percent is 52 (*Shorea robusta*), 67 (*Buchanania latifolia*), 31 (*Lagerstroemia parviflora*) and 33 (*Diospyros melanoxylon*) in plot A while it is 70 (*Shorea robusta*), 71 (*Buchanania latifolia*), 39 (*Lagerstroemia parviflora*) and 24

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(*Diospyros melanoxylon*) in plot B. Among the two plots, A shows decreased NRE than B, signifying improper nutrient transfer when nutrient concentration of soil, green leaves and leaf litters are considered.

The extent of retranslocation efficiency of N from the leaves in the study is 26-53% in *Shorea robusta* which is significantly higher than other species as 40-48%, 10-21% and 9-20% in *Buchanania latifolia, Lagerstroemia parviflora* and *Diospyros melanoxylon* respectively. Likewise, P retranslocation efficiency ranges from 11-23%, 12-23%, 8-15% and 8-9% in *Shorea robusta, Buchanania latifolia, Lagerstroemia parviflora* and *Diospyros melanoxylon* respectively while for K it is 3-6%, 4-11%, 2-14% and 5-6% respectively (Table 4 and Figure 3). Above all, we find between-species nutrient difference as well as site-dependent differences of nutrients at both plots of the forest.

CONCLUSIONS

Matha Protected Forest being dry and a nutrient-poor ecosystem, the amount of nutrient retranslocation is low that certainly retards the growth rate of plants. From the analysis it is revealed that species diversity is more in the larger Plot (A) than compared to the smaller Plot B. However it is found that P and K are more efficient in the stands. Naturally the nutrient cycling in the forest is inadequate that reduces the growth of the plants mainly at fragmented plot B. Thus proper management of the forest is required for the survival of plant species and maintenance of biodiversity in the area. Hence it can be inferred that the area having rich species diversity provide proper nutrient cycling in the forest than the area which is degraded and encroached with low species diversity.

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Table 1. Site characteristics and soil properties at Matha Protected Forest (MPF)

Site characteristics	Plot A	Plot B	Plot C	Levels of Significance
Altitude (m)	665	278		
Soil type	Red soil	Red soil	Red soil	
Surface mineral soil properties (10-15 cm)	Mean (SD)*	Mean (SD)*	Mean (SD)*	
Organic Carbon (%)	1.031(0.068)	0.755 (0.072)	0.888(0.232)	*
Nitrogen (%)	0.025(0.006)	0.029(0.007)	0.028(0.003)	**
Available P (mg kg^{-1})	15.289(2.710)	10.911(1.463)	12.178(1.601)	*
Exchangeable K (mg kg^{-1})	90.055(13.641)	68.500(4.008)	70.278(5.454)	*

Levels of significance: *, $p < 0.001$, **, $p < 0.01$ (n = 15); n is number of samples collected from each plot

* Standard deviation

Table 2. Mean nutrient concentrations with SD in green leaves of four species in Matha Protected Forest (MPF) in 4 year period from March 2007 to February 2011

Species	Nutrients	Plot A	Plot B	Plot C
Shorea robusta	N (%)	1.247(0.030)	0.875(0.011)	1.187(0.020)
	P (mg kg^{-1})	215.241(0.567)	203.010(0.510)	213.605(0.325)
	K (mg kg^{-1})	230.330 (0.291)	215.196(0.720)	229.058(0.408)
Buchanania latifolia	N (%)	1.070(0.126)	0.948(0.035)	0.986(0.078)
	P (mg kg^{-1})	266.010(0.278)	262.835(0.499)	264.585(0.419)
	K (mg kg^{-1})	188.114(0.338)	179.350(0.423)	185.666(0.366)
Lagerstroemia parviflora	N (%)	1.013(0.038)	0.894(0.050)	0.953(0.046)
	P (mg kg^{-1})	307.629(1.035)	283.524(0.813)	304.913(0.692)
	K (mg kg^{-1})	189.971(0.689)	193.302(0.487)	184.830(0.419)
Diospyros melanoxylon	N (%)	1.257(0.085)	0.980 (0.052)	1.098(0.219)
	P (mg kg^{-1})	284.286(0.449)	272.187(0.650)	279.439(0.408)
	K (mg kg^{-1})	187.176(0.682)	179.823(0.359)	185.577(0.424)

Table 3. Mean nutrient concentrations with SD in leaf litter of four species in Matha Protected Forest (MPF) in 4 year period from March 2007 to February 2011

Species	Nutrients	Plot A	Plot B	Plot C
Shorea robusta	N (%)	0.985(0.074)	0.836(0.019)	0.970(0.051)
	P (mg kg^{-1})	190.502(1.383)	154.874(0.583)	185.575(0.695)
	K (mg kg^{-1})	222.117(0.812)	192.576(1.079)	196.386(0.564)
Buchanania latifolia	N (%)	0.992(0.041)	0.920(0.040)	0.950(0.032)
	P (mg kg^{-1})	259.764(4.350)	253.277(1.659)	257.976(1.131)

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	K (mg kg^{-1})	176.386(0.938)	157.508(0.752)	171.817(1.222)
Lagerstroemia parviflora	N (%)	0.952(0.282)	0.803(0.095)	0.891(0.082)
	P (mg kg^{-1})	288.012(2.224)	239.265(1.845)	279.554(2.209)
	K (mg kg^{-1})	184.686(2.076)	165.757(2.730)	177.346(1.607)
Diospyros melanoxylon	N (%)	0.944(0.024)	0.893(0.040)	0.935(0.009)
	P (mg kg^{-1})	264.273(5.358)	244.023(1.260)	255.091(1.455)
	K (mg kg^{-1})	176.628(0.960)	172.806(0.464)	177.949(0.492)

Table 4. Major nutrient use efficiency (NUE) and nutrient retranslocation efficiency (NRE) of two different species at two plots of Matha Protected Forest (MPF)

Species	Nutrients	NUE (g g^{-1})			NRE (%)		
		Plot A	Plot B	Plot C	Plot A	Plot B	Plot C
Shorea robusta	N	101	120	103	21	4	18
	P	5274	6513	5413	11	24	13
	K	4505	5227	5108	3	10	14
Buchanania latifolia	N	101	109	105	7	3	4
	P	3867	3971	3899	2	4	2
	K	5712	6403	5862	6	12	7
Lagerstroemia parviflora	N	105	125	112	6	10	6
	P	4398	4196	3588	6	21	15
	K	5451	6101	5682	3	14	4
Diospyros melanoxylon	N	106	112	107	25	9	15
	P	3804	4106	3922	7	10	9
	K	5692	5817	5652	6	4	4

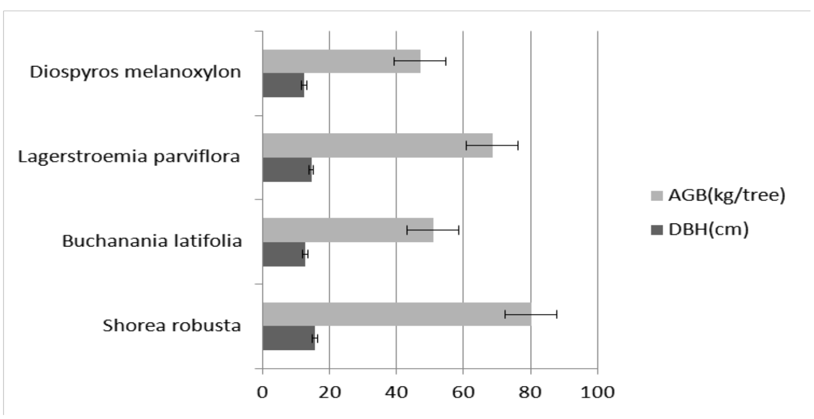

Figure 1. Graphhical representation of diameter at breast height (DBH) and above ground biomass (AGB) with standard error of four plant species at Matha Protected Forest

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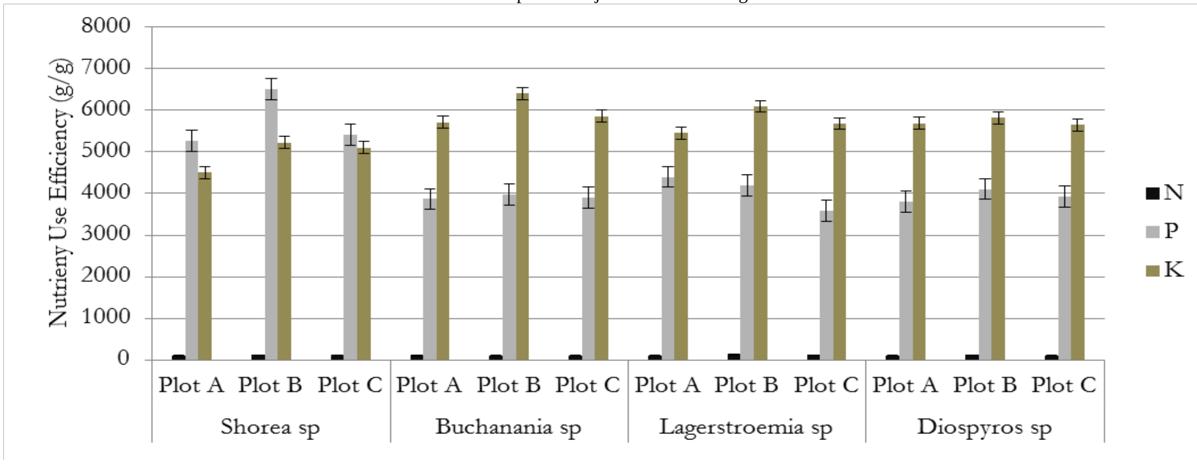

Figure 2. Nutrient Use Efficiency of four plant species at three plots of Matha Protected Forest (MPF)

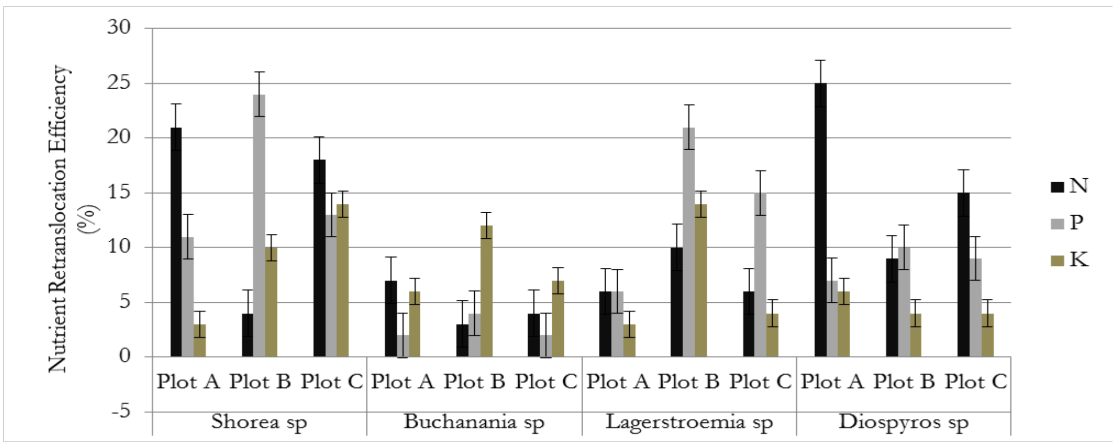

Figure 3. Nutrient Retranslocation Efficiency of four plant species at three plots of Matha Protected Forest (MPF)