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Litterfall patterns and soil nutrient chemistry in varied tropical deciduous forests

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Abstract
Vegetation affects the nutrient composition of soil through nutrient inputs via litterfall. Nutrient properties and enzyme activities of soils were examined under the influence of litterfall in natural dry miscellaneous forest (DM), natural Sal (*Shorea robusta*) mixed forest (SM) and a 50-year old commercial Teak (*Tectona grandis*) plantation forest (TP) in a tropical deciduous forest area of northern India. Annual litterfall was 6.7, 5.9 and 5.0 Mg ha^{-1} in the DM, SM and TP, respectively. The highest nutrient concentrations (4.46% N, 0.588% P and 0.773% K) were measured in the DM litter and lowest in the TP litter. Soil N, P and K were highest in DM and lowest in the TP forests. Likewise, soil enzyme activity followed the same pattern. In natural forests, higher nutrients might lead to the higher soil nutrient properties and enzyme activities compared to the monoculture commercial plantations.

Keywords: dry miscellaneous forest, *Shorea robusta*, teak plantation, litter, soil

1. Introduction
Tropical deciduous forests constitute 64.5% of the total forest area of India [1]. Forest cover in India is about 21.02% of its geography and is classified into moist (34%) and dry (30%) deciduous forest, with the remaining 36% comprising wet evergreen or semi-evergreen forest [2]. Litterfall is an important pathway for nutrient transfer from plants to soil in forest ecosystems. Litterfall sustains forest growth on one hand and exerts a great influence on nutritional and biological characteristics of forest soil. Trees and associated plant-soil interactions regulate the nutritional properties of forest soil [3, 4]. A variation in composition of soil microbial community has been observed under different forest plant species, playing a key role in litter decomposition and nutrient cycling processes [5, 6]. The effects of vegetation on soil biological processes are complex and dynamic due to spatial heterogeneity of forest soils. Tree species composition is also a key factor affecting soil biological dynamics and nutrient turnover in soil [7]. Soil enzymes are indicators of the soil quality [8] and may vary with vegetation composition and tree cover [9].

At various places in India and other parts of the world, the conversion of natural forests to commercial plantations has happend in the past. This process may affect forest soil properties and the forest productivity adversely [10]. This study aimed to assess the difference in soil properties between natural forests and a commercial plantation under the influence of differences in the litterfall. We investigated the changes in soil properties of three distinct tropical forest types, namely, two natural forests (dry miscellaneous, and sal (*Shorea robusta* C. F. Gaertn.) mixed) and a 50-year old monoculture commercial teak (*Tectona grandis* L.f.) plantation forest. It was postulated that soil nutrient content and enzyme activity may be higher in the forest type having higher annual litterfall.

2. Materials and Methods
2.1. Study area and ecological description
The study was performed during 2012-2014 in three forest types of Katarniaghat Wildlife Sanctuary (KWS) located in the Terai region of northern India ($28^{0}06'$N, $81^{0}11'$E to $28^{0}16'$N, $81^{0}18'$E) (Fig. 1). The annual precipitation here is 1500 mm [11]. The annual maximum and minimum mean temperatures recorded are 40^{0}C and 8^{0}C, respectively [11]. The three forest types were (i) dry miscellaneous natural forest (DM; $28^{0}06'7.3''$ to $28^{0}06'42.9''$N, $81^{0}18'19.1''$ to $81^{0}18'30.3''$E), (ii) Sal (*S. robusta*) mixed natural forest (SM; $28^{0}15'2.8''$ to $28^{0}15'28.2''$N,

81^{0}18'10.9" to 81^{0}14'4.7"E) and (iii) a 50-year old commercial monoculture teak (*T. grandis*) plantation forest (TP; 28^{0}15'6.3" to 28^{0}16'59.9"N, 81^{0}13'8.7" to 81^{0}11'2.6"E). The conversion of natural forest was accompanied by logging of naturally occurring trees and planting of teak sapling 50 year ago by the State Forest Department, Government of India. The trees were initially thinned at 3 to 5 years of age to improve the stocking of the plantation. There was subsequent thinning and gap filling every 5 to 10 years until the trees reached the age of 45 years, by which time stand density had been reduced to between 700 and 800 trees/ha from a starting density of 1100-1600 trees/ha. The elevation of the KWS is 124m asl. Three permanent plots (100m x 100m) were established in each forest type (N=3) with 1 km distance between replicate plots. All nine permanent plots (three per forest type) were interspersed in the study area [12].

Community characteristics of the three forest types including floristic information, density, basal area and diversity indices are described as per Hill [13] and Whittaker [14] (Table 1). In the DM, 58 tree species belonging to 48 genera were recorded. On the basis of importance value index (IVI), *Mallotus philippensis* (Lam.) Müll. Arg., *Syzygium cumini* (L.) Skeels, *S. robusta* C. F. Gaertn., *Lagerstroemia parviflora* Roxb., *Ehretia laevis* Roxb. were the five most dominant species. The ten species representing the highest IVI values occupied 59.4% of the stems and accounted for 66.21% of the basal area of the DM community. The SM community consisted of 35 tree species belonging to 33 genera. Of these, *S. robusta, M. philippensis, Terminalia elliptica* Willd., *S. cumini*, *Miliusa velutina* (Dunal.) Hook. f. & Thomson. were the five most dominant species. However, *S. robusta*, with the highest IVI value (149.73) accounted for about 50% of the total stems and 77.38% of the total basal area. In the TP, *T. grandis* had the highest IVI value (199.22), and accounted for 66.41% of total stems, and and 84.53% of total basal area.

2.2. Litterfall nutrient return

Litterfall was sampled at monthly intervals using circular litter traps (1.25 m^2 collection area). Ten litter traps were randomly placed in each of the permanent plots. Monthly litterfall values obtained from these ten traps per plot were pooled to determine seasonal litterfall i.e., for winter (October-February), summer (March-May) and rainy (June-September) seasons. We also calculated annual litterfall for the three forest types. A 500g sample of the pooled littermass per plot was oven-dried at 72^{0}C to a constant weight. Oven-dried litter samples were ground and analyzed for N, P and K concentration. For total N estimation, 1g of litter sample (N=3) was digested with H_2SO_4 and a mixture of $CuSO_4.5H_2O$ and K_2SO_4 (1:5) in a digestion unit and further analyzed using a nitrogen distillation unit [15]. A 0.1 g sample (N=3) was digested by HNO_3 and $HClO_4$ (4:1). The P content was determined by the ammonium molybdate method and the K content by flame photometer [15] in the digested samples. Finally, the annual amount of nutrient returned to the soil through litterfall (in kg ha^{-1}) was calculated by summing the product of litter nutrient concentration and total litterfall mass in each season.

2.3. Soil characteristics

At the end of the rainy season in each year, ten soil samples [16] were collected randomly from each permanent plot of each forest type using 1.2 m long circular (5 cm dia.) iron soil core sampler. The core samples were composited by depth (0-15, 15-30, 30-60 cm) before sub-samples were taken for analysis. Large fragments of plant materials (roots) were removed from soil samples manually. Chemical analysis was carried out on subsamples of soil that were air-dried and sieved (2 mm). Microbial and enzyme analyses were conducted on soil subsamples that were stored at 4^{0}C. All the analyses were performed in triplicate for each soil sample.

Soil pH and electrical conductivity (EC) were measured in soil: water (1:2.5) suspension by glass pH and conductivity electrodes, respectively (Thermo Orion). Total organic carbon (TOC) was determined by dichromate oxidation method [15]. Soil microbial biomass carbon (MBC) was estimated by chloroform fumigation extraction method [17]. The total N, P and K contents in soil were analyzed after di-acid digestion as described previously for litter nutrient analysis.

Soil enzymes play key biochemical functions in the overall process of material and energy conversion. Soil enzymes are often used as indicators of soil quality and sensitive to disturbance in the soil ecosystem. Dehydrogenase (DHA), protease (PA), acid phosphatase (APA), β-glucosidase (GA) and cellulase (CeA) activities were assayed according to [18].

2.4. Statistical analysis

Mean annual litterfall nutrient return to the soil, soil nutrient concentrations, and soil enzyme activity were statistically analyzed using ANOVA-GLM (Tukey's HSD at the 95% level of probability) to determine significant differences among different forest types and soil depths. Pearson's correlation coefficient analysis was performed between soil chemical properties and soil enzyme activities of different forests under study. All analyses were performed using the SPSS 10.

3. Results and Discussion

3.1. Litterfall

Litterfall varied among the forest types and seasons. Litterfall was highest during the summer season and lowest during the winter season in all the forest types (Fig. 2), as would be expected for these deciduous forests. Others have also found that Indian dry deciduous forests are characterized by a distinct leafless period during the dry summer season [19]. Singh *et al.* [20] also observed maximum litterfall during the summer season in Sal mixed forests.

Annual litterfall (in kg/ha) was highest in the DM followed by the SM and the TP. The variation in litterfall among the forest types may be due to their difference in floristic characteristics (Table 1). Stand structure and community composition of forests determine the quantity of litterfall [21]. The study revealed that the two natural forests contribute more littermass to soil compared to the TP. Annual litterfall ranges from 5.44 to 9.44 Mg ha^{-1} in different natural forests of the world [22, 23]. Annual litterfall measured in teak plantations in India ranged from 3.30-7.95 Mg ha^{-1} (districts of Chhindwara, Pandadoh and Seoni in Madhya Pradesh;) [24, 25] to 6.45 Mg ha^{-1} (Terai region of Nainital;) [26].

3.2. Nutrient concentration and return through litterfall

Nutrients in littermass were highest in the rainy season among all the forest types and lowest in the winter. Similar findings have been reported earlier [27, 28]. Litter nutrient concentrations and total nutrient return in litterfall varied with season (Table 2). Concentrations of N, P and K in litter varied significantly ($p<0.05$) in different forest types and seasons. The highest nutrient concentrations (N 1.49%, P 0.19% and K 0.27%) were measured in litter of the DM, whereas the lowest (N 0.81%, P 0.09% and K 0.12%) were measured in the TP.

Litter mass was highest in the DM and thus, annual nutrient return through litterfall was highest in the DM (N 99.5 kg ha^{-1}, P 13.17 kg ha^{-1} and K 17.53 kg ha^{-1}) and lowest in the TP (N 47.62 kg ha^{-1}, P 6.05 kg ha^{-1} and K 10.17 kg ha^{-1}). In the case of TP, The littermass, its nutrient concentrations and nutrient return through litterfall are found similar to the teak forest of Madhya Pradesh and Nainital [26, 29]. Vitousek & Sanford [22] reviewed the data on some tropical dry mixed forests along a fertility gradient and found that the annual return of nutrients through litterfall was in a range of 64-162, 2.6-8.8, and 21-41 kg ha^{-1} for N, P and K, respectively. Variation among forest types regarding nutrient contents in littermass and nutrient return in litterfall may be primarily due to the difference in the littermass and tree composition of natural forests and the TP [30]. Singh & Singh [31] have shown that floristic composition and the age of the forest determine the quantity of litterfall, which may affect nutrient return to the soil. In this study, the teak plantations are young compared to the two natural forest types under study.

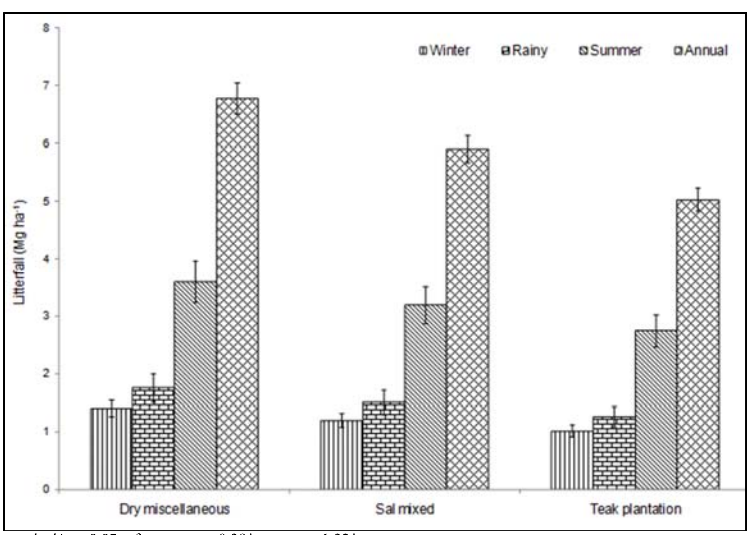
3.3. Soil nutrient characteristics

Soil pH, EC, TOC, MBC, and total NPK contents varied significantly among forest types and soil depths (Fig. 3). Soil pH decreased across the soil depth and ranged from 6.2 – 6.9 across the studied forest types (Fig. 3a). The pH was highest in the TP and lowest in the SM. Conversely, EC was found to be maximum in the DM soil (0-15 cm) and lowest in the TP (30-60 cm) (Fig. 3b). The TOC and MBC contents were highest (1.82% and 578.77 µg g^{-1}, respectively) in the DM forest at 0-15 cm soil depth, and lowest (0.68% and 156.31 µg g^{-1}, respectively) in the TP at 30-60 cm soil depth (Fig. 3c, d). Soil TOC and MBC in the DM showed 167% and 270%, respectively higher values compared to the TP. The higher MBC measured in the natural forest types (DM and SM) could be due to greater accumulation of plant residues and organic carbon due to higher litterfall, providing more substrate for soil microbes [32]. The litter provided organic matter that contributed to soil TOC and subsequent higher MBC [33].

Higher values of total soil N, P and K were measured in DM compared to TP (Fig. 3 e, f, g). This difference in nutrient content may be primarily due to the difference in litterfall and floristic composition of these forest types. France *et al.* [34] suggested that the differences in total NPK contents in soils may be due to the differences in physiographic differences and species composition of forest types. In the study, the soil nutrient quantity was found higher in natural forests with given species (Table 1) compared to teak plantation forest. Tree species can have significant impacts on soil chemical properties via litter inputs with diverse nutrient contents [35].

3.4. Soil enzyme activities

The CeA varied among all soil depths in a constant pattern across all forest types (Fig. 4a). The CeA was highest in the DM, followed by the SM and the TP. Similarly, the GA decreased significantly from the DM to the TP, but a sharp decline in the GA was observed between 0-15 cm to 15-30 cm and 30-60 cm soil depth (Fig. 4b). The APA and PA followed a similar pattern (Fig. 4 c, d). The APA can be a good indicator of soil organic phosphorus mineralization [36]. Plant growth and high soil MBC favourably affected soil enzyme activities. The increased enzyme activities would respond to meet the increasing nutrient demand by plants and microbial growth. The DM and the SM exhibited higher soil enzyme activities than the TP. This pattern was presumably influenced by soil nutrient inputs via litterfall [7]. Our results indicated that different soil chemical properties had a close relationship with respective soil enzyme activities (Fig. 3f, 4c; Table 3). Better soil nutrient conditions may support higher soil enzyme activities [37]. Similarly, DHA varied significantly among the forest types and soil depths (Fig. 4e), which is an indicator of total microbial oxidative activities in soil. The floristic composition was totally different in the DM and SM compared to the TP. Different litterfall pattern may be the reason for different levels of soil enzyme activities in these forest types owing to the difference in substrate contents in the littermass. Activities of microbe-derived extracellular enzymes are mainly regulated by the quality and quantity of litter and have been found to be maximum for the CeA, PA and DHA during the rainy season [38]. The highest biological activity noticed in the DM correlated to highest litterfall [39]. The TP had lowest enzyme activities. Soil nutrient contents (total NPK) were found to be positively and significantly ($p<0.01$) correlated with all soil enzyme activity in the three forest types (Table 3). A high positive correlation exists between soil enzyme activity, soil TOC and MBC [40]. Soil enzyme activities had non-significant negative correlation with soil pH and EC (Table 3).



hsd*$p< 0.05$ = forest types: 0.39*, seasons: 1.32*

Fig 1: Seasonal and annual litterfall (Mean±SD) in the three forest types.

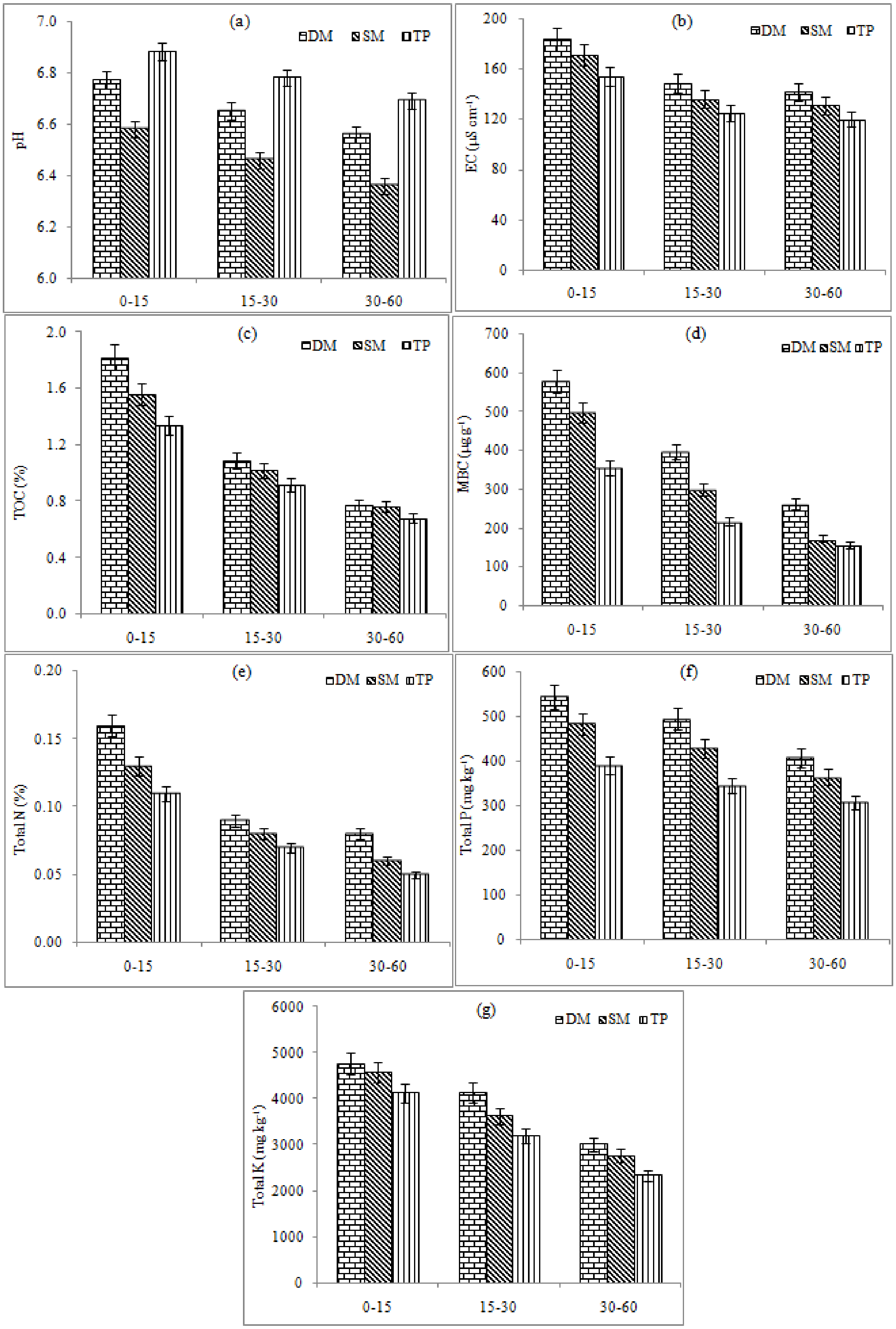


Fig 2: Soil chemical properties (Mean±SD) {a= pH, b= Electrical conductivity (EC), c= Total organic carbon (TOC), d= Microbial biomass carbon (MBC), e= Total nitrogen (TN), f= Total phosphorous (TP), g= Total potassium (TK)} at different soil depths of three forest types (DM: Dry miscellaneous; SM: Sal-mixed; TP: Teak Plantation).

HSD$_{*p<0.05}$	**Chemical Parameters**						
	pH	**EC**	**TOC**	**MBC**	**TN**	**TP**	**TK**
Forest types	0.213*	16.989*	0.164*	113.47*	0.029*	89.573*	499.305*
Soil depths	0.16*	26.083*	0.555*	186.626*	0.043*	74.949*	1781.897*

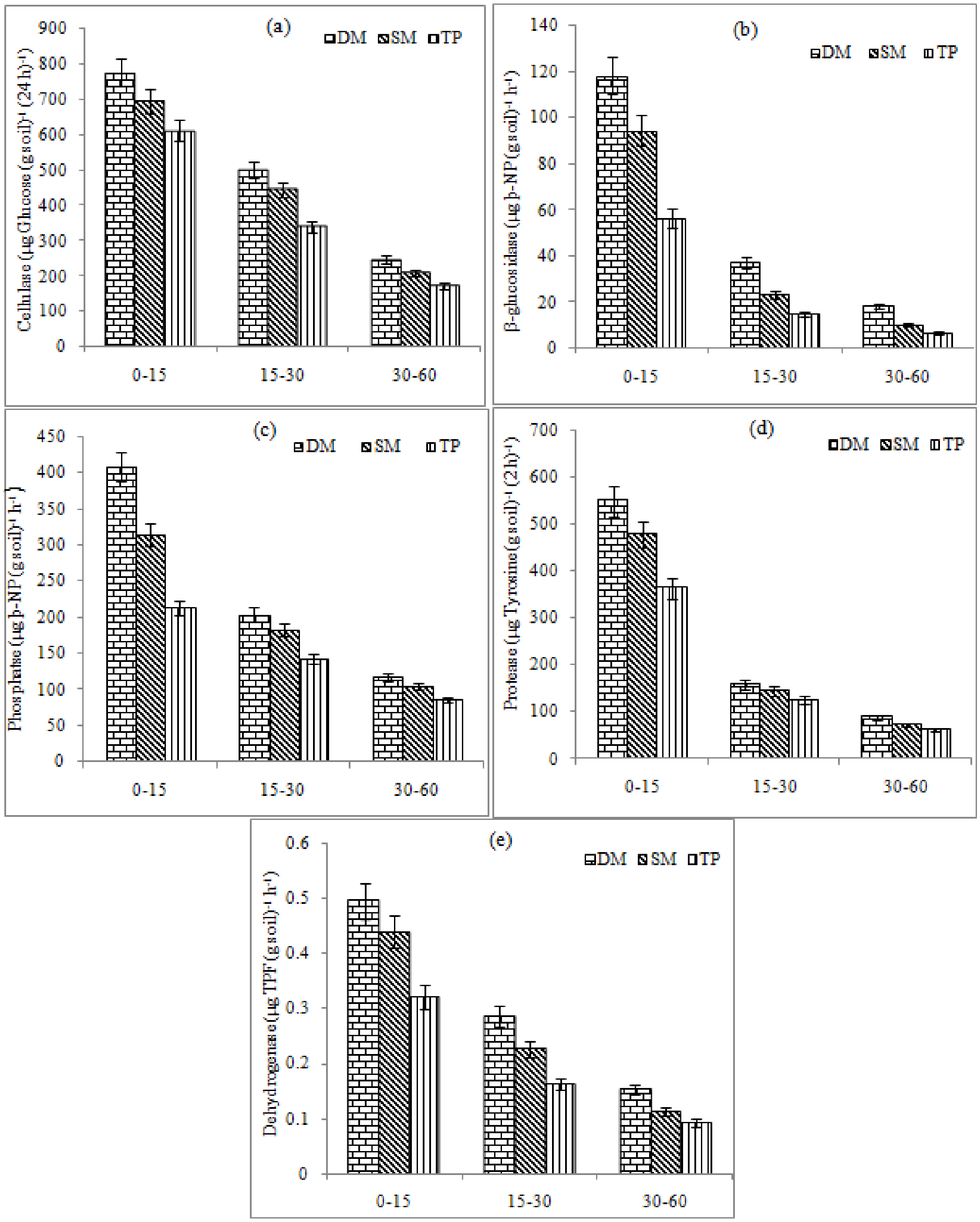


Fig 3: Soil enzyme activities (Mean±SD) {a= Cellulase (CeA), b= β-glucosidase (GA), c= Phosphatase (APA), d= Protease (PA), e= Dehydrogenase (DHA)} at different soil depths of three forest types (DM: Dry miscellaneous; SM: Sal-mixed; TP: Teak Plantation).

HSD *$^{*}p< 0.05$*	**Biochemical Parameters**				
	CeA	**GA**	**APA**	**PA**	**DHA**
Forest types	48.773*	21.229*	61.439*	27.115*	0.096*
Soil depths	434.585*	51.952*	139.495*	259.381*	0.198*

Table 1: Community structure of the three forest types of Katarniaghat Wildlife Sanctuary.

Stand parameters	**Forest types**		
	Dry miscellaneous (DM)	**Sal mixed (SM)**	**Teak plantation (TP)**
Density (stems ha^{-1})	813	793	765
Basal Area (m^2ha^{-1})	66.31	77.0	50.3
Simpson's dominance index (C)	0.099	0.35	0.72
Shannon-Wiener's diversity index (H')	4.45	2.47	1.16
Hill diversity number			
N0	58	35	25

N1	85.93	11.8	3.2
N2	10.06	2.9	1.39
Five Dominant Tree species	*Mallotus philippensis* (Lam.) Müll. Arg.	*Shorea robusta* C. F. Gaertn.	*Tectona grandis* L. f.
	Syzygium cumini (L.) Skeels	*Mallotus philippensis* (Lam.) Müll. Arg.	*Mallotus philippensis* (Lam.) Müll. Arg.
	Shorea robusta C. F. Gaertn.	*Syzygium cumini* (L.) Skeels	*Shorea robusta* C. F. Gaertn.
	Lagerstroemia parviflora Roxb.	*Terminalia elliptica* Willd.	*Lagerstroemia parviflora* Roxb.
	Ehretia laevis *Roxb.*	*Miliusa velutina* *(Dunal) Hook. f. & Thomson*	*Litsea glutinosa* *(Lour.) C. B. Rob.*

Table 2: Seasonal variation of litter nutrient concentration (%) and nutrient return (kg ha^{-1}) to the forest floor

Forest types	Seasons	Parameters			
			N	P	K
Dry miscellaneous forest (DM)	Winter	Concentration (%)	1.394	0.160	0.200
		Return (kg ha^{-1})	24.451	2.807	3.520
	Summer	Concentration (%)	1.463	0.198	0.271
		Return (kg ha^{-1})	52.585	7.130	9.760
	Rainy	Concentration (%)	1.603	0.230	0.302
		Return (kg ha^{-1})	22.526	3.230	4.250
	Total	ANR (kg ha^{-1})	99.570	13.170	17.530
Sal mixed forest (SM)	Winter	Concentration (%)	1.248	0.114	0.169
		Return (kg ha^{-1})	18.901	1.719	2.556
	Summer	Concentration (%)	1.283	0.145	0.236
		Return (kg ha^{-1})	40.858	4.630	7.526
	Rainy	Concentration (%)	1.385	0.216	0.315
		Return (kg ha^{-1})	16.626	2.580	3.760
	Total	ANR (kg ha^{-1})	76.390	8.930	13.850
Teak plantation forest (TP)	Winter	Concentration (%)	0.814	0.099	0.123
		Return (kg ha^{-1})	10.208	1.253	1.550
	Summer	Concentration (%)	0.847	0.120	0.205
		Return (kg ha^{-1})	23.345	3.287	5.635
	Rainy	Concentration (%)	1.112	0.148	0.294
		Return (kg ha^{-1})	9.750	1.505	2.980
	Total	ANR (kg ha^{-1})	43.310	6.050	10.170

ANR= Annual Nutrient Return.

HSD for litter nutrient concentration	N	P	K
Forest types	0.41*	0.04*	0.03*
Seasons	0.14*	0.05*	0.09*
HSD for litter nutrient return	N	P	K
Forest types	12.44*	1.58*	1.63*
Seasons	19.62*	2.57*	3.39*

*$p < 0.05$

Table 3: Pearson's correlation coefficient between chemical properties and enzyme activities of forest soils

Soil Parameters	CeA	GA	APA	PA	DHA
pH	-0.631	-0.559	-0.619	-0.670*	-0.715*
EC	-0.587	- 0.056	-0.204	-0.346	-0.418
TOC	0.788*	0.889**	0.988**	0.923**	0.921**
MBC	0.947**	0.715*	0.935**	0.956**	0.967**
Total N	0.827**	0.925**	0.987**	0.956**	0.952**
Total P	0.845**	0.762*	0.953**	0.957**	0.939**
Total K	0.812**	0.680*	0.884**	0.884**	0.895**

** $p < 0.01$; * $p < 0.05$

EC: Electrical conductivity, TOC: Total organic carbon, MBC: Microbial biomass carbon, CeA: Cellulase activity, GA: Glucosidase activity, APA: Acid/Alkaline phosphatase activity, PA: Protease activity, DHA: Dehydrogenase activity

Conclusions

It is concluded that litterfall, nutrient inputs and soil biochemical properties were different from the natural forests to the plantation forest. The natural forest has higher litterfall mass than teak plantation. In natural forests, higher nutrients inputs via litterfall might lead to the higher soil nutrients and enzyme activities compared to the commercial monoculture plantations in the tropical deciduous forests of India.

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Author Contributions

All authors mutually conceived the hypothesis, designed the experiments, performed the experiments; analyzed the data and contributed equally to the paper.

Conflicts of Interest

Authors do not have any conflict of interest in the paper.

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