====== **ОРИГИНАЛЬНЫЕ СТАТЬИ** ======

LITTER TURNOVER AND NUTRIENTS DYNAMIC IN A TROPICAL MOIST DECIDUOUS FOREST OF INDIA

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Litter accumulation and leaf decomposition represent the main pathway for nutrient cycling in forest ecosystems. This study investigates four species, *Pongamia pinnata* (PP), *Terminalia arjuna* (TA), *Gardenia resinifera* (GR), and *Celtis phillipensis* (CP) in a tropical moist deciduous forest of India. The goals of this study were: i) to quantify the dry weight of litter accumulation and litter decay; ii) to define the nutrient composition of litter accumulation and release of nutrients through decomposition; and iii) to estimate the relation between litter mass loss and abiotic variables. Litter samples (five replicates) were collected from a 1×1 m square frame placed randomly under the study species. The litter bag technique was used to calculate litter decomposition. The quantity of annual forest floor litter was the highest in PP (1.97 kg m^{-2} yr^{-1}), followed in decreasing order by TA (1.83 kg m^{-2} yr^{-1}), CP (1.69 kg m^{-2} yr^{-1}), and GR (1.62 kg m^{-2} yr^{-1}), with leaves representing the largest fraction with 61.2% of total litter. Decomposition of leaves was greater in the rainy season, PP and TA leaf litters decomposed faster in 10 months than the GR and CP species. Litter mass loss highly correlated with abiotic components like rainfall ($r = 0.998$ to 0.999), relative humidity ($r = 0.711$ to 0.785), and soil moisture ($r = 0.382$ to 0.839). The differences in decomposition coefficient and half-life periods are related to the structure and nutrient concentration of leaf litter and environmental factors. We can conclude that PP and TA species exhibited the highest weight loss, which may be due to high concentrations of C and N and low concentrations of lignin and cellulose that cause change in nutrients of soil and decomposers as well as the quality of decomposing litter. The forest could play a significant role in mitigation in the context of global climate change.

Keywords: Litter accumulation, litter decay, decomposition coefficient, nutrients, carbon, nitrogen, seasonal variation, abiotic variables.

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Forest litter has a significant influence on the forest ecosystem dynamics (Olson, 1963). However, the growth and productivity of forest ecosystems mainly depend on the rate of decomposition of forest floor litter. The decomposition of forest litter is a major pathway for providing organic and inorganic elements for the nutrient cycling processes (Mudrick et al., 1994). At a global scale, aboveground biomass and decomposition rates in tropical ecosystems increase along with mean annual precipitation (Gei and Powers, 2014). The amount of litterfall is directly related to aboveground biomass accumulation (Lawrence, 2005; Chave et al., 2010; Feng et al., 2019). Forest litter minimizes the soil erosion, runoff, and increases the nutrients rate in the soil. A subsequential amount of nutrients taken up by the aboveground component of the tree returns to the soil through litterfall (Saha et al., 2016).

Litter accumulation needs some significant factors like light, heat, and water, all of which have a complex impact on the abiotic environment. Litter acts as a mechanical barrier, intercepting light and altering the spectral structure. It also reduces soil temperature during the day by decreasing solar radiation absorption, but increases soil temperature at night by reducing heat loss (Jensen and Gutekunst, 2003). Additionally, litter accumulation may delay the freezing of the soil in the winter season, while soil temperature decreases too, which indirectly increases the soil moisture (Facelli and Pickett, 1991). Litter can directly increase the soil moisture by reducing water evaporation. In addition, litter accumulation can increase snow capture and retention in winter and soil moisture in early spring, but the interception effect of litter reduces infiltration by rainfall (Naeth et al., 1991). Therefore, an understanding of the modified microenvironment is crucial to elucidate the role of litter accumulation in regulating plant communities (Hou et al., 2019).

Litter decomposition plays a crucial role in the nutrient composition of forest ecosystems, where vegetation depends mainly on the recycling of nutrients in

the plant detritus. During this process, plant nutrients become available for recycling within the ecosystem (Saha et al., 2016). The decomposition rate of litter controls nutrient release in the soil. The balance between litter production and its decomposition also controls the size of the carbon reservoir in the soil (Kurz et al., 2000). Soil properties, nutrient availability, temperature, water availability, and leaf litter quality are the main factors that determine the decomposition rate of litter (Zhang et al., 2014; Giweta, 2020). The decomposition of leaf litter is a major source of nutrients in forest ecosystems. As leaves are broken down by insect and microbial decomposers, organically bound nutrients are released as free ions to the soil solution which is then available for uptake by plants. The substrate quality index includes nitrogen concentration, the ratio of carbon to nitrogen, lignin concentration, and the ratio of lignin to nitrogen (Devi and Yadava, 2010). Litter quality affects not only the rate of mass loss, but also the patterns and rates of nutrient mineralization and release (Regina, 2001). Climatic features such as temperature, rainfall, and their seasonal variations, may influence the activity of microbes and soil fauna that can significantly affect the decomposition rate. In addition, litter serves as an intermediary between vegetation and soil and is a major substrate for soil microorganisms influencing their activities (Averti et al., 2018). The litter diversity also influences the activity of soil communities and processes during decomposition (Chapman and Koch, 2007).

Thus, investigating the decay constant and associated C and N in each and every species can play a critical role. The determination of annual litter accumulation associated with C and N in each species is fundamental in getting an understanding of terrestrial C and N cycles and how they enhance the litter decay. In litter decomposition, constant and nutrient release patterns are species-specific and correlate with quality, including chemical composition, season, and environmental factors of tropical forests in India. Therefore, works were performed: i) to quantify the dry weight of litter accumulation and litter decay; ii) to define the nutrient composition of litter accumulation and release of nutrients through decomposition; and iii) to estimate the relation between litter mass loss and abiotic variables in four different species of Western Ghats, India.

MATERIALS AND METHODS

Characteristics of study area. The study was conducted in the Veerakkal forest area, Manar Beat, Karamadai Range, Western Ghats, India (11°13.849′ 76°45.052′ alt. 476 m). The forest vegetation is dominated by *Pongamia pinnata, Terminalia arjuna, Gardenia resinifera,* and *Celtis phillipensis.* The forest vegetation falls under the tropical moist deciduous type with a warm moist climate in summer and cool dry one in winter. The study explored three distinct seasons:

summer (March−May), the rainy season (June−November), and winter (December−February).

Meteorological data such as temperature, rainfall, and relative humidity of the species was investigated for the study period and visualized in Fig. 1. The overall examination of meteorological data shows that the monthly average temperature in the study area ranged between 23.9°C and 30.3°C. Moreover, the intensity of solar radiation was generally high in March through May. The annual precipitation in the study species ranged from 600 to 850 mm. The relative humidity of the area ranged between 47% and 70%.

Forest floor and litter accumulation. The forest floor (litter on the soil surface) was studied from March 2018 to February 2019 for all four species during different seasons. Twenty sets of litter samples (five replicates) were collected using a 1 m × 1 m square frame placed randomly. The samples were collected with seasonal intervals (in May, November, and February) and transported to a laboratory in polythene bags. Forest litter samples were sorted into leaf, twig, and mixed fractions. The dry weight of each component sample was oven-dried at 80°C for 48 hours and weighed (g/m²).

Chemical analysis of forest floor components. The litter samples were analyzed for nutrient composition such as nitrogen, phosphorus, and potassium. Different seasonally collected litter materials were oven-dried at 80°C for 48 hours and powdered for chemical analysis. In the course of the chemical analysis, five replicates were used for each species. Total nitrogen in the litterfall was determined by using the micro Kjeldahl method (Snell and Snell, 1949). The estimation of phosphorus and potassium followed the method of Olsen et al. (1954) and Black (1965).

Estimation of the nutrient turnover constant (*K*) and time (*t*). The turnover constant of nutrients is the rate of nutrients released in available forms for uptake by plants and soil organisms (Jenny et al., 1949). The turnover constant (*K*) of different nutrients in the forest floor was estimated by using the following formula:

$$K = \frac{A}{A + F},$$

where *K* means turnover rate, *A* means annual input of nutrients, and *F* means residual mass of litter and nutrients on the forest floor (minimum mass).

The turnover time of nutrients is the time required for nutrients release in available forms for uptake by plants and soil organisms.

Turnover time (*t*) was calculated as reciprocal of turnover rate, i.e.

$$t = 1/K,$$

where *t* means time, and *K* means turnover rate.

Litter bag technique. Freshly fallen leaves from the four species were collected during February 2018 for a decomposition study. All the leaves were air-dried for
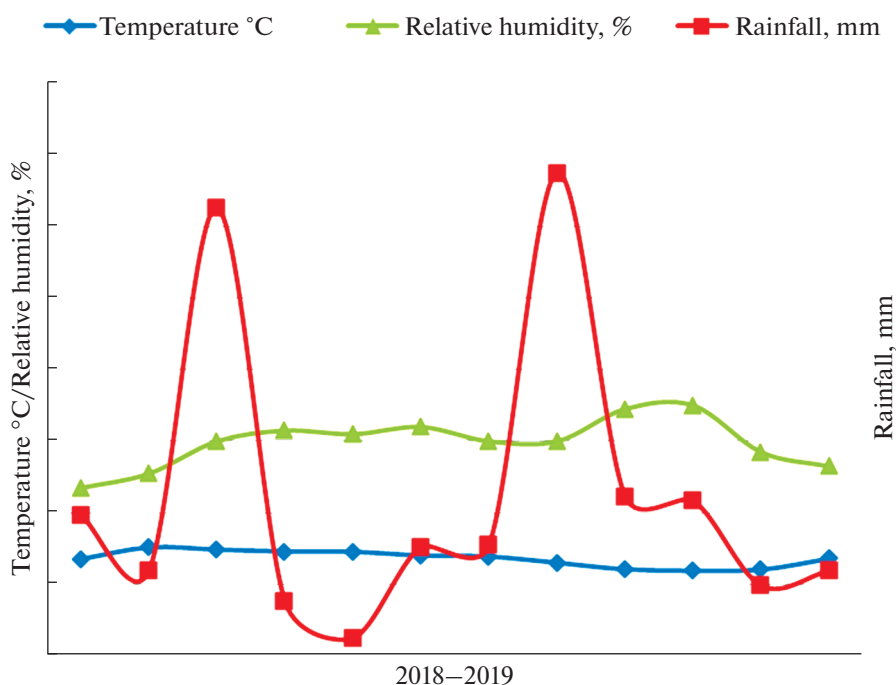
Fig. 1. Meteorological data in the study area.

48 hours after species-wise pooling of the samples from different species in a ventilation room.

A certain amount of air-dried leaf litter (20 g) of each species was collected into 20 × 20 cm nylon mesh bags (mesh size 2 mm) and placed on the forest floor at the soil depth of 10 cm. A total of 168 litter bags (42 × 4 = 168) were prepared for the study species. For each species, 42 litter bags were randomly placed on the forest floor with the respective species at the end of February 2018. After that, seven bags for each species were recovered in alternate month intervals in up to one year. The litter bag mesh size (2 mm) may decrease the rate of decomposition, because it restricts the entry of large invertebrates, scavengers, etc.

Dry weight loss. During selected month intervals from March 2018 to February 2019 (samples were collected at the end of April, June, August, October, December, and February), seven litter bag samples from each species were collected (7 × 4 = 28) and transported to the laboratory. Finally, a total of 168 litter bags were collected for all study species (28 × 6 = 168). Hereafter, large arthropods were removed from the litter bag. Litter samples were then oven-dried at 80°C and weighed to determine the remaining litter weight, litter weight loss, cumulative weight loss, and weight loss calculated from the original litter weight.

Decomposition coefficient (k). Decomposition coefficient (k) is a parameter to determine the rate of decomposition in a certain species. The decomposition coefficient for each species was calculated by using the method of Olson (1963):

$$k = A/L,$$

where A means annual litterfall, L means quantity of litter accumulation at (mean annual) time t.

Decomposition rate. Decomposition rate was calculated by using the method of Pascal (1992). Decomposition rate (in years): for 50% = 0.693/k, for 95% = = 3/k, where 0.693 and 3 are constant values.

Chemical analysis. The concentration of organic carbon, total nitrogen, lignin, cellulose, and water-soluble compounds were determined in the initial and decomposing litter samples. The methods were also used during the estimation of organic carbon (Piper, 1950), total nitrogen (Jackson, 1958), lignin (Goering and Van Soest, 1975), cellulose (Updegraff, 1969), and water-soluble compounds (Do et al., 2014).

Statistical analysis. The data on seasonal litter accumulation and chemical analysis was assessed using one-way ANOVA. All tests were considered to have significant differences using Duncan's multiple range test (DMRT) with $p < 0.05$. The relations between litter weight loss, initial litter chemistry, and abiotic variables were tested using Pearson's correlation coefficient analysis and showed significant differences using DMRT with $p < 0.05$ and $p < 0.01$. The statistical analysis was performed using the software SPSS (version 16.0).

RESULTS AND DISCUSSION

Dry weight of forest floor litter. The seasonal dry weight of the forest litter was statistically significant with the results of ANOVA ($p < 0.05$) (Table 1). Like litterfall, *Pongamia pinnata* showed maximum forest

Table 1. Seasonal litter accumulation (g/m²) in different species of Veerakkal forest area, Manar beat, Karamadai Range, the Western Ghats

Mar. 2018–Feb. 2019 seasons	Pongamia pinnata				Terminalia arjuna				Gardenia resinifera				Celtis phillipensis			
	leaf	twig	mixed fractions	total	leaf	twig	mixed fractions	total	leaf	twig	mixed fractions	total	leaf	twig	mixed fractions	total
Summer (Mar–May)	686 ± 3^a	160 ± 2^a	182 ± 3^a	1028.5	503 ± 3^a	179 ± 2^a	92 ± 2^a	775.38	448 ± 5^a	132 ± 1^a	105 ± 2^b	685.98	406 ± 2^a	128 ± 2^a	159 ± 2^a	694
Rainy season (Jun–Nov)	360 ± 4^b	99 ± 4^b	110 ± 2^b	570.2	350 ± 3^b	141 ± 3^b	96 ± 2^a	588.32	315 ± 2^b	128 ± 3^a	135 ± 2^b	580.26	386 ± 3^b	90 ± 1^b	131 ± 1^a	608.62
Winter (Dec–Feb)	223 ± 4^c	59 ± 1^c	83 ± 2^c	367.54	305 ± 1^c	90 ± 1^c	73 ± 4^b	470.52	190 ± 4^c	87 ± 1^b	73 ± 1^c	351.08	223 ± 2^c	74 ± 2^c	89 ± 1^c	388.32
Total	1270.54	319.24	376.46	1966.24	1158.7	411.92	263.6	1834.22	953.92	348.8	314.6	1617.32	1016.1	294.16	380.68	1690.94
Mean	423.51	106.41	125.49	655.41	386.23	137.31	87.87	611.41	317.97	116.26	104.86	539.10	338.7	98.05	126.89	563.64
F = df$_{(2,14)}$	3.760***	254.619***	317.773***	—	1.389***	265.088***	17.507***	—	973.456***	83.167**	415.671**	—	852.389***	180.961***	113.004**	—

Means ± S.E., $n = 5$. Different letters on the same column indicate significant differences ($p < 0.05$) according to Duncan's Multiple Range Test; F: Factor; df: degrees of freedom; *, **, ***indicates significant at 0.05% level; **ns**: non-significant.

floor litter (1.03 k m^{-2}) in summer. At the time, the minimum floor litter was observed in *Gardenia resinifera* (0.69 kg m^{-2}) during the same season. In the rainy season, forest floor litter was observed highest in *Celtis phillipensis* (0.61 kg m^{-2}) and lowest in *Pongamia pinnata* (0.57 kg m^{-2}). Together, in the winter season, the highest value of litter was found in *Terminalia arjuna* (0.47 kg m^{-2}) and the lowest was observed in *Gardenia resinifera* (0.35 kg m^{-2}). Moreover, a decreased soil temperature also indirectly improves the soil moisture. The litter accumulation in the wet season is less compared to the dry season in the tropical forest ecosystem. The previous seasonal litter accumulation studies ranged between 1.22 to 1.27 kg m^{-2} during the rainy season, and 0.61 to 0.98 kg m^{-2} during the summer season in Urban Tropical Forest, Congo (Averti et al., 2018). Similarly, Kavvadias et al. (2001) have showed in their studies that forest litter dry weight of fir forest species ranged between 82 t ha^{-1} and 32 t ha^{-1} under the maritime pine species in the forest ecosystem of Northern Greece. Similar results were noted by Sundarapandian and Swamy (1999), Qiulu et al. (1998), Liu (2012) and Giebelmann et al. (2013).

In an overall assessment, the quantity of annual forest litter was highest in PP (1.97 kg m^{-2} yr^{-1}) followed in decreasing order by TA (1.83 kg/m^2/yr), CP (1.69 kg/m^2/yr), and *Gardenia resinifera* (1.62 kg/m^2/yr); it indicates highest and lowest basal area of tree species. Overall, the forest litter was reduced in the rainy season possibly due to a variety of macroclimatic conditions in terms of effective monsoon rainfall. The forest litter in tropical and subtropical forests ranged from 0.22 to 1.25 kg m^{-2} yr^{-1} (Spain, 1984 and Vogt et al., 1986). Comparatively, in all study species, the higher forest litter mostly occurred during summer and the least occurred during winter. Likewise, the forest litter mass was found to be same trend as litter fall production. The similar findings were documented earlier by Pandey and Singh (1981), Goma-Tchimbakala et al. (2005) and Wang et al. (2008). Although, the contribution of the leaf litter component was maximum in the total forest litter in all four species, closely followed by the mixed fractions and twig components.

Chemical composition of forest litter components

Total Nitrogen. The total nitrogen concentrations were statistically significant with the results of ANOVA ($p < 0.05$). The annual total nitrogen content for all four study species ranged between 0.73 ± 0.03 to 2.12 ± 0.07% during all seasons (Fig. 2a). Together, the results of current study indicate that the range of nitrogen concentration was higher in winter in all four species, followed by summer and the rainy season. However, the study species *Pongamia pinnata* showed the maximum nitrogen concentration in the winter season (2.12 ± 0.07% leaf, 1.68 ± 0.04% twig, and 1.76 ± 0.05% mixed fractions, respectively) while *Cel-*

tis phillipensis exhibited the minimum nitrogen concentration in the same season (1.46 ± 0.03% leaf, 1.11 ± 0.03% twig and 1.32 ± 0.06% mixed fractions respectively) in all four study species. Likewise, nitrogen concentration of the forest floor ranged between 4.03 ± 0.26 and 17.38 ± 1.39 t/ha in the forest ecosystem of Northern Greece (Kavvadias et al., 2001). Moreover, litter accumulation can alter biogeochemical nutrient cycles through its decomposition (Moretto et al., 2001; Wang et al., 2017), as well as soil bacterial components and diversity (Hossain et al., 2010; Zeng et al., 2017).

In the summer season, the highest nitrogen content was reported in PP, while the lowest content of nitrogen was found in GR, respectively. Although in the rainy season, PP showed the maximum nitrogen concentration, and CP showed the minimum amount of nitrogen concentration in all seasons.

Total Phosphorus (%). The seasonal phosphorus concentrations of all the study species exhibited statistically significant ($p < 0.05$) differences in the forest litter components (Fig. 2b). The total phosphorus content in all the species ranged between 0.08 ± 0.04 to 0.37 ± 0.03% during all the seasons. According to the results of comparative analysis, the higher phosphorus content was recorded in winter season, simultaneously decreasing in the rainy season. During the winter season, the highest phosphorus concentration was observed in *Pongamia pinnata* (0.37 ± 0.03% in leaf, 0.21 ± 0.02% in twig and 0.27 ± 0.05% in mixed fractions, respectively) and the lowest phosphorus concentration was found in *Celtis phillipensis* (0.22 ± 0.06% leaf, 0.11 ± 0.03% twig and 0.17 ± 0.02% mixed fractions, respectively). Together, the maximum phosphorus content was noted in TA and the minimum phosphorus content was recorded in CP during the summer and rainy seasons. The phosphorus content of floor litter ranged between 0.44 ± 0.08 to 0.82 ± 0.09 t/ha in the forest ecosystem of Northern Greece (Kavvadias et al., 2001). The litter in forests with high tree diversity decomposes more rapidly than in other forest types (Chaubey et al., 1988; Clark et al., 2001; Giweta et al., 2020).

Total Potassium (%). The total potassium content of all the study species is visualized in Fig. 2c. In the present study, the total potassium content of forest litter samples was statistically significant ($p < 0.05$). On the other hand, the total potassium content for all seasons ranked between 0.35 ± 0.06 to 1.24 ± 0.04% in all four species. In addition, the winter season registered higher potassium concentration followed by summer and the rainy season in all the study species. However, in all three seasons, *Gardenia resinifera* showed the highest potassium content in floor litter components (1.08 ± 0.04 to 1.24 ± 0.04% leaf, 0.73 ± 0.04 to 0.85 ± 0.02% twig and 1.10 ± 0.02 to 1.17 ± 0.03% mixed fractions, respectively) and the lowest potassium content was found in PP (0.69 ± 0.03 to 0.87 ± 0.04%
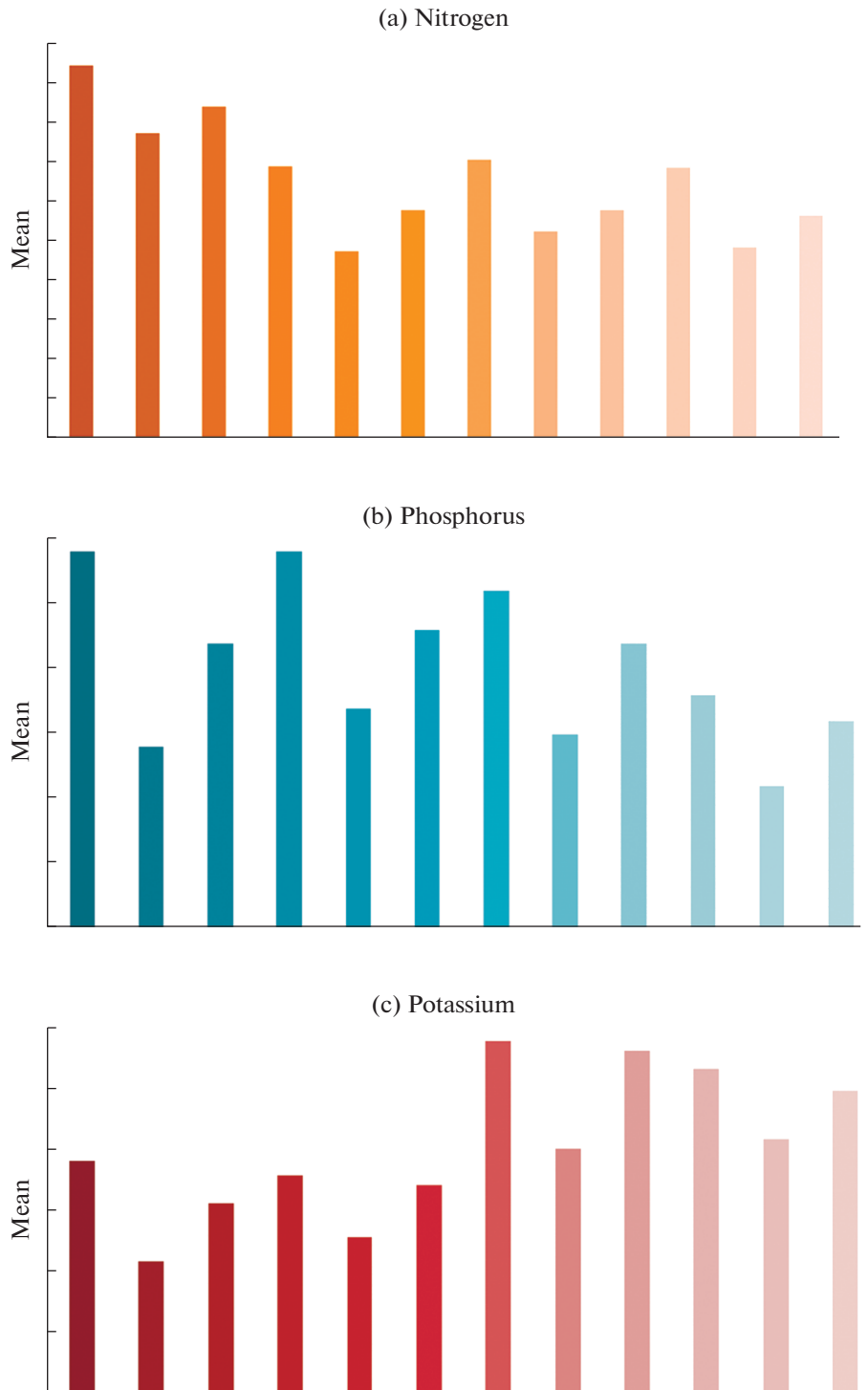
Fig. 2. N, P and K concentration of forest floor litter components in the study species. **L** − Leaf, **T** − Twig, **M** − Miscellaneous.

leaf, 0.35 ± 0.06 to $0.54 \pm 0.03\%$ twig and 0.58 ± 0.05 to $0.70 \pm 0.07\%$ mixed fractions, respectively). The leaf litter with significantly higher NPK content has a faster decay constant (Quideau et al., 2005).

Potassium is a highly mobile element, both in plants and in the soil, which is reflected in a high variability of its concentration detected in leaves. The potassium content ranged between 0.73 ± 0.12 to 1.57 ± 0.17 t ha^{-1} in the forest ecosystem of Northern Greece (Hyvarinen, 1990; Gonzalez et al., 2020; Kavvadias et al., 2001). Considering the nutrient accumulation in the forest litter, the nitrogen concentration

Table 2. Turnover constant (K) of nutrients (N, P and K) in the study species

Different Species	Litter parts	Turnover constant (K) = $A/A + F$		
		N	P	K
Pongamia pinnata	Leaf	0.62	0.50	0.58
	Twig	0.56	0.47	0.47
	Mixed fractions	0.41	0.32	0.29
	Mean	0.53	0.43	0.45
Terminalia arjuna	Leaf	0.53	0.50	0.54
	Twig	0.34	0.36	0.34
	Mixed fractions	0.30	0.30	0.27
	Mean	0.39	0.38	0.38
Gardenia resinifera	Leaf	0.48	0.60	0.59
	Twig	0.26	0.39	0.40
	Mixed fractions	0.25	0.33	0.34
	Mean	0.33	0.44	0.44
Celtis phillipensis	Leaf	0.49	0.43	0.58
	Twig	0.34	0.36	0.39
	Mixed fractions	0.20	0.19	0.25
	Mean	0.34	0.32	0.41

was highest, followed by potassium and phosphorus. In addition, the proportion of all nutrients was significantly greater in the leaf litter component compared to other litter components. Based on the above results, the concentration of all nutrients was found to peak during the winter season and be at its lowest during the rainy season. The authors recorded the mobilization of nutrients during decomposition in the rainy season, which may be a possible reason for a lower content of nutrients during that period. The poor rate of decomposition during dry months may result in immobilization of nutrients in the forest floor litter (Das and Ramakrishnan, 1985).

Turnover constant (K) of nutrients. The turnover constant (K) values of litter accumulation nutrients for all four species are shown in Table 2. During all the seasons, the mean highest turnover constant of nitrogen was recorded in PP (0.53), and the lowest was seen in GR (0.33). The turnover constant of nitrogen was 0.921 in *Quercus serrata* and *Lithocarpus dealbata,* and *Schima wallichi* was 0.923 in sub-tropical forests of India (Devi and Yadava, 2010), which are the highest values in this study. Although, the maximum turnover of phosphorus was observed in GR (0.44) and the minimum one was found in CP (0.32). Additionally, the turnover constant of potassium was considered the highest in PP (0.45) and the lowest in TA (0.38). On the other hand, leaf litter holds higher nutrient turnover (0.43 to 0.62) for all the study species. The twig and mixed fractions of litter showed lower turnover nutrients (0.19 to 0.56) in all the study species. The low nutrient litter may be characterized by a slower turn-over or higher immobilization rates (Kumar and Deepu, 1992). The soft tissues present in the leaf part result in a higher decomposition constant, hence a higher turnover of nutrients (Gosz et al., 1976). Similar studies were conducted earlier by Cortina and Vallejo (1994); Kavvadias et al. (2001).

Turnover time (t) of nutrients. The turnover time (t), mandatory for the replacement of litterfall and forest floor nutrients of study species, was calculated and represented in Table 3. During the study, the mean nitrogen turnover time of litter components was the highest in CP (3.33 years) and the lowest in PP (1.95 years) for all the seasons. The higher complete turnover of phosphorus was found to be 3.46 years in CP and at its minimum, which is 2.42 years, in both PP and GR. Further, the potassium turnover was the highest in TA (2.83), and the turnover time was lowest in GR (2.38) for all the seasons. The nutrients turnover time ranged between 20.3 and 24.3 years for pine forests, 33 years for fir forests and 14.7 to 18.9 years for beech forests in Greece which, compared to the deciduous forest, is more time for a complete turnover of nutrients (Kavvadias et al., 2001). Typically, a complete turnover for all the species of forest floor litter takes more than one year. The turnover of leaf litter nutrients was faster (1.61−2.33 years) than that of other litter components. The twig and mixed fractions required more years for the replacement of nutrients (2−5 years) in all the study species. The turnover time of leaf litter nutrients for Marao, Padrela, and Bornes was 1.67 years, 2.22 years, and 2.12 years, respectively in the high forest stands of Northern Portugal. Moreover, twig and

Table 3. Turnover time (*t*) of nutrients (N, P and K) in the study species

Different Species	Litter parts	Turnover time (*t*) = $1/K$		
		N	P	K
Pongamia pinnata	Leaf	1.61	2.00	1.72
	Twig	1.79	2.13	2.13
	Mixed fractions	2.44	3.13	3.45
	Mean	1.95	2.42	2.43
Terminalia arjuna	Leaf	1.89	2.00	1.85
	Twig	2.94	2.78	2.94
	Mixed fractions	3.33	3.33	3.70
	Mean	2.72	2.70	2.83
Gardenia resinifera	Leaf	2.08	1.67	1.69
	Twig	3.85	2.56	2.50
	Mixed fractions	4.00	3.03	2.94
	Mean	3.31	2.42	2.38
Celtis phillipensis	Leaf	2.04	2.33	1.72
	Twig	2.94	2.78	2.56
	Mixed fractions	5.00	5.26	4.00
	Mean	3.33	3.46	2.76

mixed fractions required more years for the replacement of nutrients (2 to 5 years) in all the study species. The non-leaf litter parts required 2.8 to 4.6 years for a complete turnover of floor litter nutrients in Portugal (Patricio et al., 2012), which is quite similar to the values reported in the present study.

Dry weight loss. The loss of litter weight for the four study species includes remaining litter mass, weight loss percent, cumulative weight loss, and weight loss calculated based on the original litter weight of leaf litters (Table 4). In the present study, the leaf litter in litter bags decreased linearly within the period of decomposition. Over the tenth month of decomposition, cumulative weight loss was 94.1% in *Pongamia pinnata* and 95.6% in *Terminalia arjuna* while the litter loss of *Gardenia resinifera* and *Celtis phillipensis* were 93.35% and 83.80%, respectively. However, over the twelfth month, *Pongamia pinnata*, *Terminalia arjuna,* and *Gardenia resinifera* decomposed completely (100% weight loss), but *Celtis phillipensis* leaf litter decomposed by 97%. Also, *Pyrus pyrifolia* leaf litter decomposed by 97.67% and *Tectona grandis* decomposed by 99%, whereas in *Eucalyptus tereticornis* decomposed by 87.70% as was found within 10 months in Punjab, India (Rani et al., 2016). The rate of litter decomposition is largely a determining factor for productivity of the forest ecosystems, as plant nutrients became available for recycling within the system during litter decomposition, which accounts for 69–87% of the total essential elements for the forest plants required every year (Ifo, 2010).

In comparison, *Pongamia pinnata* and *Terminalia arjuna* leaf litters decomposed faster than other species (10 months), while it took *Celtis phillipensis* the longest to decompose (12–13 months). Simultaneously, *Gardenia resinifera* leaf litter lost its mass completely within the period of 11 months. Similarly, *Macaranga peltate* and *Terminalia paniculata* leaves lost their mass completely within the period ranging from 10 to 12 months in the tropical deciduous forest, Kodayar, Western Ghats (Sundarapandian and Swamy, 1999). The time it took for the original biomass of *Artocarpus chaplasha* leaf litter to decompose equals to 10 months (Sarkar et al., 2016). Also, *Vatica lanceaefolia* and *Magnolia hookeri* decomposed in 9 and 7 months in Hollongapar, Assam.

On the other hand, the rate of litter decomposition was faster during the initial period of 2–3 months, followed by a slower decomposition rate and again much faster rate in the wet season. The rate of litter decomposition was high in August to October, which corresponds to the rainy season as compared to the dry and winter season. Furthermore, all study species exhibited a rapid mass loss during the rainy season and a slower one in winter season; because weight loss was the highest in the rainy season, it might be due to physical determinants, particularly soil moisture content, temperature, and evapotranspiration for the decomposer activity (Tripathi et al., 2009; Saha et al., 2016; Sarkar et al., 2016).

Decomposition coefficient. The decomposition coefficient is a valuable ecosystem constant that characterizes the decomposition rate as the segment of the

Table 4. Dry weight loss of decomposing leaf litter in the study species

Seasons	Feb. 2018–Feb. 2019	Litter weight remaining , g	Litter weight loss, %	Cumulative Weight loss, %	Weight loss calculated from original litter weight, %
		Pongamia pinnata			
	Feb 2018	20	0	0	13.6
Summer	Apr	17.28 ± 0.3	13.6	13.6	12.25
Rainy	Jun	14.83 ± 1.0	14.18	25.85	20.05
	Aug	10.82 ± 0.6	27.04	45.9	31.95
	Oct	4.43 ± 0.7	59.06	77.85	22.15
Winter	Dec	1.18 ± 0.5	73.36	94.1	16.25
	Feb 2019	0	100	100	–
		Terminalia arjuna			
	Feb 2018	20	0	0	16.4
Summer	Apr	16.72 ± 0.8	16.4	16.4	13.95
Rainy	Jun	13.93 ± 0.4	16.68	30.35	18.8
	Aug	10.17 ± 0.2	26.99	49.15	22.4
	Oct	3.69 ± 0.3	63.72	81.55	32.4
Winter	Dec	0.88 ± 0.4	76.15	95.6	14.05
	Feb 2019	0	100	100	–
		Gardenia resinifera			
	Feb 2018	20	0	0	22.5
Summer	Apr	15.5 ± 0.3	22.5	22.5	14.15
Rainy	Jun	12.67 ± 0.2	18.25	36.65	19.35
	Aug	8.80 ± 0.6	30.54	56.0	16.15
	Oct	4.57 ± 0.1	48.07	77.15	21.15
Winter	Dec	1.33 ± 0.2	70.89	93.35	16.2
	Feb 2019	0	100	100	–
		Celtis phillipensis			
	Feb 2018	20	0	0	7.55
Summer	Apr	18.49 ± 0.4	7.55	7.55	14.9
Rainy	Jun	15.51 ± 0.2	16.12	22.45	20.2
	Aug	11.47 ± 0.1	26.04	42.65	29.85
	Oct	5.50 ± 0.5	52.05	72.5	11.3
Winter	Dec	3.24 ± 0.2	41.09	83.8	13.2
	Feb 2019	0.60 ± 0.2	81.48	97.0	–

Means ± S.E., n = 5.

litter standing crop decompose annually (Jenny et al., 1949; Swift et al., 1979). The decomposition rates (decomposition coefficient) of litter for the four study species are displayed in Table 5. The annual decomposition coefficient (k) were the highest in *Pongamia pinnata* (2.52), followed by *Gardenia resinifera* (2.28), *Terminalia arjuna* (2.18), and *Celtis phillipensis* (2.11), respectively. The tree species are recognized to modify the floor litter decomposition through long-term plant-soil interactions (Pascal, 1992; Jaryan et al., 2014). Generally, the rate of decomposition of foliar litter was higher in PP, which was revealed due to a fairly high annual decomposition coefficient (k). Similarly, the decomposition coefficient for the leaf component was typically >1.0 per year while compared to other litter components in all four study species.

According to the results, the time required for half-life loss (t_{50}) of leaf litter part was reported to be <1.0 year for decomposition (i.e., 0.57 to 0.61 years), although the twig and mixed components were found to be greater than one year (>1.0) for litter loss in all the study spe-

Table 5. Decomposition coefficient (k) and decomposition rate of litter components in the study species

Species	Litter parts	Decomposition coefficient	Decomposition rate	
		$k = A/L$	for 50% (t_{50}) (0.693/k)	for 95% (t_{95}) (3/k)
Pongamia pinnata	Leaf	1.17	0.59	2.56
	Twig	0.83	0.83	3.61
	Mixed fractions	0.52	1.33	5.77
	Total	2.52	0.27	1.19
Terminalia arjuna	Leaf	1.14	0.61	2.63
	Twig	0.47	1.47	6.38
	Mixed fractions	0.57	1.21	5.26
	Total	2.18	0.32	1.38
Gardenia resinifera	Leaf	1.22	0.57	2.46
	Twig	0.55	1.26	5.45
	Mixed fractions	0.51	1.35	5.88
	Total	2.28	0.30	1.32
Celtis phillipensis	Leaf	1.13	0.61	2.65
	Twig	0.65	1.07	4.61
	Mixed fractions	0.33	2.10	9.09
	Total	2.11	0.33	1.42

cies. On the other hand, 95% leaf litter loss (t_{95}) was found to be greater than 2 years (>2.0). Whatever, twig litter components required over three years (>3.0) for decomposition, while mixed fractions of litter required a maximum of 5 to 9 years for 95% decomposition in all four study species.

Comparative data of decomposition coefficient (k) at the global level. The annual decomposition coefficient (k) for all four study species was compared to some other forests at the global level (Table 6). Coefficient value of *Quercus gambelii* indicated (2.50) in tropical forests of America (Gonzalez and Seastedt, 2001) and 2.01 to 2.59 in lowland tropical rain forests of Malaysia (Dent et al., 2006). Likewise, the decay constant of *Casuarina equisetifolia* was 1.83 in Pudukkottai tropical forest (Uma et al., 2014) and 3.29 in a tropical forest of Western Himalaya (Jaryan et al., 2014), which indicates more or less closer values to the present study.

Initial chemical characteristics of leaf litter. The initial concentration of chemical substances such as organic carbon, total nitrogen, lignin, cellulose, water soluble compounds, C/N ratio, and lignin/N ratio of leaf litter, are vital for the decay process. Litter decomposition rates vary greatly among the species that decompose in identical environments. These alterations in decomposition are mainly due to differences in litter traits, such as leaf toughness, nitrogen, lignin, C/N ratio, and lignin/nitrogen ratio. Among the various traits, nitrogen and lignin content of plant material are the most significant in regulating the rates of decomposition (Gartner and Cardon, 2004). The

correlation coefficient between a decomposition period and initial nitrogen were found to have a negative correlation ($r = -0.929$). Contrary to this, a relation between the decomposition period and initial lignin content showed a significant strong positive correlation ($r = 0.954$), while the concentration of initial cellulose showed a non-significant strong positive correlation ($r = 0.897$) with the decomposition period (Table 7). A higher nitrogen content promotes decomposition, which has a suppressing effect due to the impedance formed by its presence on lignin degrading enzymes (Sjoberg, 2004). On the other hand, the C/N ratio at the initial month was found to have a non-significant strong positive correlation ($r = 0.820$) with the decomposition period. The C/N ratio of initial leaf litter was observed to be a good predictor of litter decomposition and nutrient release (Sandhu et al., 1990). Likewise, the lignin/N ratio showed a significant strong positive correlation (0.969) between the initial lignin/N ratio and decomposition period. Contrary to this, a negative relation between the initial lignin/N ratio and decay period ($r = -0.473$) was recorded in subtropical forests of China (Yang et al., 2004).

Nutrient release during the decomposition period. The values of organic carbon, water soluble compounds, and C/N ratio of leaf litter decreased subsequently during decomposition. On the other hand, the total nitrogen, lignin, cellulose, and lignin/N ratio increased linearly during decomposition after a sharp decline at the initial decomposition period (Table 8). Alexander (1977) reported that the carbon compounds are the readily available energy source for decompos-

Table 6. Decomposition coefficient (k) of the four study species in comparison with other forests at the Global level (during the period from 1999 to 2016)

Country and locality	Type of formation	Decomposition coefficient ($k = A/L$)	Authors
1. America			
Colorado	Tropical and Sub-alpine forest		
	Quercus gambelii	2.50	Gonzalez and Seastedt (2001)
	Cecropias cheberiana	5.00	Gonzalez and Seastedt (2001)
2. China			
	Tropical riparian species and Upland	1.27 1.90	Ruan et al. (2005)
	Sub-tropical monsoon		
	Cunninghamia lanceolata	1.16	Yang et al. (2004)
	Ormosia xylocarpa	4.62	Yang et al. (2004)
	Fokienia hodginsii	3.92	Yang et al. (2004)
	Castanopsis kawakamii	4.46	Yang et al. (2004)
	Michelia macclurei	0.99	Wang et al. (2008)
3. Europe			
Belgium	European forest	0.38	Portillo − Estrada et al. (2016)
4. Malaysia	Lowland tropical rain forest		
	Alluvial forest	2.55	Dent et al. (2006)
	Sandstone ridge forest	2.59	Dent et al. (2006)
	Sandstone valley forest	2.01	Dent et al. (2006)
5. India			
Madurai	Tropical forest	0.40	Sundarapandian and Swamy (1999)
Manipur	Sub-tropical forest		
	Schima wallichi	0.33	Bijayalaxmi Devi and Yadava (2010)
	Quercus serrata	0.46	Bijayalaxmi Devi and Yadava (2010)
	Lithocarpus dealbata	0.54	Bijayalaxmi Devi and Yadava (2010)
Himachal Pradesh	Western Himalaya	3.29	Vikrant jaryan et al. (2014)
Pudukkottai	*Casuarina equisetifolia*	1.83	Uma et al. (2014)
Assam	Tropical semi evergreen forest		
	Atrocarpus chaplasha	3.23	Sarkar et al. (2016)
	Vatica lanceaefolia	3.28	Sarkar et al. (2016)
	Lagerstroemia speciosa	7.82	Sarkar et al. (2016)
	Magnolia hookeri	5.90	Sarkar et al. (2016)
Tamil Nadu	Tropical moist deciduous forest		
Western Ghats	*Pongamia pinnata*	2.52	Present study species
Karamadai forest	*Terminalia arjuna*	2.18	Present study species
	Gardenia resinifera	2.28	Present study species
	Celtis phillipensis	2.11	Present study species

Table 7. Coefficient of correlation (r) between litter decomposition period and litter chemistry at the initial period in four study species

Species	Total decomposition period, months	Initial total nitrogen, %	Initial lignin, %	Initial cellulose, %	C/N	Lignin/N	Correlation coefficient (r)				
							Decomposition period vs initial total N	Decomposition period vs initial lignin	Decomposition period vs initial cellulose	Decomposition period vs C/N	Decomposition period vs lignin/N
Pongamia pinnata (Species-I)	10	1.93	13.78	7.52	23.33	7.14	−0.929[ns]	0.954*	0.897 [ns]	0.820[ns]	0.969*
Terminalia arjuna (Species-II)	10	2.03	14.13	6.14	23.34	6.90					
Gardenia resinifera (Species-III)	11	1.84	18.48	10.76	23.23	10.04					
Celtis phillipensis (Species-IV)	13	1.72	21.18	12.11	23.66	12.31					

* Correlation was significant at $p < 0.05\%$ level; ns: non-significant.
Source: www.statskingdom.com.

ers. The concentration of nitrogen in the decomposing litter increased in the course of decomposition. Release of nutrients depends not only on litter composition, but also on soil type, microbial communities, and soil properties (Kutsch and Dilly, 1999). The correlation between litter mass loss and chemical composition of the decomposing litter were analyzed by ANOVA ($p < 0.05$ and $p < 0.01$) and shown in Table 9.

The nitrogen availability is essential for litter decomposition, as an increased soil N value can cause change in the soil nutrient level and decomposers as well as the quality of decomposing litter (Liu et al., 2017). According to this study, the relation between the total nitrogen concentration and lignin/N ratio of decomposing leaf litter strongly positively correlated ($r = 0.924$ to 0.983 and $r = 0.942$ to 0.996) with litter mass loss of all four species. Similarly, the nitrogen concentration of decomposing leaf litter strongly positively correlated ($r = 0.924$ to 0.983) with litter mass loss of all four species (Devi and Yadava, 2010). Nitrogen concentration positively correlated ($r = 0.738$) and showed a positive relation with N content in various studies (Devi, 2002; Das and Das, 2010; Jamaludheen and Kumar, 1999; Sarkar et al. (2016). However, the chemical composition of organic carbon, lignin, cellulose, water soluble compounds, and C/N ratio of decomposing leaf litter showed a slightly negative correlation with litter mass loss in all species. The relation between lignin, cellulose, and mass rate of leaf litter from hard woods and other species is strongly negative. It is known that lignin and cellulose can control the decomposition rate through its own resistance to

enzymatic attack and by physically interfering with decay of other chemical fractions of cell walls (Alexander, 1977; Bisht et al., 2014; Sarkar et al., 2016). This study assessed the standard permissible limit and clearly expressed that the highest N concentration and lowest C/N ratio exhibited the highest decay rate among all four species.

Though, the results of ANOVA highlighted that the decomposing leaf litter chemistry was found to exhibit significant differences ($p < 0.05$ and $p < 0.01$) in all the study species. In contrast, *Pongamia pinnata* exhibited non-significant total nitrogen values. Also, the chemical composition of organic carbon, total nitrogen, WSC, and C/N ratio were non-significant in *Terminalia arjuna*.

Coefficient of correlation between litter mass loss (%) and abiotic variables

To analyze the effect certain environmental factors have on litter mass loss in the four study species, abiotic variables such as temperature, rainfall, rainy days, relative humidity, and soil moisture were linked to litter mass loss percent and compared with the results of ANOVA ($p < 0.05$) in terms of statistics (Table 10). The moisture and temperature are considered vital variables that determine the decomposition rate (Meentemeyer, 1984). The relation between the litter mass loss and rainfall was significant, displaying a highly positive correlation in all the study species ($r = 0.998$ to 0.999). Such factors as relative humidity ($r = 0.711$ to 0.785) and soil moisture ($r = 0.382$ to 0.839) showed a non-

Table 8. Concentration (%) of organic carbon, total nitrogen, lignin, water-soluble compounds and C/ N ratio in the decomposing leaf litter of different species during a different season

Seasons	Mar. 2018– Feb. 2019	Chemical composition (%)						
		Organic carbon	Total nitrogen	Lignin	Cellulose	WSC	C/N	L/N
		Pongamia pinnata (Species-I)						
Summer	Apr	40.81 ± 0.65	1.68 ± 0.02	14.55 ± 0.57	8.77 ± 0.35	5.52 ± 0.15	24.29	8.66
Rainy	Jun	37.58 ± 0.34	1.75 ± 0.04	15.20 ± 0.35	10.07 ± 0.19	5.79 ± 0.33	21.47	8.69
	Aug	35.84 ± 0.82	1.86 ± 0.06	15.86 ± 0.66	13.24 ± 0.22	4.66 ± 0.28	19.27	8.53
	Oct	34.22 ± 0.26	1.89 ± 0.03	16.32 ± 0.40	13.15 ± 0.45	3.73 ± 0.29	18.11	8.63
Winter	Dec	32.63 ± 0.66	1.90 ± 0.02	18.65 ± 0.82	15.95 ± 0.38	3.40 ± 0.12	17.17	9.82
	Feb 2019	–	–	–	–	–	–	–
		Terminalia arjuna (Species-II)						
Summer	Apr	43.87 ± 0.88	1.72 ± 0.02	14.78 ± 0.34	6.65 ± 1.43	5.66 ± 0.12	25.51	8.59
Rainy	Jun	38.83 ± 0.72	1.81 ± 0.04	16.47 ± 0.63	8.22 ± 0.56	4.95 ± 0.31	21.45	9.10
	Aug	38.17 ± 0.76	1.93 ± 0.01	17.22 ± 0.55	11.61 ± 1.15	4.23 ± 0.17	19.78	8.92
	Oct	36.99 ± 0.63	1.96 ± 0.02	17.81 ± 0.26	13.04 ± 0.78	4.50 ± 0.43	18.87	9.09
Winter	Dec	36.14 ± 1.08	1.96 ± 0.03	20.24 ± 0.41	14.10 ± 0.26	4.58 ± 0.18	18.44	10.33
	Feb 2019	–	–	–	–	–	–	–
		Gardenia resinifera (Species-III)						
Summer	Apr	38.76 ± 0.75	1.65 ± 0.02	18.93 ± 0.26	11.37 ± 0.35	4.81 ± 0.04	23.49	11.47
Rainy	Jun	36.61 ± 0.23	1.77 ± 0.05	19.65 ± 0.38	14.23 ± 0.80	4.68 ± 0.28	20.68	11.10
	Aug	35.90 ± 0.46	1.80 ± 0.03	20.38 ± 1.10	16.89 ± 0.21	4.23 ± 0.15	19.94	11.32
	Oct	33.37 ± 0.42	1.85 ± 0.01	21.62 ± 0.65	17.34 ± 0.45	4.01 ± 0.20	18.04	11.69
Winter	Dec	32.03 ± 0.87	1.89 ± 0.02	24.07 ± 0.93	19.08 ± 0.39	3.93 ± 0.33	16.95	12.74
	Feb 2019	–	–	–	–	–	–	–
		Celtis phillipensis (Species-IV)						
Summer	Apr	36.41 ± 0.42	1.69 ± 0.01	23.26 ± 0.42	15.93 ± 0.35	6.49 ± 0.33	21.54	13.76
Rainy	Jun	34.88 ± 0.26	1.71 ± 0.03	24.37 ± 0.30	18.35 ± 0.26	6.14 ± 0.76	20.40	14.25
	Aug	34.53 ± 0.27	1.73 ± 0.05	24.69 ± 0.83	20.67 ± 0.45	5.55 ± 0.30	19.96	14.27
	Oct	32.69 ± 0.11	1.75 ± 0.05	25.10 ± 0.18	20.95 ± 0.80	5.27 ± 0.09	18.68	14.34
Winter	Dec	30.15 ± 0.65	1.78 ± 0.04	26.48 ± 0.37	21.63 ± 0.77	4.89 ± 0.13	16.94	14.88
	Feb 2019	29.34 ± 0.52	1.80 ± 0.02	30.54 ± 0.48	23.80 ± 0.84	4.83 ± 0.08	16.30	16.97

Means ± S.E., n = 5.

Table 9. Coefficient of correlation (r) between litter mass loss (%) and leaf litter chemistry at decomposing period in four study species

Species	Chemical composition, %						
	Organic carbon	Total nitrogen	Lignin	Cellulose	WSC	C/N	L/N
Pongamia pinnata	−0.974*	0.945[ns]	−0.926**	−0.939*	−0.960*	−0.963**	0.990**
Terminalia arjuna	−0.878[ns]	0.924[ns]	−0.939*	−0.968*	−0.716[ns]	−0.899[ns]	0.996**
Gardenia resinifera	−0.988**	0.950*	−0.960**	−0.958**	−0.976**	−0.973**	0.954**
Celtis phillipensis	−0.968**	0.983**	−0.843*	−0.948*	−0.984**	−0.976**	0.942**

Source: www.statskingdom.com.
 * Correlation was significant at the level of $p < 0.05\%$;
** Correlation was significant at $p < 0.01\%$ level; **ns**: non-significant.

Table 10. Coefficient of correlation (r) between litter mass loss (%) and abiotic variables in the four study species

Abiotic variables	Pongamia pinnata	Terminalia arjuna	Gardenia resinifera	Celtis phillipensis
Percent weight loss vs Temperature	−0.990 [ns]	−0.983 [ns]	−0.969 [ns]	−0.975 [ns]
Percent weight loss vs Rainfall	0.998*	0.999*	0.998*	0.999*
Percent weight loss vs Rainy days	−0.576 [ns]	−0.538 [ns]	−0.481 [ns]	−0.503 [ns]
Percent weight loss vs Relative humidity	0.711 [ns]	0.742 [ns]	0.785 [ns]	0.769 [ns]
Percent weight loss vs Soil moisture	0.439 [ns]	0.382 [ns]	0.736 [ns]	0.839 [ns]

Source: www.statskingdom.com.
* Correlation was significant at the level of $p < 0.05\%$; ns: non-significant.

significant highly positive correlation to the mass loss in all the species. Likewise, a correlation of soil moisture with residual litter weight is positive (Barbhuiya et al., 2008; Sarkar et al., 2016), which is similar to the present study. Other factors like temperature and rainy days have a non-significant negative correlation with the mass litter loss in all the study species.

CONCLUSION

This study helps to determine an annual litter accumulation associated with C and N in each species, which is fundamental in getting an understanding of C and N soil cycles and how they enhance litter decay. N, P, and K are necessary for litter decomposition, as increased litter nitrogen can cause change in the nutrient level of soil and decomposers as well as the quality of decomposing litter. Decomposition constant and nutrient release pattern are species-specific and correlate with quality, including chemical litter composition as well as seasonal and environmental factors of tropical forests in India. This forest type could play a significant role in mitigation in the context of global change. In today's situation of climate change, being able to recognize the forest litter and decomposition due to anthropogenic disturbances on nutrients cycle is an absolute necessity.

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