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RESEARCH ARTICLE

Production, decomposition and nutrient contents of litter in subtropical broadleaved forest surpass those in coniferous forest, Meghalaya

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Abstract
Litter plays a crucial role in forest ecosystem functioning as its production and decomposition govern the pools and fluxes of forest nutrient cycling. The release of nutrients through litterfall and decomposition influences forest productivity. Therefore, these two factors are considered to be important indicators of forest ecosystem health. Such processes vary across different ecosystem types because of natural as well as anthropogenic factors. Hence, studying such processes would help in better understanding and management of forest ecosystems. Litter production and decomposition rates between a broadleaved and a coniferous forest ecosystem of Meghalaya in Northeast India were compared. We selected six subtropical broadleaved forest stands in Muthlong, Ialong, Nongbah, Mukhla, Nongkrem and Mawnai, and six adjacent coniferous forest stands dominated by pine. We estimated leaf litter production, decomposition and nutrient release, and analyzed the nitrogen and phosphorus contents in the litter of both the forest types. The study revealed that litter production and decomposition rates, and the litter nitrogen and phosphorous contents were significantly higher in the broadleaved forest compared to the pine forest. The variability in the litter characteristics was greater in the broadleaved forest compared to the coniferous forest indicating that the former is functionally more dynamic than the latter. Such dynamism in the broadleaved forest could be an important factor for providing greater ecological services compared to the coniferous forest, which nevertheless requires an in-depth study.

Keywords Nitrogen and phosphorus · Litter production and release · Seasonal and annual vaiation · PCA

Introduction

Litter is a significant component of forest ecosystems that links the plant and soil through the process of litterfall, decomposition and nutrient release (Santa Regina and Tarazona 2001). It plays a crucial role in forest ecosystem functioning as its production and decomposition provide the essential organic matter in soil and regulate the cycling of nutrients in forest ecosystems (Weltzin et al. 2005). The rates at which these processes occur determine the thickness of the litter layer in the forest (Mcadam et al. 2007). Maintenance of a thick litter layer along with rapid turnover time plays a significant role in plant nutrition (Weerakkody and Parkinson 2006; Leon and Osorio 2014) as dense root systems of plants are developed inside such layers (Tanner et al. 1998). Therefore, nutrient cycling in a forest ecosystem is influenced by decomposition of fine litter through soil biota that releases nutrients to the soil and influences forest productivity (Berg 2000). Thus, the rates of litter production and decomposition are considered as indicators of forest ecosystem health.

Litterfall is an important process that governs the carbon and nutrient cycling in forest ecosystems (Odiwe and Muoghalu 2003; Gairola et al. 2009). It has also been suggested that forest litter has a significant effect on snow albedo, and regulates the responses and feedbacks of terrestrial ecosystems to climate change (Winkler et al. 2010). Hence, litterfall can be used to measure, model, and predict the dynamics of an ecosystem (Liski et al. 2005).

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Litter decomposition plays a vital role in the nutrient budget of a forest ecosystem (Wedderburn and Carter 1999). It is a complex process that involves several physical, chemical and biological processes, mostly mediated by the microbial and soil faunal communities, and is accelerated by favourable environmental conditions (Swift et al. 1979). Litter decomposition accounts for 70–90% of the annual nutrient requirements for forest growth (Vogt et al. 1986). The rate of decomposition also plays a key role in the formation of organic matter and nutrient stock in the soil besides meeting the need for plant uptake (Isaac and Nair 2005). It is significant to study litter decomposition in the context of increasing anthropogenic impacts on biogeochemical cycles (Krishna and Mohan 2017).

Although many studies have been carried out on litterfall and decomposition dynamics, most of these are largely in temperate forests (Kavvadias et al. 2001; Trofymow et al. 2002; Ranger et al. 2003). These processes are influenced by various ecological and anthropogenic factors that vary across different ecosystem types. Understanding such interactions would not only provide an insight into the functioning of ecosystems in changing environments but will also help in the effective management of forest ecosystems. The present study was designed to assess how difference in vegetation type influences litter production, nutrient input and decomposition rates in the forest ecosystems.

Materials and methods

Study sites

Six broadleaved forest stands viz., Muthlong, Ialong, Nongbah, Mukhla, Nongkrem and Mawnai (Fig. 1) were selected in Meghalaya, Northeastern India for the study. These forest stands are sacred forests conserved by the traditional communities since time immemorial based on various religious beliefs. For comparison, six community forests, dominated by *Pinus kesiya* were selected adjacent to these sacred forests. Five permanent plots of 20 m × 20 m size were laid in each of the broadleaved sacred forest and coniferous forest stands. In each permanent plot, litter traps were laid, and litterbags were buried to carry out the study. The broadleaved forest stands comprised mostly broadleaved trees such as *Castanopsis tribuloides, Myrica esculenta, Engelhardtia spicata, Quercus dealbata, Cinnamomum glanduliferum, Belschmedia* spp.*, Lyonia ovalifolia, Schima wallichi, Ilex venulosa, Eurya* spp., *Neolitsea* spp., *Lindera* spp. and *Rhododendron* spp., while the coniferous forest stands had *Pinus kesiya* as dominant species with a few trees of *Myrica esculenta*, *Schima wallichii* and *Eurya japonica*.

Litter production

Litter production was estimated by following the litter trap method (Kamei et al. 2009). Permanent litter traps of

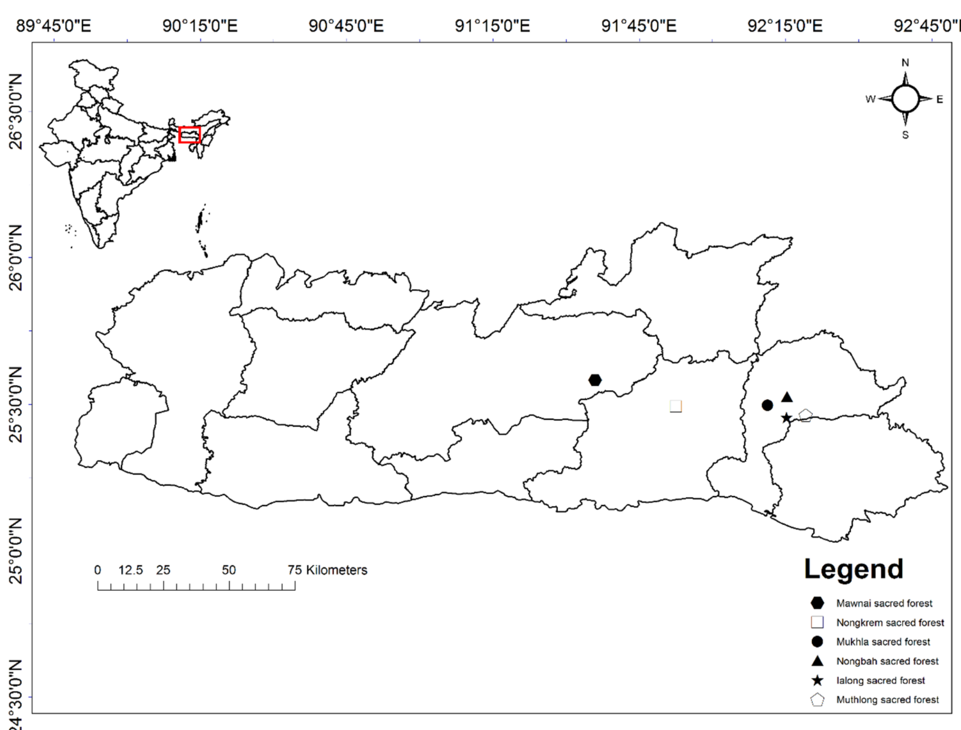

Fig. 1 Location of the six broadleaved sacred forests in Meghalaya. The coniferous forests were located adjacent to these sacred forests

1 m × 1 m size were laid randomly on the forest floor after clearing the accumulated litter. Annual litter production was estimated by summing all the positive increments during successive samplings. Similarly, the annual nutrient input to the forest floor through litter was computed by multiplying the annual values of litterfall with its corresponding nutrient concentration. Litter turnover rate (k_L) was calculated using the mathematical model of Reiners and Reiners (1970), and its turnover time (T) was calculated as a reciprocal of turnover rate ($1/k_L$).

Litter decomposition

The decomposition rate was studied using litterbags (Gilbert and Bocock 1960). Fresh senesced leaves of the dominant species were collected from the permanent plots and air-dried. Ten gram of the air-dried leaves containing mixed leaf litter was placed in each litter bag, and these litterbags were buried in the surface soil layer (0–10 cm) in their respective plots. The litterbags were retrieved at monthly intervals for one year. The annual decomposition rate was calculated using a negative exponential decay model (Olson 1963). Nitrogen and phosphorus loss constants (k_N and k_P) were calculated following Kamei et al. (2009). The time (in years) required for 50% (t_{50}) and 99% (t_{99}) was calculated as $t_{50} = 0.93/k$ and $t_{99} = 5/k$. Percent of nutrients remaining in the undecomposed litter at time *t* was computed using the formula given by Blair (1988).

Nutrient content in litter

Total Kjeldahl nitrogen (TKN) and total phosphorus (TP) in the litter were determined by Kjeldahl digestion of the sample with conc. H_2SO_4 using Kjeltabs as a catalyst. TKN was analyzed following the ammonia reduction method and Total Phosphorous (TP) by the vanado-molybdate method using FIASTAR 5000 auto-analyzer (FOSS, Denmark).

Standard data visualization tools viz., line graphs and boxplots were used to elucidate the general trends in the data.

Results

Litter production

The annual litter production and its nutrient contents were significantly ($P < 0.05$) greater in the broadleaved sacred forest (11,734.14 kg ha^{-1} $year^{-1}$; BF) than the coniferous forest (6687.01 kg ha^{-1} $year^{-1}$; CF) (Fig. 2). The TKN and TP contents in the litter were also significantly higher (Tukey HSD test, $P < 0.05$) in the broadleaved forest compared to the coniferous forest (Table 1). The turnover rate ranged from 1.4 to 3.2 $year^{-1}$ while the turnover time ranged from 0.3 to 0.7 years (Table 1). The turnover rate was significantly higher ($P < 0.05$) in the broadleaved sacred forest while the turnover time was higher in the coniferous forest (Table 1). The seasonal variation in the litterfall showed a bimodal

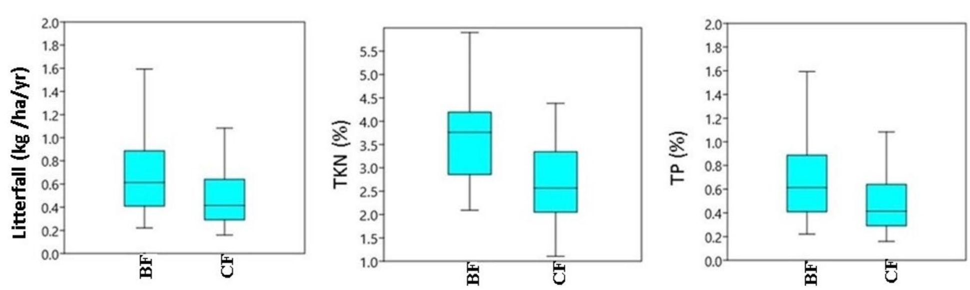

Fig. 2 Boxplots representing variation in litterfall (kg ha^{-1} $year^{-1}$), and TKN (%) and TP (%) contents in the litter of the broadleaved and coniferous forests

Table 1 Mean annual production (kg ha^{-1} $year^{-1}$), turnover rate (k, $year^{-1}$), turnover time (year), TKN and TP contents of litter along with its annual nutrient input on the forest floor (values are mean ± SE)

Parameters	BF	CF
Litter production (kg ha^{-1} $year^{-1}$)	$11{,}734.14 \pm 456.11^a$	6687.01 ± 386.77^b
Turnover rate (k, $year^{-1}$)	3.21^a	1.41^b
Turnover time (t, year)	0.31^a	0.70^b
Total Kjeldahl N (%) in litter	3.65 ± 0.20^a	2.63 ± 0.15^b
Total P (%) in litter	0.68 ± 0.10^a	0.48 ± 0.07^b
Annual input of N through litter (kg ha^{-1} $year^{-1}$)	42,829.61	17,586.84
Annual input of P through litter (kg ha^{-1} $year^{-1}$)	7979.21	3209.76

Within a row, values followed different superscripts are significantly different from each other (Turkey HSD test, $P < 0.05$)

BF broadleaved forest, *CF* coniferous forest pattern with its peaks during spring and autumn seasons and its minimum occurrence was during winter (Fig. 3).

Leaf litter decomposition

The leaf litter decomposition was characterized by an initial faster rate of decomposition, and the highest decomposition rate was during the rainy months in both the forests (Fig. 4). The decomposition rate of the mixed leaf litter was significantly higher ($P < 0.001$) in the broadleaved forest ($k = 1.27$) than the coniferous forest ($k = 0.97$; Table 2). Similarly, t_{50} and t_{99} values were higher in the broadleaved forest than the coniferous forest (Table 2). The high rate of decomposition in the broadleaved forest resulted in a lower amount of the remaining mixed leaf litter mass in the litterbags than the coniferous forest (Fig. 5). TKN and TP contents of the remaining mixed leaf litter in the litterbag were significantly higher (Tukey HSD test, $P < 0.05$) in the broadleaved forest compared to the coniferous forest (Fig. 5).

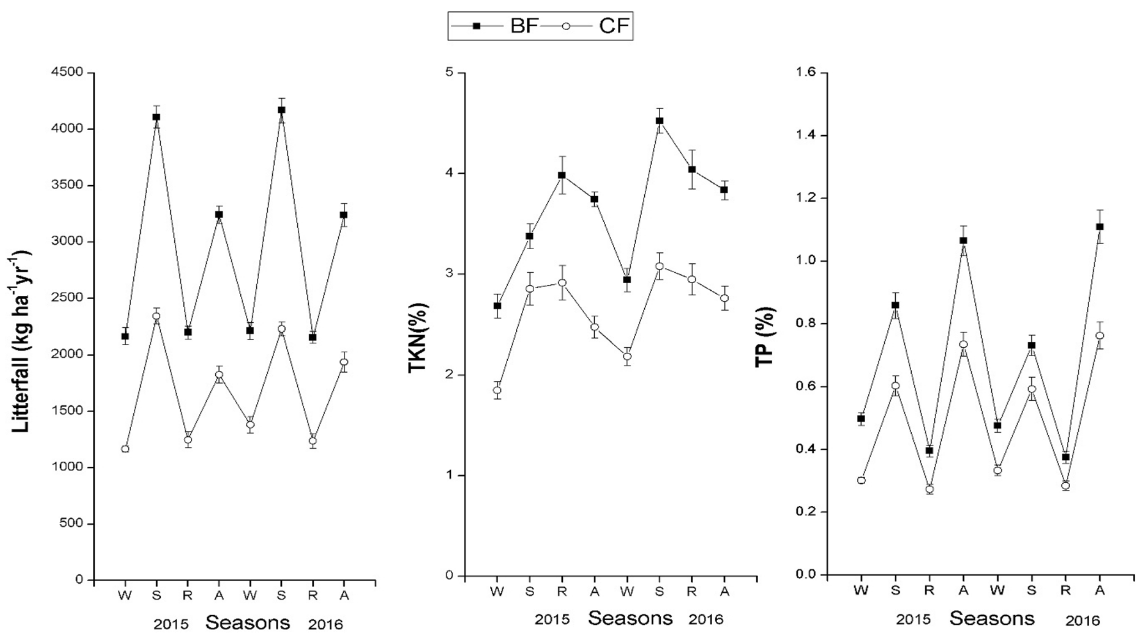

Fig. 3 The seasonal variation in litterfall and its TKN and TP contents in the broadleaved and coniferous forests. *BF* broadleaved forest and *CF* coniferous forest

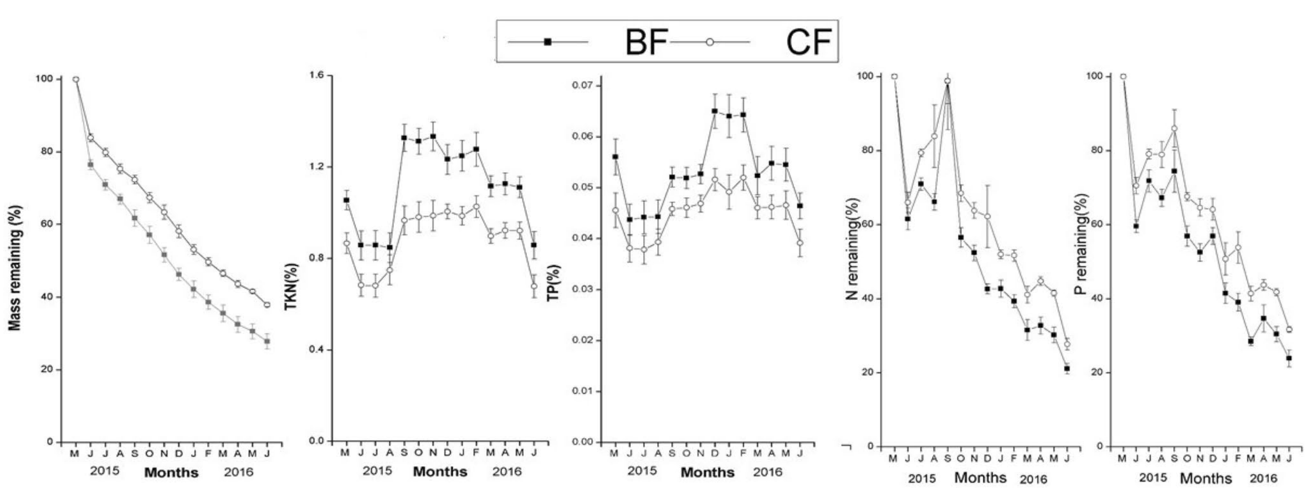

Fig. 4 Monthly changes in the mass of the mixed leaf litter in the litterbags, its TKN and TP contents, and N and P (%) remaining in the undecomposed litter in the broadleaved and coniferous forests

Table 2 Annual decay constant (k), N and P loss constants (k_N and k_P), and time required for 50% (t_{50}) and 99% (t_{99}) decay (in years) of leaf litter in the broadleaved (BF) and coniferous forests (CF)

Parameters	BF	CF
Annual decay constant (k)	1.27	0.97
t_{50}	0.56	0.71
t_{99}	4.05	5.15
Nitrogen loss		
k_N	1.51	1.22
t_{50}	0.46	0.57
t_{99}	3.33	4.13
Phosphorous loss		
k_p	1.49	1.12
t_{50}	0.48	0.63
t_{99}	3.43	4.5

Nutrient release through litter

The nutrient release through litter was estimated from the litterfall and decomposition. The annual input of nitrogen and phosphorous through litterfall was significantly higher in the broadleaved sacred forest than the coniferous forest (Table 1). Similarly, the nutrient release through decomposition was estimated through N-loss and P-loss constants and was higher in the broadleaved forest ($k_N = 1.51$, $k_P = 1.49$) compared to the coniferous forest ($k_N = 1.22$, $k_P = 1.12$; Table 2).

The PCA plot depicts the two forest stands through the two convex hulls (Fig. 6). The overlapping between the convex hulls reflects their similarity in environmental conditions, which could arise due to disturbance in the broadleaved forest. The first axis which is represented by litterfall has a high positive correlation with litterfall (LF) and TKN and TP contents in the mixed leaf litter (LDTKN and LDTP). In the second axis represented by TKN content in litterfall (LFTKN), is highly correlated with TP content in litterfall (LFTP) and the mass of the mixed litter remaining during decomposition (LD). TP content in litterfall (LFTP) shows a negative correlation with litterfall (LF) and its TKN and TP contents (LFTKN, LFTP). The percent of the mass remaining of the mixed leaf litter (LD) was positively correlated with LFTKN, LD and LDTKN, and was negatively correlated with LF, LFTP and LDTP. LDTKN was positively correlated with LF, LFTKN, LD and LDTP and negatively correlated with LFTP and LDTKN. LDTP was positively correlated with LFTKN, LFTP, and LDTP, and the same is negatively correlated with LD and LDTKN.

Discussion

Litter production

Litter production in a forest ecosystem is determined by various factors such as climatic conditions, species composition and successional stages (Haase 1999; Sundarapandian and Swamy 1999). The mean annual litterfall values obtained in the present study (6687.01–11,734.14 kg ha^{-1}) were within the range reported from the tropical evergreen forest and moist deciduous forests (Ramachandra and Proctor

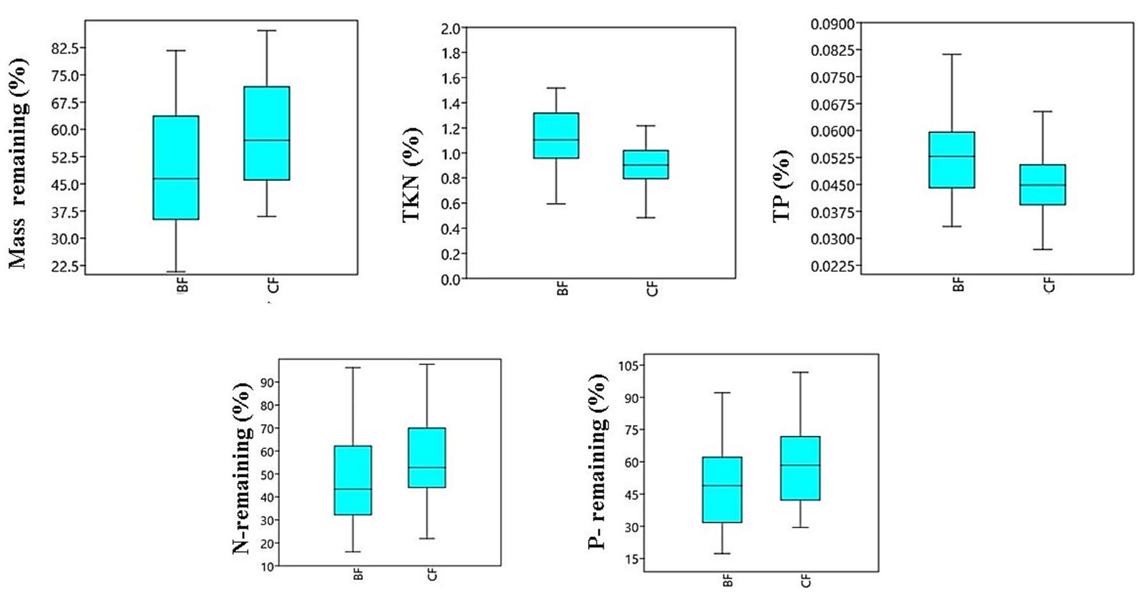

Fig. 5 Boxplots showing the percentage mass remaining of leaf litter in the litterbags, TKN (%) and TP (%) contents, and the percentage of N and P remaining during decomposition in the broadleaved and coniferous forests

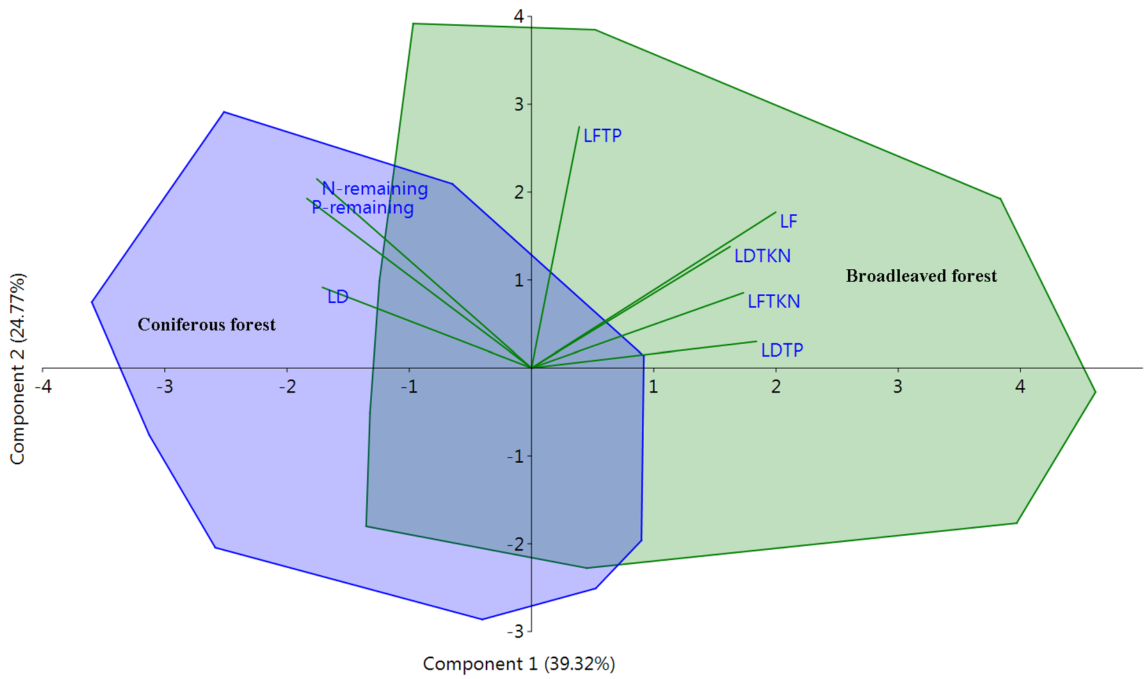

Fig. 6 Principal component analysis (PCA) axis differentiating the broadleaved and coniferous forest types based on characteristics of the foliage litter. Characterization has been done based on (i) litter production (LF), (ii) total Kjeldahl nitrogen content in litter (LFTKN), (iii) total phosphorous content in litter (LFTP), (iv) percent of mass remaining in the mixed leaf litter during decomposition (LD), (v) total Kjeldahl nitrogen content of the mixed leaf litter (LDTKN), and (vi) total phosphorous content of the mixed leaf litter after retrieving from the litterbag (LDTP), (vi) N-remaining, and (vii) P-remaining. The size of the convex hulls reflects the variability in the litter characteristics, while the vector lines depict the type and magnitude of the variability contributed by different litter characteristics in the two forest types

1994), tropical dry evergreen forest (Pragasan and Parthasarathy 2005) and humid subtropical forest in Meghalaya (9535–12,827 kg ha^{-1} $year^{-1}$; Kamei et al. 2009). The litterfall in the broadleaved forest was significantly higher than the coniferous forest ($P < 0.05$), which corroborates with the findings reported by Trofymow et al. (2002) and Xu and Hirata (2002). This could be attributed to the characteristics of the species such as their traits, tree density, and differential response by different species to the prevailing environmental conditions (George and Kumar 1998; Yang et al. 2005). Several workers have reported the bimodal pattern in seasonal production of litter (Khiewtam and Ramakrishnan 1993; Arunachalam et al. 1998; Yang et al. 2005; Kamei et al. 2009) with the first peak in spring and later peak in autumn. This seasonal pattern can be attributed to the physiological leaf senescence during the spring season and due to high rainfall and higher input from the belowground litter during the autumn season (Xu et al. 2000; Yang et al. 2005).

Litter decomposition

The litter decomposition rates at regional scales with similar climatic conditions are primarily controlled by the substrate quality of litter (Berg 2000). The rapid mass loss in the early stages could result due to the easily degradable compounds and tissues, while the slower mass loss in the later stages could result due to the accumulation of more recalcitrant compounds such as lignin and cellulose (Berg 2000). Moreover, the high leaf litter decomposition rates during the rainy months in both the forests showed the effect of higher rainfall, air temperature and relative humidity on decomposition, whereas the low soil moisture and low air temperature during winter months resulted in a slower rate of decomposition (Tripathi and Singh 1992). The high decomposition rate in the broadleaved forest as compared to the coniferous forest was also reported by Prescott et al. (2000) which can be attributed to litter quality (Chapman and Koch 2007) and quantity (Olson 1963) that influence the activity of soil communities and processes during decomposition. The present findings are also in agreement with the results of Knops et al. (2001), Hobbie et al. (2006) and Joly et al. (2017) suggesting that plant species richness can influence decomposition by impacting the quality of litter and microclimate in which the litter decomposes. Further, the initial substrate quality of litter such as concentrations of nitrogen (N), phosphorus (P), and potassium (K) have also been found to play a significant role in litter decomposition in different ecosystems (Osono and Takeda 2001, 2004).

Nutrient release through litter

The release of nitrogen and phosphorous through litterfall was significantly higher in the broadleaved forest than the coniferous forest. Greater input of nitrogen and phosphorous in the broadleaved forest was attributed to large quantity and high resource quality of litter (Moraes et al. 1999) as compared to the coniferous forest. The observed differences in nutrient input between the two forests were also in agreement with the findings of Yang et al. (2004) and Neumann et al. (2018). During the decomposition period, a negative exponential pattern for nutrient release from the decomposing leaf litter was found, which was characterized by an initial rapid and subsequent release phase (Jamaludheen and Kumar 1999). The high N and P release during decomposition in the broadleaved forest compared to the coniferous forest could be attributed to the high decomposition rate in the broadleaved forest compared to the coniferous forest (Prescott et al. 2000). These differences in the nutrient content of litter was due to the differences in species composition that may have different nutrient allocation pattern and the nutrient relocation strategy adopted by the species (Yang et al. 2005). Also, nitrogen and phosphorous being the major limiting nutrients for tree growth in many subtropical forests due to high soil acidity, relatively high return of nitrogen and phosphorous through litter puts the broadleaved species in a more advantageous position than the conifers in terms of nutrient availability (Yang et al. 2004; Neumann et al. 2018).

Conclusions

Plant litter is one of the major pathways of nutrient transfer to the soil in which the supply of nutrients in an ecosystem is highly influenced by litter quality, its input, and the decay rate. It also serves as an important nutrient reservoir in maintaining the fertility of the soil and the integrity of the ecosystem. The processes of litter production and decomposition represent a major flux of both fixed carbon (C) and nutrients in most terrestrial ecosystems and quantifying rates of litter mass loss and the associated changes in nutrients bound in the litter are important aspects of evaluating ecosystem function. The study concludes that the broadleaved forests have a strong nutrient conservation mechanism, as evident from high litter production, decomposition rate, and release of nutrients. Moreover, these forests represent a major carbon and nutrient pool that help in maintaining and supporting the ecosystem services. Therefore, conserving these forests can help in climate change adaptation and ensuring the flow of several ecosystem services.

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