Effect of ecological conditions on woody litter decomposition pattern in eight woody species of a dry tropical forest in Vindhyan Highlands

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Abstract

A study on litter decomposition of eight woody species, viz. *Shorea robusta, Buchanania lanzan, Diospyros melanoxylon, Lagerstroemia parviflora, Lannea coromandelica, Terminalia tomentosa, Holarrhena antidysenterica* and *Lantana camara* was done. Litter decomposition was monthly monitored using litter bag technique over a 12-month period in a dry tropical deciduous forest of Vindhyan highland, India. Wood litter weight loss ranged from 14.08% in *T. tomentosa* at Kotwa site to 25.25% in *T. tomentosa* at Hathinala site and month wise wood litter weight loss ranged from 0.60% in January for *L. parviflora* to 47.53% in August for *L. coromandelica*. The chemical composition of litter affected decomposition pattern. Nitrogen and phosphorus mineralization rates and decay pattern varied significantly from species to species. *T. tomentosa* having higher nitrogen content and lower C/N ratio exhibited faster weight loss than other species such as *S. robusta*, *D. melanoxylon*. The initial nitrogen, phosphorus contents of litter showed significant positive relation with weight loss in monthly retrieved litter. C/N ratio showed significant negative relationship with decay constant. Soil temperature and soil moisture had positive relation with weight loss. Our results suggest that dry tropical deciduous forest species are characterized by faster decomposition, indicating a faster rate of organic matter turnover and rapid nutrient cycling due to intra-annual changes in the environmental conditions. This could influence the soil nutrient content in system.

Keywords Litter decomposition, environmental, weight loss, woody species, C/N ratio, decay constant, dry tropical deciduous.

INTRODUCTION

Litter decomposition is an important process that connects many aboveground and belowground processes. The decomposition of dead leaves and roots is one of the major pathways by which carbon fixed during photosynthesis is returned to the atmosphere (Coûteaux et al., 1995). The process also contributes to soil. Decomposing plant litter and soil organic matter play an important role in the terrestrial global carbon cycle (Schimel, 1995). Decomposition of leaf litter, by which organic matter and nutrients are returned to the forest soils, has received considerable attention for sustainable soil fertility (Swift et al., 1979; Hobbie 1992; Moretto et al., 2001; Xuluc-Tolosa et al., 2003; Moore et al., 2006; Sayer 2006). The rate of decomposition dependents on environmental controls such as climate, litter quality and soil characteristics. Studies have indicated association of the decomposition with the carbon and nitrogen contents of the litter (Fog, 1988; Kemp et al., 2003; Meentemeyer, 1978; Swift et al., 1979). Complexes of bacteria, fungi, and soil organisms have an important role in decomposing leaf litter. The micro-fauna, which can move freely through the litter bag net, have been shown to cause an increase in weight loss (Berg et al., 1980; Berg and Staaf, 1981). Plant detritus and soil organic carbon are the largest carbon pools in terrestrial biosphere (Moore and Braswell, 1994), and therefore, understanding litter decomposition processes and the factors controlling litter decomposition is important for studying nutrient cycling, developing carbon budgets as well as assessing implications of global climate change. Litter decomposition rates are a function of litter quality, biota and microclimate (Seastedt et al., 1983), as well as edaphic properties (Heneghan et al., 1998). The successional changes of soil organisms have been demonstrated during the decomposition process of various litters using the litter bag method (Berg and Soderstrom**,** 1979). The roles of soil organisms in nutrient cycle may change during the decomposition processes of litter (Hasegawa and Takeda, 1995; Warren and Zou, 2002). In decreasing order of importance, the key factors regulating decomposition are commonly assumed to be climate, litter quality (e.g. N content, C/N ratio) and decomposer communities (e.g. bacteria, fungi, and soil macro- and micro fauna) (Meentemeyer 1984). Many studies have concluded that the combination of climate (e.g. mean annual temperature, mean annual precipitation etc) and litter quality (N content, C: N ratio) are the primary factors controlling litter decomposition (Coûteaux et al. 1995; Aerts, 1997; Moorhead et al. 1999; Gholz et al. 2000; Silver and Miya 2001). Across a wide variety of litter type C/N ratio seems to be top interpreter of decay rate (Perez-Har-guindeguy et al. 2000). The significance of litter decomposition to nutrient cycling and ecosystem role has been known, and a several studies has been undertaken (Gillon et al. 1999; Moore et al. 2006), various in response to provincial or species-specific concerns. Attempts to calculate the effects of climate change have newly driven studies of litter from broad ranges of plant types (Perez-Harguindeguy et al. 2000). The effect of litter quality is observable from the different decay rates of different tissue types, but identifying the particular litter characteristics that are every time and directly associated to decomposability has verified unpredictably complicated. Different species have dissimilar nutrient discharge patterns, which are linked to quality, time of year, and ecological factors (Abiven et al., 2005; Arunachalam et al., 2003). The Vindhyan highlands that are covered by dry tropical deciduous forest have high woody species diversity (Jha and Singh 1990; Sagar and Singh 2004). However, there is too small information on the comparative rates of decay of leaf and wood litter of these species and litter chemical parameters helpful for predicting their decompose rates in dry tropical deciduous forest. Thus, in this study we have quantified the monthly woody litter decomposition rates and nutrient dynamics of the dominant dry tropical deciduous forest woody species: *S. robusta, B. lanzan, D. melanoxylon, L. parviflora, L. coromandelica, T. tomentosa, H. antidysenterica* and *L. camara* of Vindhyan highlands, Uttar Pradesh, India, to know their role in the organic matter and nutrient returns that has a bearing on the total productivity of the ecosystem.

MATERIALS AND METHODS

Study site

The study was conducted on four sites, viz. Kotwa ($25^0$00’17’’ N and $82^0$37’38’’ E, 196 m.a.s.l.), Ranitalli ($24^0$18’11’’ N and $83^0$04’22’’ E, 287 m.a.s.l.), Neruiadamer ($24^0$18’33’’ N and $83^0$23’05’’ E, 323 m.a.s.l.), Bokarakhari ($24^0$24’13’’ N and $83^0$12’01’’ E, 245 m.a.s.l.) and Hathinala ($24^0$18’07’’ N and $83^0$05’57’’ E, 291 m.a.s.l.) of the Vindhayan dry tropical region, Sonbhadra District and Kotwa in Mirzapur district, Uttar Pradesh (Fig. 1). The area experiences a tropical monsoon climate. The sites are located between two meteorological stations, Obra and Renukut. Ranitalli site is nearest to Obra and Hathinala site is nearest to Renukoot. Mean annual rainfall is 926 mm at Obra and 1146 mm at Renukoot (Pandey et al., 1992). The soils are residual ultisols, sandy loam in texture, and reddish to dark grey in colour and are extremely poor in nutrients (Singh et al., 1989). Physio-chemical property of five experimental sites (Table 1). The mean monthly site wise soil moisture content (%) was shown in Fig. 2.

Litter decomposition

Woody litter decomposition experiment was carried out during a 12-month period. The collected litter was spread separately in thin layer for drying at room temperature (25 – 30^0C). In order to study the effect of environmental conditions on the rate of decomposition, litter bags were placed at the forest floor of each month and recovered at the end of each month. Thus, results in twelve times within the year. Litter decomposition studies were carried out by using the litter bag (15 × 15 cm) technique (Gilbert and Bocock, 1960). Nylon net litter bags, each containing 10 gm of air dried leaf litter, were placed on the forest floor at each site to study the percentage weight loss. The mesh size of the bags was 1 mm which easily allows the microbial activity of soil micro-flora and fauna. 288 litter bags were used in which 24 litter bags (i.e. three replicate for each species) placed on the soil surface in each month; each site and three replicate litter bags were sampled at each month for each species at each site for wood litter weight loss. The bags were sealed with stainless steel staples and labeled with aluminum tags. Each litter bag was attached to the ground by nylon wire to prevent movement and ensure good contact between the bags and the surface layer on experimental sites. Each litter bag collected was put on individual bag and transported to the laboratory. Before the measurement of litter weights, litter was cleared of any adhering plant and soil fragments. Weights of wood litter were recorded before and after oven drying to constant weight at 80 ^{0}C. After the measurement of weights, wood litter samples were taken for chemical analysis. Carbon and nitrogen estimated by CHN analyser and phosphorus by

phosphomolybdic blue colorimetric method (Anderson, 1989). Litter weight losses for eight woody plant species (Table 2), during twelve months of the study period were calculated using the following formula:
[Weight loss (%) = (Initial wt. – Final wt.) / (Initial wt.) × 100]

Decay constant (k)
The monthly decay constant (k/mo) for wood litter weight loss was calculated by following the negative exponential decay model (Olson 1963, Ezcurra, E., and J. Becerra. 1987): k = -ln (X/X_0)/t, where, X_0 is the initial dry weight, X is the dry weight remaining at the end of the investigation, and t is the time period (month or year). The time required for 50% (t_{50}) and 95% (t_{95}) weight loss was calculated as t_{50} = 0.693/k and t_{95} =3/k.

RESULTS

The coefficient of variation for wood litter weight loss was maximum for *S. robusta* and *D. melanoxylon* (90%) followed by *H. antidysenterica* (89%), *L.coromandelica* (88%), *L. parviflora* (87%), *B. lanzan* (86%), *L. camara* (85%) and minimum for *T. tomentosa* (82%), which had maximum wood weight loss. Wood litter weight loss of all species also positively related to soil temperature and soil moisture as in Fig. 3. Analysis of variance indicated that wood litter weight loss of all species had significant site effect. *S. robusta* ($F_{4,\ 120}$ = 10.84, *P* = 0.000), *B. lanzan* ($F_{4,\ 120}$ = 64.46, *P* = 0.000), *D. melanoxylon* ($F_{4,\ 120}$ = 13.13, *P* = 0.000), *L. parviflora* ($F_{4,\ 120}$ = 9.34, *P* = 0.000), *L. coromandelica* ($F_{4,\ 120}$ = 8.72, *P* = 0.000), *T. tomentosa* ($F_{4,\ 120}$ = 81.72, *P* = 0.000), *H. antidysenterica* ($F_{4,\ 120}$ = 25.54, *P* = 0.000) and *L. camara* ($F_{4,\ 120}$ = 18.35, *P* = 0.000). ANOVA also indicated that wood litter weight loss of all species had significant site × month effect. *S. robusta* ($F_{44,\ 120}$ = 4.47, *P* = 0.000), *B. lanzan* ($F_{44,\ 120}$ = 6.40, *P* = 0.000), *D. melanoxylon* ($F_{44,\ 120}$ = 4.58, *P* = 0.000), *L. parviflora* ($F_{44,\ 120}$ = 1.80, *P* = 0.000), *L. coromandelica* ($F_{44,\ 120}$ = 3.51, *P* = 0.000), *T. tomentosa* ($F_{44,\ 120}$ = 5.00, *P* = 0.000), *H. antidysenterica* ($F_{44,\ 120}$ = 6.64, *P* = 0.000), and *L. camara* ($F_{44,\ 120}$ = 3.28, *P* = 0.000). Mean carbon content of decomposed woody litter varied from 37.07±0.01% in August to 38.07±0.01% in December and January, mean nitrogen content varied from 0.75±0.01%in January to 0.80±0.003% in July and August, mean phosphorus content varied from 0.085±0.001% in January to 0.09±0.00% in July and mean C/N ratio varied from 47.01 in August to 50.76 in January in Fig. 4. Site wise variation in wood litter weight loss at five sites varied from 14.08% in *T. tomentosa* at Kotwa site to 25.25% in *T. tomentosa* at Hathinala site. Month wise wood litter weight loss ranged from 0.60% in January for *L. parviflora* to 47.53% in August for *L. coromandelica* in Fig. 5. C/N ratio of monthly retrieved woody litter weight loss minimum in July and August; maximum in January and December.

Decay constant (k)

The coefficient of variation for k was 89% for wood litter weight loss. ANOVA also indicated a significant site effect ($F_{4, 960}$ = 7220, P = 0.000), species ($F_{7, 960}$ = 1462, P = 0.000) and month wise effect ($F_{11, 960}$ = 229900, P = 0.000). Monthly decay constant of wood litter varied from 0.2259 at Kotwa site to 0.3041 at Hathinala site (1.3-fold), species wise decay constant varied from 0.2332 for *H. antidysenterica* to 0.2834 for *S. robusta* (1.2-fold) and month wise decay constant varied from 0.0116 in January to 0.5998 in August (59-fold) (Table 3 and 4).

DISCUSSION

In this study we find that wood litter weight loss for different tree species were positively related with soil temperature and soil moisture content (Fig. 1). During decomposition, decay of the organic nitrogen into an inorganic form mainly depends on the C/N ratio of the material. The initial weight loss is promoted by high nitrogen and low C/N ratio (Edmonds, 1990, Jamaludheen and Kumar, 1999). Taylor et al., (1989), found that C/N ratio to be a better interpreter of weight loss than the lignin/N ratio in a microcosm decomposition study of leaf litter. C/N ratio of woody litter was more than 25 for all species. This validates the high quality of their litter as Myers et al., (1994), reported that substrate with C/N ratio is less than 25 is of high quality and releases N at faster rate than low quality residues (C/N > 25). Mean carbon content and C/N ratio of decomposed litter decreased while nitrogen and phosphorus increased, in our results. Carbon concentration was negatively related with nitrogen and phosphorus concentration in decomposed litter and showed positive relation with C/N ratio. N and P concentrations in the decomposing wood litter of different plant species were highly changeable and followed a similar pattern during the decay process. Along with this, N and P concentration in decomposing litter increased constantly until the end of the study, the degree of increase, however, differed among the species (Fig. 4), as Singh et al., 1999 also reported. Our result showed that increase of the weight loss from the mid of the experiment in *T. tomentosa*, *L. coromendelica*, due to high N content (Fig. 5). However, the slow rate of initial decay was followed by a rapid phase of decomposition, may be because of the quicker breakdown of litter by the decomposing population that initially took time to colonize the litter (Songwe et al., 1995) and slower decay at the later stage could, however, be due to the accumulation of more unbreakable materials as shown in our results. The changeable rate of decomposition seemed to be because of not only to the nutrient content of the leaves but also to their morphological characteristics (Songwe et a., 1995). The decrease of carbon content with time must be related to the carbohydrates and phenolic compounds degradation at the beginning of the process (Schlesinger 1985), which is also related to mineralization in humid periods (Santa Regina, San Miguel, and Gallardo, 1986). When the litter is exposed to decomposition microorganisms, the easily decomposable components are attacked earliest. The soluble and polymer carbohydrates (cellulose and hemicelluloses) disappearing as faster than the other (Hirobe et al., 2004a, b). Many studies have also supported that litter with high N concentrations and a low C/N ratio is decomposed more rapidly than those with low N concentrations and a high C/N ratio (Finzi et al., 1998; Berg and Laskowski, 2006; Kamei et al., 2009). In this study lower mass loss during winter, summer season and faster in rainy season may be due to cold and dry conditions in winter, and warm and humid condition in rainy season , respectively; also reported by Sangha et al., 2006, Arunachalam et al., 1998, this also in dry season Mathani et al., 1996). Litter mass loss showed positive correlation with rainfall and soil moisture (Dasseler et al., 2000; Okeke et al., 1992; Austin et al., 2000). Soil nutrient content could not be related to litter mass loss, which is in agreement with Prescott (1995), Aerts and De Caluwe (1997), who has indicated that N availability did not alter litter decomposition rates in forests. These suggest that a small amount of the N release from litter was mineralized by soil microbes (Prescott, 1995). The increase in N concentration in all species is a worldwide study in decomposing litter (Mellilo et al., 1982; Moro and Domingo, 2000; Songwe et al., 1995). Woody litter decomposed faster, which may be due to decomposition of wood by termite activity. That was observed during our study period that termites attacked woody litter robustly. Termites accelerate the litter decomposition of tropical forest which is an important faunal component (Peterson et al., 1982; Yamashita et al., 1998; Sandhu et al., 1990 and Swift et al., 1979). Phosphorus mineralization during decomposition was quite similar to that of N release; the rate of release was slightly slower than that of nitrogen (Berg and Staff 1980). Subsequent increase in N and P concentrations could be the result of microbial immobilization (Maithani et al., 1996), nutrient inputs from through fall, and atmospheric precipitation (Bocock, 1963) and or atmospheric N fixation (Wood, 1974) as also observed in our leaf and wood litter decomposition study. Annual decay constant varied from 1.16 in *S. robusta* to 1.53 in *T. tomentosa*, which was maximum (Table 3). While Roy and Singh reported (1994) k = 1.93-2.26 for dry tropical deciduous forest litter. Therefore, our range is lower than this but supported the range k = 0.64-1.30, reported by K.P. Singh et al., 1999. Moisture availability in the form of rainfall is naturally a key climate state factor that directly or indirectly controls the construction and function of tropical forest ecosystems since seasonal variation in temperature tends to be small (Richards and Caldwell 1987; Clark et al., 2003; Feeley et al., 2007). Many studies also supported that litter with high nitrogen content decomposed more rapidly (Kamei et al., 2009; Tripathi and Singh, 1992a). The decomposition activity is driven by the decomposer (Tian et al., 1997, Tian and Tateishi, 2002). The activity is also regulated by the nutrient availability and carbon energy resources.

CONCLUSION

On the whole, it can be concluded that the nutrient in decomposing wood litter are recycled rapidly within the forest soil surface. Litter weight loss was relatively high and differed significantly among the species and on soil temperature and soil moisture condition. Both initial nitrogen and phosphorus concentration had positive influence on decomposition while litter decomposition of eight species was negative relationship with C/N ratio. Therefore, it is obvious that initial nutrients concentrations along with soil moisture and temperature take part in determining the litter decomposition in the dry tropical deciduous forest and thus organic matter turnover, nutrient cycling in the forest.

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Table 1. Physio-chemical properties of the five experimental sites located in Vindhyan highlands (Mean±SE).

Parameters	Kotwa	Ranitalli	Neruiadamer	Bokarakhari	Hathinala
Sand (%)	70.3±0.89	72.0±1.36	67.7±0.93	65.4±1.58	63.0±0.93
Silt (%)	26.9±1.20	26.0±1.91	28.1±0.95	27.9±1.78	26.3±0.98
Clay (%)	02.1±0.50	2.0±0.79	4.2±0.63	6.7±1.21	10.1±1.73
pH	07.0±0.10	7.1±0.17	6.9±0.23	6.4±0.13	6.5±0.18
Total-C (%)	1.20±0.10	1.3±0.15	1.2±0.27	1.4±0.29	1.5±0.38
Total-N (%)	0.11±0.00	0.14±0.03	0.13±0.01	0.11±0.01	0.13±0.02
Total-P (%)	0.02±0.00	0.02±0.01	0.03±0.02	0.02±0.01	0.05±0.02
C/N ratio	10.91	9.29	9.23	12.73	11.54

Table 2. List of the species for decomposition study of five experimental sites located in Vindhyan highlands.

Name of the species	Common name	Family	Growth form
Shorea robusta Gaertn. f.	Sal	Dipterocarpaceae	Tree
Buchanania lanzan Spreg.	Piyar	Anacardiaceae	Tree
Diospyros melanoxylon Roxb.	Tendu	Ebenaceae	Tree
Lagerstroemia parviflora Roxb.	Siddh	Lythraceae	Tree

Lannea coromandelica L.	Jigan	Anacardiaceae	Tree
Terminalia tomentosa (Roxb.) Wight & Arn.	Asna	Combrataceae	Tree
Holarrhena antidysenterica Wall.	Koraya	Apocynaceae	Tree
Lantana camara L.	Lantana	Verbenaceae	Shrub

Nomenclature based on 'Flora of Madhya Pradesh' 1997 (eds. Mudgal V, Khanna KK, Hajra PK) Botanical Survey of India, Calcutta, India.

Table 3. Mean decay constant (monthly) of different woody litter species on different sites.

Site*	k
Kotwa	0.2259[a]
Ranitalli	0.2656[b]
Neruiadamar	0.2753[c]
Bokarakhari	0.2840[d]
Hathinala	0.3041[e]
Species**	
S. robusta	0.2834[a]
B. lanzan	0.2834[a]
D. melanoxylon	0.2752[b]
L. parviflora	0.2782[c]
L. coromandelica	0.2789[c]
T. tomentosa	0.2692[d]
H. antidysenterica	0.2332[e]
L. camara	0.2663[f]

*Values are across species and months
**Values are across sites and months
Values suffixed with different letters for sites and species are significantly different from each other at $P < 0.05$.

Table 4. Monthly decay constants of woody litter during a one year cycle in Vindhyan highlands.

Month	Decay constant k (/mo)
January	0.0116
February	0.0299
March	0.0524

April	0.0591
May	0.0896
June	0.4468
July	0.5710
August	0.5998
September	0.5917
October	0.5267
November	0.2355
December	0.0375

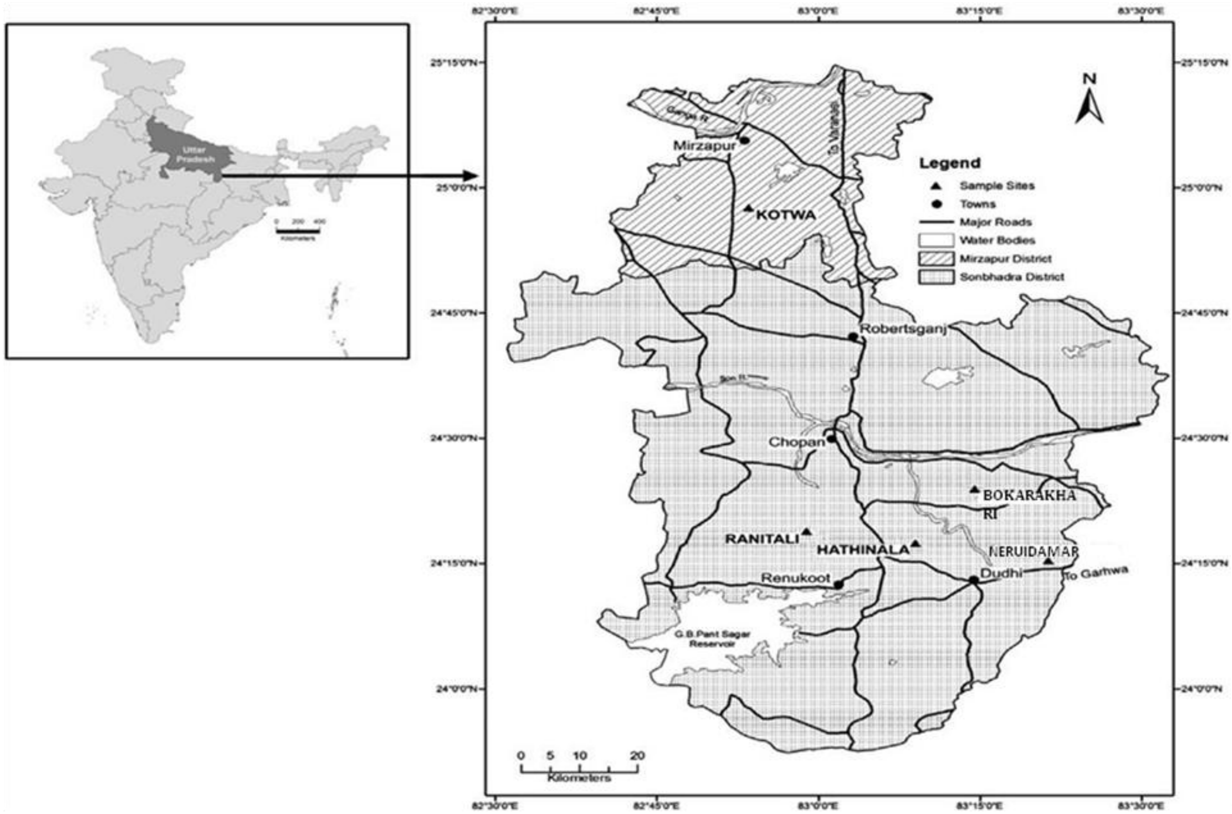

Figure 1. Map showing the study sites.

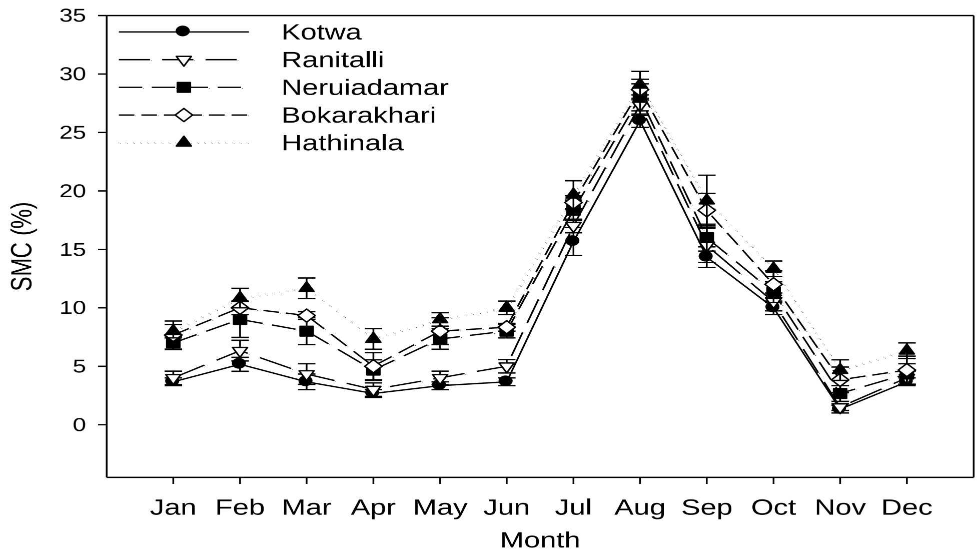

Figure 2. Monthly soil moisture content (SMC) at five experimental sites.

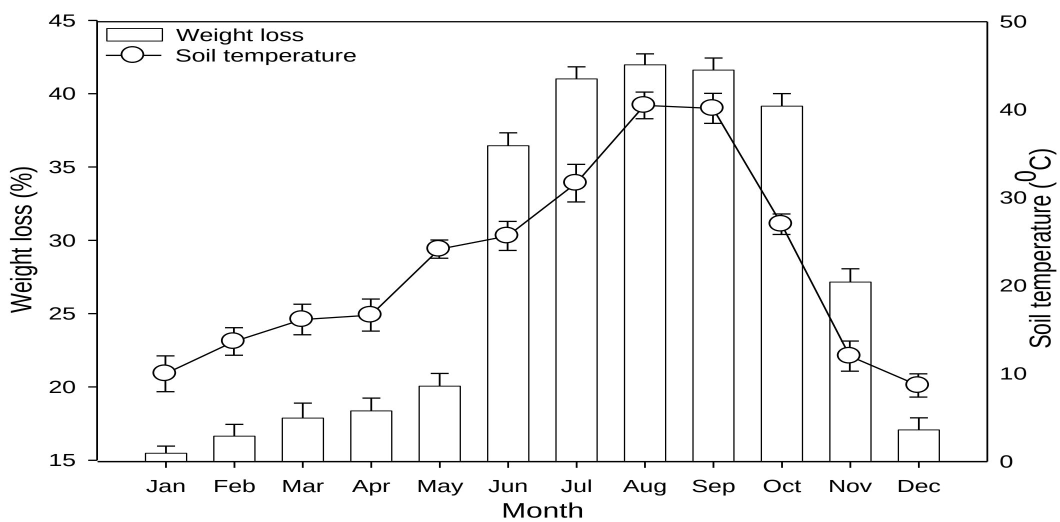

Figure 3. Monthly woody weight loss (%), soil temperature.

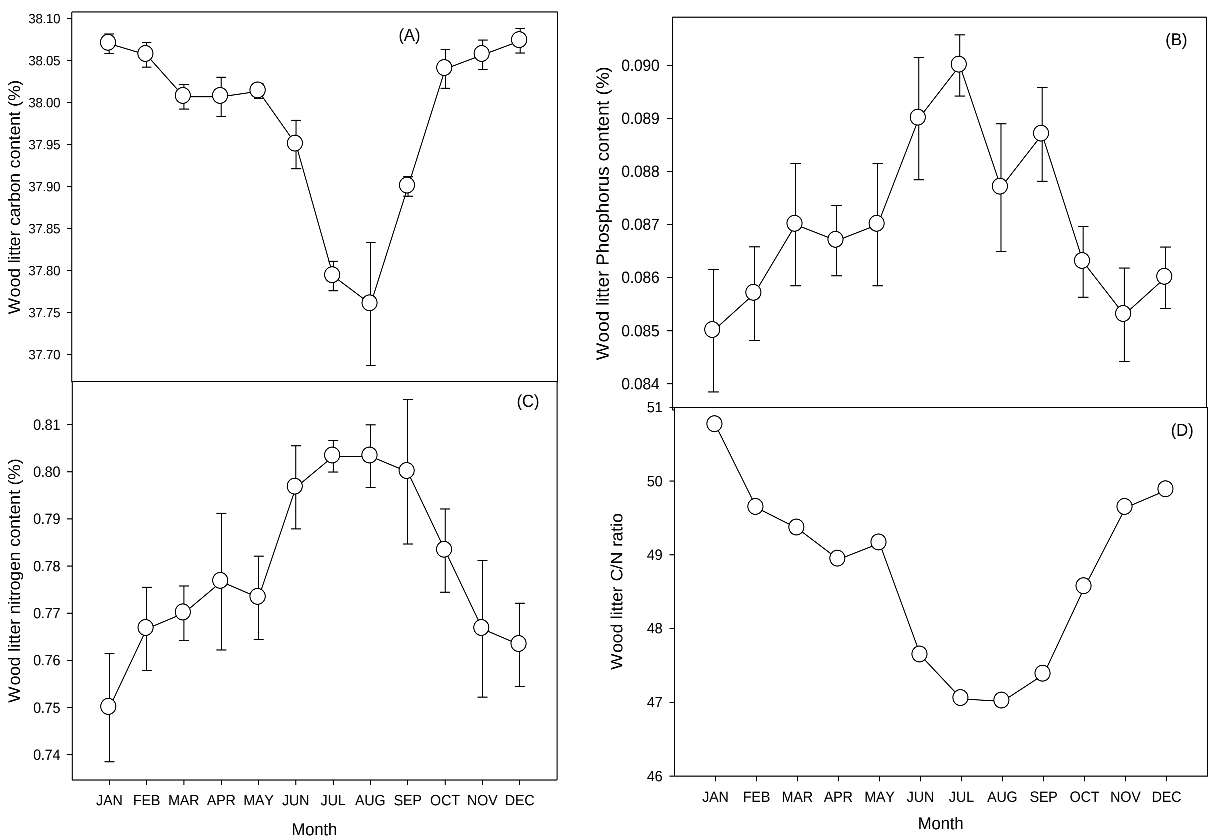

Figure 4. Monthly woody litter weight loss (%) and litter carbon content (%).**B.** Monthly woody litter weight loss (%) and litter phosphorus content. **C.** Monthly woody litter weight

loss (%) and litter nitrogen content. **D.** Monthly pattern woody litter weight loss (%) and C/N ratio.

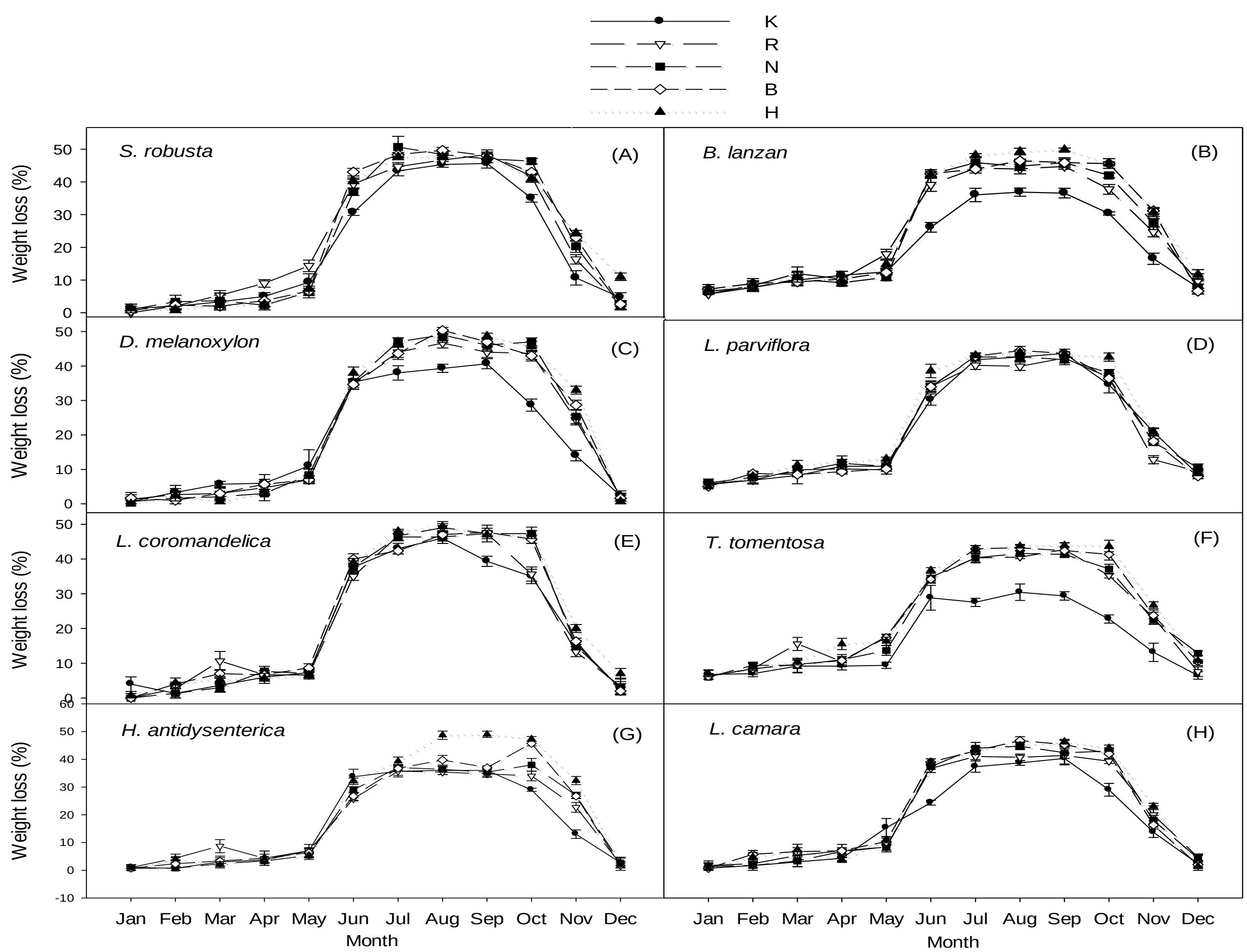

Figure 5. Decomposition pattern of woody litter as exhibited by weight loss of eight species at five sites: A, *S. robusta*; B, *B. lanzan*; C, *D. melanoxylon*; D, *L. parviflora*; E, *L. coromandelica*; F, *T. tomentosa*; G, *H. antidysenterica*; H, *L. camara*.

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