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Leaf litter decomposition and nutrient dynamics in four tree species of dry deciduous forest

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Abstract: The present study was conducted in a tropical dry deciduous forest at Barnawapara wildlife sanctuary, Raipur, Chhattisgarh, India. Leaf litter decomposition and nutrient release were studied in four tree species viz., *Shorea robusta* C.F. Gaertn.f., *Madhuca indica* J.F. Gmel., *Diospyros melanoxylon* Roxb. and *Schleichera oleosa* (Lour.) Oken. The objectives of the study were to determine the weight loss and nutrient mineralization pattern of leaf litter of these four major species. The weight loss was fastest in *S. robusta* and slowest in *M. indica*. Monthly weight loss was positively related ($P < 0.05$) with the climatic factors (rainfall, temperature and relative humidity) except for *M. indica* for which the relationship was not significant. Weight remaining was inversely related ($P < 0.01$) to N and P concentrations, but was positively related to K concentration. The nutrient content in the residual litter decreased continuously with time for all species, except in the case of P for *S. robusta* and *D. melanoxylon*. We conclude that *S. robusta* decomposed at fasters rate followed by *D. melanoxylon, S. oleosa* and *M. indica*. The former species also released the two important nutrients (N and P) at a faster rate as compared to the other species. *M. indica* showed the slowest decomposition rate and nutrient release.

Resumen: El presente estudio tuvo lugar en un bosque tropical caducifolio en el Santuario para la Vida Silvestre Barnawapara, Raipur, Chhattisgarh, India. Se estudiaron la descomposición del mantillo foliar y la liberación de nutrientes en cuatro especies arbóreas: *Shorea robusta* C.F. Gaertn, *Madhuca indica* J. F. Gmel., *Diospyros melanoxylon* Roxb. y *Schleichera oleosa* (Lour.) Oken. Los objetivos del estudio fueron determinar la pérdida de peso y el patrón de mineralización de nutrientes del mantillo de estas cuatro especies principales. La pérdida de peso más rápida se presentó en *S. robusta* y la más lentaen *M. indica*. La pérdida mensual de peso estuvo relacionada positivamente ($P < 0.05$) con los factores climáticos (lluvia, temperatura y humedad relativa) excepto para *M. indica*, especies en la que la relación no fue significativa. El peso remanente estuvo inversamente relacionado ($P < 0.01$) conlas concentraciones de N y P, pero se relacionó positivamente con la concentración de K. El contenido de nutrientes en elmantillo residual disminuyó continuamente con el tiempo en todas las especies, excepto en el caso del P para *S. robusta* y *D. melanoxylon*. Concluimos que *S. robustatiene* la tasa de descomposición más rápida, seguida por *D. melanoxylon*, *S. oleosa* y *M. indica*. La primera de estas especies también liberó dos nutrientes importantes (N y P) a unatasa más rápida en comparación con otras especies. *M. indica* presentó las tasasde descomposición y de liberación de nutrientes más lentas.

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Resumo: O presente estudo foi realizado numa floresta tropical decídua no santuário de vida selvagem de Barnawapara, Raipur, Chhattisgarh, na Índia. Foi estudada a decomposição e libertação de nutrientes na folhada de quatro espécies de árvores: A *Shorea robusta* C.F. Gaertn.f., a *Madhuca indica* J.F. Gmel., *Diospyros melanoxylon* Roxb. e *Schleichera oleosa* (Lour.) Oken. Os objetivos do estudo foram determinar a perda de peso e padrão de mineralização de nutrientes da folhada destas quatro espécies principais. A perda de peso foi o mais rápida em S. robusta e mais lenta em *M. indica*. A perda mensal de peso estava positivamente relacionada (P < 0,05) com os fatores climáticos (queda pluviométrica, temperatura e humidade relativa), exceto para a *M. indicaem* que a relação não foi significativa. O peso remanescenteestava inversamente relacionado (P < 0,01) com as concentrações em N e P, mas estava positivamente relacionado com a concentração em K. O teor de nutrientes na folhada residual diminuiu continuamente ao longo do tempo para todas as espécies, exceto no caso de P para a *S. robusta* e a *D. melanoxylon*. Conclui-se que a *S. robusta* decompõem-se a uma taxa mais elevada, seguida pela *D. melanoxylon*, *S. oleosa* e *M. indica*. A primeira espécie também libertou dois importantes nutrientes (N e P) num ritmo mais rápido, em comparação com as outras espécies. A *M. indica* evidenciou a taxa de decomposição e libertação de nutrientes mais lenta.

Key words: Climatic factors, dry deciduous forest, immobilization, litter decomposition, nutrient release, weight remaining.

Introduction

The importance of litter production in the forest ecosystems has long been recognized because the majority of organic matter produced by plants through photosynthesis is returned to the soil as litter. Litter fall may be a seasonal or a continuous process, and represents one of the most important pathways for the transfer of energy and material. The ways in which these two processes are accomplished, determine to a large extent the structural and functional features of the ecosystems. Litter decomposition plays a crucial role in regulating the nutrient budget of forest ecosystem where vegetation depends mainly on the recycling of nutrients contained in the plant detritus. During this process plant nutrients become available for recycling within the ecosystem. Decomposition of plant residues and the resulting release of nutrient elements are key functions of soil microorganisms (Rottmann *et al.* 2010). Singh *et al.* (1990) have stated that abundance of decomposing microbes depends partly on the native litter through its influence on soil properties. Decomposition process plays an important role in maintaining soil fertility in terms of nutrient cycling and the formation of soil organic matter (Bargali *et al.* 1993; Guendehou *et al.* 2014; Gupta & Singh 1977; Pandey & Singh 1982; Singh *et al.* 2007; Upadhyay & Singh 1989; Usman *et al.* 2000). Decomposition is regulated by soil organisms, environmental conditions and chemical nature of the litter. Decomposition and nutrient release are two key processes in tropical forests, where the vegetation is generally sustained on soils with low fertility (Lavelle *et al.* 1993). Therefore, forest productivity depends on efficient nutrient cycling mechanisms that ensure rapid turnover of litter nutrients (Vendrami *et al.* 2012). Foliar litter occupies a major fraction of the litter in forest ecosystems and may be totally decomposed within a year in subtropical and tropical areas (Meentemeyer 1984). It is thus of importance to investigate the pattern of forest leaf litter decomposition and its influence on the ecosystem functioning.

Much literature has accumulated in recent years on litter decomposition of plants of various forest ecosystems of the tropical and the temperate regions. In the present region a few studies on leaf litter decomposition of planted multipurpose species are available (Bargali *et al.* 2006; Pandey *et al.* 2006; Singh *et al.* 2007). However, no quantitative study on leaf litter decomposition in natural dry deciduous forests is known from this part of India. In view of this, the present study was carried out with the following major objectives: (1) to determine the weight loss pattern of leaf litter in four major species of dry deciduous forest, and (2) to analyse nutrient mineralization pattern from the leaf litter of these species.

Material and methods

Site

The study was conducted in Barnawapara Range of Barnawapara wildlife sanctuary (North Raipur Division) situated in north-eastern corner of Raipur district of Chhattisgarh, India. It is located between 21° 20' 0" to 21° 25' 47" N latitudes and 82° 21' 17" to 82° 26' 27" E longitudes. The general topography is undulating due to the presence of rock out crops. The area adjoining Nawapara forest village has a number of hillocks scattered all over the area. The slopes of hillocks are moderate to steep. Tilsa pathar is the highest site at an altitude of 463 m above m.s.l. The streams flowing in the area have steep bank, rich in alluvial soil and sustain a rich vegetation. Dry deciduous forest, grasslands, agricultural lands and human habitations surround the study area.

Climate

The climate of the study area is dry humid tropical and comprises three seasons *viz.* rainy (mid June to September), winter (November - February) and summer (March to mid June). The average annual rainfall ranges from 1200 - 1350 mm. About 80 percent of the annual rainfall is received from south-west monsoon during June to August (Fig. 1). Number of rainy days varies from 90 - 100 days. The mean monthly maximum temperature ranges from 27.3 °C in January to 41.8 °C in May and mean monthly minimum temperature ranges from 12.7 °C in December to 27.3 °C in May. The mean annual maximum and minimum temperatures are 33.1 °C and 20.5 °C, respectively. Relative humidity increases with the onset of south-west monsoon and it generally rises to more than 80 % in July.

Soils

Physicochemical properties of study site were studied by Kumar & Singh (2008). Soil was sandy loam in texture. Proportions of sand, silt and clay in soil were 41 %, 30 % and 34 %, respectively. Bulk density was 0.93 g cm^{-3}. Water holding capacity of soil was 61.0 %. Soil contains 0.94 % organic carbon; 184.1 kg ha^{-1} available nitrogen whereas total nitrogen in soil was 0.16 %. Soil holds 16.34 kg ha^{-1} available phosphorus and 280.5 kg ha^{-1} available K. The nitrate and ammonium nitrogen in soil, respectively, were 5.56 µg g^{-1} and 4.44 µg g^{-1}.

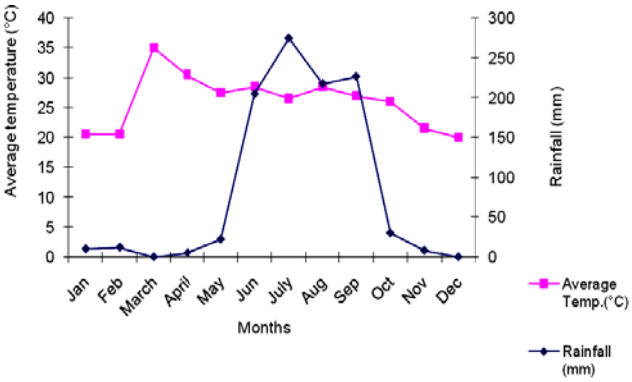


Fig. 1. Climatic diagram of the study area.

Vegetation

Tree species composition was studied by Bargali *et al.* (2014). *Shorea robusta*, *Madhuca indica*, *Diospyros melanoxylon* and *Schleichera oleosa* were the dominant species, followed by *Cleistanthus collinus, Pterocarpus marsupium, Cassia fistula, Lagerstroemia parviflora, Gentiana kurroo, Anogeissus latifalia, Adina cordifolia* and *Emblica officinalis.*

Experimental set up

After reconnaissance survey of Barnawapara wildlife sanctuary, mature, nearly senesced but attached leaves of *Shorea robusta*, *Madhuca indica*, *Diospyros melanoxylon* and *Schleichera oleosa* were collected. The collections were brought to the laboratory and air dried. Nylon litter bags of 20 x 20 cm size with 1 mm mesh were used to quantify decomposition rates. Ten gram of air dried leaf samples of each species were kept separately in each litter bag. A mesh size of 1 mm was sufficient to permit movement of micro arthropods which are the predominant litter feeders (Singh *et al*. 1990). Moisture content of the litter was determined by oven drying three sub-samples for each species at the time the bags were placed in the field. During July 2007, 120 litter bags of each species were placed separately in the forest in such a manner that they were in contact with soil and care was taken not to disturb the floor vegetation as much as possible.

Five litter bags of each species were recovered randomly at monthly interval between August 2007 and June 2008. Immediately after recovery, the litter bags were placed individually in the polyethylene bags and transported to the laboratory. The recovered residual material was carefully washed with water to remove soil particles, then oven dried at 60 °C to constant weight.

Litter mass loss and decay rate coefficient

The rate of litter material loss was expressed as the percentage material remaining (% R) after a given time, calculated as:

$$\% R = W(t_x)/W(t_i) \times 100$$

where, $W(t_x)$ is the dry weight (g) of the leaf material after time (t_x), and $W(t_i)$ is the initial weight of the leaf material (Petersen & Cummins 1974). In the present study % R was calculated monthly as well as for the entire period.

The mean relative decomposition rate (RDR) was computed by using the formula:

$$RDR\ (g\ g^{-1}\ day^{-1}) = \ln(w_1 - w_0)/(t_1 - t_0)$$

where, w_0 = mass of litter present at time t_0; w_1 = mass of litter present at time t_1; t_1-t_0 = sampling interval (days)

Chemical analysis

Three samples of dried materials for each species were ground in a Wiley Mill to pass a 1 mm mesh screen. Samples of initial as well as incubated materials were analyzed for nitrogen by micro Kjeldahl method (Jackson 1958); 0.5 g sample was digested in 10 ml diacid containing concentrated H_2SO_4 and perchloric acid (5:1 ratio), followed by distillation and titration. Using the procedure outlined by Allen *et al*. (1974), 0.2 g plant samples were digested in 10 ml triacid mixture (nitric acid, perchloric acid and sulphuric acid in 5:1:1 ratio), cooled and diluted to 100 ml. Using 5 ml aliquots, total P was determined colorimetrically by blue colour in a spectrophotometer, and total K by flame photometer (Jackson 1958).

Nutrient release pattern

The monthly release pattern of nutrients (N, P and K) from the leaf litter was calculated by differences in nutrient quantities from initial month to the next month and the net release was calculated by summing up of nutrient release for the entire period. Correlation and regression were calculated following Snedecor & Cochran (1969).

Results

Weight loss pattern

The dry matter loss in leaf litter of all the four species at monthly intervals was analysed to access the decomposition rate. The rate of decomposition within 332 days (Figs. 2-4) was highest in *S. robusta* followed by *D. melanoxylon, S. oleosa* and *M. indica*. Although weight loss continued throughout the study period, relatively highest weight loss occurred within the initial 129 days after the placement of litter bags. The relationship between percent weight loss of leaf litter and time elapsed showed significant positive correlation (P < 0.01) for all the species. The rate of decomposition (% day^{-1}) at monthly intervals showed different patterns. In *S. robusta* it was 0.28 % day^{-1} and for *D. melanoxylon* and *S. oleosa* 0.27 % day^{-1}, whereas, *M. indica* showed the minimum rate (0.21 % day^{-1}) of decomposition rate after 332 days. The monthly relative decomposition rate (g g^{-1} d^{-1}) was 0.001 - 0.09, 0.005 - 0.058, 0.001 - 0.10 and 0.001- 0.10 for *S. robusta*, *M. indica*, *D. melanoxylon* and *S. oleosa*, respectively (Table 1). It was maximum during rainy and minimum during winter season.

Changes in nutrient concentration in decomposing litter

There was a continuous increase in N concentration of residual litter throughout the decomposition cycle in all the species. At the end of the study period (332 days) the N concentration was two times higher than the initial value for *S. robusta, M. indica* and *D. melanoxylon.* In *S. oleosa,* the final N concentration was more than one and half times higher than the initial. Phosphorus concentration also increased continuously in the residual litter for all the species. At the end of the study period, P concentration was about twice as much as the initial value in the leaf litter. A continuous decrease in potassium concentration was observed for all the species; this pattern was distinctly different from that of N and P.

Cumulative weight loss

The correlation coefficient between weight remaining and N concentration and between, weight remaining and P concentration was negative (P < 0.01) for all the four species (Table 2). However, weight remaining and potassium concentration were positively correlated.

Table 1. Relative decomposition rate (g g^{-1} d^{-1}) for decomposing leaf litter of four tree species (*S. robusta, M. indica, D. melanoxylon,* and *S. oleosa*).

Days elapsed	*S. robusta*	*M. indica*	*D. melanoxylon*	*S. oleosa*
31	0.09	0.05	0.10	0.10
62	0.08	0.014	0.054	0.02
89	0.05	0.058	0.061	0.05
129	0.02	0.016	0.017	0.02
151	0.001	0.009	0.001	0.001
182	0.002	0.001	0.008	0.002
212	0.003	0.033	0.001	0.003
241	0.021	0.014	0.004	0.021
272	0.020	0.005	0.003	0.020
302	0.001	0.021	0.033	0.001
332	0.006	0.006	0.013	0.006

Table 2. Relationship between percent weight remaining of leaf litter (Y) and days elapsed (X) (Ln Y = a + bX) for the four tree species.

Trees species	Intercept (a)	Slope (b)	Correlation coefficient (r)
S. robusta	90.824	-0.2738	-0.972*
M. indica	90.89	-0.2738	-0.972*
D. melanoxylon	69.073	-0.2100	-0.863*
S. oleosa	79.73	-0.2210	-0.953*

*Significant at $P < 0.01$.

Table 3. Relationship between percent weight loss (WL) and rainfall (R, mm), temperature (T, °C) and relative humidity (RH, %).

X vs Y	Tree species	Intercept (a)	Slope (b)	Correlation coefficient (r)
R vs WL	*S. robusta*	2.933	0.078	0.699*
	M. indica	8.381	-0.006	0.280^{NS}
	D. melanoxylon	4.035	0.067	0.639*
	S. oleosa	4.480	0.057	0.638*
T vs WL	*S. robusta*	18.483	2.182	0.675*
	M. indica	12.620	1.763	0.513*
	D. melanoxylon	16.928	2.029	0.663*
	S. oleosa	10.261	1.966	0.695*
RH vs WL	*S. robusta*	-19.075	0.450	0.721*
	M. indica	0.341	0.126	0.335^{NS}
	D. melanoxylon	-12.068	0.340	0.579*
	S. oleosa	-9.989	0.301	0.609*

*Significant at $P < 0.05$, NS - not significant.

Effect of physical environment on weight loss

To ascertain the influence of abiotic factors on weight loss, the monthly weight loss values were regressed against rainfall, temperature and relative humidity of respective periods (Table 3). The percent weight loss was significantly correlated with the above climatic factors except for *M. indica.*

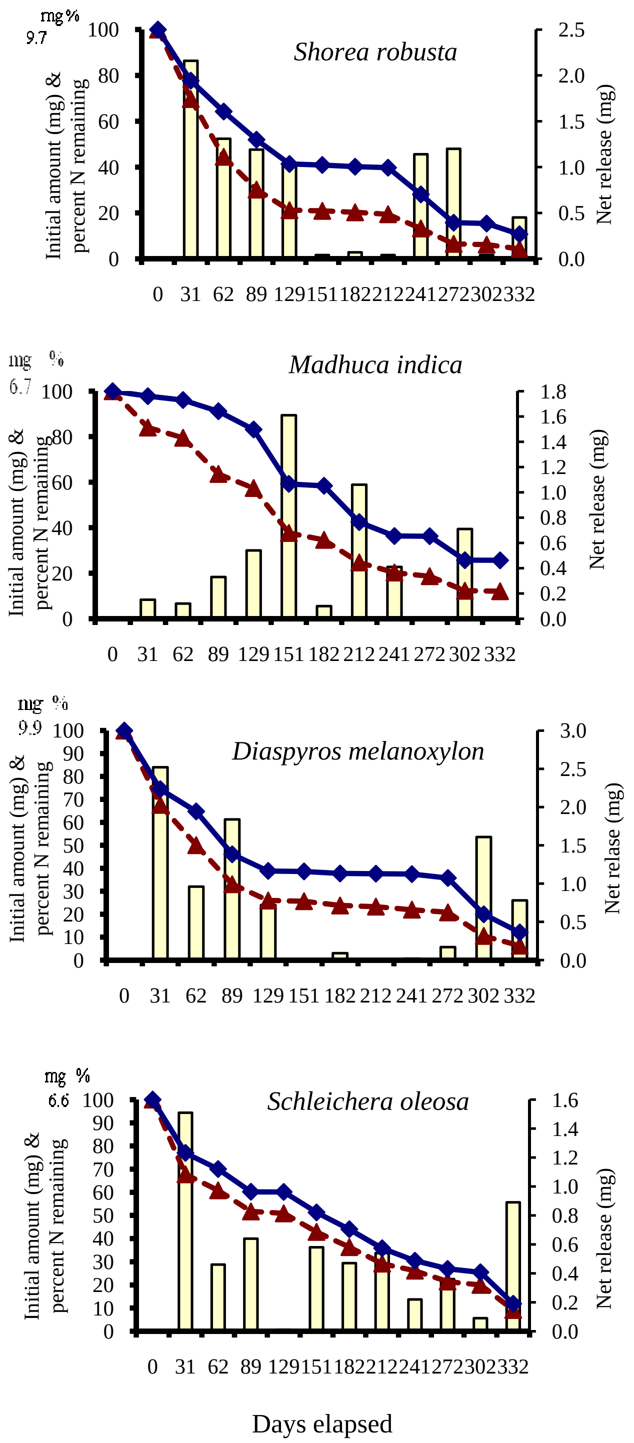
Nutrient release pattern

The release of N and P in the first 129 days was faster in *S. robusta* and *D. melanoxylon* (58.7 to 70.6 %). During the same period *M. indica* released only 17 % N and 32.1 % P; whereas, *S. oleosa* showed a release of 40 % N and 33.5 % P (Figs. 2 & 3). At the end of the study period the percent N and P release were 75.2 - 89.4 % and 77.14 %, respectively. Absolute increase in K was not observed for any species (Fig. 4). The pattern of K release was closely parallel to that of weight loss; however, in the later phase weight loss was slower than K release. Decrease of K was more pronounced in S. *robusta* and *D. melanoxylon* within 89 days (72.3 and 71.1 %, respectively).

Discussion

Weight loss pattern

All the four species showed 87.9 - 95.7 % disappearance after 332 days of litter incubation. Across the seasons higher weight loss occurred during rainy and summer seasons compared to the winter season except in *M. indica*; this species



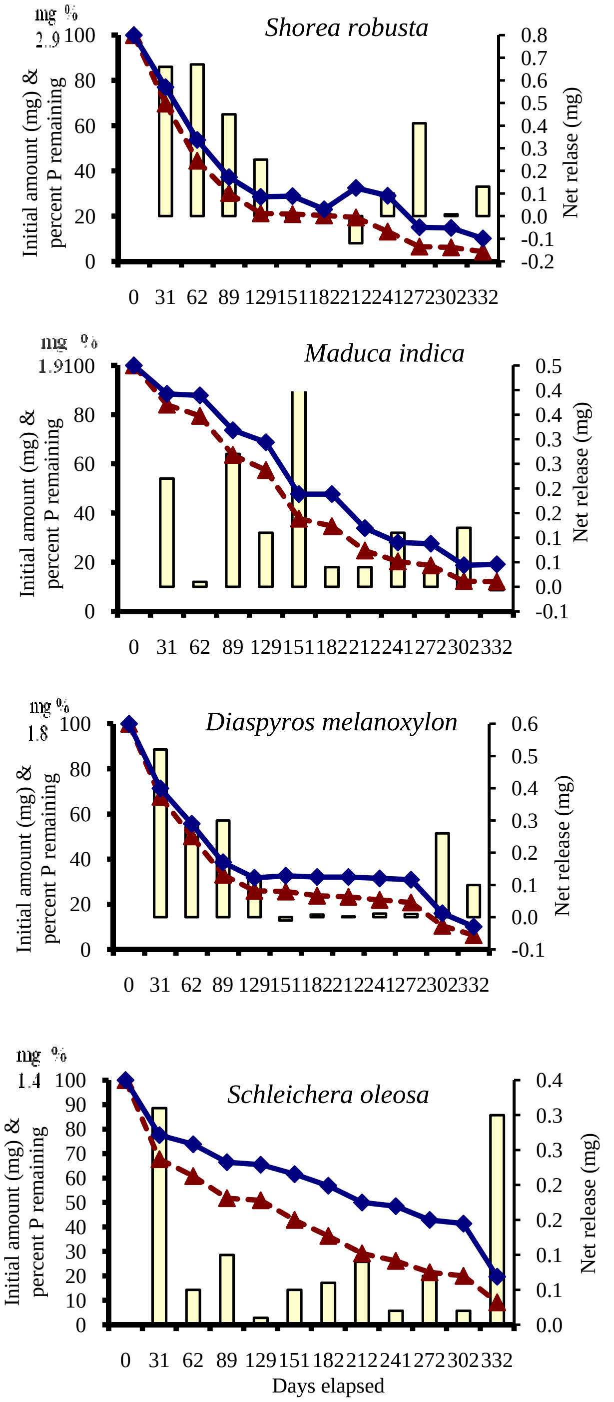


Fig. 2. Changes in the absolute amount of Nitrogen (solid line) in litter mass enclosed in litter bags placed at Barnawapara forest site. The initial mass of Nitrogen in the bag is given on the left side of the left y-axis. The columns indicate the net release between measurements (right y-axis). The broken line indicate the per cent weight remaining of the enclosed litter.

Fig. 3. Changes in the absolute amount of Phosphorus (solid line) in litter mass enclosed in litter bags placed at Barnawapara forest site. The initial mass of Phosphorus in the bag is given on the left side of the left y-axis. The columns indicate the net release between measurements (right y-axis). The broken line indicate the per cent weight remaining of the enclosed litter.

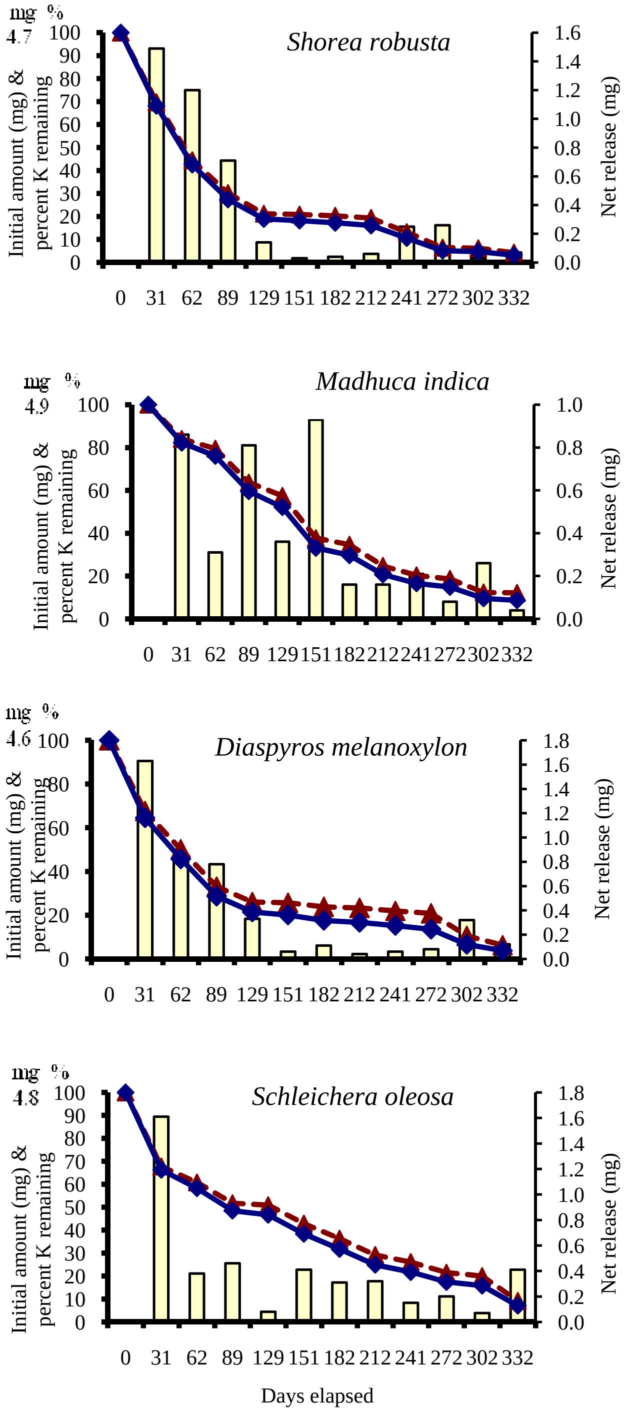


Fig. 4. Changes in the absolute amount of Potassium (solid line) in litter mass enclosed in litter bags placed at Barnawapara forest site. The initial mass of potassium in the bag is given on the left side of the left y-axis. The columns indicate the net release between measurements (right y-axis). The broken line indicate the per cent weight remaining of the enclosed litter.

showed maximum decomposition during rainy but minimum during summer season. Greater decomposition during the rainy season is perhaps due to pronounced microbial activity under favorable temperature and moisture conditions and accentuated leaching due to rainfall (Pandey & Singh 1982). Continuous decomposition of litter after the loss of soluble components is primarily a result of biotic processes. The rate of decomposition (% day^{-1}) at monthly intervals showed different patterns. In the case of *S. robusta* it was 0.28 % day^{-1} and for *D. melanoxylon* and *S. oleosa* 0.27 % day^{-1} whereas, *M. indica* showed the minimum value (0.21 % day^{-1}) of decomposition rate after 332 days. Differences in the rate of decomposition among species of different forest sites have been reported by several authors (Bargali *et al.* 1993; Pandey & Singh 1982; Upadhyay & Singh 1989; Upadhyay *et al.* 1989).

Gupta & Singh (1977) have shown highest disappearance rate, 36 - 53 % during rainy season, while a weight loss of 15 - 26 % was recorded in winter season. Higher weight loss in the summer season than in winter season is possibly related to favourable microbial activity and warmer temperatures. Upadhyay & Singh (1989) have concluded that the rate of decomposition is markedly affected by the amount of water soluble compounds, leachable substances and nitrogen content of fresh litter. In the present study the regression equation relating nutrient concentration to weight loss indicated significant correlation ($P < 0.01$) for all the species. Several workers (Bargali *et al.* 1993, 2006; Bargali 1995, 1996; Pandey & Singh 1982; Pandey *et al.* 2006; Singh *et al.* 2007) have suggested that the higher initial nitrogen content in leaf litter promotes decomposition. Upadhyay *et al.* (1989) reported lower initial nitrogen for the slow decomposing litter and higher for the fast decomposing litter.

Nutrient concentration

An increase in N concentration in decomposing litter is a generally occurring phenomenon (Arslan *et al.* 2010; Bargali *et al.* 1993, 2006; Gosz *et al.* 1973; Pandey & Singh 1982). Similar pattern was observed in the present study also. There existed significant ($P < 0.01$) inverse linear relationship between N concentration in residual material and percent weight remaining for all tree species. Melillo *et al.* (1982) have emphasized the significance of these relationships in the framework of immobilization and mineralization of N during decomposition. The weight loss in enclosed litter and increased N concentration in residual material reflect N immobilization by microorganisms. The critical N level is also an important factor for the weight loss rates; it was higher for *S. robusta* (0.97 %) and *D. melanoxylon* (0.99 %) compared to *M. indica* (0.67 %) and *S. oleosa* (0.66 %). The weight loss was higher in the former set of species compared to latter one. There is a greater tendency towards higher critical N levels for higher decomposition rates and vice - versa (Bargali *et al*. 1993; Pandey & Singh 1982; Staaf & Berg 1982). Melillo *et al*. (1982) have generalized that this relationship is inversely linear in cases where (i) physical removal of material from bags is minimized, (ii) nitrogen is sufficiently low in concentration in the litter material to be limiting to microbes; and (iii) a continuous external source of N is available.

Phosphorus ranks next to N in importance for living plants, however, in comparison with other nutrients; the concentration of phosphorus in the soil solution is generally low (Stewart *et al.* 1990). It has been suggested that the P in decomposing litter is subject to the same pattern of immobilization and uptake by micro-organisms as found for N (Peterson & Rolfe 1982). Gosz *et al.* (1973) also observed increase in P concentration for sugar maple and beech leaf litter. There existed significant inverse relationship between percent weight remaining and P concentration in residual material for all tree species ($P < 0.01$).

K is highly mobile, readily leached ion, usually occurring in amounts in excess of decomposer demand (Upadhyay *et al.* 1989; Peterson & Rolfe 1982). Nearly all published results indicate that K is subject to extensive leaching from decomposing leaf litter (Staaf & Berg 1982; Peterson & Rolfe 1982) and K is not bound by cell wall and is highly water soluble (Gosz *et al*. 1973). There existed significant positive relationship between percent weight remaining and K concentration in residual material ($P < 0.01$) showing 79.2 to 92 % variability.

Nutrient release pattern

According to Vitousek & Sanford (1986), the general pattern of nutrient release from decomposing leaves involves two phases, early immobilization of N and often P followed by net nutrient release. Gosz *et al.* (1973), however, suggested that nutrient dynamics in decomposing litter may show three sequential phases: (i) the initial release phase in which leaching predominates; (ii) the net immobilization phase in which nutrients are imported into the residual material through the activity of microorganism; and (iii) the net release phase in which an absolute decrease in the nutrient mass of the decomposing litter occurs (Gosz *et al*. 1973). However, in the present study, none of the nutrients showed all the three phases across all the four litter species. N and P showed a similar pattern of release in all tree species. Potassium showed a continuous net release from the beginning in all the tree species. *S. robusta* and *D. melanoxylon* released all nutrients at faster rates compared to *M. indica* and *S. oleosa*. The species wise pattern of nutrient release for N and P was: S. *robusta* > *D. melanoxylon* > *S. oleosa* > *M. indica,* and for K it was *D. melanoxylon* > *S. oleosa* > S. *robusta* > *M. indica.* The latter released all the nutrients at a slower rate as compared to other species. *S. robusta,* the dominant species released the N and P at a faster rate which would certainly affect the production capacity of the forest.

Conclusions

Based on the present study on litter decomposition of four tree species of Barnawapara wildlife sanctuary, we conclude that S. *robusta* decomposed at faster rate followed by *D. melanoxylon, S. oleosa* and *M. indica*. The former species also released the two important nutrients (N and P) at faster rate compared to other species. *M. indica* showed the slowest decomposition rate and nutrient release pattern.

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