LEAF LITTER DECOMPOSITION OF EVERGREEN AND DECIDUOUS *DILLENIA* SPECIES IN HUMID TROPICS OF NORTH-EAST INDIA

A. Arunachalam* & N. D. Singh

Restoration Ecology Laboratory, Department of Forestry, North Eastern Regional Institute of Science and Technology, Nirjuli - 791109, Arunachal Pradesh, India

Received October 1999

ARUNACHALAM, A. & SINGH, N. D. 2002. **Leaf litter decomposition of evergreen and deciduous *Dillenia* species in humid tropics of north-east India.** Litterbags were used to study the decomposition of abscissed leaves of two tree species belonging to one genus, *Dillenia indica* (evergreen) and *Dillenia pentagyna* (deciduous) in a humid tropical forest of Arunachal Pradesh, north-eastern India. Hundred per cent decomposition was observed after 150 days for *D. indica* and 120 days for *D. pentagyna.* The leaf litter decomposition of the two species showed different temporal trends; decomposition of *D. indica* leaf litter showed an initial lag phase, followed by a rapid decay phase and a final slow decay phase, while *D. pentagyna* leaf litter decomposed rapidly initially up to 60 days, but declined sharply afterwards. A composite linear equation showed a good fit for the observed decay patterns. The annual decay constant (k) was significantly higher ($p < 0.01$) for *D. pentagyna* (9.11) than for *D. indica* (6.15). The nutrient concentrations differed significantly between species. The mature as well as decomposing leaves had more nutrient concentrations compared with the abscissed leaves (leaf litter). The retranslocation of nitrogen before abscission was greater in *D. indica,* while percentage phosphorus retranslocation was similar in both species. The nutrient release patterns indicated that the N and P mineralisation of *D. pentagyna* leaf litter is faster compared to *D. indica,* as associated with their respective decay rates.

Key words: Leaf litter - decomposition - nutrient release - evergreen - deciduous - *Dillenia*

ARUNACHALAM, A. & SINGH, N. D. 2002. **Penguraian sarap daun species *Dillenia* malar hijau dan daun luruh di hutan lembap tropika di timur laut India.** Beg sarap digunakan untuk mengkaji penguraian daun absis dua spesies pokok daripada satu genus, *Dillenia indica* (malar hijau) dan *D. pentagyna* (daun luruh) di hutan lembap tropika di Arunachal Pradesh, timur laut India. Seratus peratus penguraian dicerap selepas 150 hari bagi *D. indica* dan 120 hari bagi *D. pentagyna.* Penguraian sarap daun dalam kedua-dua spesies mempamerkan trend masa yang berbeza; penguraian sarap daun *D. indica* menunjukkan fasa selang masa permulaan, diikuti oleh fasa reput pantas dan akhirnya reput perlahan, manakala sarap daun *D. pentagyna* mengurai dengan pantas pada mulanya sehingga 60 hari, tetapi kadar penguraian merosot dengan mendadak selepas itu. Persamaan linear komposit menunjukkan padanan yang baik bagi pola reput yang dicerap. Pemalar reput tahunan (k) lebih tinggi dengan bererti

**E-mail: aa@nerist.ernet.in*

($p < 0.01$) bagi *D. pentagyna* (9.11) berbanding *D. indica* (6.15). Kepekatan nutrien berbeza dengan bererti antara spesies. Daun yang matang dan daun yang terurai mempunyai lebih kepekatan nutrien berbanding daun absis (sarap daun). Translokasi semula nitrogen sebelum pengabsisaan adalah lebih banyak dalam *D. indica,* manakala peratus translokasi semula fosforus adalah sama dalam kedua-dua spesies. Pola pelepasan nutrien menandakan bahawa pemineralan N dan P dalam sarap daun *D. pentagyna* adalah lebih cepat berbanding dengan *D. indica,* seperti yang ditunjukkan oleh kadar reput species ini.

Introduction

In humid tropics, the rates of accession and decomposition of litter are the key processes in maintaining the nutrient budget of the ecosystems through the recycling of organically-bound plant nutrients. The tropical forest soils of north-eastern India, particularly the sub-Himalayan region of Arunachal Pradesh are usually nutrient-poor owing to their geologically recent origin but also due to several recurrent natural (landslides, floods, etc.) and human-induced (shifting cultivation, tree cutting, etc.) disturbances. In addition, high rainfall also leads to severe leaching of nutrients as vast tracts of forest area are cleared, leaving the systems open. It has been reported that the litter type associated with nutrient-poor soils may also result in the conservation of nutrients through relatively slow rates of decomposition (Monk 1966). Many workers have considered resource quality as a critical factor in determining the rate of decomposition (e.g. Melillo *et al.* 1982). Litter quality is known to vary across species types, climatic conditions and soil factors (Swift *et al.* 1979, Couteaux *et al.* 1995).

We identified two species belonging to the genus *Dillenia,* of which one is evergreen (*D. indica*) and the other is deciduous (*D. pentagyna*), in a tropical rain forest of this region. The different leaf longevity may lead to differential nutrient requirements and therefore different nutrient contents of their leaves. This in turn may have a direct influence on the rate of decomposition and subsequent nutrient release. *Dellenia indica* has a uniform litter fall all through the year whereas *D. pentagyna* has a unimodal litter fall pattern, with maximum fall between November and February. In this paper the decay and nutrient release patterns of leaves of *D. indica* and *D. pentagyna* were considered to attain better understanding of nutrient cycling in tropical rain forest ecosystems.

Materials and methods

Study area

The study was conducted in a tropical rain forest, near Banderdewa forest division, about 24 km from Itanagar, the capital of Arunachal Pradesh (latitude 27° 07' N, longitude 93° 22' E, 126 m asl) in north-eastern India. The experimental plot is on the quartzite rocks of Shela group. It has a north-east exposure and the slope is less than 5°. The regional climate has two seasons, a cool (16 °C) and dry (RH = 54%) winter (November–February) and a warm (34 °C) and wet (RH = 80–98%) summer (March–October), with mean annual precipitation (1800 mm) distributed fairly evenly throughout the year. The rainfall and temperature variations that occurred during the study period are given in Figure 1. The soil of the study site is slightly organic (organic-C = 3.17–5.28%) and acidic (pH = 4.9–5.7) (Table 1). The characteristics of the species studied are also given in Table 1. Leaf size of *D. pentagyna* was larger (20–60 × 10–20 cm) compared with that of *D. indica* (14–30 × 5–12 cm).

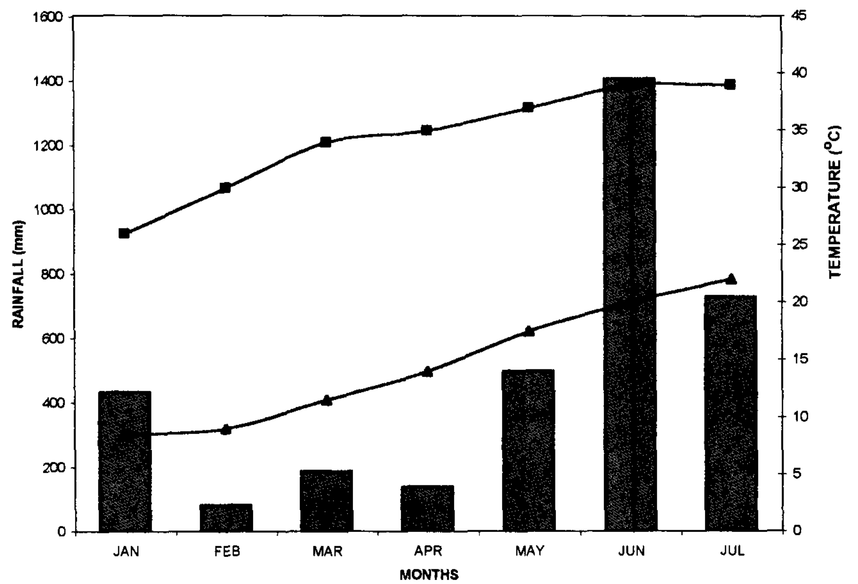

Figure 1 Rainfall pattern (□) as well as mean monthly minimum (▲) and maximum (■) air temperatures during the study period

Initial litter chemistry

Mature green and freshly fallen senescent (abscissed) leaves of *D. indica* and *D. pentagyna* were each collected from a single identified tree in the forest in January 1999. The litter samples were air-dried in the laboratory and subsamples were kept at 80 °C for 48 h before determining the dry mass. The oven-dried samples were powdered in a Cyclotec (TECATOR) and analysed for their chemical composition. The ash content was determined by igniting 1 g of ground litter sample at 550 °C for 6 h in a muffle furnace. A total of 50% of the ash-free mass was calculated as the carbon content. Nitrogen was estimated following semi micro-Kjeldhal method in a Kjeltec Auto 1030 Analyser (TECATOR). The total phosphorus was analysed colorimetrically, while lignin was measured gravimetrically (Anderson & Ingram 1993).

Table 1 Tree characteristics and soil properties under the canopy of *Dellenia indica* and *D. pentagyna*

Parameters	*D. indica* (evergreen)	*D. pentagyna* (deciduous)
Tree characteristics		
Tree density (tree ha^{-1})	48	56
Height (m)	13.5	14.7
Dbh (cm)	17.2	20.9
Litter mass ($g\ m^{-2}$)		
Leaf	180.3 (92.5)	190.7 (95.68)
Twigs (< 2 mm diameter)	10.1 (5.18)	3.3 (1.66)
Miscellaneous	4.5 (2.31)	5.3 (2.66)
Soil properties*		
Texture	Sandy loam	Sandy loam
Soil moisture content (%)	29.3	30.2
pH (1:2.5 w/v H_2O)	5.7	4.9
Soil organic carbon (%)	3.17	5.28
Total Kjeldhal nitrogen (%)	0.53	0.68
Available phosphorus (mg g^{-1})	3.89	4.10

Total stand density = 1600 trees ha^{-1}
Values in parentheses are the per cent of the total litter mass.
* n = 3

Litter decomposition

Decomposition of litter was studied using the nylon bag (15 × 15 cm) technique (Gilbert & Bocock 1960). The mesh size was 2 mm, small enough to prevent major losses of litter samples, yet large enough to permit aerobic microbial activity and free entry of small soil animals. However, these bags exclude larger arthropods and mature earthworms, which are important primary accessors of litter. This might cause the litter system to be dominated by termites, bacteria, fungi and actinomycetes. Consequently, the technique could underestimate litter decomposition rates. For the experiment, 10 g of air-dried material was placed in each bag which was then stitched with nylon thread. For each litter type, 60 bags were prepared and randomly dispersed on the forest floor on 1 January 1998. After every 30 days, five litter bags of each litter type were brought to the laboratory. The litter was washed in a bucket of tap water by swirling briefly. It was then carefully decanted through a 2-mm mesh sieve to remove any extraneous matter. According to Anderson and Ingram (1993), such brief washing permits little leaching. The litter was then dried at 80 °C for 48 h and weighed.

Computation

Organic matter decay of the litter samples was computed using negative exponential decay model (Olson 1963):

$$X/X_0=\exp(-kt)$$

where
X is the weight remaining at time t,
X_0 the initial weight,
exp the base of natural logarithm,
k is the decay rate coefficient and
t is the time (year).

The times required to achieve 50% (t_{50}) and 99% (t_{99}) decay were calculated as

$$t_{50}= 0.693/k \text{ and } t_{99}= 5/k.$$

Statistical analysis

In order to distinguish between different phases of weight-loss pattern during decomposition multiple regressions were developed using dummy factors (0 or 1) as the indicator variables (Zar 1974). The composite linear-regression model used for this purpose was (Arunachalam *et al.* 1996):

$$Y = a + bX^1 + cX^2 + dX^3...,$$

where
Y is the percentage of initial mass remaining,
a the Y intercept,
b the rate of change in Y with respect to time,
c the shift parameter for adjustment of the Y intercept in phase II and
d the shift parameter for adjustment of Y intercept in phase III.

The values of c and d were taken as zero if decay was slow and as one if the decay was rapid. The effects of climatic variables and initial litter chemistry on the rate of decomposition were assessed using a simple linear regression function, $Y=a+bX$. Tukey's test at probability level $p < 0.05$ was used to compare the means across the species (Zar 1974).

Results

Leaf chemistry of Dillenia *species*

The concentrations of N and P were greater in green leaves compared to the abscissed leaves in both *D. indica* and *D. pentagyna* (Table 2). About 32 and 13% of N had been retranslocated before senescence in *D. indica* and *D. pentagyna* respectively, while 25% of P was retranslocated in both the species. The percentage of lignin concentration as well as the ratios of C/N, C/P and lignin/N were all higher in *D.indica* (Table 3).

Table 2 Concentration (%) of nitrogen and phosphorus in mature, abscissed and decomposing foliage of *Dillenia indica* and *D. pentagyna*

Litter samples	N	P
Mature green leaves (January 1999)		
D. indica	1.9	0.8
D. pentagyna	2.4	1.2
Abscissed leaves (January 1999)		
D. indica	1.3	0.6
D. pentagyna	2.1	0.9
Decomposed leaves (March–July 1999)		
D. indica	1.72	0.7
D. pentagyna	1.92	0.9
Per cent change before abscission		
D. indica	- 31.6	- 25.0
D. pentagyna	- 12.5	- 25.0
Per cent of the initial content*		
D. indica	10.6	9.3
D. pentagyna	4.6	5.0

n = 3
*Per cent remaining = 100 × (final weight × final concentration)/(initial weight × initial concentration)
For *D. indica* the values are for 150th day and for *D. pentagyna* the 120th day.
Values for decomposed leaves are the average of the monthly data.

Table 3 Leaf chemistry of *Dillenia* spp.

Species	C %	N %	P %	Lignin %	C/N	C/P	Lignin/N
D. indica	42a	1.3a	0.6a	29a	32a	70a	23a
D. pentagyna	49b	1.9b	0.9b	18b	26b	54b	9b

n = 3
Values with the same letters in each row are not significantly different at p = 0.05.

Weight-loss pattern

Mass loss of *D. indica* leaf litter during the first 30 days was slow (Figure 2). This was followed by a rapid decay phase (1.7% weight loss day^{-1}) during the next 30 days and then a steady decomposition rate of 0.3–0.4% weight loss day^{-1} till the end of the study period of 150 days, thus showing a three-phased decay pattern. On the other hand, the leaf litter of *D. pentagyna* showed a two-phased decay pattern, with an initial fast decomposition rate of 1.84% weight loss day^{-1} up to 60 days and then declined sharply to 0.37% weight loss day^{-1} on the 90th day and 0.17% day^{-1} on the 120th day. A composite linear regression model, $Y = a + bX^1 + cX^2 + dX^3 + eX^4$ showed a good fit for weight loss pattern in senescent leaves of *D. indica* while a multiple regression equation, $Y = a + bX^1 + cX^2$ fitted well for the observed decay pattern for *D. pentagyna* leaves.

Decay constants

The variation in the annual decay coefficients (k) were statistically significant ($p < 0.05$) between the two species (Table 4). The dry mass remaining (% of initial) at the end of the experiment, i.e. 150 days for *D. indica* and 120 days for *D. pentagyna*, was 8 and 5 respectively.

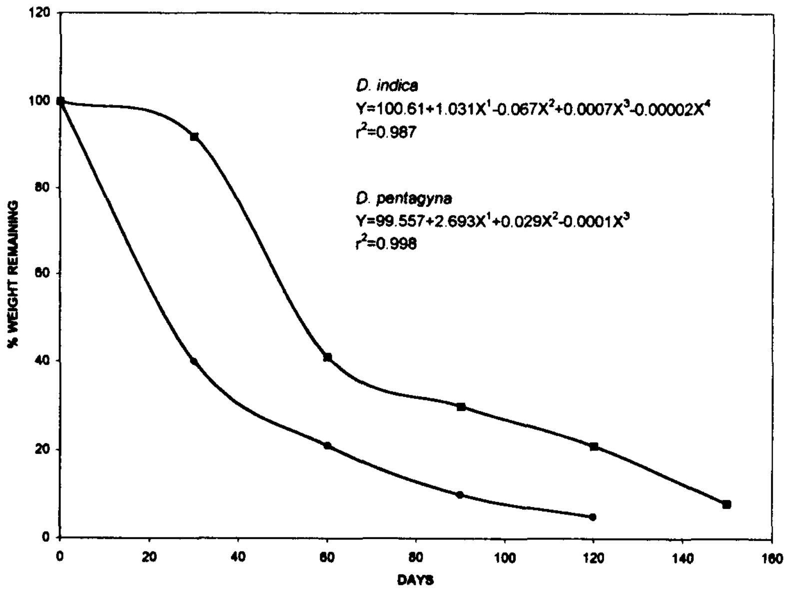

Figure 2 Decay pattern for leaf litter of *Dillenia indica* (■) and *D. pentagyna* (●).

Table 4 Annual decay constants (k) for the litter decomposition

Species	k	t_{50}	t_{99}
D. indica	6.15a	0.11a	0.813a
D. pentagyna	9.11b	0.08b	0.549b

Values in each column with same letters are not significantly different at p = 0.01.

Discussion

Residue quality

N and lignin concentrations of the leaf materials of the two *Dillenia* species were well within the reported range (0.36–3.9% and 28.3–29.2% respectively) for tropical tree species (Bloomfield *et al.* 1993). Nutrient concentrations were significantly higher ($p < 0.05$) in evergreen *D. indica* leaf litter than in the deciduous *D. pentagyna*. Myers *et al.* (1994) reported that substrates with C/N < 25 is of high quality and tend to release N at a faster rate compared to lower quality residues (C/N > 25). Therefore, it could be concluded that the litter of *Dillenia* species was of high quality and would therefore be expected to release N rapidly. Nevertheless, the C/N ratio in this study was lower compared to the reported range for humid subtropical forest ecosystems (46–77) (Arunachalam *et al.* 1998).

The importance of retranslocation of nutrients prior to litter fall in tropical forests has been stressed by Attiwill *et al.* (1978). This process has been termed as biochemical nutrient cycling by Switzer & Nelson (1972). In this study, at least one-third of the N in *D. indica* was retranslocated prior to senescence and abscission. The value was about 12.5% for *D. pentagyna.* This could well explain greater nutrient concentration in the latter species. Interestingly, the retranslocation rate of P remained the same (25%) in both species indicating the steady-state condition of this nutrient uptake by the *Dillenia* species. From the relatively moderate N concentration of live foliage in both species, leaf litter had even lower N. Similar results have been reported for evergreen tree species like *Arbutus unedo* and *Quercus coccifera* of Greek Maquis ecosystems (Arianoutsou 1993) as well as for *Ceanothus* evergreen shrub live foliage and litter (Schlesinger 1985). The relatively slight increase in the N and P concentrations in the aged litter-bag material compared to freshly abscissed leaves may indicate enrichment from the environment. For N, it can also mean its conservation relative to carbon loss. Accumulation of N has been reported for various periods after initiation of decomposition (e.g. Melillo *et al.* 1982, Schlesinger 1985). However, unlike organic fractions which are respired, N and P are often retained in microbial biomass during litter decay. For example, Gosz *et al.* (1973), working on the decomposition and nutrient release in several plant species (yellow birch, sugar maple and beech), found that the concentrations and absolute weight of N and P in decomposing leaf litter increased with time. It was reported that the mobility series for P is greater than N (Arunachalam *et al.* 1998). The present study in the humid tropics conforms the above trend.

Since leaves comprised more than 90% of the total litter mass in the humid tropical forests of the sub-Himalayan tract of India, these inputs and accumulation may be the key factors in the nutrient cycling processes on the forest floor. At the experimental site, leaf litter mass, 180 g m^{-2} for *D. indica* and 191 g m^{-2} for *D. pentagyna*, "immobilised" and/or accumulated 2.34 g m^{-2} and 3.62 g m^{-2} of N respectively for the two species (Table 1). For phosphorus, the amount was 1.08

and 1.72 g m^{-2} bound in *D. indica* and *D. pentagyna* leaf litter mass on the forest floor respectively. It could be concluded that the deciduous species accumulated more N and P in their litter. With this, and also the fact that it decomposed faster than evergreen species, the deciduous species could prove to be a potential species of conservation and recycling of plant nutrients in humid tropical forests.

Decay pattern

Leaf litter of *D. indica* had an intial time lag in decomposition, which was probably due to the delay in colonisation and establishment of microbial population in the litter. It contained more lignin and less N compared to *D. pentagyna* foliage. The rapid rate of decay after an initial lag phase was the net effect of a large number of processes such as utilisation of readily available energy sources by microbes, loss of water soluble components and non-structural carbohydrates from the litter (Bloomfield *et al.* 1993) as well as removal of litter particles by soil microfauna, also operating in the top soil system (Swift *et al.* 1979). A decline in the decomposition rate after the rapid phase of decay may be attributed to higher percentage of recalcitrant fractions like cellulose, lignin and tannin during the advanced stage of litter decay. These substances are known to control the rate of decay by showing resistance to enzymatic attack and by physically interfering with the degradation of other chemical fractions of the cell wall (Bloomfield *et al.* 1993). The excessive initial weight loss in the foliage of *D. pentagyna* can be due to relatively greater moisture content and larger surface area of this species. These may facilitate the colonisation of microorganisms, which in turn, may increase the rate of loss of water soluble components.

Several workers have established a positive correlation between initial N and decay rate, and a negative correlation between initial lignin and decay rate (Singh & Gupta 1977, Vogt *et al.* 1986, Arunachalam *et al.* 1998). This study also fully corroborates the above findings as substantiated by the faster decay rate in *D. pentagyna* that contained greater N concentration and lower lignin. On the other hand, several authors failed to find strong dependence of either lignin or lignin/N ratio on decay rate coefficients (e.g. Melillo *et al.* 1982). However, before confirming this position for tropical species, more such species with a wider range of initial lignin and nitrogen contents need be analysed. In this regard, it has been suggested that as decomposition proceeds the influence of N decreases while that of lignin increases (Berg 1984). Hence, the rate of decomposition is reduced with time.

Leaf litter of *Dillenia* spp. had a faster decay rate in the present study ($k = 6.2$ and 9.1 per year) than the reported values for *D. pentagyna* (4.0) (Mohan Kumar & Deepu 1992) and for *D. indica* (4.4) (Toky & Ramakrishnan 1984) in the Western Ghats and Meghalayan forests of India respectively. The difference observed could be attributed to population dynamics of decomposers, especially macroarthropods, and also to the microclimate of the forest and soil (Arunachalam *et al.* 1996). Furthermore, in tropical forests, usually there is very little or no accumulation of litter, implying a fast turnover of organic matter in the soil (Swift *et al.* 1979). Changes in temperature and moisture availability, their interactions and the higher activity of the decomposer organisms need to be analysed as they may, to a greater extent, explain the large variation in litter decomposition rates existing between these two floristic regions, i.e. Western Ghats and Eastern Himalayas in India.

Acknowledgements

The first author is thankful to the Council of Scientific and Industrial Research as well as the Indian Council of Forestry Research and Education for financial support.

References

ANDERSON, J. M. & INGRAM, J. S. I. 1993. *TSBF-Handbook of Methodology*. CAB International, Wallinford, UK.

ARIANOUTSOU, M. 1993. Leaf litter decomposition and nutrient release in a maquis (evergreen sclerophyllous) ecosystem of North-Eastern Greece. *Pedobiologia* 37: 65–71.

ARUNACHALAM, A., PANDEY, H. N., TRIPATHI, R. S. & MAITHANI, K. 1996. Fine root decomposition and nutrient mineralisation patterns in a subtropical humid forest following tree cutting. *Forest Ecology and Management* 86: 141–150.

ARUNACHALAM, A., MAITHANI, K., PANDEY, H. N. & TRIPATHI, R. S. 1998. Leaf litter decomposition and nutrient mineralisation patterns in regrowing stands of a humid subtropical forest after tree cutting. *Forest Ecology and Management* 109: 151–161.

ATTIWILL, P. M., GUTHRIE, H. B. & LEUNING, R. 1978. Nutrient cycling in a *Eucalyptus obliqua* (L'Herit) forest. I. Litter production and nutrient return. *Australian Journal of Botany* 26: 79–91.

BERG, B. 1984. Decomposition of root litter and some factors regulating the process: long-term root litter decomposition in a Scots pine forest. *Soil Biology and Biochemistry* 16: 609–617.

BLOOMFIELD, J., VOGT, K. A. & VOGT, D. J. 1993. Decay rate and substrate quality of fine roots and foliage of two tropical tree species in the Luqillo experimental forest, Puerto Rico. *Plant and Soil* 150: 233–245.

COUTEAUX, M. M., BOTTNER, P. & BERG, B. 1995. Litter decomposition, climate and litter quality. *Tree* 10: 63–66.

GILBERT, O. & BOCOCK, K.L. 1960. Changes in the leaf litter when placed on the surface of soils with contrasting humus types. II. Changes in the nitrogen content of oak and ash litter. *Journal of Soil Science* 11: 10–19.

GOSZ, J. R., LIKENS, C. E. & BORMANN, F. H. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook forest, New Hampshire. *Ecological Monographs* 43: 173–191.

MELILLO, J. M., ABER, J. D. & MURATORE, J. E. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63: 621–626.

MOHAN KUMAR, B. & DEEPU, J.K. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular India. *Forest Ecology and Management* 50: 181–201.

MONK, C. D. 1966. An ecological significance of evergreeness. *Ecology* 47: 504–505.

MYERS, R. J. K., PALM, C. A., CUEVAS, E., GUNATILLEKE, I. U. N. & BROSSARD, M. 1994. The synchronisation of nutrient mineralisation and plant nutrient demand. Pp. 81–116 in Woomer, P. L., Swift, M. J. (Eds.) *The Biological Management of Tropical Soil Fertility*. John Wiley and Sons.

OLSON, J. S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44: 322–331.

SCHLESINGER, W. H. 1985. Decomposition of chaparral shrub foliage. *Ecology* 66: 1353–1359.

SINGH, J. S. & GUPTA, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Review* 43: 449–528.

SWIFT, M. J., HEAL, O. W. & ANDERSON, J. M. 1979. *Decomposition in Terrestrial Ecosystems.* Five Volumes. University of California Press, Berkeley.

SWITZER, G. L. & NELSON, L. E. 1972. Nutrient accumulation and cycling in Loblolly pine (*Pinus taeda* L.) plantation ecosystems: the first twenty years. *Proceedings of the Soil Science Society of America Journal* 36: 143–147.

TOKY, O. P. & RAMAKRISHNAN, P. S. 1984. Litter decomposition related to secondary succession and species type under slash and burn agriculture (jhum) in north-eastern India. *Proceedings of Indian National Science Academy* 50: 57–65.

VOGT, K. A., GRIER, G. C. & VOGT, D. J. 1986. Production, turnover and nutrient dynamics of above- and below-ground detritus of world forests. *Advances in Ecological Research* 15: 303–377.

ZAR, J. H. 1974. *Biostatistical Analysis.* Prentice-Hall Inc., Englewood Cliff, New Jersey.