Malay. Nat. J. 37: 199–208 (1984)

MALAYAN NATURE JOURNAL

Elemental content of litterfall in a Lower Montane Rain forest in Central Java, Indonesia

L.A. BRUIJNZEEL (SWAMI PREM SAMPURNO)
Institute of Earth Sciences, Free University, P.O. Box 7161, 1007 MC Amsterdam, The Netherlands.

Abstract. Litterfall in a Lower Montane Rain Forest in Central Java, Indonesia, was estimated for eight months. Litter was divided into three categories: leaves, branches/twigs and seeds/fruit/flowers. Material was analyzed for Ca, Mg, K, P, N, Na, Si, Al, Fe, Mn and Cu. During the study period 500 g/m^2 of litter reached the forest floor (77% leaves) corresponding to *c.* 738 g/m^2/yr. Production figures for this and another Javan rain forest appears to be on the low side of the range published for tropical forests. Leaf litter contains relatively large amounts of Ca, Mg, K, Si, Fe and Al, whereas concentrations of P and Mn are low in comparison to findings elsewhere in the tropics. Annual accession of chemical elements to the forest floor via litterfall is similar to that of other humid tropical forests.

INTRODUCTION

The present paper contains data on chemical element content of litterfall in Lower Montane Rain forest of South-Central Java, Indonesia. These were collected as reference material for an investigation of chemical element cycling in various forest plantations in conjunction with a study of the chemical weathering of volcanic deposits (Bruijnzeel 1983).

Although the present observations lasted for less than a full year (viz. June 1977 to February 1978), it is felt that the scarcity of investigations of nutrient returns in upland South-East Asian rain forests justifies the present contribution.

The 0.5 ha study site was situated on the northern rim of the South Serayu mountains at *c.* 650 m above sea level near Pringombo, South-Central Java (7°27′ S, 109°45′E). Mean annual rainfall at Pringombo (1927–1975) amounts to 4570 m with a short dry season from July to September, when on average two months experience less than 60 mm of rain (Schmidt & Ferguson 1951). The soils developed in the andesitic volcanic ash substratum are well-drained humic andosols (FAO/UNESCO 1974) of intermediate fertility. A species list, compiled by Koorders-Schumacher (1910–1913), is available for the section of the forest where the observation site was located. Further details on climate, soils, geological setting and vegetation can be found in Bruijnzeel (1983).

SAMPLE COLLECTION AND TREATMENT

Litter was collected from five randomly placed litter traps every 30 days between 1 June 1977 and 1 February 1978. After each collection the traps were moved to a new position on a 5 x 5 m grid in a random fashion, sampling a total area of approximately 0.5 ha. Trays consisted of a wooden frame (board width 25 cm) supporting 1 m^2 of plastic screen with a mesh-width of 1.6 mm and were mounted 10 cm above ground level to reduce effects of soil splash and soil organisms. Samples were transported to the laboratory on the day of sampling, dried at 70°C for 24 hours, weighed and sorted into leaves, twigs/branches and seeds/fruits, usually leaving only minor amounts of unidentified material. After shipment to the Netherlands samples were ground to pass through a 1-mm sieve prior to wet ashing and further chemical analysis according to procedures specified by Bruijnzeel (1983).

RESULTS AND DISCUSSION

Litter production

Monthly amounts of litter collected from June 1977 until February 1978 are given in Fig. 1. Production of leaf litter during the three months of considerable rainfall (viz. June, December and January) was very similar (39±0.2 g/m^2). More leaves were shed during the (longer than normal) dry period, with a peak in October. Standard errors of the mean ranged from 5% (July) to 19% (June) with an overall value of 11%.

Standard errors for woody litter were much larger, but the number of collectors needed to arrive at a standard error of the mean of 10% would become unpractical. Total dry weight of litter reaching the forest floor during the eight months of observation amounted to 500 g/m^2, 77% of which consisted of leaf litter. About 13% was made up of branches and twigs, whilst seeds, fruits, flowers and pieces of bark constituted the remainder (10%).

In order to arrive at an estimate of *annual* litter production tentative monthly amounts of 39, 10 and 2 g/m^2 were assumed for leaf-, woody- and "seed" litterfall for the remaining four rainy months (based on observations in the other wet months and data from West Java collected by Yamada (1976). Adding these one obtains an annual total production of 682 $g/m^2/yr$.

The above figures must be regarded as underestimates since litter con-

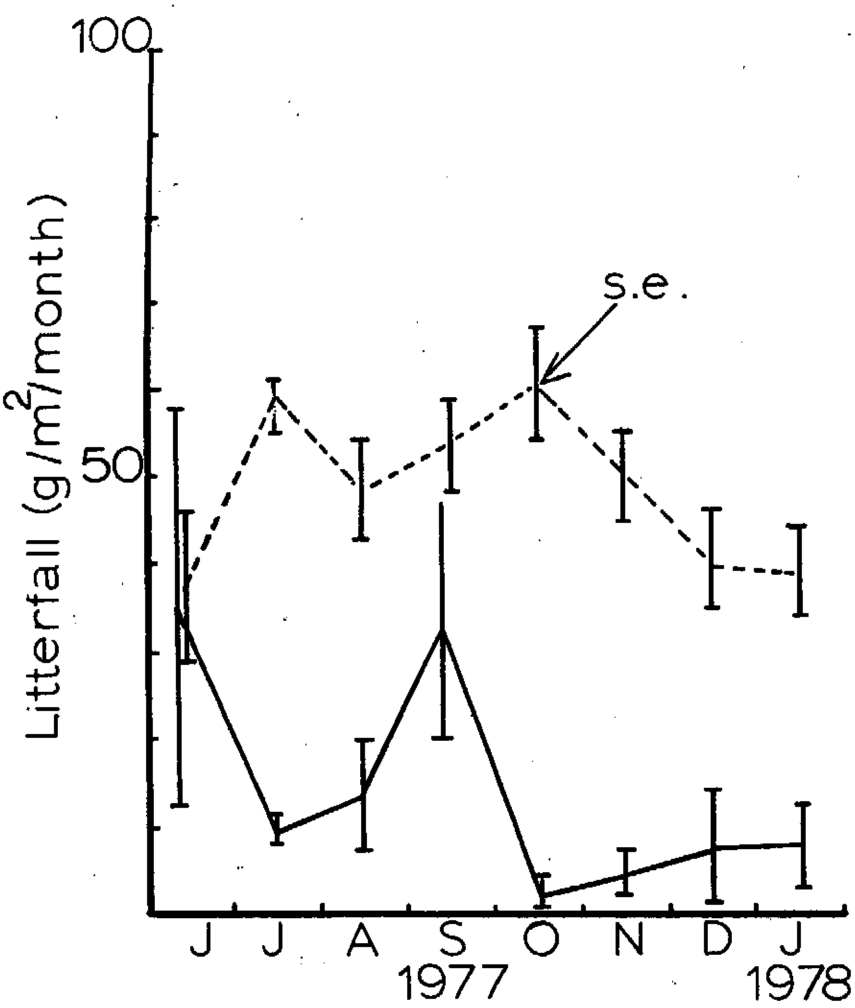

Figure 1. Monthly litterfall (g/m² dry wt) at Pringombo between 1 June 1977 and 1 February 1978. Dashed line: leaf litter; Continuous line: woody litter. Vertical bars denote standard errors of the mean.

fined in traps for some time in a warm and damp environment loses weight due to leaching and decomposition (Kirita & Hozumi 1969). In an attempt to account for this, observations on leaf-litter disappearance under similar climatic conditions reported by Wiegert & Murphy (1970) and Krämer (1978) have been used. A weight loss of 10% has been assumed for wet months and half of that for months of intermediate rainfall (non-woody litter). In this way a total production of 738 g/m² /yr is calculated with 78% (575 g/m² /yr) accounted for by leaves. Table 1 brings together some data on litterfall in tropical forests experiencing high annual amounts of precipitation and only short dry seasons. Such comparisons can be misleading because of the use of widely different methods for estimating the branchfall component. Also, although leaf fall is usually determined according to more readily comparable procedures, there remain such complicating factors as sampling intensity (and therefore degree of weight loss) and year-to-year variability as caused by climatic fluctuations (Brasell *et al.* 1980). Therefore, although reported annual leaf fall ranges from 4490 (West Java; Yamada 1976) to 10480 kg/ha/yr (Panama; Golley *et al.* 1975), leaf-litter production in mature forests from the wet tropics has to be regarded as fairly uniform, with no clear difference between Lowland or Lower Montane Rain forests.

Nevertheless production of the present site and the Lower Montane Rain forests of Malesia seem to fall within the lower part of the range presented in Table 1.

Table 1. Litter production in various natural forests of the humid tropics (kg/ha/yr).

Forest type	Litter production		Altitude (m.a.s.l.)	Annual precipitation (mm)
	Total	Leaves		
Lower Montane Rain forest				
Central Java, Indonesia[1]	6815 (7380)*	5410 (5750)*	650	4570
West Java, Indonesia[2]	5958	4490	1550	3380
Malaysia[3]	6300	–	600	2000
Papua New Guinea[4]	7550	4180*	2500	3985
Puerto Rico[5]	9660*	5050*	510	3500
Guatemala[6]	9680 (11040)*	7020 (8385)*	1000	3000
Northern Panama[7]	11800	10480	500	2500
Zaire[3]	–	8500	1650	2000
Queensland[8]	9870	6900	700	2100
Lowland Rain forest				
Malaysia[9]	9375	6365	75–150	2054
Colombia[10]	8370	6645	10	3000

*corrected for decay in traps

[1]This study; [2]Yamada (1976); [3]Bray & Gorham (1964); [4]Edwards (1982); [5]Odum (1970); [6]Kunkel-Westphal & Kunkel (1979); [7]Golley *et al.* (1975); [8]Brasell *et al.* (1980); [9]Lim (1978); [10]Fölster & de las Salas (1976).

The periodicity of leaf fall observed at Pringombo is similar to that of many other tropical forests: a continuous and somewhat irregular fall with a main peak at the end of the dry season (Yamada 1976; Lim 1978; Kunkel-

Westphal & Kunkel 1979). Branch fall is more irregular and usually associated with events of intense precipitation (Yamada 1976; Lim 1978). The ratio between branch- and leaf fall found at Pringombo (0.19) is very similar to the ones reported for rain forests in West Java (0.21; Yamada 1976), New Guinea (0.19; Edwards 1977) or Malaysia (0.24; Lim 1978). However, much higher ratios are often obtained when the technique of forest floor clearance is applied (*e.g.* 0.81 for a Puerto Rican forest (Odum 1970), or 0.67 for the Guatemalan forest (Kunkel-Westphal & Kunkel 1979). It can be concluded that the use of small trap collectors may seriously underestimate this component.

Chemical concentrations in litterfall

The seasonal trend in chemical concentrations in leaf fall at Pringombo is given in Fig. 2.

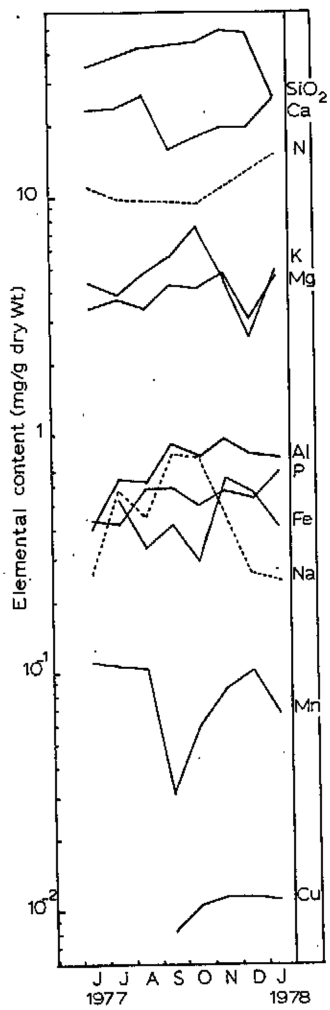

Figure 2. Seasonal variation in element content (mg/g dry wt) in leaf fall at Pringombo.

Calcium, Fe, Mn and (probably) N and Cu show a minimum concentration in September or October, whereas Na and K then attain maximum values. Silica increases steadily throughout the observation period, but is unexpectedly low in January. A similar rise in concentration as the dry season progresses is exhibited by Al, which becomes essentially constant from September onwards. Phosphorus and Mg concentrations finally scatter around slightly positively sloping lines.

Such variations are thought to be the result of climatic and biotic factors, such as deposition of terrestrial dust and ocean-derived aerosols on the canopy and forest floor, leaching of the litter by rainfall or conversely, splash-in of soil particles (although no sediment could be discovered on the samples) and last but not least, the timing of leaf fall of different species.

It has been shown (Bruijnzeel 1983) that significant amounts of Na, and to a lesser extent of Ca and K, enter the forest ecosystem during the dry season as dry deposition. Also, concentrations of K and especially Na dropped sharply with the onset of the rains in November, reflecting the leaching effect. Where concentrations of Na remain low for all wet months, those for K show a more irregular behaviour. Many other elements (Ca, Mn, P, Si, Al, etc.) do not exhibit any clear trend in relation to rainfall either, suggesting that biotic rather than climatic/methodic factors are dominant. No specific data have been collected in this regard, however.

Average concentrations of chemical elements in the three categories of litter are given in Table 2.

No significant differences in chemical composition were found between leaf- and woody litter, apart from Si and Al ($P < 0.01$). This is interpreted as the presence of a re-translocation of nutrients from the leaves into the twigs before leaf abscission in order to retain them within the plant biomass as long as possible (Steinhardt 1979; Enright 1979). "Seed" litter contained less Ca and Mg than either leaf- or branch litter ($P < 0.01$) and was also lower in Si ($P < 0.01$), Al and Na ($P < 0.05$) than leaf liteer.

If concentrations of chemical elements in leaf- and "seed" fall for the remaining months (February – May) are estimated by taking the average of the values observed in January and June, annual values can be computed for comparison with studies of longer duration elsewhere. However, no large differences were found between these calculated values and those presented in Table 2, and the latter have therefore been retained in Table 3, which puts together some data on the elemental content of leaf fall in various tropical forests.

Leaf litter at Pringombo is relatively rich in Mg and especially Ca, whilst most other elements fall within the reported range. Values for N, P and K are remarkably similar to those published by Edwards (1982) for Lower Montane Rain forest in Papua New Guinea growing on a comparable soil type. Data on Si-, Al- and Cu-concentrations in leaf fall are somewhat scarce

Table 2. Average concentrations (and standard errors of the mean) of chemical elements in litterfall at Pringombo between 1 June 1977 and 1 February 1978 (mg/g dry weight).

	Leaf litter	Branch litter	"Seed" litter
Ca	21.6±1.4	22.5±2.3	8.5±1.3
Mg	3.9±0.2	3.3±0.3	2.4±0.4
Na	0.5±0.1	0.3±0.05	0.25±0.1
K	4.8±0.5	4.8±0.8	6.3±1.6
P	0.55±0.03	0.46±0.03	0.65±0.16
N*	11.2±1.3		
SiO_2	40.8±3.0	15.8±3.3	8.5±1.8
Al	0.74±0.06	0.29±0.05	0.37±0.1
Fe	0.46±0.05	0.31±0.05	0.49±0.19
Mn	0.08±0.01	0.06±0.01	0.03±0.01
Cu**	0.011±0.001	0.013±0.001	0.013±0.002

* June, July, October & January
** September – January

in the literature, rendering definite conclusions in this regard difficult. The concentration of Mn seems exceptionally low when compared to the range given in Table 3 and may reflect soil characteristics (Bruijnzeel 1983). Similarly high Fe concentrations have been observed for litterfall in nearby plantations of *Tectona grandis* L. (Bruijnzeel 1983) and for forest-floor litter in Montane Rain forest in West Java (van Schuylenborgh 1958).

Return of chemical elements to the forest floor via litterfall

The annual return of chemical elements to the forest floor via litterfall (as complementary to that via canopy leaching which has not been studied at this site) has been calculated for the three categories of litter. Concentrations of chemical elements in leaf- and "seed" fall for the period February to May had to be estimated as related above, whilst in the case of branch fall overall means were used. Results for nutrient returns via leaf fall and total litterfall are given in Table 4, along with data from other tropical forests.

Leaf litter clearly provides the bulk of nutrients returning to the forest floor via litterfall. At Pringombo, Ca and SiO_2 alone make up 84% of the total, a figure that rises to 97% when Mg and K are added.

Table 3. Average nutrient concentrations of leaf fall in various tropical forests (mg/g dry weight).

	Ca	Mg	Na	K	P	N	SiO_2	Al	Fe	Mn	Cu
Central Java[1]	21.6	3.9	0.5	4.8	0.55	11.2	40.8	0.74	0.46	0.08	0.011
Papua New Guinea[2]	13.1	2.9		4.6	0.6	11.3					
Malaysia[3+]	7.0	2.2		3.8	0.3	11.7					
Colombia[4+]	13.6	1.3		3.3	0.4	12.4	24.9	0.13	0.09	0.52	
Panama[5]	10.2	2.3	1.1	1.2	0.8				0.13	0.24	0.005
Puerto Rico[6]	7.6	1.7	1.0	1.9*	0.2				0.2*	0.28	
Amazonia[7+°]	2.0	2.0	0.8	2.0	0.3	15.0			1.8	1.1	0.035
Venezuela[8°]	7.3	2.6	0.04	5.7	0.6	11.5		1.83	0.12	0.67	

+Lowland Rain forest °seasonal climate

[1] present study; [2] Edwards (1982); [3] Lim (1978); [4] Folster & de las Salas (1976); [5] Golley *et al.* (1975); [6] Jordan (1970); *Odum (1970); [7] Klinge & Rodrigues (1968); Steinhardt (1979).

Table 4. Return of nutrients via litterfall in selected tropical forests (kg/ha/yr).

	Ca	Mg	Na	K	P	SiO_2	Al	Fe	Mn	Cu	N
Total Litterfall											
Central Java[1] *	144	25	3	35	3.7	226	4.3	3.7	0.54	0.08	
Papua New Guinea[2]	95	19		28	5.1						
Malaysia[3+]	69	18		31	2.8						
Colombia[4+]	124	12		29	3.5	182	1.2	0.8	4.4		
Panama[5]	115	26	13	20	8,5			1.5	3	0.11	
Puerto Rico[6]	50	12	4	(2)				1.1	2.3		
Venezuela[8] **	43	14	0.3	33	4.0		9.3	0.8	2.7		
Leaf fall											
Central Java[1]	120	21	2.5	26	3	207	3.8	3.2	0.46		62
Papua New Guinea[2]	54	12		18	2.5						91
Malaysia[3+]	45	14		24	2.0						75
Colombia[4+]	90	8		22	2.7	165	0.9	0.6	3.4		103
Panama[5]	107	24	11	12	8.5			1.5	2.5		
Puerto Rico[6]	42	9	2	10	1			1	1.6		
Amazonia[7] **	14	11	5	11	1.9			1.2	0.7		96
Venezuela[8] **	25	9	0.1	19	2.1		6.2	0.4	2.3		39

[1–8] see Table 3 * uncorrected for decay in traps + lowland forest

** distinctly seasonal climate

The annual returns of nutrients via litterfall at Pringombo are relatively high when compared to other Lower Montane Rain forests (Table 4). Apparently the relatively high elemental concentrations found in the present litter more than make up for the fairly low production of litter itself (Table 1). Returns of N and Mn, however, are somewhat low. Figures presented here will be compared with corresponding data obtained in nearby forest plantations of *Agathis loranthifolia* Salisb., *Pinus merkusii* Jungh. et de Vr. and *Tectona grandis* L. in a separate paper.

Acknowledgements. The investigations were supported by a grant from the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) under project no. W 76–45. Logistic support of the NUFFIC/UGM "Serayu Valley Project" is gratefully acknowledged. Chemical determinations were carried out by Mr H.J.M. Nelissen, Mr H. Wesselman, Mr P. Overweg and Miss R. Vooijs. Saskia Kars and Romée de Vries are thanked for drawing figures and typing of the manuscript. Special thanks are due to prof. dr. W.H.O. Ernst.

REFERENCES

Brasell, H.M., Unwin, G.L. & Stocker, G.C. (1980). The quantity, temporal distribution and mineral-element content of litterfall in two forest types at two sites in tropical Australia. *J. Ecol.* **68**: 123–139.

Bray, J.R. & Gorham, E. (1964). Litter production in the forests of the world. *Adv. Ecol. Res.* **2**: 101–157.

Bruijnzeel, L.A. (1983). *Hydrological and biogeochemical aspects of man-made forests in south-central Java, Indonesia.* Ph.D. thesis. Free Univ., Amsterdam, 258 pp (available from the author).

Edwards, P.J. (1977). Studies of mineral cycling in a montane rain forest in New Guinea II. The production and disappearance of litter. *J. Ecol.* **65**: 971–992.

Edwards, P.J. (1982). Studies of mineral cycling in a montane rain forest in New Guinea V. rates of cycling in throughfall and litter fall. *J. Ecol.* **70**: 807–827.

Enright, N.J. (1979). Litter production and nutrient partitioning in rain forest near Bulolo, Papua New Guinea. *Malay. Forester* **42(3)**: 202–207.

FAO/UNESCO (1974). *Soil map of the world. Vol. 1.* The Legend; Sheet IX. South-east Asia. UNESCO, Paris.

Fölster, H. & de las Salas, G. (1976). Litterfall and mineralization in three tropical evergreen forest stands. *Acta Cient. Venez.* **27**: 196–202.

Golley, F.B., McGinnis, J.T., Clements, R.G., Child, G.I. & Duever, M.J. (1975). *Mineral cycling in a Tropical Moist Forest Ecosystem.* University of Georgia Press, Athens.

Jordan, C.F. (1970). A progress report on studies of mineral cycles at El Verde. In: Odum, H.T. & Pidgeon, R.F. (eds.) *A tropical rain forest,* pp. H 217–219. U.S.A. E.C., Oak Ridge, Tennessee.

Kirita, H. & Hozumi, K. (1969). Loss of weight of leaf litter caught in litter trays during the period between successive collections – a proposed correction for litterfall data to account for the loss. *Jap. J. Ecol.* **19**: 243–246.

Klinge, H. & Rodrigues, W.A. (1968). Litter production in an area of Amazonian Terra Firme forest. Part I. Litterfall, organic carbon and nitrogen contents of litter. Part II. Mineral content of litter. *Amazoniana* **1**: 287–302; 303–309.

Koorders-Schumacher, A. (1910–1913) *Systematisches Verzeichnis der zum Herbar Koorders gehörenden, in Niederländisch-Ostindien, besonders in den Jahren 1888–*

1903 gesammelten, Phanerogamen und Pteridophyten. I. Abteilung. Java, pp. 48–50. Buitenzorg.
Krämer, G. (1978). *Quantitative Untersuchungen zum Streuumsatz in einem Bergregenwald Guatamalas, C.A., mit besonderer Berücksichtigung der daran beteiligten Tiergruppen der Meso- und Makrofauna.* Ph. D. Thesis, University of Munich.
Kunkel-Westphal, I. & Kunkel, P. (1979). Litterfall in a Guatemalan primary forest, with details of leaf-shedding by some common tree species. *J. Ecol.* 67: 665–686.
Lim, M.T. (1978). Litterfall and mineral-nutrient content of litter in Pasoh Forest Reserve. *Malay. Nat. J.* 30: 375–380.
Odum, H.T. (1970) Summary: an emerging view of the ecological system at El Verde. In Odum, H.T. & Pidgeon, R.F. (eds.). *A tropical rain forest.* pp. I 191–289. U.S.A. E.C., Oak Ridge, Tennessee.
Schmidt, F.H. & Ferguson, J.H.A. (1951). Rainfall types based on wet and dry period ratio's for Indonesia and Western New Guinea. *Kem. Perh. Djawat. Meteor. Geofis., Djakarta* No. 40, 18 pp.
Schuylenborgh, J. van (1958). On the genesis and classification of soils derived from andesitic tuffs under humid tropical conditions. *Neth. J. Agric. Sci.* 6: 99–123.
Steinhardt, U. (1979). Untersuchungen über den Wasser- und Nährstoffhaushalt eines andinen Wolkenwaldes in Venezuela. *Göttinger Bodenkundliche Berichte* 56: 1–185.
Wiegert, R.C. & Murphy, P. (1970). Effect of season, species, and location on the disappearance rate of leaf litter in a Puerto Rican forest. In: Odum, H.T. & Pidgeon, R.F. (eds.). *A tropical rain forest.* pp. H 101–104. U.S.A.E.C., Oak Ridge, Tennessee.
Yamada, I. (1976). Forest-ecological studies of the Montane forest of Mt. Pangrango, West Java. III. Litter fall of the tropical Montane forest near Cibodas. *South East Asian Studies* 14(2): 193–229.