CONTRIBUTIONS OF THROUGHFALL, STEMFLOW AND LITTERFALL TO NUTRIENT CYCLING IN A SECONDARY LOWLAND RAIN FOREST IN ILE-IFE, NIGERIA

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MUOGHALU, J. I. 2003. **Contributions of throughfall, stemflow and litterfall to nutrient cycling in a secondary lowland rain forest in Ile-Ife, Nigeria.** Inputs of nutrients through precipitation and transfer of nutrients to the soil from canopy via litterfall, throughfall and stemflow were investigated on a secondary lowland rain forest at Ile-Ife, Nigeria. The objective was to determine the relative contributions of litterfall and net precipitation components to nutrient cycling in the forest. The results indicated that the concentration of all nutrients (N, P, Ca, Mg, K, Na, Mn, Fe, Zn, Cu) in the different litter components (leaves, small wood, fruits and flowers) were consistently higher than in the precipitation components. Net precipitation contained bulk of the amounts of K, Mg, Na, Zn and P transferred to the forest floor. Throughfall accounted for the highest proportion of nutrients reaching the forest floor from the canopy except for Ca, N and micronutrients (Mn, Fe, Cu), which were greater in leaf litter. Stemflow, wood and reproductive litter contributed only small amounts to the cycling of the elements. The period of highest nutrient deposition to the forest floor via litter occurred in the dry season, from November till March. The highest nutrient transfers via precipitation took place in the rainy season from March till November.

Key words: Nutrient fluxes - rainfall - secondary rain forest - stemflow chemistry

MUOGHALU, J. I. 2003. **Sumbangan jatuhan telus, aliran batang dan jatuhan sarap terhadap kitaran nutrien di hutan hujan tanah pamah di Ile-Ife, Nigeria.** Input nutrient melalui kerpasan dan pemindahannya ke tanih daripada kanopi dalam jatuhan sarap dan juga melalui jatuhan telus serta aliran batang diselidik di hutan hujan tanah pamah di Ile-Ife, Nigeria. Tujuan kajian ialah untuk menentukan sumbangan relatif jatuhan sarap dan komponen kerpasan bersih terhadap kitaran nutrien di hutan. Keputusan menunjukkan kepekatan semua nutrien (N, P, Ca, Mg, K, Na, Mn, Fe, Zn, Cu) dalam komponen sarap yang berlainan (daun, kayu kecil, buah dan bunga) kekal tinggi dalam komponen kerpasan. Kerpasan bersih mengandungi sebahagian besar K, Mg, Na, Zn dan P yang dipindahkan ke lantai hutan. Jatuhan telus menyebabkan paling banyak kandungan nutrien sampai ke lantai hutan dari kanopi kecuali bagi Ca, N dan mikronutrien (Mn, Fe, Cu) yang menunjukkan jumlah tertinggi dalam sarap daun. Aliran batang serta sarap kayu, buah dan bunga hanya menyumbangkan sedikit kepada kitaran unsur. Tempoh pemendapan nutrien ke lantai hutan melalui sarap paling tinggi pada musim kering, dari November hingga Mac. Pemindahan nutrien melalui kerpasan paling tinggi pada musim hujan iaitu Mac hingga November.

Introduction

Most tropical forest vegetation thrives on poor soil because the forest literally feeds on itself. Most of the nutrients the plants need are supplied by litter which covers the forest floor and is rapidly decomposed and recycled. Atmospheric deposition of nutrients also generally forms an important contribution to the nutrient cycle of forest ecosystems in humid tropical regions where soils are often low in fertility (Vitousek & Sanford 1986). Litterfall, throughfall and stemflow are the main fluxes through which nutrients move from the vegetation to the soil surface (Herbohn & Congdon 1998). Nutrients are primarily transferred as litterfall which is subsequently leached by percolating water and decomposed by organisms (Eaton *et al.* 1973). Throughfall and stemflow involve the transfer of nutrient elements from the forest canopy directly to the available nutrient pool without the intervention of any process of decomposition on the forest floor (Eaton *et al.* 1973). The forest canopy traps a substantial amount of dust particles and aerosols containing organic and inorganic nutrients, particularly in areas with distinct dry season (Crozat 1979, Servant *et al.* 1984, Stoorvogel 1993). These are washed down to the forest floor as precipitation moves through the canopy (Pathak & Singh 1984). Further, precipitation that drips from the foliage or runs down the bole of tree may be substantially enriched in nutrient elements (Pathak & Singh 1984). The total flux of precipitation-borne nutrients to the forest floor is the sum of the materials falling through or dripping from the canopy (throughfall) and travelling down along the trunk (stemflow) (Parker 1983).

Precipitation is an important source of nutrient input to forested ecosystem. Therefore, estimation of the fluxes of elements from incident precipitation, throughfall and stemflow have been a routine part of nutrient budget studies in temperate forests (Likens *et al.* 1977, Schlesinger 1978, Sollins *et al.* 1980). However, corresponding studies in tropical rain forests are comparatively rare and, in addition, these studies have mostly focused on throughfall only (Bernhard-Reversat 1975, Brasell & Sinclair 1983, Brinkmann 1985, Sinun *et al.* 1992, Burghouts *et al.* 1998), particularly for secondary growth forests (Nye 1961, Bruijnzeel 1983).

Nutrient cycling rates in forests are usually inferred from comparison of nutrient concentrations and their amounts in litterfall, forest floor litter and crown drip (Vitousek & Sanford 1986, Proctor 1987). Today the acreage of secondary forest in many tropical countries surpasses that of their undisturbed forest. Thus knowledge of the contributions of litterfall and net precipitation to the nutrient cycling in secondary forests will provide information of value to the understanding and management of such forests.

This paper estimates the quantities of nutrients in litterfall as well as incident and net precipitation in order to evaluate their relative importance as pathways of nutrient transfer to the soil in a secondary lowland rain forest in Ile-Ife, Nigeria.

Materials and methods

Study area

The study was carried out in a 50 × 50 m sample plot established in a 56-year-old secondary lowland rain forest at the base of an inselberg at Ile-Ife (latitude 7° 33' N, longitude 4° 32' E), Nigeria. The elevation of the forest site is about 285 m asl. Vegetation of the Ife area is dry deciduous forest (Onochie 1979) or

Guineo-Congolian drier forest type (White 1983). Isichei *et al.* (1986) reported that the basal area of trees in the forest was 32.2 $m^2 ha^{-1}$ and stem density of woody plants ≥ 2 m in height was 798 plants per 0.25 ha. The authors further found that the 11 most abundant species are *Albizia zygia, Blighia unijugata, Bombax buonopozense, Bosqueia angolensis, Commiphora kerstingii, Elaeis guineensis, Ficus mucuso, Funtumia elastica, Holarrhena floribunda, Manihot glaziovii* and *Pycnanthus angolensis*. The most frequently occurring plant families are Apocynaceae, Moraceae, Euphorbiaceae, Mimosaceae, Rubiaceae and Sapindaceae.

The mean annual rainfall is about 1413 mm $year^{-1}$ in a five-year survey (Duncan 1974), with two peaks, one in July and the other in September. Annual rainfall values for the years of study were 1492 mm in 1990 and 1603 mm in 1995. There are two seasons, dry and rainy. The dry season occurs in November till March and the rainy season in March till November. Temperature ranges between a mean annual minimum of 22.5 °C and a mean maximum of 31.4 °C. In our study, monthly mean maximum temperatures were 31.2 and 32.2 °C and minimum temperatures were 22.7 and 21.3 °C in 1990 and 1995 respectively.

The area is underlain by rocks of the Basement Complex which are of the Precambrian age (Wilson 1922, De Swardt 1953). The Basement Complex consists of heterogenous group of rocks (gneisses, schists, granites and minor rock types such as pegmatites). The forest covers the base and lower slopes of the inselberg (named Hill 1, 410 m asl) and is underlain by granite gneiss (a gneiss of granitic composition, i.e. composed of alkali feldspar, quartz, plagioclase feldspar, biotite and minor amphibole). Intruding from this rock are numerous small veins of pegmatites (very coarse-grained rocks composed essentially of alkali feldspar and quartz). Each vein rarely exceeds 20 cm in width.

Soils in the area have been classified as Lixisols (FAO/UNESCO 1974) and Ultisols (USDA 1975). The soil temperature regime is isohyperthermic and the soil moisture is Ustic (up to 90 cumulative days of dryness). Soils are usually acidic and contain less than 10% clay, which is mainly kaolinite, and hence are characterised by low cation exchange capacity and low water holding capacity (Ayodele 1986).

Sampling procedure

Litterfall

Twenty 1 × 1 m stationary litter traps of 1.0-mm nylon mesh screen suspended 50 cm above ground, were laid out at random in the plot. The litter from these traps was collected every fortnight from 2 January to 31 December 1990. The collected litter was sorted into leaf, wood (2.5 cm diameter) and reproductive structures (flowers and fruits). Trash fraction (litter material < 2 mm) was not determined. All fractions were oven dried at 80 °C to constant weight and weighed. The collections in each month were combined to obtain litterfall data per month. Oven-dried samples were ground for chemical analysis.

Precipitation

Incident rainfall was sampled in an open area 150 m from the forest. Two rainfall collectors and a standard rain gauge equipped with a sharp-trimmed funnel (12.5 cm diameter) were mounted in the open on a support 1.5 m above the ground to collect incident rainfall. The funnel of each collector was fitted with fibreglass screen inserts to trap coarse debris.

Throughfall and stemflow were collected under the crowns and along the stems of nine trees of three species of the forest. Throughfall was sampled by placing two polyethylene collecting bottles, each fitted with a polyethylene funnel (the same diameter as the rain gauge funnel), and a rain gauge under the crown of each tree and supported 1.5 m above ground level.

Samples from the collectors were used for chemical analyses, while the rain gauges gave measurements of rainfall and throughfall volumes.

A collar was fitted at breast height on the stem of tree under the crown from which throughfall was collected. A funnel under the hole in each collar was used to drain stemflow through plastic tubing into a polyethylene bottle.

Incident rainfall, stemflow and throughfall were collected within 24 hours after each rainfall event. The receivers and funnels were washed and rinsed with distilled water after each collection before being replaced, and fibreglass inserts were changed regularly. Sample collection was carried out in 1995 during the rainy season (March to November). After measuring the volumes of different rainfall fractions (incident rainfall, throughfall and stemflow) at the end of each rain event, 100 ml or less of each fraction, depending on the amount of rainfall, was taken from all collectors and stored in 31 plastic bottles at temperature just above freezing in a refrigerator. Replicate samples for each type of rainwater per month were bulked and stored in the same storage bottle for chemical analysis.

Chemical analysis

Ground litter samples were analysed for nitrogen, phosphorus, calcium, magnesium, potassium, sodium, manganese, iron, copper and zinc using the method described by Tel and Rao (1982). Monthly nutrient concentration of each litterfall fraction was multiplied with the corresponding dry weights to compute the amounts of nutrients transferred to the forest floor. The quantity for each month was summed to give the annual amount.

Subsamples of each rainwater fraction were taken from the bulked samples at the end of each month after vigorous agitation and analysed for Ca, Mg, K, Na, Mn, Fe, Cu, Zn, phosphate-phosphorus (PO_4-P), ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N). Concentrations of dissolved cations were determined directly on the water samples using an atomic absorption spectrophotometer (Buck Scientific Model 200 A) except for Na and K where a flame photometer (Model Corning 400) was used. Analyses of NO_3-N, NH_4-N and PO_4-P were performed on a Technicon Autoanalyzer using Standard Technicon procedures. The amount of each element was determined by multiplying the volume in litres for each month by the corresponding element concentration for the month. The quantities for each month were summed to give annual amounts for each type of water.

The one-way analysis of variance using monthly rainfall as replicate did not show any significant difference between the annual rainfall in 1990 and 1995 ($F_{s\,1,17} = 0.52 < F_{0.05,\,1,17} = 4.45$). Therefore, the calculated deposition for 1995 may be assumed to give a reasonable estimate of the 1990 deposition. A one-way analysis of variance was also used to test for significant differences in the concentration of elements and the amount deposited among litterfall and precipitation components.

Results

Concentration of nutrient elements in litter and precipitation components

The concentration of all nutrient elements (N, P, Ca, Mg, K, Mn, Fe, Zn, Cu) and Na were consistently much higher in the different litter components (leaf, wood and reproductive parts) than in precipitation components (incident, stemflow, throughfall) (Table 1). The total concentrations of the nutrient elements, with the exception of Zn, were highest in stemflow followed by those in throughfall and then incident precipitation. Concentrations of Mn and Cu in the water samples were below detection limits (Table 2). Ratios of element concentrations in throughfall to incident rain were Ca = 1.8, Mg = 6.7, K = 110.9, Na = 4.6, Fe = 100, Zn = 0.5, NO_3-N = 1.7, NH_4-N = 0.7 and PO_4-P = 26.8. The ratios of concentration in stemflow to incident precipitation were Ca = 3.1, Mg = 10.0, K = 165.6, Na = 6.2, Fe = 100, Zn = 0.42, NO_3-N = 2.2, NH_4-N = 1.4 and PO_4-P = 43.4, i.e. approximately two folds or more for some but unchanged for Fe and Zn.

Among the different litter components, leaf litter had the highest concentrations of Ca, Mg, Mn, Fe, Zn and N. Wood litter had the highest concentrations of Cu and Na while reproductive litter had the highest concentrations of K and P (Table 1). The elements were grouped according to their order of concentrations in different litter fractions: (1) Ca, Mn, Fe, Zn in leaf litter > wood litter > reproductive litter, (2) Mg and N in leaf litter > reproductive litter > wood litter, (3) K and P in reproductive litter > leaf litter > wood litter, and (4) Na and Cu in wood litter > reproductive litter > or < leaf litter respectively.

Deposition of nutrient elements in forest floor via litterfall and precipitation

Annual litterfall in 1990 was 4.6 t ha^{-1} $year^{-1}$; 4.2 t ha^{-1} $year^{-1}$ (91.3%) as leaf litter, 0.3 t ha^{-1} $year^{-1}$ (6.5%) as small wood (< 2.5 cm diameter) and 0.1 t ha^{-1} $year^{-1}$ (2.2%) as reproductive parts (fruits and flowers). Annual rainfall in the area was 1603 mm. Throughfall was 1263 mm (78.8%) and stemflow was 84 mm (5.2%) of the incident rainfall, implying that 16% was intercepted by the vegetation.

Table 1 Mean monthly nutrient element concentration of precipitation and litter components in a secondary lowland rain forest in Ile-Ife, Nigeria

Component	Nutrient element concentration ($\mu g\ ml^{-1}$) ± SE						
	N	P	Ca	Mg	K	Na	Mn
Precipitation 1995							
Incident	-	-	1.11 ± 0.11	0.22 ± 0.05	0.24 ± 0.06	0.63 ± 0.08	0.00
Throughfall	-	-	2.03 ± 0.16	1.48 ± 0.22	26.62 ± 2.69	2.88 ± 0.68	0.00
Stemflow	-	-	3.42 ± 0.43	2.19 ± 0.40	39.74 ± 5.16	3.89 ± 1.10	0.00
Litterfall 1990							
Leaf	1 4898.26 ± 686.28	836.79 ± 29.43	21 709.17 ± 1008.31	3 375.83 ± 151.51	9 300.00 ± 859.20	1 506.67 ± 238.42	443.83 ± 20.25
Wood	8505.11 ± 880.74	597.38 ± 71.92	14 788.75 ± 1564.44	1 792.92 ± 195.77	5 616.67 ± 727.77	2 048.00 ± 967.03	272.10 ± 81.08
Flower and fruit	1 2636.47 ± 1109.87	1 104.50 ± 217.37	10 071.25 ± 499.51	2 388.75 ± 230.29	13 883.33 ± 2629.68	1 920.00 ± 718.55	159.67 ± 22.72

	Fe	Zn	Cu	NO_3-N	NH_4-N	PO_4-P
Precipitation 1995						
Incident	0.00	0.12 ± 0.07	0.00	2.10 ± 0.68	0.34 ± 0.28	0.04 ± 0.01
Throughfall	0.02 ± 0.01	0.06 ± 0.02	0.00	3.46 ± 0.62	0.22 ± 0.14	1.07 ± 0.12
Stemflow	0.03 ± 0.01	0.05 ± 0.01	0.00	4.53 ± 0.96	0.49 ± 0.31	1.73 ± 0.28
Litterfall 1990						
Leaf	2 958.33 ± 428.84	45.83 ± 3.46	9.50 ± 0.50	-	-	-
Wood	1 591.40 ± 316.75	42.00 ± 3.10	11.20 ± 1.83	-	-	-
Flower and Fruit	928.00 ± 216.38	37.83 ± 7.48	7.50 ±1.40	-	-	-

SE = Standard Error

Table 2 Mean monthly and annual nutrient inputs from precipitation and litterfall components in a secondary lowland rain forest in Ile-Ife, Nigeria

Component		Nutrient element ± SE					
		N	P	Ca	Mg	K	Na
Precipitation							
Incident	kg ha^{-1} month^{-1}	-	-	1.93 ± 0.18	0.39 ± 0.09	0.50 ± 0.12	1.32 ± 0.19
	kg ha^{-1} year^{-1}	-	-	17.37 ± 1.87	3.55 ± 1.15	4.48 ± 1.52	11.87 ± 1.08
Throughfall	kg ha^{-1} month^{-1}	-	-	2.70 ± 0.29	1.82 ± 0.25	36.64 ± 4.51	4.60 ± 1.13
	kg ha^{-1} year^{-1}	-	-	24.31 ± 5.32	17.03 ± 1.52	329.78 ± 76.43	41.37 ± 10.55
Stemflow	kg ha^{-1} month^{-1}	-	-	0.30 ± 0.06	0.17 ± 0.04	3.59 ± 0.73	0.34 ± 0.09
	kg ha^{-1} year^{-1}	-	-	2.68 ± 1.29	1.52 ± 0.75	32.14 ± 8.29	3.03 ± 1.30
Litterfall							
Flower and fruits	kg ha^{-1} month^{-1}	0.07 ± 0.02	0.006 ± 0.002	0.05 ± 0.01	0.01 ± 0.003	0.07 ± 0.04	0.006 ± 0.003
	kg ha^{-1} year^{-1}	0.86 ± 0.13	0.07 ± 0.02	0.58 ± 0.05	0.13 ± 0.02	0.89 ± 0.24	0.04 ± 0.00
Leaf	kg ha^{-1} month^{-1}	5.27 ± 0.74	0.30 ± 0.04	7.63 ± 1.18	1.22 ± 0.20	3.49 ± 0.68	0.48 ± 0.16
	kg ha^{-1} year^{-1}	2.03 ± 1.53	3.35 ± 0.09	91.58 ± 2.60	14.63 ± 0.43	41.93 ± 1.50	2.88 ± 0.41
Wood	kg ha^{-1} month^{-1}	0.23 ± 0.03	0.02 ± 0.01	0.39 ± 0.12	0.05 ± 0.01	0.15 ± 0.04	0.08 ± 0.05
	kg ha^{-1} year^{-1}	2.70 ± 0.32	0.19 ± 0.02	4.73 ± 0.41	0.62 ± 0.04	1.76 ± 0.12	0.45 ± 0.11

Component		Mn	Fe	Zn	Cu	NO_3-N	NH_4-N	PO_4-P
Precipitation								
Incident	kg ha^{-1} month^{-1}	0.00	0.00	0.22 ± 0.11	0.00	3.55 ± 1.35	0.23 ± 0.13	0.07 ± 0.01
	kg ha^{-1} year^{-1}	0.00	0.00	1.30 ± 0.15	0.00	31.96 ± 13.16	2.09 ± 1.48	0.62 ± 0.08
Throughfall	kg ha^{-1} month^{-1}	0.00	0.01 ± 0.005	0.08 ± 0.02	0.00	3.65 ± 0.60	0.33 ± 0.26	1.45 ± 0.23
	kg ha^{-1} year^{-1}	0.00	0.12 ± 0.02	0.73 ± 0.35	0.00	32.99 ± 2.28	2.99 ± 2.23	13.05 ± 2.08
Stemflow	kg ha^{-1} month^{-1}	0.00	0.001 ± 0.0005	0.004 ± 0.002	0.00	0.28 ± 0.15	0.01 ± 0.008	0.11 ± 0.04
	kg ha^{-1} year^{-1}	0.00	0.01 ± 0.00	0.03 ± 0.01	0.00	2.47 ± 0.87	0.20 ± 0.12	0.93 ± 0.45
Litterfall								
Flower and fruits	kg ha^{-1} month^{-1}	0.001 ± 0.001	0.0002 ± 0.0002	0.0002 ± 0.0001	0.0001 ± 0.00004	-	-	-
	kg ha^{-1} year^{-1}	0.005 ± 0.001	0.01 ± 0.01	0.001 ± 0.0002	0.0001 ± 0.0001	-	-	-
Leaf	kg ha^{-1} month^{-1}	0.13 ± 0.02	0.80 ± 0.12	0.004 ± 0.001	0.01 ± 0.004	-	-	-
	kg ha^{-1} year^{-1}	0.79 ± 0.26	4.79 ± 0.48	0.07 ± 0.02	0.02 ± 0.01	-	-	-
Wood	kg ha^{-1} month^{-1}	0.01 ± 0.003	0.002 ± 0.0002	0.00002 ± 0.00001	0.0001 ± 0.00004	-	-	-
	kg ha^{-1} year^{-1}	0.04 ± 0.01	0.29 ± 0.04	0.008 ± 0.002	0.002 ± 0.001	-	-	-

Greater quantities of Mg, K, Na, Zn and P were deposited on the forest floor (monthly and annually) via precipitation than via litterfall, while greater quantities of Ca, Cu, Fe, Mn and N were deposited via litterfall (Table 2). The highest amount of each element, with the exception of Zn in incident rainfall, reached the forest floor via throughfall compared with other water fractions (Table 2). All nutrients from litterfall showed maximum amounts in the leaf litter component (Table 2).

The relative contributions of litterfall and net precipitation to annual deposition of nutrients (Table 3) indicate that throughfall accounted for the highest proportion of K (81.1%), Mg (50.2%), Na (69.4%), Zn(85.9%) and P (73.3%) reaching the forest floor. Leaf litter was the major pathway for the cycling of Ca, N and micronutrients (Mn, Fe, Cu) in this forest (Table 3). Stemflow, wood litter and reproductive parts litter contributed negligible proportions to nutrient cycling (stemflow 0–7.9%, wood litter 0.4–9.1%, flowers and fruits 0.08–0.8%) (Table 3) in the forest.

The greatest amount of each nutrient was deposited via precipitation between March and November (rainy season) and via litterfall from November till March (dry season) (Table 4).

Discussion

In this study, the fluxes of nutrient investigated were (1) nutrient inputs into the forest through incident (bulk) precipitation, and (2) nutrients transferred to the soil from canopy in litterfall and net precipitation (throughfall and stemflow). From the results, greater amounts of Ca, N, Mn, Fe and Cu were cycled via litterfall while K, Mg, Na, Zn and P were cycled mainly via net precipitation (Table 3). This is ecologically significant because most of the nutrient in precipitation are in soluble form (as opposed to bound in litterfall) and hence are readily available to plants. Greater elemental fluxes in throughfall than those in litterfall have been reported, e.g. for K (Nye 1961, Grubb 1977, Edwards 1982, Lamb 1991, McDowell 1998, Burghouts *et al.* 1998) and S, K, Na and Mg (Parker 1983). The different components of precipitation and litterfall contributed different proportions to the nutrient fluxes in the forest (Table 3). The order among the litterfall components was leaf > wood > flowers and fruits, while that for the precipitation components, throughfall > stemflow. The trend among litterfall components was mainly determined by the quantity of each component falling to the forest floor, where leaf litter comprised over 91% of the total litter falling to the forest floor. The trend among the precipitation components was determined by the concentrations of the elements in each component and its volume. For instance, although incident precipitation had the highest volume, its nutrient element concentrations were least, while stemflow had the highest concentration of the elements but its volume was least (Tables 1 and 4).

Nutrient returns via litterfall in this study are lower than generally reported for humid tropics (Anderson *et al.* 1983, Burghouts *et al.* 1998) but similar to values reported for teak plantation in Nigeria (Egunjobi 1974). Also, the nutrient returns in rainfall and throughfall in this study are generally higher than that for forests in the more humid tropics (Burghouts *et al.* 1998) but similar to amounts reported for West Africa (Nye 1961, Matheiu 1976, Roose 1981).

Table 3 Annual input of nutrient elements by net precipitation and litterfall and per cent relative contribution of their components to the input to soil in a secondary lowland rain forest at Ile-Ife, Nigeria

Nutrient element	Input by net precipitation (kg ha^{-1} $year^{-1}$)	Input by litterfall (kg ha^{-1} $year^{-1}$)	Total input (net precipitation + litterfall) (kg ha^{-1} $year^{-1}$)	Percentage contribution of litter and precipitation components: Precipitation component			Litterfall component			
				Throughfall	Stemflow	Total net precipitation	Leaf	Flowers and fruits	Wood	Total litterfall
Ca	27.0	96.89	123.89	19.6	2.2	21.8	73.9	0.5	3.8	78.2
Mg	18.56	15.38	33.94	50.2	4.5	54.7	43.1	0.4	1.8	45.3
K	361.92	44.58	406.5	81.1	7.9	89.0	10.3	0.2	0.4	11.0
Na	44.4	3.37	47.77	69.4	5.1	92.9	6.1	0.08	0.9	7.1
Mn	0.0	0.84	0.84	0.0	0.0	0.0	94.0	0.6	4.8	100
Fe	0.13	5.08	5.21	2.3	0.2	2.5	91.9	0.2	5.6	97.5
Zn	0.77	0.08	0.85	85.9	4.1	90.6	8.2	0.1	0.9	9.4
Cu	0.0	0.02	0.02	0.0	0.0	0.0	90.5	0.4	9.1	100
N	38.65	65.58	104.23	34.5	2.6	37.1	59.5	0.8	2.6	62.9
P	13.99	3.81	17.80	73.3	5.3	78.6	19.9	0.4	1.1	21.4

Table 4 Seasonal variation in litterfall, precipitation and nutrient inputs in a secondary lowland rain forest at Ile-Ife, Nigeria

Season	Quantity or volume	Element (kg ha^{-1}): N	P	Ca	Mg	K	Na	Mn	Fe	Zn	Cu	NO_3-N	NH_4-N	PO_4-P
Dry season (November–March)														
Litterfall	2599.8 kg ha^{-1}	36.35	2.20	58.73	9.53	29.84	1.96	0.45	3.62	0.042	0.014	-	-	-
Incident rainfall	165.6 mm			3.07	1.12	1.13	1.10	0	0	0.14	0	1.8	1.07	0.09
Throughfall	152.8 mm			4.41	4.44	50.76	10.21	0	0.06	0.16	0	4.59	0.09	1.08
Stemflow	8.9 mm			0.47	0.34	4.22	1.02	0	0.007	0.009	0	0.17	0.04	0.30
Rainy season (March–November)														
Litterfall	1963.2 kg ha^{-1}	29.24	1.61	38.17	5.85	14.74	1.41	0.38	1.47	0.041	0.009	-	-	-
Incident rainfall	1437.7 mm			14.30	2.43	3.35	10.78	0	0	1.80	0	30.17	1.02	0.53
Throughfall	1110.6 mm			19.9	12.59	279.02	31.15	0	0.06	0.57	0	28.40	2.90	11.97
Stemflow	74.6 mm			2.2	1.19	27.93	2.01	0	0.003	0.03	0	2.30	0.15	0.64

Nutrient accessions in litterfall and precipitation were distinctly seasonal in the forest with the highest deposition of nutrients in the forest via litterfall in the dry season (November to March) and the highest amount deposition via precipitation (March to November) in the rainy season (Table 4). The period of greatest litterfall occurred when there was little or no decomposition (Swift *et al.* 1981, Muoghalu *et al.* 1993, 1994) and, subsequently, only little release of nutrients. Litterfall was also greatest when there was little plant growth and reduced metabolic activity. However, the period of highest nutrient deposition via precipitation corresponded to the period of very active plant growth and metabolic activity in the forest and of rapid decomposition of litter in the forest.

The results of this study showed that net precipitation is the largest for the cycling of K, Mg, Na, Zn and P while Ca, N and micronutirents, Cu, Fe and Mn, are recycled mainly via litterfall in the forest. The periods of the highest nutrient deposition via litterfall and precipitation occurred at different times of the year and depended on the rates of litterfall and the volumes of precipitation components and concentrations of the elements in them.

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