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Comparing Throughfall and Litterfall Nutrient Fluxes in a Rubber (*Hevea brasiliensis* Willd. Muell-Arg) Plantation Agro-ecosystem at Ikenne, South-west Nigeria

Oludare H Adedeji[1*] and Adeniyi S Gbadegesin[2]

[1] Department of Environmental Management and Toxicology, University of Agriculture
PMB 2040, Abeokuta, Nigeria
[2] Department of Geography, University of Ibadan, Ibadan, Nigeria
Corresponding author: E-mail: hakeemdare1222@yahoo.co.uk

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Abstract

This study compares nutrient fluxes (throughfall and litterfall) in a rubber (*Hevea brasiliensis* Willd. Muell-Arg) plantation agro-ecosystem at Ikenne, SW Nigeria. Throughfall samples were collected bi-weekly under the rubber canopies (40-, 15-, and 5-year-old) using throughfall funnel collectors with 10 replicates. Litterfall was collected on a monthly basis in the three rubber stands using twenty-four 0.25 m^2 litter traps (eight replicates in each of the three rubber stands) positioned randomly to estimate total annual litter production (dry biomass) and its main fractions. Throughfall and litterfall samples were analyzed for total nitrogen, sodium, phosphorus, calcium, potassium and magnesium. The annual means of throughfall in the different stands were compared by solution type using one-way analysis of variance (ANOVA), followed by a post-hoc separation of means by the Scheffe-test ($p < 0.05$). The litterfall data were analyzed using one-way analysis of variance based on the representative of 12 months. The results revealed a clear pattern of increased levels of base cations and fluxes of throughfall compared to those occurring in precipitation. Fluxes of Ca^{2+} in throughfall are typically 1.5-2 times greater than those occurring in rainfall. Among the rubber stands, fluxes of K^+ are also greater in throughfall, consistent with previous studies. The enrichment of elements in throughfall has been ascribed to the dissolution and washout of atmospheric materials deposited on the canopy. Comparison of total annual litterfall nutrient budgets show that the 15-year-old rubber stand was cycling more Mg^{2+}, N, Na^+, K^+ , P, and Ca^{2+} in litterfall than the 40- and 5-year-old rubber stands.

Keywords: Agro-ecosystem; canopy interception; *Hevea brasiliensis*; litterfall; nutrient cycling; throughfall; Ikenne

Introduction

Nutrient uptake and cycling are important components for understanding the long-term dynamics of structure and function of forest ecosystems. Input and output of nutrients are considered key indicators of variation of soil fertility and of sustainability of forest management [1]. Generally, nutrients in the vegetation pool are transferred to the soil pool relatively rapidly either by throughfall, stemflow and litterfall of leaves, and fine roots, or slowly (over several decades) by the death of tree stems and coarse roots [2] Quantification of nutrient fluxes throughfall and other sources such as stemflow and bulk precipitation is important for evaluating biogeochemical cycles of ecosystems [3]. Throughfall analysis and canopy exchanges in the forest ecosystem have received considerable attention, especially in Europe and USA [4, 5]. These studies have increased our understanding of the factors affecting throughfall chemistry and flux, including nutrient inputs via wet deposition [6, 7] and wash-off of dry substances deposited atmospherically on the leaf surface [8]. Litterfall and subsequent decomposition of litter represents an important set of energy flows and nutrient transfer. Studies of litterfall and nutrient return via litterfall are vital to the understanding of nutrient cycling processes in plantation agro-ecosystems [9]. Estimation of the fluxes of elements in throughfall and litterfall are used as a routine part of nutrient budget studies in agro-ecosystems [10-12]. However, few studies of nutrient dynamics in agroforestry and plantation systems in south-western Nigeria exist, making it difficult to assess the extent to which these land uses are sustainable, considering the region’s highly weathered soils. This study therefore aims to examine and compare nutrient fluxes (through-fall and litterfall) in a rubber (*Hevea brasi-liensis* Willd. Muell-Arg. Family Euphor-biaecae) plantation agro-ecosystem at Ikenne, SW Nigeria. It is expected that this study will contribute to a better understanding of mineral cycling in rubber plantation agro-ecosystems and improve prediction and forecast of changes.

Materials and methods

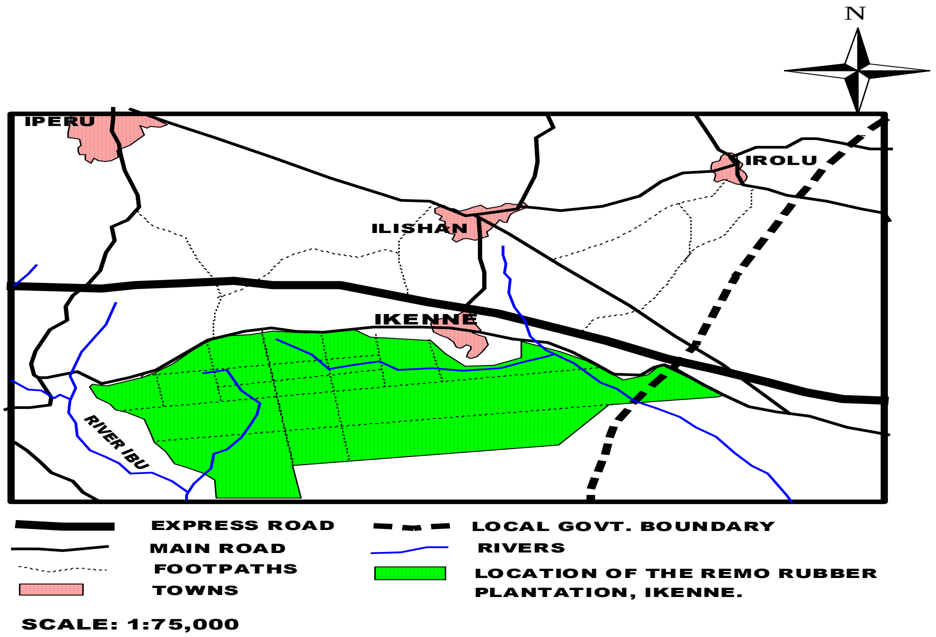
1) Study site

The study was carried out at Remo Rubber Plantation, Ikenne, south-west Nigeria, located at Latitude 6^o 50' to 6^o 54' N and Longitude 3^o 40' to 3^o 45' E (Figure. 1). The plantation was established on 1,111 hectares of land, of which rubber covers about 500 ha; however, 98% of the stands are old and have outlived their economic lives. The terrain is undulating lowland, with an elevation of about 110 m above sea level. Mean annual precipitation in the area was between 1,500 mm and 1,750 mm with a maximum in July and a mean annual temperature of 27^{o}C. The soils of the area are Ultisols, considered marginal for agricultural production since they are highly weathered, low in cation exchange capacity (CEC), base saturation and pH (West *et al.*, 1998). Vegetation prior to plantation establishment consisted of tree species such as *Isotonia boonei, Cola gigantean, Antiaris africana, Pentaclethra macrophylla,* and *Elaeis guineensis* [13].

About 450 trees of the RRIM 501 clone were planted per hectare in different blocks within the plantation in 1961, 1991, and 2000. Weeding is done manually or mechanically, depending on availability of finance; fertilizers are not used in the plantation for cost reason.

2) Sampling

Samples for determination of fluxes of throughfall and litterfall were taken in three experimental plots, each representing the three stand ages (40-, 15-, and 5-year-old) in the Remo Rubber Plantation. Each experimental plot (50×20 m) comprises a central zone, surrounded by a buffer zone approximately 1 metre wide. Throughfall samples were collected bi-weekly using funnel type collectors based on the design of Lawrence and Fernandez [14] because of its simplicity and ease of installation and manipulation. A total number of 30 throughfall collectors (10 in each rubber stand age) were randomly distributed in plots of approximately 0.1ha in each stand age. This was to achieve a precision of 2% and a confidence of 95% [15]. Throughfall collectors were located within the plots taking care to avoid edge effects. Bulk open field deposi-tions (rainfall) were sampled using the same continuously exposed collectors used for the throughfall. Samples collected were then pooled according to stands, and sample aliquots for each stand were taken for laboratory analysis. In order to check on possible contamination on the site, field blank tests were carried out at least once every three months. For this purpose, samples of 50-100 ml deionized water was poured into the sample collectors at the time of collection on days without precipitation, and subjected to the same procedure as an ordinary precipitation sample [16]. Litterfall was collected on a monthly basis in all the three rubber stands (i.e. 40 years, 15 years and 5 years) using twenty-four 0.25 m^2 litter-traps (eight replicates in each of the three rubber stands). The litter-traps were positioned randomly [17] to give a 0.15% sample within each plot (approximately 0.1ha) to estimate total annual litter production (dry biomass) and its main fractions. The litter-traps were constructed of HDPE, and measured 15cm deep with a fine 2mm mesh nylon screen at the base; they were fixed to wooden posts approximately 1.5m above ground level to avoid animal disturbance. The 12 monthly collections used for this study were collected from July 2005 to June 2006.



SOURCE: MINISTRY OF LANDS AND HOUSING SURVEY DIVISION, ABEOKUTA, OGUN STATE.

Figure 1 Map of Remo Rubber Plantation, Ikenne, Southwestern Nigeria

3) Laboratory analyses

Throughfall samples were taken to the laboratory in pre-labelled 120cm^3 capacity snap lid collection bottles and immediately frozen at 4 ^{0}C. The analyses were performed on filtered samples (0.4cm) except for measurement of pH and conductivity, for which unfiltered samples were used. Water pH was measured electrochemically, while conductivity (Konduktometer CG 855, Schott) was measured within one week of sampling. Cation concentrations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) were determined by flame atomic absorption spectrometry (AAS Atomic Absorption Spectrum-932, GBC Scientific Equipment Pty. Ltd, Australia). Inductively Coupled Plasma Atomic Emission Spectrum (ICP-AES, IRIS ER, Thermo Jarrel Ash Corporation, USA) was used to determined sulphate (SO4-S) sulphur. Phosphorus was determined using molybdenum blue colorimetric procedure (Institute of Soil Academia, Sinica, 1978). Total N was obtained by Kjeldahl digestion followed by analyses of NH_4^+ -ions (micro-Kjeldahl distillation and titration with 0.001 NHCI). NO_3^- - N was determined after reduction to NO_2^-- N by colorimetric method (Sulphanilamide/N-I-napthyethylene-diamine dihydrochloride. For litterfall, litter-traps in each plot were emptied and the contents of each trap were weighed (ambient air-drying status) all together before being sorted, to assess variability among collectors within plots. All litter was oven-dried at 80 ^oC and then weighted to the nearest 0.01g. The oven-dried litters were then sorted into leaves, twigs (< 2.5 cm in diameter) and reproductive litter (seeds). Miscellaneous fraction (unrecognizable plant debris < 2 mm and frass) and insects present in the monthly litter samples were also sorted separately, oven-dried, and weighed but not analyzed for nutrient content. All oven-dried litters were stored at room temperature in sealed polyethylene bags and each sample was then oven-dried again and milled to powder for chemical analyses. Nutrient analyses included determinations of sodium and the following major elements: nitrogen, phosphorous, calcium, potassium, and magnesium.

4) Statistical analyses

Volume weighted means were calculated for throughfall by dividing the product of element concentration and water flux amount by the total water flux of the year for fortnight periods and subsequently summing the terms. The annual means of the different stands were compared by solution types using one-way analysis of variance (ANOVA), followed by a post-hoc separation of the means by the Scheffe-test ($p < 0.05$). Litterfall data were analyzed using one-way analysis of variance. Samples were based on the representative of 12 months for litterfall, and to compare litterfall amount and nutrient contents concentrations. All statistical analyses were performed using SPSS for Window (Version 17.0).

Results and discussion

1) Dynamic of throughfall (TF)

Throughfall amount varied among the different stands in the study area (Table 1). For instance, in the 40-year-old rubber plantation, nearly all net precipitation (TF+SF) came as throughfall. Throughfall (TF) constituted 64.3% of gross precipitation (990.1mm) in the 15 and 5-year-old rubber stands respectively (Table 1). Average pH for TF was 6.1, 6.27, and 6.28 for the 40, 15, and 5-year-old rubber strands respectively (Table 2).

2) Nutrient inputs

2.1) Nutrient concentration in throughfall

Acidity (pH) of throughfall solutions decreased as total rainfall increased, with obviously lower pH values in throughfall solutions showing more H+ leaching. Within the sampling periods, the average electrical conductivity was 19.5 μScm^{-1} and throughfall was observed to be significantly ($p < 0.05$) different. Seasonal variation of pH in throughfall revealed maximum pH values in the rainy season and minimum values in the dry season.

Table 1 Precipitation (P) partitioning into throughfall, stemflow, and interception loss in the 40, 15, and 5-year-old rubber stands at the Remo Rubber Plantation, Ikenne (July 2005-June 2006)

	40-year-old		15-year-old		5-year-old	
	mm y^{-1}	% of P	mm y^{-1}	% of P	mm y^{-1}	% of P
Throughfall	990.1	64.3	1036.6	67.3	1075.0	70
Stemflow	258.9	16.8	303.4	19.7	210.2	14
Interception	291.3	18.9	200.3	13	255.1	16
Precipitation	1540.3	100.0	1540.3	100.0	1540.3	100.0

2.2) Annual nutrient input

Total annual nutrient inputs reaching the plantation floors in each stand indicated that canopy leaching increased each nutrient amount. Nevertheless, the amounts differed among nutrients. 91 % of the total annual K^+ and 67 % of the total annual Mg^{2+} throughfall input was attributed to the canopy. In contrast, 87 % of total N, 86 % of P, 52 % of Ca^{2+} and most of the Na^+, SO_4^{2-}-S, NH_4^+-N and NO_3^--N annual throughfall inputs came from precipitation. The relative inputs of anions in throughfall at all the study stands were $C1^- > SO_4^{2} > NO_3^-$ indicating that Cl^- is the most abundant anion. Furthermore, the input of dissolved substances such as Na^{2+} and $C1^-$ from sea-salt aerosol varied regularly with precipitation amount and season.

Nutrient fluxes were greater in the wet season than in the dry season for all stands, with the 15-year-old rubber stand showing the highest fluxes. For example, total annual nutrient returns via throughfall for the 15-year-old stand were 28.39, 4.49, 38.9, and 3.54 kg ha year $^{-1}$ for Ca^{2+}, Mg^{2+}, K^+ and Na^+ respectively, while that of the 40-year-old stand were 22.7, 3.64, 36.3, and 3.17 kg ha year $^{-1}$ for Ca^{2+}, Mg^{2+}, K^+ and Na^+ respectively (Table 2 and 3).

Table 2 Volume-weighted mean concentrations (± SD) in throughfall (40, 15, 5-year-old stands) and bulk precipitation (BP) in rubber (*Hevea brasiliensis*) plantation agro-ecosystem at Remo Rubber Plantation, Ikenne, SW Nigeria in dry season (n= 6) and wet season (n=11). Nutrient concentrations in throughfall compared in analysis of variance

	Stand age									BP		
	40-	15-	5-	40-	15-	5-	40-	15-	5-			
	Dry			Wet			Annual			Dry	Wet	Tot.
pH	6.22	6.28	6.28	6.5	6.47	6.85	6.37	6.38	6.57	6.24	6.39	6.32
Ca^{2+}	15.42^{a}	16.58^{a}	15.52^{a}	18.09^{b}	17.95^{b}	16.24^{a}	16.75^{b}	17.27^{b}	15.88^{a}	14.95^{a}	17.29^{b}	15.85^{a}
Mg^{2+}	0.11^{a}	0.12^{a}	0.11^{a}	0.12^{a}	0.15^{a}	0.12^{a}	0.11^{a}	0.13^{a}	0.11^{a}	0.13^{a}	0.12^{a}	0.12^{a}
K^+	1.67^{a}	1.69^{a}	1.74^{a}	1.94^{c}	2.12^{b}	1.79^{a}	1.81^{b}	1.91^{b}	1.76^{a}	1.58^{a}	1.93^{b}	1.76^{b}
Na^+	2.95^{b}	2.90^{a}	2.70^{a}	3.09^{b}	3.02^{a}	2.98^{a}	3.02^{b}	2.96^{a}	2.84^{a}	2.82^{a}	2.91^{a}	2.87^{a}
H^+	0.11^{a}	0.11^{a}	0.10^{a}	0.12^{a}	0.12^{a}	0.12^{a}	0.11^{a}	0.05^{b}	0.05^{b}	0.11^{a}	0.13^{a}	0.12^{a}
SO_4^{2+}	0.04^{a}	0.04^{a}	0.05^{a}	0.05^{a}	0.06^{a}	0.06^{a}	0.05^{a}	0.05^{a}	0.05^{a}	0.05^{a}	0.05^{a}	0.05^{a}
NO_3^-	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$
NH_4^{3-}	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	$<0.001^{a}$	<0.001a
Cl^-	7.94^{b}	7.43^{a}	7.47^{a}	9.53^{c}	8.19^{b}	7.73^{a}	8.20^{b}	7.81^{a}	7.60^{a}	7.23^{a}	7.78^{b}	7.50^{a}

Note: Different letter between solution composition in the columns indicate significant differences at the 95% level of confidence

Table 3 Seasonal and annual input of nutrients via bulk precipitation and throughfall (all stands) in rubber (*Hevea brasiliensis*) plantation agro-ecosystem at Remo Rubber Plantation, Ikenne, SW Nigeria in dry season (n= 6) and wet season (n=11)

Items	Season	Ca^{2+}	Mg^{2+}	K^+	Na^+	SO_4	NO_3	NH_4	Cl^-
					kg ha year $^{-1}$				
Bulk Precipitation	Dry	0.83	0.16	0.28		0.15	0.01	<0.001	<0.001 0.29
	Wet	9.95	1.52	1.85		3.32	0.05	<0.001	<0.001 5.64
	Total	10.78	1.68	2.13	3.47	0.06	<0.001	<0.001	5.93
40-year-old	Dry	0.92	0.15	3.78		0.15	0.02	<0.001	< 0.001 0.32
	Wet	21.73	3.49	32.5	3.02	0.09	<0.001	<0.001	15.82
	Total	22.65	3.64	36.3	3.17	0.11	<0.001	<0.001	16.14
15-year-old	Dry	1.56	0.29	3.31	0.27	0.01	<0.001	<0.001	0.66
	Wet	26.83	4.2	35.6	3.28	0.06	<0.001	<0.001	18.5
	Total	28.39	4.49	38.9	3.54	0.07	<0.001	<0.001	19.2
5-year-old	Dry	0.46	0.09	2.31		0.11	0.01	<0.001	<0.001 0.16
	Wet	14.49	1.96	25.7		2.45	0.03	<0.001	<0.001 9.18
	Total	14.95	2.05	28.01		2.56	0.04	<0.001	<0.001 10.24

3. Litter production

3.1) Small litterfall

There is a strong relationship between rainfall and literfall in the plantation, with average litterfall usually higher towards the end of the dry season and at the beginning of the wet seasons. Monthly litterfall however varied with rainfall pattern, and the average monthly litterfall was highest in the 15-year-old plantation plot and decrease in the order of 15-year-old > 40-year-old > 5-year-old rubber stands. Annual litterfall was calculated for a full year comprising of two different seasons, and was always lowest in the 5-year-old rubber plantation stand. For instance, leaf litter constituted 42.3 % of litterfall in the 15-year-old stand, but not more than 39.01 % in the 5-year-old stand. Furthermore, average litterfall and standard deviation in the 15-year-old rubber plantations was 4436 kg ha^{-1} y^{-1} (approximately 4.5± 0.16 t ha^{-1} yr^{-1}).

This is significantly higher ($p < 0.01$) than that of the 40-year-old and the 5-year-old rubber stands, which are 3.8±0.29 t ha^{-1} yr^{-1} and 2.9± 0.66 t ha^{-1} yr^{-1}, respectively. This also showed that there was a significant ($p< 0.01$) variation in litterfall among the microsites (rubber stands within the plantation).

Two peaks of litterfall were observed, the main one in the late dry season (March -April), and a lesser one during heavy rains (July-September). Seasonal patterns of total and leaf litterfall were similar, with high litterfall in the dry season and early rains. The fall of reproductive parts (seeds) peaked in September; with highest values in the 40-year-old stand (119 kg ha^{-1}).

Leaf litter production was highest in April and May, 2006 (254 and 216 kg ha^{-1} respectively) for the 15-year-old rubber stand (Table 4). The twig fraction in 15-year-old rubber stand reached a peak in February 2006 (116 kg ha^{-1}) with total annual production of 1,206 kg ha^{-1}. In the 40-year-old rubber stand, there was a clear peak of leaf litterfall in April (160 kg ha^{-1}), corresponding to 10 % of total annual production.

Generally, the patterns of annual litterfall inputs were similar in all three stand ages in this study, although the proportion of specific litter components varied significantly. These monthly variations were confirmed by F-test ($P < 0.01$)

in the three stands. The highest values of leaf litter production were observed at the beginning of the rainy period (Table 4). This peak was determined by leaf production. Reproductive parts (seeds) had highest values in December 2005 (93 kg ha^{-1}) for the 15-year-old rubber stand and in April 2006 (86 kg ha^{-1}); in the 5-year-old rubber stand, the twig fraction had the highest values (Table 6).

Table 4 Mean monthly leaf litterfall oven dry weight (kg/ha-1) in 40, 15, and 5 year old stand in Remo rubber plantation

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
	←			2005		→	←			2006		→	
Stand age													**Total**
40 Yrs	103	110	120	125	127	141	144	148	155	160	156	131	1620
15 Yrs	145	153	155	160	164	169	183	190	211	254	216	198	2198
5 Yrs	74	71	74	87	94	107	98	105	113	129	115	90	1157

Table 5 Mean monthly seeds oven dry weight (kg/ha-1) in 40, 15, and 5 year old stand in Remo rubber plantation

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
	←			2005		→	←			2006		→	
Stand age													Total
40 Yrs	104	106	119	98	91	87	89	84	90	96	98	102	1164
15 Yrs	90	88	91	89	84	93	85	80	78	86	85	83	1032
5 Yrs	70	78	83	80	72	73	75	76	79	86	78	70	920

Table 6 Mean monthly twig litter oven dry weight (kg/ha^{-1}) in 40, 15, and 5 year old stand in Remo rubber plantation

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
	←			2005		→	←			2006		→	
Stand age													Total
40 Yrs	74	89	87	89	92	102	100	98	84	80	76	74	1045
15 Yrs	85	90	96	99	98	102	108	116	110	108	106	88	1206
5 Yrs	65	68	72	74	76	87	84	83	70	68	72	70	889

3.2) Variability of litter fall

The relative variation of litterfall in the rubber plantation was observed through the seasons. Leaves always represent the largest fraction in the entire plantation stands sampled, accounting for between 39.1-49.5 % of total litterfall. In the rubber plantation, reproductive parts (seeds) were the second largest component (27.18 %) in 15-year-old rubber plantations, compared with 27.29 % and 29.97 % in the 40-year-old and the 5-year-old rubber stands, respectively. The twig or small branch component was slightly higher in the 40-year-old and the 5-year-old rubber stands, where they constituted 30.40% and 31.02% of the total, respectively. In all stands, the largest litterfall was observed in April 2006, at the end of the dry period and onset of the wet season proper. Litterfall was lowest from June 2005 to September 2005, and increased again from October 2005 during the dry season to the beginning of the wet season for 2006 when it started to decrease again. There were few variations in monthly concentrations of macronutrients in leaf litterfall in all three stands. However, the 15-year-old stand released more nutrient elements than the two other stands. This may be attributed to the quality of litter, which was high, and reabsorption of nutrients into leaf tissues before senescence. Although there were no clear significant differences among mean seasonal nutrient concentrations of elements in leaf and twig litter parts, concentration of all elements in leaf and twig litter were greater in wet months than in dry months.

The mean concentration of $Ca^{2+,}$ and N^- showed the highest concentrations of 74.3 $kgha^{-1}$ and 63 kg ha^{-1} respectively for the 15-year-old stand. NH_4^+ and NO_3^- were the lowest in both the wet and dry seasons. The values were similar in all litterfall components, but it was highest in leaf litter than in twigs and reproductive parts (seeds). Leaf litter was evidently more important, representing between 39.1 and 49.5% of total litter in all three stands. Mean concentration of nitrogen in litter components was similar in twigs and seeds, but leaf litter had a higher concentration. Nutrient inputs via litterfall were in the order: $Ca^{2+} > N > K^+ > Mg^{2+} > Na^+ > P$ for the 15- and 5-year-old stands. Reproductive litter contributed < 20 % of the N and P input, but > 18 % of all other elements. The concentration of elements varied for all components during the year, with leaf litter displaying clear annual patterns. Mean annual concentrations of macronutrients were lower in 5- and 40-year-old rubber stands than in the 15-year-old stand.

3.3) Element return through litter

Concentrations of Ca^{2+}, Na^+, Mg^{2+}, and K^+ were sharply higher in leaf litter component. Accumulation of nutrient elements in the 40-year-old litter ranged from 2.5 kg ha^{-1} for P and 37.9 kg ha^{-1} for Ca^{2+}. Element content in the standing crop of litter on the floor decreased in the order $Ca^{2+} > N > K^+ > Mg^{2+} > Na^+ > P$. Table 7 showed the litterfall rates (dry weight) and nutrient return rates for six different elements in all litter components. Ca^{2+} and $C1^-$ showed significantly higher nutrient return rates than the other elements. K^+ and Mg^{2+} also showed higher returns, indicating relative enrichment. The estimated amount of mineral elements returned from litter to the soil in the 15-year-old rubber stand were 12.8 kg ha^{-1} in Mg^{2+}, 63 kg ha^{-1} in N, 4.68 kg ha^{-1} in Na^+, 22.4 kg ha^{-1} K^+, 4.27 kg ha^{-1} in P, and 74.3 kg ha^{-1} for Ca^{2+}. For the 40-year-old rubber stand, the estimated amounts of mineral elements returned from litter to the soil were 9.96 kg ha^{-1} in Mg^{2+}, 55 kg ha^{-1} in N, 3.75 kg ha^{-1} in Na^+. In addition, for the 40-year-old rubber stand, the amount of nutrient returned for K^+, P and Ca^{2+} were 15.2 kg ha^{-1}, 3.58 kg ha^{-1} and 52.9 kg ha^{-1}, respectively [18]. Returns in the 5-year-old rubber stands were lower, but followed a similar pattern. These results indicate that the 15-year old rubber trees return more nutrients via litterfall than the other stands, and that the amount of nutrient return corresponds positively with the amount of dry weight of litterfall. This result also showed that the rubber trees return more nutrients around the age of 15 years, from which point there may be a tendency for nutrient returns to diminish with age, especially when there is no application of organic or inorganic fertilizers (as is the case in the current study area). Comparison of total annual litterfall nutrient budgets in Tables 7 shows that the 15-year-old rubber stands cycled more Mg^{2+}, N, Na^+, K^+, P, and Ca^{2+} in litterfall than the 40- and 5-year-old rubber stands.

Table 7 Total litterfall rates (kg ha^{-1} yr^{-1}) for dry weight and nutrients returned through litterfall in Remo Rubber Plantation, Ikenne, southwestern Nigeria (40, 15, 5-year-old stands)

Component	Dry weight	Total N	P	K	Ca	Mg	Na
40-year-old							
Leaves	1620	33.8	2.5	10.3	37.9	8.0	3.3
Twig	1045	8.6	0.34	2.1	11.8	1.3	0.22
Seeds	1164	12.6	0.74	2.8	3.2	0.66	0.23
Total	3829	55	3.58	15.2	52.9	9.96	3.75
15-year-old							
Leaves	2198	38.6	3.7	16.8	57.2	10.2	4.0
Twig	1206	10.6	0.56	2.5	13.4	1.8	0.43
Seeds	1032	13.8	0.89	3.1	3.7	0.78	0.25
Total	4436	63	4.27	22.4	74.3	12.8	4.68
5-year-old							
Leaves	1157	28.7	1.92	8.8	34.5	7.4	2.87
Twig	889	7.3	0.27	2.3	9.8	0.92	0.18
Seeds	920	10.2	0.66	2.03	2.7	0.43	0.20
Total	2966	46.2	2.85	13.13	47	8.75	3.25

3.4) Throughfall vs. litterfall

Studies of temperate forests have shown that throughfall tends to be enriched in base cations and exhibit organic carbon, and depleted in NH_4^+-N and NO_3^--N relative to precipitation [18, 23]. Confirming these observations, the results of the current study reveal a clear pattern of increased base cations and fluxes of throughfall compared to precipitation (Table 2 and 3). This is particularly true for Ca^{2+} unlike K^+, which was found to be highly enriched in the natural *Lithocarpus/Castanopsis* forest at Xujiaba, Ailao SW China [24]. Fluxes of Ca^{2+} in throughfall are typically 1.5 - 2 times higher than those in rainfall. Among the rubber stands, fluxes of K^+ are also greater in throughfall, consistent with the findings of other studies [25-28]. The enrichment of elements in throughfall has been ascribed to the dissolution and washout of atmospheric material deposited on the canopy [18, 29-30] or due to exchange between rainfall and elements in internal plant parts as reported in other studies [27-28, 32]. The external origin (dry deposition) and internal cycling (leaching process) can take place for most of the elements at different intensities. Throughfall is enriched in sodium probably because of the marine influence (tropical air mass from the Atlantic Ocean). However, wet deposition appears to be the dominant pathway for deposition of aerosol from marine sources in the study area. The amount of sodium in precipitation is nevertheless considerably low compared to other studies [27], an indication that the origin of nutrients in precipitation in the study area may be from sources other than marine aerosols, such as atmosphere, smoke, and dust [18].

Conclusion

The study revealed that nutrient return via throughfall is low compared with litterfall Annual release of nutrients such as calcium from litterfall by the 15-year-old stand was 1.3 times higher than that of the 40-year-old stand while, total nitrogen returned via litterfall was 1.2 times and 1.4 times higher in the 15-year-old stand than the 40-year-old and the 5-year-old stands respectively. Concentrations of foliar nutrients (e.g. N and P) in the rubber plantation are consistently higher in the 15-year-old stand. Generally, there appears to be a lower leaching of elements such as K^+ (considered to be the most easily leached element), compared to other tropical rainforest sites. The relative low foliar K^+ concentration might be due to the fact that the amount of leachable K^+ declines with increasing rainfall intensity. In view of the low soil nutrient status in the rubber plantation under study, coupled with the non-use of artificial fertilizers, the rubber stands do not obtain sufficient levels of nutrients to support healthy growth and sustainable productivity. Therefore, there is a need to augment the nutrient supply to the sites by addition of both organic and inorganic fertilizers, especially for older stands.

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