Dynamics and Fluxes of Nutrient in Throughfall in Rubber Plantation (*Hevea brasiliensis willd.* Muell-arg) at Ikenne, SW, Nigeria

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ABSTRACT

The study examined the dynamics of throughfall and nutrient fluxes in rubber plantation (*Hevea brasiliensis* willd. Muell-arg) at Ikenne, SW Nigeria. Throughfall were collected using funnel-type collectors placed under the rubber trees. Data collected were analysed using one-way analysis of variance (ANOVA) and the student t- test to test for significant differences between the different nutrient fluxes of three rubber age stands (5, 15,40). Net throughfall fluxes were positive for nutrients such as K^+, Na^+, Mg^{2+} and Cl^- while the fluxes negative for NO_3^-, NH_4^+ and SO_4^{2-}. Throughfall constituted over 60% of the inputs of Ca^{2+}, Na^+ and Cl^- while most of the K^+ and two thirds of the Mg^{2+} input were attributable to canopy leaching. Average annual nutrient inputs (kg-ha-') via throughfall for the 15 year old stand were 28.39, 4.49, 38.9 and 3.54 kg ha^{-1} $year^{-1}$ for Ca^{2+}, Mg^{2+}, K^+ and Na^+, respectively, compared to those of the 40 year old stand which were 22.7, 3.64, 36.3 and 3.17 kg ha^{-1} $year^{-1}$ for the same elements respectively. The study revealed that nutrient fluxes in throughfall have a distinct seasonal pattern, with the highest nutrient fluxes during the raining season due to high input fluxes from rainfall. The 15 year old stand appears to be more efficient in nutrient return to the soil than the 5 year old and the 40 year old stands. The implication of these findings is that there is a need to augment soil nutrients through fertilizers application appears to be more crucial in these stands.

Key words: Agroecosystem, atmospheric deposition, nutrient fluxes, throughfall chemistry, *Hevea brasiliensis*

INTRODUCTION

That nutrient cycling processes plays important role in site fertility of natural forests as well as plantation agroecosystems had being discussed by different researchers (Du Toit and Scholes, 2002; Laclau *et al.*, 2005; Laclau *et al.*, 2010; Smethurst, 2010; Dovey *et al.*, 2011). It is very important to understand the functioning of the individual ecosystems especially in the context of their interactions (Janik and Pichler, 2008). Nutrient inputs and outputs in tropical ecosystems and agroecosystems are directly related to the magnitude of the fluxes of water moving into and out of ecosystems, resulting in an additional transfer of nutrients with different components (Parker, 1983; Crockford and Richardson, 2000; Herrmann *et al.*, 2006). In the forest and many

agroecosystems, trees partition rainfall into throughfall and stemflow, resulting in a spatial distribution of nutrient and water fluxes reaching the soil centred on the trunks of trees (Bruijnzeel, 2001; Johnson and Lehmann, 2006). Water and nutrient inputs via rainfall and throughfall influences all soil chemical and biological processes, including pedogenic transformations, turnover of nutrient pools, accumulation and mobilization of possibly toxic substances and buffering reactions (Thimonier, 1998; Erisman *et al.*, 2002; Proctor, 2005). Biogeochemical cycling studies are important to the understanding of forest decline (Chappell *et al.*, 2001; Herrmann *et al.*, 2006), as well as the development of methods of sustainably managing ecosystems in the human landscape (Boyle and Farrell, 2004). A thorough balance of the nutrient fluxes (e.g., atmospheric deposition) in agroecosystems is crucial to the understanding of the net nutrient transport and to infer the biogeochemical processes. Atmospheric deposition is the addition of nutrients as wet deposition (precipitation, dry deposition foliar gaseous uptake (EPA, 2001); industrial pollution, biomass burning, lightning and coastal windblown sea-spray or mist (De Vries *et al.*, 2003; Zimmermann *et al.*, 2003).

Estimation of the fluxes of elements in precipitation and throughfall can be used as a routine part of nutrient budget studies in forests (Liu *et al.*, 2002; Carlyle-Moses, 2004; Tobon *et al.*, 2004a, b; Levia and Frost, 2006). Herrmann *et al.* (2006) emphasised that local knowledge of throughfall chemistry variations is an important prerequisite to understand the processes that occur within the forest stand. Throughfall can provide a valuable quantification of the total inputs to the forest floor of critical chemicals involved in acidification or eutrophication processes, such as nitrogen and sulphur compounds (Thimonier, 1998; Erisman *et al.*, 2002). Data relating to the fluxes of water-dissolved nutrients through ecosystems and biogeochemical cycles of nutrients are however, scare in many sub-Saharan African countries except few (Laclau *et al.*, 2003; Adeniyi, 2006; Holwerda *et al.*, 2006; Heartsill-Scalley *et al.*, 2007) in equatorial rainforest of Congo. Agroecosystem studies place more attention on atmospheric deposition (Muoghalu and Oakhumen, 2000), in view of the increasing prospect of acid deposition from rapid urbanization, transportation and possible forest decline and climate change.

In the late 1950s and 1960s many reserves of natural forest in south western part of Nigeria, were cleared and replaced with mono-cultural tree-based plantations such as those of rubber, oil palm and cocoa. The development of rubber cultivation in West Africa was due to the interest of European rubber traders that encouraged local farmers and governments to establish plantations e.g., Ikenne and Araromi rubber estates (Opeke, 1982). For many years, these plantations flourished and contribute a lot of foreign exchange earnings to the country. However, the discovery and exportation of crude oil in commercial quantity have led to the neglect and abandonment of these plantations. The few plantations remaining have received little or no attention as there are no additional inputs (such as fertilizers) to promote the nutrient status of the stands, hence, low output. Precipitation is the main nutrient input sources into this plantation with litterfall and litter decomposition contributing substantially to the internal cycling of nutrients. Precipitation chemistry is indicative of chemical composition of the atmosphere overtime (Das *et al.*, 2005), hence, the need to monitor the chemistry of the atmospheric deposition to agroecosystem and also assess the pollution status in view of the forest decline due to acid depositions.

The objective of this study was to examine dynamics in rainfall and throughfall nutrient fluxes in Rubber Plantation (*Hevea brasiliensis willd.* Muell-arg) at Ikenne, SW Nigeria. This study emphasises on throughfall chemistry because stemflow flux contributions can be relatively insignificant in the study area. It is expected that this study will assist in understanding how

elements and nutrients flows through tree-based agroecosystems and therefore assist plantation managers to determine fertilization schedules and amounts. It will also improve prediction and forecast of changes which in turn can inform decisions on sustainable agriculture and environmental conditions in the study area in particular and Nigeria in general.

MATERIALS AND METHODS

Study site: The study site is located in the Remo Rubber Plantation, Ikenne (Latitude 6°50'N and Longitude 3°40'E (Fig. 1). The climate is characterized by two mark seasons, the rain and dry seasons. Precipitation varies from 1500 to 1750 mm annually, with nearly all falling as rain in the wet season (April-October) with a break in August. The dry season starts from November to March. The mean annual temperature is about 27°C with high relative humidity (80%). The mean diurnal and temperature ranges vary between 8-10°C during the dry season and between 3.5 and 5°C during the wet season. The mean temperature of the coolest month is 18°C. The site lies on typical sedimentary rock (Abeokuta formation) of the southern part of Nigeria which is underlain by crystalline basement complex rocks of the Precambrian period (Kehinde-Phillips, 1992).

The relief is generally undulating with no area exceeding 150 m above sea level. Periaswamy and Ashaye (1982) classified the soil of the area as Ultisols due to the annual rainfall and base saturation often less than 50%. Ultisols are considered marginal for agricultural production since the soils are highly weathered, low in CEC, base saturation and pH. The soils belong to the suborder *Ustults* with appreciable exchangeable Al characteristic of Ultisols (Soil Survey Staff, 1975). Trees species commonly found include *Isotonia boonei, Anthocleista vogeli, Cola gigantea antiaris africana, Pentaclethra macrophylla* and *Elaeis guineensis* (Gbadegesin, 1992). Three rubber stands (40, 15 and 5 year old) were selected in the plantation
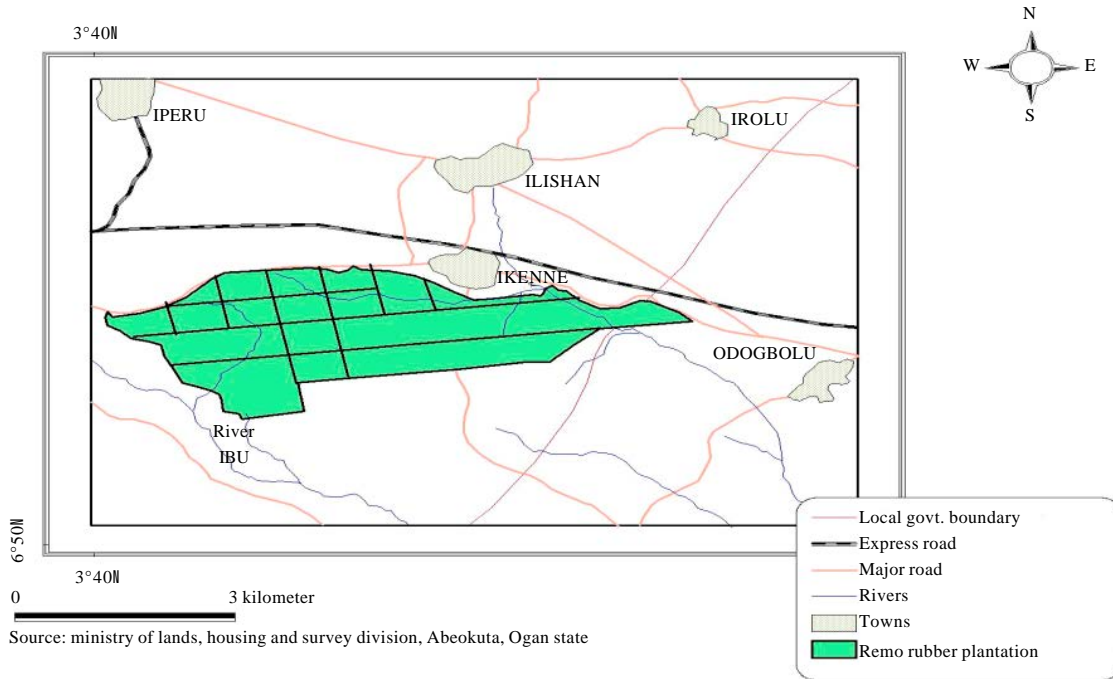

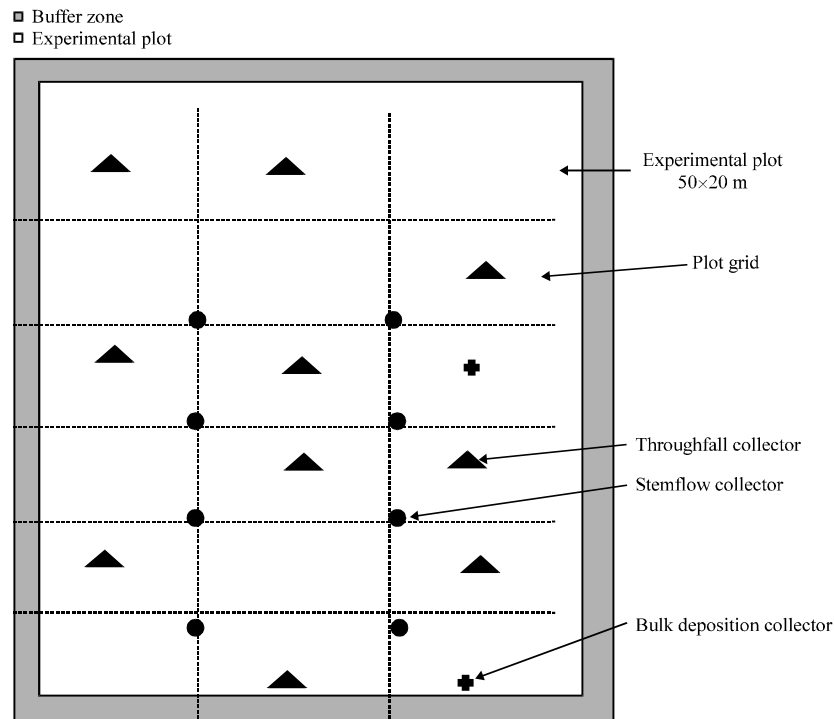Fig. 1: Remo Rubber Plantation, Ikenne, South western Nigeria

Fig. 2: Typical experimental plot with distribution of throughfall, stemflow and bulk deposition collectors in the plot

because they represented the existing age stands found in the area. Rubber plantations were first established in 1965 on about 1,111 hectares of land cleared of the original rainforest, using a randomized complete block split plot with five blocks of GT1 clone and 9 blocks of the RRIM 600 clone. In 1991, about 15 hectares of the 40 year old plantation were clear cut and planted with three blocks of GT1 clone in a randomized complete split plot while in 2000, the 5 year old were established on another 15 hectares of the 40 year old plantation which were also clear cut and planted in a randomized complete split of two blocks of the GT1 clone. The GT1 clone presented a greater amount of sclerenchyma fibres which suggests that it is more resistant than RRIM 600 clone in withstanding drought periods, by reducing wilting (Martins and Zieri, 2003). Tree density ranged between 400-450 trees per hectare in the three stands. Gaps within the rows erstwhile used for intercropping of banana, cocoyam and maize but now overgrown with weeds are found in the 40 year old plots {diameter at breast height (DBH) = 12 cm, with closed canopy and spatially homogeneous} while the 15 year and 5 year old plots (DBH between 2-8 cm) are regularly cleared, but not intercropped with any other crop during the study period. The projected top-canopy coverage of the stands is about 80, 68 and 52% for the 40, 15 and 5 year old plots, respectively. The average height of the rubber trees in the plantation is between 10-30 m.

Sampling sites and frequency: Samples for the determination of fluxes of throughfall were taken from three experimental plots within the three stand ages. Two subplots of 1 ha (50×20 m) were established under each age stands for the purpose of the study and each subplot comprises a central zone, surrounded by a buffer zone approximately 1 m wide (Fig. 2). In view of sample instability and logistic reasons, an event-based i.e., bi-weekly collection of samples was used in this

study. Studies have revealed only a minor influence of the collection interval (Thimonier, 1998; Clarke *et al.*, 2010). The biases due to sampling of a restricted fraction of the canopy was remove by sampling more than one plot and also using several throughfall collectors at once (Holwerda *et al.*, 2006). Collectors were placed under the rubber trees of the three stand age relative to their DBH in such a way that the sampled area was a true representative of the respective gap and canopy proportion (Thimonier, 1998; Clarke *et al.*, 2010). Throughfall samples were collected bi-weekly for a 12 months (July, 2005-June, 2006), in the morning, with a tolerance interval of 12 h to avoid the start of new precipitation or to allow an on-going event to end. In each sampling period, when rainfall (bulk samples) and throughfall were collected, the collecting bottles were changed, even when there was no precipitation, to avoid any accumulation of dust and detritus in the collectors.

Rainfall and throughfall measurements: Ten sets of throughfall collectors were randomly distributed in an approximately 0.1 ha plot in each stand age. This was to achieve a precision of 2% with a confidence level of 95% (Houle *et al.*, 1999; Nelson, 2002). The funnel-type gauges used for the purpose of this study were based on a design by Lawrence and Fernandez (1993) and Mululo Sato *et al.* (2011) because of its simplicity and ease of installation and manipulation. Throughfall collectors were placed within the plots to avoid edge effects. The collectors were also made of opaque materials to slow down any possible biological activity before the samples are collected from the field (Thimonier, 1998). Each sample for analysis was usually a composite sample, from ten collectors in the each rubber stand. Samples collected were then pooled according to stand age and the sample aliquots for each stand to be sent to the analyzing laboratory were then taken. Bulk open field depositions (rainfall) were sampled using the same type of continuously exposed collectors used for the throughfall. Samples were filtered through Whatman filter paper number 41, into clean, acid-washed, 250 mL HDPE bottles and labelled with the sample type and sampling date. Previous work has illustrated the importance of gaps in spatial variability of throughfall (Loescher *et al.*, 2002; Clarke *et al.*, 2010), so we exclude this source of variability and focused on intra-crown processes by placing all the subplots in areas where tree density was higher than the stand average. Stemflow samples were collected with collar consisting of vinyl tubing, cut longitudinally and attached to eight selected tree trunks in an upward spiral using galvanized nails.

Silicone sealant was applied to seal the collar to the trunk and plug nail heads. The uncut section of each stemflow collar was connected to an 80 L capacity collection bin lined chemically inert sampling bag. Five collectors were randomly distributed and placed above the ground adjacent to the three rubber stand ages in order to obtain a measurement representative for the study area. This was also to ensure that any samples, that were clearly polluted, could be discarded without the loss of the whole sample for the sampling period (Thimonier, 1998; Mosello *et al.*, 2002; Clarke *et al.*, 2010). In order to check for possible contamination on the site, field blank tests were carried out at least once every three month. For this purpose, samples of 50-100 mL deionised water were poured into the sample collector at the time of collection in days without precipitation and subjected to the same procedure as an ordinary precipitation sample (Dovey *et al.*, 2011). All samples were delivered to the laboratory on the same day they were collected. Laboratory tests were carried out at the Institute for Agricultural Research and Training, in Ibadan, Nigeria.

Chemical analyses: Samples were syringe filtered through a 0.45 µm membrane filter into 50 mL plastic tubes, cooled at -20°C and taken to the laboratory for chemical analyses. The filtration method captures microorganisms greater than 0.45 µm in size and also improves sample conservation. The analyses were performed on filtered samples (0.45 µm) except for measurement of pH and conductivity for which unfiltered samples were used. Pooled samples were stored in the refrigerator at 4°C prior to analyses. Analytical methods were based on the standard procedures described in European Monitoring and Evaluation Programme manual (EMEP, 1996). Cation concentrations (Ca^{2+}, Mg^{2+} and K^+) were determined by flame atomic absorption spectrophotometer (SH-3800). SO_4^{2-}, NO_3^-, Cl^- and Na^+ by ion chromatography (Dionex-320 systems, Dionex, CA, USA). Ammonia-nitrogen was determined colorimetrically using the phenol-hypochlorite method () read on a UV at 635nm. Conductivity and pH values were measured at 25°C in unfiltered solutions described in ISO 7888 (1985) by electrometry and in ISO 10523 (1994) by photometry respectively.

Flux calculation: Element fluxes in rainfall and throughfall were calculated as the volume-weighted unit based on measurements at each sampling dates. Element fluxes of each component were calculated by the multiplication of the volume-weighted mean nutrient concentration by the respective water volumes (Liu *et al.*, 2002; Heartsill-Scalley *et al.*, 2007). Net throughfall fluxes were obtained from throughfall minus bulk precipitation (Zhang *et al.*, 2007). Continuous observation of throughfall and bulk precipitation for a 12 month period allowed the application of the Na-ratio method i.e., the canopy budget model (Ulrich and Pankrath, 1983). The model was used to estimate the contribution of Dry Deposition (DD) and canopy leaching to throughfall. In the canopy budget model, Na is assumed not to be leached from canopy and it is used as a tracer of DD of particles of Ca^{2+}, Mg^{2+} and K^+. DD is calculated through $(TF_{Na}-BP_{Na})/BP_{Na}$ (DD factor) multiplied by the ionic flux in BP (Draaijers and Erisman, 1995; Zhang *et al.*, 2006). It is also assumed that canopy leaching of SO_4^{2-} and Cl^- are negligible and, therefore the DD contributions of SO_4^{2-} and Cl^- equals the net TF flux. The net flux is obtained from TF-BP. Though some assumptions of the model are arguable, however, some comparing studies have shown good agreement between the results of this model and those obtained by other approaches such as inferential techniques or artificial surfaces or the multiple regression models (Lin *et al.*, 2001).

Statistical analyses: Although several solution samples were taken during the study period, data from 34 weekly samples analyzed for each hydrological component. Elemental concentrations between stands were compared statistically using one-way analysis of variance. Differences were considered statistically significant at p (0.05). The statistical analyses were performed using SPSS for windows Version 11.0 (SPSS, 2003).

RESULTS

Gross rainfall: Precipitation data was collected for 34 weeks of rainfall and no statistical difference among the three stands in rainfall was observed during the sampling period. The total incident rainfall in the Remo Rubber Plantation during the study period (July 2005-June 2006) was 1540 mm with the highest amount of rainfall occurring in the rainy season (Fig. 3). The month of June 2006, was wetter than the average. Monthly precipitation measured in the study area by automatic rain gauge for the study period ranged from a minimum of 2.3 mm in December 2005
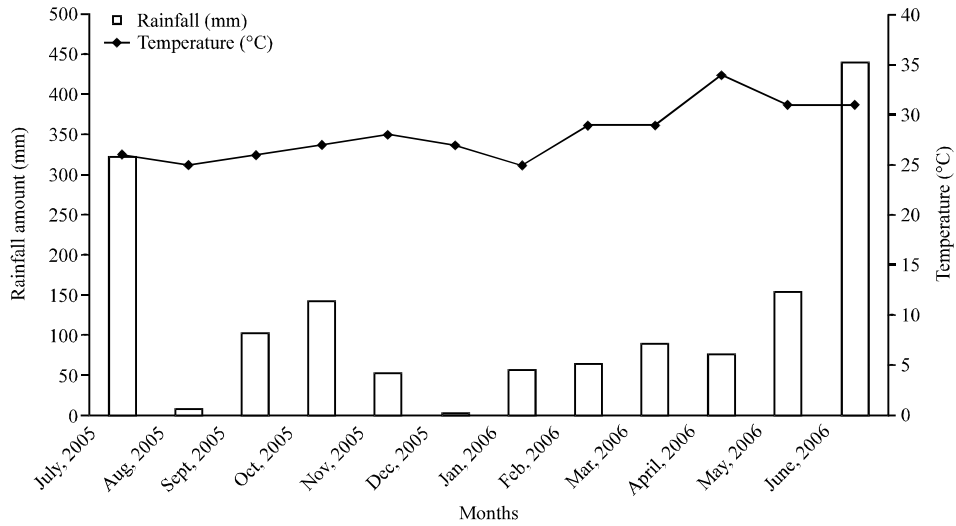
Fig. 3: Incident rainfall and temperature during the study period (July, 2005-June, 2006) at Remo Rubber Plantation

Table 1: Precipitation (P) partitioning into throughfall and interception loss in the 40, 15 and 5 year old rubber stands at the Remo Rubber Plantation, Ikenne

Parameters	40 year old		15 year old		5 year old	
	mm year^{-1}	% of P	mm year^{-1}	% of P	mm year^{-1}	% of P
Throughfall	990	64	1037	67	1075	70
Stemflow	259	17	303	20	210	14
Interception	291	19	200	13	255	16
Precipitation	1540	100	1540	100	1540	1000

to a maximum of 440.9 mm in June 2006 (Fig. 3), with a monthly average of 128.36 mm. During the study period no measurable rainfall or throughfall was observed between November and December (2005) because of the dry season. Average temperature ranges between 24-34°C for the study period.

Throughfall and interception: Precipitation (P) partitioning into throughfall and interception loss in the 40, 15 and 5 year old rubber stands at the Remo Rubber Plantation results are summarized in Table 1. The amount of incident rainfall intercepted by the canopies (both open and closed canopies) in the rubber plantation varied among the different stand ages. Throughfall is very important source of water and nutrients to the rubber plantation, however, it amount varied significantly (p<0.05) among the different stands in the study area. In the rubber plantation, nearly all the net precipitation (TF+SF) came as throughfall. TF constituted 64% of gross precipitation (990 mm) in the 40 year old rubber stand age while it was 1037 mm (67%) and 1085 mm (70%) in the 15 and 5 year old rubber stands, respectively (Table 1). The amount of net precipitation and net throughfall (TF+SF-OF) were not significantly (p<0.05) different among the stands in the study area throughout the study period. Stemflow amounts in the 15 and 5 year old trees were 19 and 13%, respectively compared to about 14% in the 40 year old trees, probably because of their smooth barks that increases amount of stemflow. In all the plots studied the stemflow amount is greatly reduced during the dry season (November-March). High throughfall

in the 5 year old rubber stands may be attributed to the high rainfall during the study period and due to the fact that there are many gaps within the stands (canopy cover was about 52%). The older trees that have canopy cover of 80 and 68% for the 40 and 15 year old trees, respectively have lesser throughfall compared to the 5 year old plantation because of their higher interception. The study also showed that interception increases with decreased rainfall and rainfall intensity especially during the dry seasons. The management of the rubber plantation aim for closed canopy by as the plantation get older. Although greater percentage of all net precipitation (TF+SF) came as throughfall (TF), stemflow amount and nutrient fluxes are vital to the circulation of nutrients in the plantation.

Nutrient inputs

Nutrient concentration in throughfall: More water and dissolved nutrients were transferred during the rainy season in the study area (82% of total rainfall). However, the dry season was relevant for this study because it represented a significant period (4 months in a year) and had a strong influence on physiological activity of the vegetation. The pH of the bulk open field precipitation for the study area was slightly acidic ranging between 5.83 (July 2006) to 6.59 (August 2005). There is no significant difference in the throughfall pH in all the three stands investigated during the study period. Average throughfall pH ranged from was 6.23 to 6.52 (Fig. 4). Throughfall pH is however slightly acidic in the 15 year old and 40 year old rubber stands than the 5 year old and the bulk precipitation. For solutions (throughfall and bulk samples) collected in this study, alkalinity was detected which can be attributable to the neutralizing effects of the base cations (i.e., Ca^{2+}, K^+ and Mg^{2+}) that were derived from the dust particles principally of local origin (e.g., agriculture and road transportation). Mean value for electrical conductivity ranged from 28.5 to 37.2 μS cm^{-1}. Mean concentration of nutrients in bulk precipitation and throughfall in rubber plantation agroecosystem is shown in Table 2. Of all nutrients returned via throughfall into the plantation floor, calcium is the highest and it ranged from 15.85 μeq L^{-1} in the
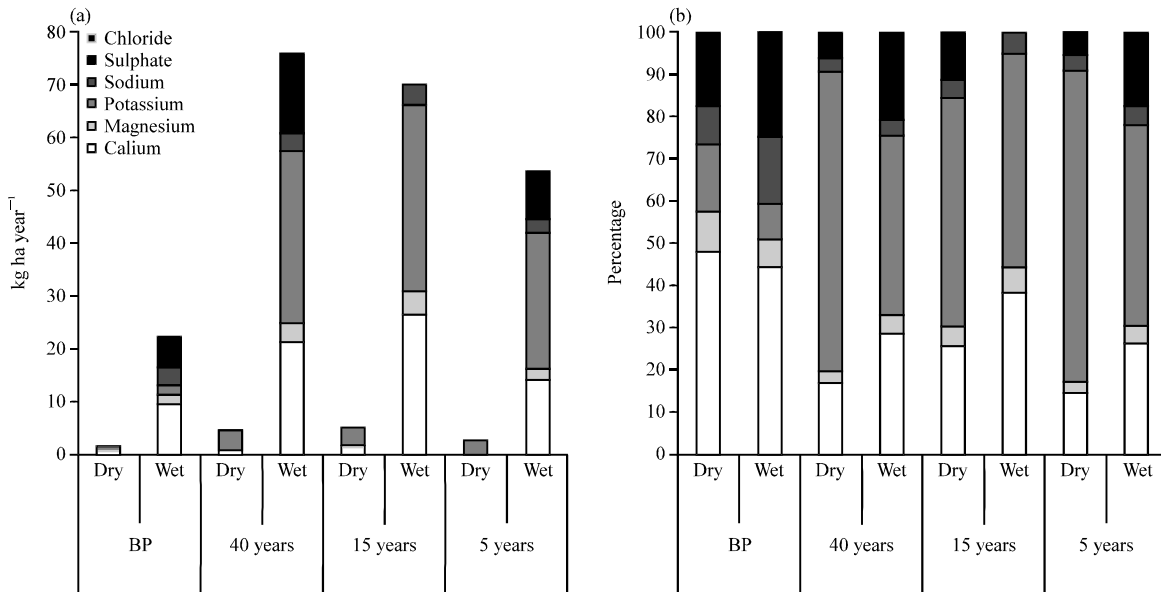

Fig. 4(a-b): Mean concentration of nutrients in bulk precipition and throughfall in rubber plantation agroeco system

Table 2: Annual mean fluxes of bulk precipitation, throughfall net throughfall (NTF) and DD and Canopy Exchange (CE) (kg ha year^{-1}) in rubber (*Hevea brasiliensis*) plantation (40-, 15- 1nd 5 year old) stands, Ikenne during the observed periods

	Ca^{2+}	Mg^{2+}	K^+	Na^+	SO_4^{2-}	NO_3^-	NH_4^+	Cl^-
40 years old								
Wet Season								
BP	9.95	1.52	1.85	2.45	0.05	<0.001	<0.001	5.64
TF	21.73	3.49	32.50	3.55	0.09	<0.001	<0.001	15.82
NTF	11.78	1.97	30.65	1.10	0.04	<0.001	<0.001	10.18
DD	4.46	0.68	0.83	1.10	0.04	<0.001	<0.001	10.18
CE	7.32	1.29	29.82	0.00	0.00	0.000	0.000	0.00
Dry season								
BP	0.83	0.16	0.28	0.15	0.01	<0.001	<0.001	0.29
TF	1.42	0.20	3.78	0.19	0.02	<0.001	<0.001	0.32
NTF	0.59	0.04	3.50	0.04	0.01	<0.001	<0.001	0.03
DD	0.18	0.03	0.06	0.04	0.01	<0.001	<0.001	0.03
CE	0.42	0.01	3.44	0.00	0.00	0.000	0.000	0.00
15 years old								
Wet season								
BP	9.95	1.52	1.85	2.45	0.05	<0.001	<0.001	5.64
TF	26.83	4.20	35.60	3.62	0.06	<0.001	<0.001	18.50
NTF	16.88	2.68	33.75	1.17	0.01	<0.001	<0.001	12.66
DD	4.95	0.73	0.88	1.17	0.01	<0.001	<0.001	12.66
CE	11.93	1.96	32.87	0.00	0.00	0.000	0.000	0.00
Dry season								
BP	0.83	0.16	0.28	0.15	0.01	<0.001	<0.001	0.29
TF	2.56	0.29	3.31	0.27	0.01	<0.001	<0.001	0.66
NTF	1.73	0.13	3.03	0.11	0.01	<0.001	<0.001	0.37
DD	0.57	0.11	0.17	0.11	0.00	<0.001	<0.001	0.37
CE	1.16	0.02	2.86	0.00	0.00	0.000	0.000	0.00
5 years old								
Wet season								
BP	9.95	1.52	1.85	2.45	0.05	<0.001	<0.001	5.64
TF	14.49	1.96	25.70	3.02	0.06	<0.001	<0.001	9.18
NTF	4.54	0.44	23.85	0.57	0.01	<0.001	<0.001	3.54
DD	2.32	0.35	0.43	0.57	0.01	<0.001	<0.001	3.54
CE	2.22	0.09	23.42	0.00	0.00	0.000	0.000	0.00
Dry season								
BP	0.83	0.16	0.28	0.15	0.01	<0.001	<0.001	0.29
TF	0.46	1.29	2.31	0.17	0.01	<0.001	<0.001	0.36
NTF	0.63	0.13	2.03	0.02	0.00	<0.001	<0.001	0.07
DD	0.11	0.02	0.03	0.02	0.00	<0.001	<0.001	0.07
CE	0.02	0.11	2.00	0.00	0.00	0.000	0.000	0.00

$p<0.05$

bulk precipitation to 17.27 µeq L^{-1} in the 15 year old rubber stand. Concentrations of base cations Mg^{2+}, K^+ and Na^+ are 0.13, 1.91 and 3.02 µeq L^{-1}, respectively in the 15 year old rubber stand which were higher than the values obtained for bulk precipitation and the two other rubber stands examined in this study. Concentrations of calcium and potassium and sodium differ significantly in the 40 year old and 15 year old rubber stands compared to the 5 year old rubber stand and the open bulk precipitation. On the other hand there are no significant differences in the concentrations of anions such as SO_4^{2+}, NO_3 and NH_4 which are very low in all the rubber stands. However, chloride significantly differs among the rubber stands as shown in Fig. 4.
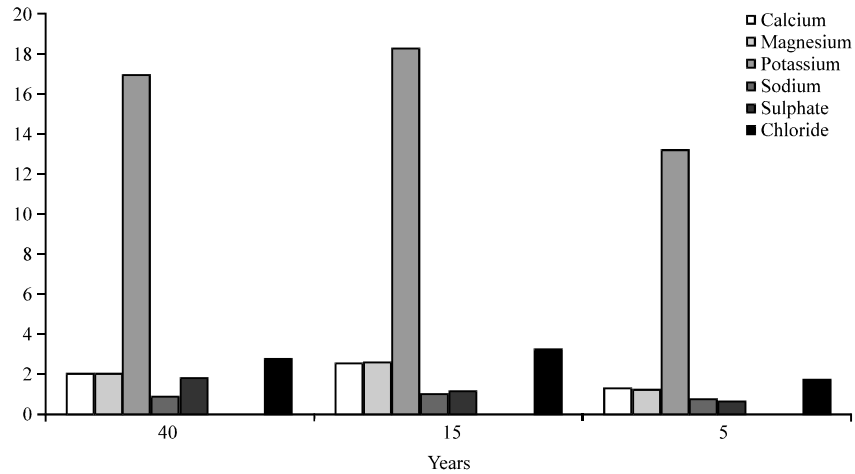
Fig. 5: Enrichment of major ions in throughfall

The study showed a marked change in the nutrient concentrations in throughfall compared to bulk precipitation. The nutrient content of throughfall is altered on its way through the canopy and rnay either decrease or increase before reaching the soil (Bhat *et al.*, 2011), however it is difficult to distinguish between these two sources. A decreases implies direct absorption by foliage or foliar epiphytes (including lichens, fungi. and bacteria) (Herrmann *et al.*, 2006) while an increase indicate nutrients that have collected on foliage through dryfall and also nutrients leaching from foliage or foliar epiphytes (Bhat *et al.*, 2011). Net throughfall fluxes (throughfall-precipitation transfer) in this study showed consistent canopy effects on rainfall chemistry. While, Ca^{2+}, K^+ and Mg^{2+} were added to rainfall by foliage, NH_4^+ and NO_3^- - N were absorbed or removed. The order of nutrients in bulk precipitation and throughfall was $Ca^{2+}>Cl^->Na^+>K^+>Mg^{2+}>NH_4^+$. The chemical composition of throughfall in the area was dominated by calcium and chloride. Table 2 shows the descriptive chemistry of throughfall at Remo Rubber Plantation during the study period. There were differences in all throughfall nutrient fluxes the rubber stands and seasons. There are significant differences in the nutrients inputs in the two seasons in the study area (p<0.05) with the wet season witnessing more volume of throughfall inputs compared to the dry season. Figure 4 and 5 shows seasonal and annual input of nutrients via bulk precipitation and throughfall in the study area during the observed periods at 0.05 significant levels. Concentrations of Ca^{2+}, Na^+, K^+ and Cl^- were relatively high throughout the sampling periods compared to total N, NH_4^+, NO_3^--N, Mg^{2+} and SO_4^{2-}-S concentrations which were quite low especially during the dry season. Potassium becomes enriched tropical forests throughfall throughout the tropics but nitrate and phosphate enrichment is inconsistent (Parker, 1983). Significant differences (p<0.05) were observed between precipitation and throughfall in concentrations of nutrient elements and enrichment occurred within the rubber plantation for all nutrient elements except for NO_3^--N and NH_4^+-N.

Maximum values obtained for throughfall concentration of most elements occurred in the 15 year old rubber stand, with calcium having the highest concentration of 22.45 µeq L^{-1} $year^{-1}$ followed by the 40 year old rubber stand (19.96 µeq L^{-1} $year^{-1}$) and then the 5 year old rubber stand (18.71 µeq L^{-1} $year^{-1}$). Median and maximum concentrations of chloride was however, higher in the 40 year old rubber stand.

Annual nutrient input: Annual mean fluxes of bulk precipitation, throughfall net throughfall (NTF) and DD and Canopy Exchange (CE) (kg ha year^{-1}) in rubber (*Hevea brasiliensis*) plantation (40, 15 and 5 year old) stands, during the observed periods (p<0.05) positive net throughfall (NTF) were observed for all the cations indicating their leaching from the canopies. The positive NTF for these elements occurred both in the wet and dry season. There were no significant statistical differences in the throughfall concentration of nutrients such as nitrogen, nitrite, nitrite and ammonia. In addition, the distribution of data does not differ among stands regarding these nutrients. However, statistically significant differences in calcium, potassium and magnesium (p<0.05) were detected in throughfall samples among the three rubber stands, total annual nutrient inputs reaching stand floors indicated that canopy leaching increased nutrient amount; however, amount differed among nutrients. The highest concentration in throughfall was Ca^{2+}, however, the most enriched throughfall was K^+ in all the stands.

DISCUSSION

Throughfall: In forest environment, tree canopies partition rainfall into temporary canopy storage, throughfall and stemflow (Park and Cameron, 2008). Throughfall forms the largest proportion of incident rainfall reaching the forest floor. Studies have shown that throughfall contributed to the bigger part of around 80 to 90 percent, whereas stemflow only accounted for about 1 percent of total precipitation, the rest being lost by interception (Chuyong *et al.*, 2004). The total measured throughfall volume of the whole study period was 990, 1037 and 1075 mm for the 40, 15 and 5 year old rubber stands respectively. These formed 64, 67 and 70% of incident rainfall for the 40, 15 and 5 year old rubber stands respectively. The value reported in this study is similar to the 60-74% of rainfall for a montane rain forest in New Guinea, with rainfall of 3700-3900 mm (Edwards, 1982). The proportional amount of throughfall in the different rubber *Hevea brasiliensis* stands at the Remo Rubber plantation, however lies in the lower range of values recorded for some montane and lowland forests. For instance Filoso *et al.* (1999) and Marin *et al.* (2000) working in rainforests in the Amazon basin reported 78-91% while Chuyong *et al.* (2004) observed throughfall percentage of between 92-97% in part of Africa while in Asia, Sinun *et al.* (1992) reported throughfall representing 80% of incident rainfall and Brasell and Sinclair (1983) record 76-88% in rainforests on the Atherton Tablelands, Australia, with annual rainfall of 2256-3805 mm. Parker (1983) observed that the amount of precipitation controls magnitude of throughfall. Throughfall is dependent upon spaces in the vegetation canopy (Ward and Robinson, 2000; Germer *et al.*, 2006) and it is concentrated near crown of the trees and vegetation (Newson, 1997).

Chemistry of throughfall deposition and input fluxes: Mean volume-weighted bulk deposition in the different rubber stands were characterised by positive alkalinity, weak acid anion concentrations and marine influence. The rainfall composition of the study area ranks it as a pristine area and the "pristine" status can be attributed to low sulphur and nitrogen concentration; neutral pH of rainfall water and no significant difference between rainy and dry season pH values. The acidifying effect of sulphur dioxide in precipitation is not a threat in the study area compared to many European and North American forests (Parker, 1983; Levia and Frost, 2006). Acidity is a very important feature of atmospheric deposition and in precipitation; most acidity is contributed by sulphuric acid (H_2SO_4) and nitric acid (HNO_3) and deposition of associated nutrients. Nitrate (NO_3^-) and sulphate (SO_4^{2-}) particularly has important impacts on the environment (Levia and Frost, 2006). Nitrate can cause eutrophication of coastal and water bodies while sulphate can

combine with calcium and other nutrients necessary for plant growth, causing them to leach more quickly from the soil (Castro and Driscoll, 2002; Hofhansl, 2008). Studies from the temperate forests have shown that throughfall tended to be enriched in base cations and exhibit organic carbon and depleted in NH_4^+-N and NO_3^--N relative to precipitation (Parker, 1983; Levia and Frost, 2003; 2006).

Throughfall chemistry has been found to depend on factors like latitude, elevation, seasonality, proximity to the sea, species composition, forest age and local land use (Levia and Herwitz, 2000). The chemical composition of throughfall in the area was dominated by calcium and chloride. The results of this study reveal a clear pattern of increase base cation and fluxes of throughfall compared to precipitation. This is particularly true for Ca^{2+} unlike K^+ found to be highly enriched in the natural Lithocarpus/Castanopsis forest at Xujiaba, Ailao SW China (Liu *et al.*, 2003) and fluxes of Ca^{2+} in throughfall are typically 1.5-2 times higher than those in rainfall. Elemental concentration in precipitation and throughfall exhibited seasonality. These however, differ significantly ($p<0.05$) because there is variation in the amount and intensity of rainfall in the year. The highest concentration in throughfall was Ca^{2+}, however, the most enriched throughfall was K^+ in all the stands probably because it is not tightly bound in structural tissues or enzyme complexes as Ca^{2+} and Mg^{2+} (Zhang *et al.*, 2006; Dovey *et al.*, 2011). Mayer *et al.* (2000) also observed large increases in cations under the tree canopy (two to 13 times) in a tropical rain forest, with K^+ enrichment being the largest. Among the rubber stands, fluxes of K^+ are also increased in throughfall and this is similar to results from other studies (McDowell, 1998; Liu *et al.*, 2002). Differences between the flux of sodium in precipitation and throughfall are indicative of the magnitude of deposition of marine aerosols (Parker, 1983; Das *et al.*, 2005). The high humidity of the tropical lowland forest region where the study area is situated should be conducive to high rates of dry deposition. 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 (McDowell, 1998), an indication that the origin of nutrients in precipitation in the study area is from sources other than marine aerosols, such as atmosphere, smoke and dust (Parker, 1983).

Ca^{2+} and SO_4^{2-}-S are mainly from precipitation while over 70% of total K^+ and total Mg^{2+} probably leach from canopy. This is in agreement with forest sites (Marques and Ranger, 1997; Liu *et al.*, 2003). The extents to which elements are leached from a forest canopy depends upon such factors as temperature, precipitation amount and intensity, the residence time of water on the leaves and leaf index and indirectly depends upon the availability of minerals in the soil (Edwards, 1982; Parker, 1983). The throughfall data for the rubber stands reflect a generally lower cycling rate of mineral elements than the tropical lowland forest. Net flux and deposition ratios provide information on the effects of the canopy on precipitation chemistry and are useful for comparisons between forests (Levia and Frost, 2003; Levia and Frost, 2006). In the rubber plantation, the 15 year old stand appears to have higher nutrient cycling returns to the soil than the 40 and 5 year old stand. Generally, in the rubber plantation, there appear to be a lower leaching of elements like K^+ which is considered to be most easily leached element (Tukey, 1970) compared to other tropical tree dominated ecosystems. The relatively low foliar K^+ concentration might be a factor and also the fact that the amount of leachable K^+ decline with increasing intensity of rainfall (Liu *et al.*, 2002). Whilst the concentrations of Ca, Na, P, K and C1 were relatively high throughout the sampling periods; total N, NH_4^+, NO_3^--N, Mg and SO_4^{2-}-S concentrations were

relatively lower throughout the study especially during the dry season . Low net throughfall fluxes of N may be associated with an economic use of these elements by trees and epiphytes (Veneklaas, 1990; Clark *et al.*, 1998). Significant differences (p<0.05) were observed between precipitation and throughfall in concentrations of nutrient elements and the enrichment occurred within the rubber plantation for all the nutrient elements except for NO_3^--N and NH_4^+-N. An increment enrichment factor relative to rainfall was observed in throughfall. The ratio of nutrient concentration in throughfall to precipitation were the same for total N, NH_4^+-N and NO_3^--N because there is no traces of changes. However, the ratios of nutrient concentration in throughfall to precipitation were 1.10 for Ca^{2+}, 1.08 for Mg^{2+}, 1.05 for Na^+, 1.40 for K^+ and 2.71 for Cl^-.

Enrichment ratio: Enrichment ratios were defined as the ratio of throughfall constituent flux over the corresponding rainfall constituent. Element enrichment in is mostly due to both dry deposition and leaching of intercellular solutes from leaves (Rodrigo *et al.*, 2003). Generally, some nutrients such as NH_4^+ -N and NO_3^- -N do not show such enrichment because they are absorbed by plant surfaces. Major cations such Ca^{2+}, Mg^{2+} and K^+ had enrichment ratios that were more than one in all the stands while enrichment ratios were less than one for Na except in the 15 year old stand. In fact, enrichment ratios for K was greater than 10 in all stands, showing that K^+ is the most enriched of all the nutrients investigated in this study. The enrichment of elements in throughfall has been ascribed to the dissolution and washout of atmospheric material deposited on canopy (Lovett *et al.*, 1996; Weathers *et al.*, 2001; Laclau *et al.*, 2003; Levia and Frost, 2003; 2006) or due to exchange between rainfall and elements in internal plant parts (Marques and Ranger, 1997; McDowell, 1998; Liu *et al.*, 2002). The external origin (dry deposition) and internal cycling (leaching process) can take place for most of the elements, with different intensities. The quantities of nutrient elements leached are associated to the levels of exchangeable elements in the foliage (Levia and Frost, 2003). Chemical composition of rainfall intercepted by the canopy is enhanced by wash-off of dry deposition collected by the canopy and foliar leaching of nutrients into rainwater (Fan and Hong, 2001; Johnson and Lehmann, 2006). Total annual nutrient inputs reaching stand floors indicated that canopy leaching increased nutrient amount; however, amount differed among nutrients. Wiggenhauser *et al.* (2013), among other scholars have shown that during the passage through the canopy, water and nutrient fluxes are spatially redistributed resulting in a heterogeneous input of water and dissolved nutrients into the soil.

Variations in bulk precipitation and throughfall: The result of the one-way analysis of variance among bulk precipitation and throughfall in all the rubber stands showed that the amount returned to the soil varied significantly (p<0.05, F = 628). These variations were also noted within stands. In the 40 year old stand the result of the one-way analysis of variance showed that there were significantly differences (p<0.05, F = 956) while the values were (p<0.05, F = 614) and (p<0.05, F = 2230), for the 15 and 5 year old stands respectively. Analysis of variance of the flux of nutrients in the plantation also revealed significant variations between and within rubber stands. For instance in the 15 year old stand, the ANOVA results were (p<0.05, F = 14.9).

Trends in deposition: Throughfall (TF) and open bulk precipitation (OF) were measured in three stands in 2005-2006. Although the patterns of fluxes vary between sampling dates and ions, a number of trends are apparent in the study. Deposition of H^+ is either unchanged or substantially depleted by the vegetation while Ca^{2+}, Na^+ and K^+ exhibited large net increase in deposition to the

different rubber stands. There was a large flux of Cl^- while NO_3^- and NO_2^- showed depletion as precipitation passed through the canopy. Calcium and chloride inputs from TF were higher than in the bulk precipitation samples reflecting washouts and excretion. Throughfall Mg^{2+}, SO_4^{2-}, Na^+ and K^+ input was also greater than in bulk precipitation. Ammonium and nitrate inputs were low in all the solution samples. The interaction of canopy on the nitrogen flow is dependent of the nitrogen deposition level (Tobon *et al.*, 2004a). An adsorption of the deposited N in the canopy is registered when the deposition is low whereas, in more polluted areas of the world, a higher N flow is measured in the TF than in the OF. The Post Hoc test for linear trend showed that there are significant linear trends ($p < 0.05$) in the nutrient deposition in all the sampled stands.

CONCLUSION

The composition of rainfall in all the rubber stands in this study point to the fact that the area has not been subjected to intense air pollution inputs and can be considered as pristine. Base cations (Ca^{2+}, K^+, Na^+ and Mg^{2+}) amount and fluxes are increased in throughfall and stem flow while NH_4^+-N and NO_3^--N are greatly reduced. Ca^{2+} and Na^+ annual throughfall inputs are mainly from precipitation while K^+ and Mg^{2+} are mainly from canopy leaching. The annual fluxes of all cations were higher in throughfall than in bulk open depositions. During this study, 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.

The dominating neutralizing component in the collected samples (throughfall) was Ca^{2+} and may be due to suspended particles, rich in carbonates/bicarbonates of Ca^{2+} which buffered the rainwater acidity. Net flux (throughfall flux minus bulk precipitation) and deposition ratios (ratio of throughfall flux to bulk precipitation flux) are in the lower part of the range reported for some montane rainforests. The one way analysis of throughfall and stemflow depositions showed significant variations in K^+, Na^+ and Mg^{2+} while there is no significant variations in NH_4^+-N, NO_3^--N and SO_4^{2-} probably due to their extremely lower fluxes compared to base cations like Ca^{2+} and Mg^{2+}. This is also an indication of low level of pollution in the area. Going by the amount of nutrients in different rubber stand ages, it can conclude that there are significant differences in the composition of nutrients in the three stand ages. The atmospheric deposition data for the study area show a generally low cycling rate of mineral elements. The tree canopies capture dusts, aerosols and gases in dry deposition and dissolved ions in precipitation and cloud droplets. Intercepted chemicals may be absorbed directly by the plant foliage or microbes living on leaf surfaces, or they may be washed off leaves and enter the soil system in throughfall and stemflow solutions. Generally, NH_4^+, NO_3^- and H^+ are absorbed by the canopies, whereas base cations and organic acids are leached from foliage. Inputs of these elements in the different rubber stands are higher in the 15 year old stand than the 40 and 5 year old stands. This in effect shows that the rubber stands reached the highest capacity to cycle nutrients effectively and efficiently at about the 15 years after which the ability to function well in nutrient cycling starts to decline. These observations illustrate the sensitivity of nutrient cycling to the changing atmospheric loading of nutrient elements which have potential effects on the soil characteristics and consequently the plantation growth and vigour. Old rubber stands like the 40 year old have gone past their productive capacity and need to be felled and new ones planted.

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