Nutrient Inputs via Stem Flow in a Rubber - *Hevea brasiliensis Wild Muell-Arg. Euphorbiaecae* - Agro-ecosystem Plantation at Ikenne, Southwest, Nigeria

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Abstract

Nutrients via stem flow are important in tropical agro ecosystems that receive little or no external sources of essential nutrients. This study compares stem flow of three age stands (40, 15, and 5 year-old) of rubber (Hevea brasiliensis) in Ikenne, South west, Nigeria. Stem flow solutions were collected with stem flow collars spiralled round eight selected trees in a 0.1ha (50m x 20m) experimental plot established in each of the three rubber stands. Collected data were analysed statistically using one-way analysis of variance (ANOVA); and the student t- test to assess the significant differences ($P < 0.05$). Total nutrient returns via stem flow 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 22.7, 3.64, 36.3, and 3.17 kg ha^{-1} year $^{-1}$ for Ca^{2+}, Mg^{2+}, K^+ and Na^+ respectively, in the 40-year-old stand. Except for Cl^-, anions were greatly reduced suggesting nutrient uptake and less pollution. High amount of Ca^{2+} also suggest the contribution of dry deposition of local origin to the leached metabolites. The 15-year-old stand appears to have more efficient nutrient return compared to the younger 5-year-old stand on one hand and the older 40-year-old stand on the other. There is the need for augmented nutrients in the plantation by adding fertilizers in quantities that will not alter nutrient cycles and at the same time ensure sustainable and productive agro-ecosystem.

Keywords: Nutrient inputs, agro-ecosystem plantation, stem flow, *Hevea brasiliensis*

Introduction

Sustainable growth of forests and tree crop agro ecosystems depends on the cycling of nutrient elements. As management practices and environmental factors can result in changes in soil structure and nutrition, it is necessary to understand the cycling of nutrient for proper forest management (Nilsson *et al.,* 1995). Studies of nutrient uptake and cycling are important components for understanding the long-term dynamics of structure and function of forest ecosystems (Vitousek and Sanford, 1986; Tamm, 1995; Nilsson et al, 1995; Ranger et al., 2001). Input fluxes into any production system include soil mineral weathering and atmospheric deposition (McDowell, 1998; Weathers et al., 2000; Balestrini and Tagliaferri, 2001; Balestrini et al., 2002).

In the aboveground, incident precipitation is redistributed spatially by trees into stem flow and through fall. The difference between the sum of these two fluxes and the incident rainfall gives the canopy interception (Chuyong et al., 2004). Fluxes of nutrients as through fall and stem flow are more rapid, when compared to the rate at which nutrient are released (mineralization) from decomposition of litters.

Nutrient inputs and outputs 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 (Hedin, 1995; Parker G.G. 1983). The potential importance of the atmosphere as a nutrient source to forest ecosystems has received increased attention (Soulsby and Reynolds, 1994; Mitchell et al., 2001) most especially in temperate forest and agro ecosystems. It has been established that in major forest ecosystems, inputs of nutrients through atmospheric deposition appeared to be of low magnitude (Jordan 1982; Brouwer 1996), and thus develop a tight internal nutrient cycle and related nutrient conserving-mechanisms (Jordan and Herrera 1981; Bruijnzeel 1991).

Anthropogenic activities such as that of industries can have dramatic effects on atmospheric chemistry, just like other non-industrial human activities, such as deforestation, agriculture and biomass burning can also have a large impact on atmospheric chemistry (Linsey et al. 1987; Mosello and Marchetto, 1999; Nelson, 2002). Estimation of the fluxes of elements in precipitation, through fall, and stem flow can be used as a routine part of nutrient budget studies in forests (Crockford and Richardson, 1996; Schlesinger, 1997; Levia and Frost, 2006). As the tree canopy partition rainfall into stem flow, the intercepted water washes off nutrients that were deposited in the canopy by dry atmospheric deposition or animal droppings (Crockford & Richardson, 2000).

Stem flow water can further be partitioned into water intercepted by the litter layer or water which actually reaches the soil surface (Owens and Schreiber, 1992). It is regarded as a spatially localized input point of precipitation and nutrients to the forest floor at the tree base (Levia and Herwitz, 2002). In most forests, through fall is by far the dominant pathway taken through the canopy (Wilby, 1997), however, stem flow has higher nutrient concentrations than through fall (by up to an order of magnitude (Parker, 1983) due to a longer canopy residence time for stem flow water than for through fall, which is in turn more greatly enriched than the incident precipitation (Johnson and Lehmann, 2006). Greater leachability of bark tissue also contributes to a chemical concentration gradient of water fluxes in the order: stem flow > through fall > precipitation (Levia & Herwitz, 2000; Johnson and Lehamnn, 2006). Nagata et al. (2001) reported temporal variations in the amount of stem flow produced by an individual tree vary as seasonally variable rainfall intensities alter the amount of rainfall partitioned to stem flow.

The chemical composition of stem flow for an individual tree is also influenced by climatic factors such as rainfall intensity and wind speed as well as the duration of the dry period preceding the storm (Mina, 1967, Liu et al., 2003). Stem flow was also found to be related to physical tree characteristics such as diameter, basal area or crown projection area (Ford and Deans, 1978; Hanchi and Rapp, 1997), suggesting that these relationships could be exploited to estimate stem flow at the stand level. In addition, canopy architecture and leaf morphology affect the chemical concentrations of stem flow water. Stem density and crown structure may be important for stem flow generation (Hölscher et al., 2005; Dietz et al., 2006). Levia & Herwitz, (2000) pointed out that intercepted water may become more enriched due to canopy features that increase residence time of water in the canopy, such as leaf concavity and shallow branch angle. Furthermore, older trees of the same species tend to have greater trunk surface roughness, resulting in less stem flow due to increased storage capacity (Houle *et* al., 1999; Levia, 2003; Levia & Frost, 2003), while rough-barked species show higher nutrient concentrations than smooth-barked species (Parker, 1983). In general, stem flow deposits within a small area around the tree trunk and the effects of stem flow on soil characteristics are more prominent near the trees (Gersper and Holowaychuck, 1971; Andersson, 1991; Chang and Matzner, 2000).

In forested and agricultural ecosystems, stem flow may be of hydro-ecological and biogeochemical importance ((Levia and Frost, 2003). Although, some studies (e.g. Parker, 1983; Crockford and Richardson, 1990; Hölscher *et al*., 1998; Owen *et al*., 2003), have reported that the quantitative contributions of stem flow to the nutrient cycle are small, however, some other studies (e.g. Andersson, 1991; Chang and Matzner, 2000) revealed that stem flow can be significant under some circumstances. For instance, Gersper and Holowaychuk (1971) reported that quantitative variations in the physico-chemical properties of soils near the trees were caused by stem flow, suggesting that the quality and quantity of stem flow and through fall from individual tree influences soil properties. It also affects soil moisture distribution (Durocher, 1990), soil chemistry (Matschonat and Falkengren-Grerup, 2000; Chang and Matzner, 2000), soil erosion (Herwitz, 1988), runoff generation, ground water recharge, and the distribution of under-story vegetation and epiphytes (Andersson, 1991; Levia and Frost, 2003).). Chang and Matzner (2000) reported that the stem flow of beech represented a significant input of elements to the soils. According to Murakami (2009) stem flow typically accounts for several percent of rainfall, and is often a minor component of the water budget in forest hydrology in comparison with through fall, that amounts to 60 to 90% of rainfall.

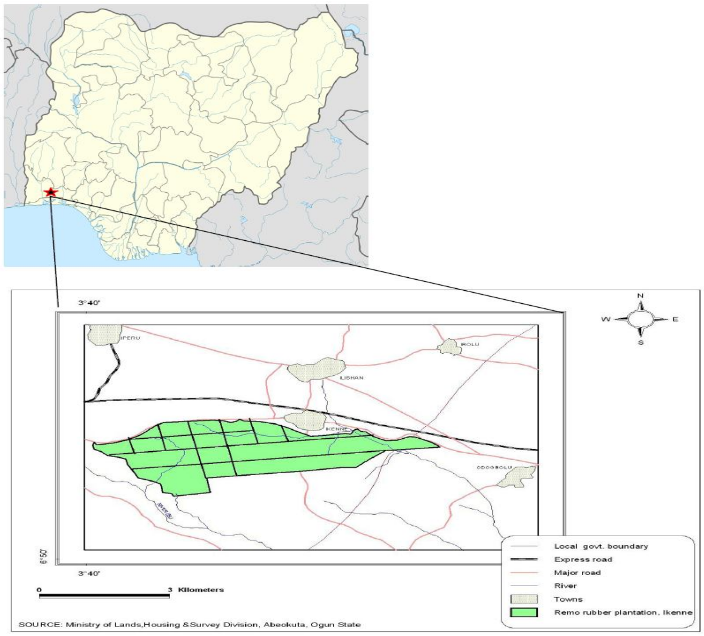
Overall, the understanding of biogeochemical cycling in tropical and subtropical forests is still relatively poor compared with temperate forests (Bruijnzeel and Proctor, 1995; Vitousek and Sanford, 1986). There is the paucity of reliable experimental data on the contribution of atmospheric deposition most especially stem flow to the nutrient dynamics of forests and tree crop agro ecosystems in tropical forests such as south western Nigeria, except few (e.g. Muoghalu and Johnson, 2000; Muoghalu and Oakhumen, 2000). It is also known that stem flow studies have received far less attention (Chuyong et al., 2004). There is the need to critically evaluate the current understanding of stem flow in agro ecosystem such as rubber; identify gaps in our present knowledge of stem flow; and stimulate further research in areas where present knowledge is weak.

A better understanding of the partitioning of incident gross precipitation into stem flow will result in improved knowledge of the hydrology and biogeochemical cycles of nutrients. This paper therefore examines nutrient inputs via stem flow in a *Hevea brasiliensis Wild Muell-Arg. Euphorbiaecae* agro ecosystem plantation at Ikenne, South west, Nigeria. The paper looks at mineral cycling in plantation agro ecosystems, assess ways, which improves prediction and forecast of changes, which in turn can inform decisions on sustainable agro ecosystem.

Study Area

The study was conducted at the Remo Rubber Plantation located in Ikenne, southwest, Nigeria (Latitude 6^{o} 50' N and Longitude 3^{o} 40' E (Figure 1). Precipitation varies from 1500 mm to 1750 mm annually, with nearly all falling as rain in the wet season (April-October). The mean diurnal and temperature ranges vary between $8^{o}C$ to $10^{o}C$ during the dry season and between $3.5^{o}C$ and $5^{o}C$ during the wet season. The rainy climate has the temperature of the coolest month to be >$18^{o}C$ ($68^{o}F$). The mean annual temperature is about $27^{o}C$ with high relative humidity (80%) (Ayoade, 1988). The site lies on the sedimentary rock (Abeokuta formation) of the southern part of Nigeria, which is underlain by the crystalline basement complex rocks of the Precambrian period (Kehinde-Phillips, 1992).

The relief is generally an undulating one, and hardly does any area exceed 150m above sea level. Periaswamy and Ashaye (1982) classified the soil of the area as Ultisols due to the annual rainfall with base saturation often less than 50 %. The soils belong to the suborder *Ustults* with appreciable exchangeable Al characteristic of Ultisols (Soil Survey Staff, 1975; Lal, 1989; Juo and Franzluebbers, 2003). Ultisols are considered marginal for agricultural production since the soils are highly weathered, low in CEC, base saturation and pH. Trees species commonly found include *Isotonia boonei, Anthocleista Vogeli, Cola gigantea Antiaris africana, Pentaclethra macrophylla,* and *Elaeis guineensis* (Gbadegesin, 1992; Aweto and Obe, 1993). Deterioration of the soil structure is noted in the study area, which has led to several soil degradation processes like crusting, surface and sub-surface compaction, surface runoff, and accelerated soil erosion. Anthropogenic influences (e.g. population increase, urban development, transportation) can have considerable effect on the atmospheric chemistry of the area, which was once pristine.



SOURCE: Ministry of Lands,Housing &Survey Division, Abeokuta, Ogun State

Figure 1: Map of Remo Rubber Plantation, Ikenne, South western, Nigeria

Materials and Methods

The study was conducted for 2 years from mid-June 2005 to mid-June 2007. Stem flow samples were collected bi-weekly based on representative trees in each stand taking into account tree age, class, diameter, and height. Ten replicate trees were sampled in each age stand for stem flow collection. The choice of fewer stem flow collectors was based on the recommendation of the ICP Forest manual (Programme Coordinating Centre, 1994) that gives a guideline number of 5 to 10 stem flow gauges especially for homogenous, even-aged stands. Stem flow was collected with collars consisting of vinyl tubing, cut longitudinally and attached to each tree trunk in an upward spiral using galvanized nails.

Silicone sealant was applied to seal the collar to the trunk and to plug nail heads. The uncut section of each stem flow collar was connected to an 80-litre capacity collection bin lined with a chemically inert sampling bag. The collars were mounted at the breast height (1.3 m above the forest floor), and were checked regularly for leakages. The spirals were steep enough to allow a rapid emptying of the rain water from the collars. Total stem flow amount was extra polated for each plot by formulae of the Programme Coordinating Centre (1994), which is expressed as:

$$\text{Total volume in the plot (mm)} = \frac{\text{Total Stemflow of n trees}}{\text{Plot area (ha)}} x \frac{\text{Total basal area of all trees in the plot}}{\text{Total basal area of the n trees}} x10^{4} \qquad 1$$

Where n is the number of trees used in the stem flow measurements (Thimonier, 1998). In addition, the percentage of rainfall partitioned to stem flow (SF %) integrates the canopy architectural and climatological factors influencing rainfall partitioning. SF% was determined as the percentage of incident rainfall delivered as stem flow on a volumetric basis as follows:

$$SF\% = \frac{SF}{PPT} x100 \qquad 2$$

Where SF is the volume of stem flow on per hectare of forest basis and PPT is the volume of rainfall per hectare of open area.

The bi-weekly stem flow 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. All samples were filtered in the laboratory. Water pH was measure 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). Sulphate (SO_4-S) sulphur was determined by Inductively Coupled Plasma Atomic Emission Spectrum (ICP-AES, IRIS ER, Thermo Jarrel Ash Corporation, USA). 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 NHCl). NO_3^--N was determined after reduction to NO_2^- - N by colorimetric method (Sulphhanilmide /N-I-napthyethylene-diamnie dihydrochloride, Institute of Soil Academic, Sinica, 1978). To ensure sample integrity, glass wares were soaked in two phases: (i) IM HNO_3 solution; and (ii) a 10 % HCl solution (Sevruk, 1989; Levia, 2003). De-ionized water was also used to rinse glassware during preparation of standard for atomic spectrometry.

Mean stem flow volumes were calculated for each of rubber tree sampled, and then multiplied by the number of trees for each stand age. These values were then summed to provide estimates of the total stem flow for the stand. Stem flow from the sampled trees were summed over the entire period and the total volume used to compute the funneling ratio from the equation of Herwitz (1986):

$$FR = {}^{V}\!/_{BG} \qquad 3$$

Where FR = funneling ratio, V = stem flow volume (l), B = basal area (m^2) and G = the depth equivalent of rainfall (mm). Funneling ratio relates stem flow volume to the expected volume from a rain-gauge with a collecting area equivalent to the stem's basal area (Herwitz; 1986; Chuyong, 1994; Chuyong et al., 2004). Trees with ratios exceeding unity indicate that funneling of rain water had occurred. These ratios were used to compare the magnitude of stem flow for the different rubber trees. Volumetric weighted means were found by multiplying individual nutrient concentrations by their sample volumes, summing and then dividing by the total volume collected (Liu, et al., 2002; Chuyong et al., 2004). Stem flow inputs of the each sample tree were also summed over the entire period and expressed per unit sample plot. These were then used to compare the nutrient inputs of the different stands. Elemental concentrations in stem flow in the three different rubber stands were compared statistically using one-way analysis of variance. Differences were considered statistically significant at *P* (0.05) unless otherwise stated using the student *t*- test. The statistical analyses were performed using the SPSS for windows Version 11.0 (SPSS, 2003).

Results and Discussion

Hydrological Fluxes

Although the amount of bulk open field deposition (OF), through fall (TF), were also measured during this study, only the nutrient inputs and concentration in stem flow was considered in this paper. The mean annual rainfall in the area was 1540.3 mm (Table 1). Annual precipitation measured in the study area by automatic rain gauge for the study period ranges from a minimum of 2.3mm in December 2005 to a maximum of 440.9mm in June 2007. Canopy interception in the different rubber stand was characterized by a distinct seasonal pattern, a low capacity for water storage, and was greatly influenced by the total rainfall and rainfall intensity. The amount of incident rainfall intercepted by the canopies in the rubber plantation varied among the different stand ages. It ranged from 13% of precipitation in the 15-year-old rubber stand to 18.9% in the 40-year-old rubber stand (Table 1).

Table 1: Precipitation (P) partitioning into through fall, stem flow, and interception loss in the 40, 15, and 5 year-old rubber stands at the Remo Rubber Plantation, Ikenne (July 2005-June 2007).

	40 year-old		**15 year-old**		**5 year-old**	
	mm y^{-1}	% of P	mm y^{-1}	% of P	mm y^{-1}	% of P
Through fall	990.1	64.3	1036.6	67.3	1075.0	70
Stem flow	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

Canopy interception in the 5-year-old rubber stand is 16% of incident rainfall. Monthly interception ranged from 6.2 to 19.4% in the rainy season and 18.5 to 70.3% in the dry season. Interceptions exceeded 25 mm for most of the rainy season, with the greatest interception of 89 mm in June 2006. During the dry season, most of the incident rainfall was low and of low intensity, therefore intercepted by the canopy. Overall, the amount of interception loss by the rubber canopy increased with rainfall. However, the rate of interception, expressed as the ratio of interception by canopy to rainfall, decreased with rainfall.

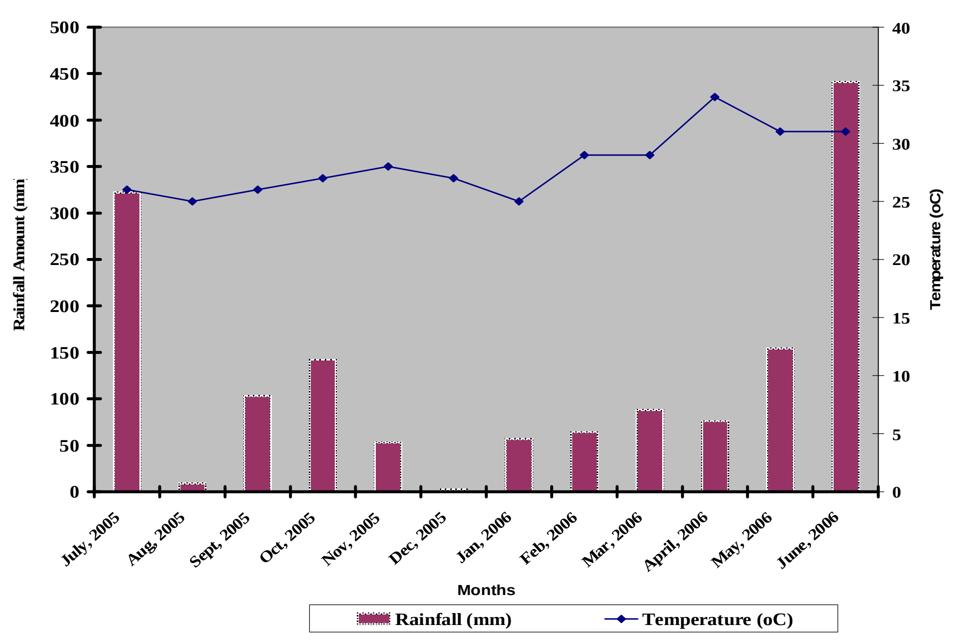


Figure 2: Incident rainfall and temperature at Remo Rubber Plantation (July 2005-June 2007)

Dynamics of Stem Flow (SF)

Comparison of stem flow from stems of different stand ages

Within the rubber plantation, the amount of stem flow comprised only 17% of the annual rainfall on the average. Estimated total stem flow (expressed in mm of incident rainfall) for the study period (June 2005 to June 2007) were 258.9 mm, 303.4 mm and 210.2 mm (Table 1), constituting 16.8, 19.7 and 14% of the annual incident rainfall in 40 years, 15 years and 5 year-old rubber stands respectively. Monthly stem flow was significantly and positively correlated with incident rainfall (r = 0.96, 0.94 and 0.95 for the 40 years, 15 years and 5 year-old rubber stands forests respectively, n = 35, P < 0.05). Stem flow estimates for the three rubber stands were very variable and high values. This variability among different stand age (also within the same stand) was reflected in their funneling ratios (FR) which ranged from 0.8 to 35.6, with majority of the rubber trees sampled in the study having FR >10.0.

In this study stem flow was higher in the 15 year-old stand, which is smaller in size to the 40-year-old stand. The stem flow is significantly increased in the 15-year-old rubber stand (19.7% of total incident rainfall). This is quite high compared with 9.02 % for Lenga trees *Nothofagus pumilio* in Chile (Godoy, Oyarzun & Bahamondes, 1999), or 0.70% for Red pine *P~nzrs resinosa* in Canada (Mahendrappa, 197), or 1.96% for Stone oak, zhui shu *Lithocarptrs-Castanopsis* association with bryophytes in China (Liu, Fox & Xu, 2003). It is however similar to the 20.00 % reported for Vismia (fallow species) *Ksmia* spp. in Brazil (Schroth *et al.,* 2001) and 22.00 % for Monterey Pine *Pinus radiate in* Chile (Uyttendaele & Iroume, 2002). Some studies have found a positive correlation between stem flow on the one hand, and tree basal area (Crockford and Richardson, 2000) and stem angle (Martinez-Meza and Whitford, 1996) on the other. Stem flow amounts were found to increase with tree size or canopy size, i.e. tree age, because larger and taller trees tend to have a greater catchment area for rainwater. Johnson (1990) found that stem flow yield decreased with tree age from 39% (age 14) to 2% (age 63) of total rainfall in five stands in the UK

Maximum monthly stem flow occurred in June 2006, the same period with the maximum monthly rainfall, with 84 mm (19% of that month's rainfall). Stem flow was greatly reduced during the dry seasons (November to March) because the rubber canopies intercept much of the incident rainfall. However stem flow is greater in the 15-year-old rubber stand indicating the potential for more nutrient release than the two other stands. Many forest and agricultural hydrologist have observed that stem flow production increases with the magnitude of a precipitation events (Xiao et al., 2000; Kuraji et al., 2001). For smooth-barked trees, once the interception storage capacity is reached, stem flow generation closely match the rainfall pattern of the precipitation event.

Since stem flow water and nutrient inputs are controlled in part by branching angle (Levia and Herwitz, 2002; Levia, 2003), tree species with larger proportion of erectophile branches may have higher stem flow leachate inputs than those with gently sloping branches. Rubber trees have steep sloping leaves and therefore produce considerable high amount and nutrient inputs. Individual stem flow increased in a linear function with increasing rainfall depth Stem flow data from wet and dry seasons were statistically compared to determine the influence of leaves on stem flow generation in the study area. Stem flow amounts collected during wet season differ significantly ($P < 0.05$) from those of dry season demonstrating that in the rubber plantation, the absence of leaves during winter months affect generation of stem flow.

Rubber trees especially the younger ones have smooth barks tend to increase the amount of stem flow more than the older trees. SF amount was 258.9 mm (16.8 %) of gross precipitation in the 40 year-old rubber stand, while it was 303.4 mm (19.7%) and 210.2 (14%) of gross precipitation for the 15 and 5 year-old stands respectively (Table 1).

Nutrient concentration in stem flow

The weighted monthly pH values (5.8 to 7) for precipitation is close to neutrality. The solution flowing along the trunk surface already contained elements caught in the canopy but also collected large amounts of elements from contact with stem bark. This is an indication that the canopy partitioning of incident rainfall exerts a strong influence on nutrient fluxes delivered via stem flow. The enhancements in concentration with respect to rainfall was just about 1-1.5 times for NO_3^--N, SO_4^{2-}-S and total N, but was much higher and more variable for Ca^{2+}, Mg^{2+}, K^+, and Na^+ (Table 2, Figure 3), which were significantly higher in stem flow from stems of the 15 year-old rubber stand than the two other stands. The median of the volume weighted mean concentrations of cations such as Ca^{2+} (18.96µeq l^{-1}) is greater than that of anions such as Cl^- (10.87µeq l^{-1}) in the 15 year-old stand as well as the two other stands. The most abundant cation (in terms of equivalent concentration, which is molarity times the ion valence) was Ca^{2+}, followed by Na^+, K^+ and Mg^{2+}. The order of abundance of anions was Cl^-, $SO_4{}^{2-}$, $NO_3{}^-$, and $H^{+,}$

Table 2: Descriptive chemistry of seventeen stem flow collections at Remo Rubber Plantation, Ikenne, south-western Nigeria (July 2005-June 2006)

N		**Ca^{2+}**	**Mg^{2+}**	**K^+**	**Na^+**	**NH_4^+**	**H^+**	**SO_4^+**	**NO_3^-**	**Cl^-**
					$\mu\ eql^{-1}\ yr^{-1}$					
					40 year-old					
Min.		11.97	0.04	1.34	2.52	<0.01	<0.01	0.04	<0.01	7.33
Max.		20.95	0.13	2.56	4.04	<0.01	<0.01	0.07	<0.01	11.83
Median	17.46	0.12	2.04	2.43	<0.01	<0.01	0.05	<0.01	9.28	
St. Dev.		2.90	0.01	0.27	0.22	<0.01	<0.01	0.01	<0.01	1.66
St. Error	0.70	<0.01	0.07	0.10	<001	<0.01	<0.01	<0.01	0.40	
C.V. (%)	11.49	11.61	12.39	11.86	85	87.09	15.56	101.74	12.81	
				15 year-old						
Min.		14.99	0.08	1.53	2.39	<0.01	<0.01	0.05	<0.01	7.39
Max.		25.45	0.16	2.87	4.73	<0.01	<0.01	0.09	<0.01	13.69
Median	18.96	0.11	2.42	2.63	<0.01	<0.01	0.07	<0.01	10.87	
St.Dev.		3.36	0.02	0.36	0.39	<0.01	<0.01	<0.01	<0.01	1.76
St. Error	0.81	<0.01	0.09	0.09	<001	<0.01	<0.01	<0.01	0.43	
C.V. (%)	17.54	15.75	12.84	12.63	37.68	45	14.18	17.10	9.83	
				5 year-old						
Min.		10.97	0.09	1.23	2.48	<0.01	<0.01	0.05	<0.01	7.19
Max.		27.45	0.13	2.41	4.15	<0.01	<0.01	0.06	<0.01	10.97
Median	15.96	0.12	1.92	2.54	<0.01	<0.01	0.06	<0.01	9.82	
St.Dev.		2.54	0.02	0.22	0.31	<0.01	<0.01	<0.01	<0.01	1.65
St. Error	0.85	<0.01	0.08	0.10	<001	<0.01	<0.01	<0.01	0.36	

C.V. (%)	8.52	10.13	16.77	12.72	74.15	65.8	14.139	50.58	5.69

Note: Values of through fall chemistry were expressed in μeql^{-1} yr^{-} to show the degree of concentration of each ion.

Total annual nutrient inputs reaching the rubber floors in each stand indicated that canopy leaching increased each nutrient amount. Canopy partitioning of incident rainfall exerts a strong influence on nutrient fluxes delivered via stem flow in the rubber stands. Comparing fluxes the three different stands and rainfall regimes shows larger stem flow fluxes of $Ca2^{+}$, Na^{+}, K^{+} and Mg^{2+} regardless of season. In contrast, $SO_4{}^{2-}$, $NO_3{}^{-}$, and $H^{+,}$ showed an indeterminate relationship with stem flow partitioning. High amount of precipitation does not simply imply larger stem flow fluxes for these plant-mobile nutrients. However, to a certain extent, increased precipitation generally results in larger volumes of more dilute stem flow.

The total annual stem flow input to the rubber stands on per hectare basis constitute a minor component, accounting for 4 % of that through fall for most nutrients due to the high amount of water flowing through them. Johnson and Lehamnn (2006) argued that dilute nutrient concentrations in precipitation imply that foliar leaching is much more common than foliar uptake.

Foliar leaching of cations from plant tissue is driven by exchange reactions with rainfall-supplied hydrogen ions (Fan & Hong, 2001). These H^{+} ions more easily displace those nutrients that are mobile within the plant. Although K^{+} is a more mobile nutrient in plants and therefore is more easily leached to stem flow than Ca^{2+} (which is incorporated into cell walls) as reported by authors (Bruijnzeel, 1991; Marques and Rangers, 1997; Johnson and Lehamnn, 2006), there is far more Ca^{2+} in the stem flow for this study suggesting external sources of Ca^{2+} deposition (most probably due to anthropogenic influences e.g. bush burring, dust and soil erosion). Foliar uptake occurs when lower elemental concentrations are found in plant tissue than in rainfall. In addition, epiphytic plants and lichens contribute to uptake of nutrients from intercepted rainfall (Houle *et* al., 1999). The nutrient inputs through stem flow are however quite substantial considering the fact that the plantation is not receiving additional inputs of nutrient in form of fertilizers. Stem flow leaching of Ca^{2+}, K^{+}, Na^{+}, and Mg^{2+} are of particular significance due to their key roles in plant metabolism (Marschner, 1995).

Elevated K^{+} concentrations may also be the result of burning (Delmas, 1982) which is a common phenomenon in many parts of West Africa during land preparation for farming. Biomass burning has been cited as the reason for acidic precipitation in some parts of the tropics (Lacaux et al. 1987). There is also the presence relatively low H^{+} concentration (relatively high pH) of atmospheric depositions (stem flow and through fall) collected during the study suggest the presence of alkaline buffer, probably $HCO_3{}^{-}$, associated with various base cations, Ca^{2+}, K^{+} , $Mg^{2+}$and Na^{+}.

The result of the one-way analysis of variance of stem flow solutions among the rubber stands showed that the amount returned to the soil varied significantly ($P < 0.05$). The flux of nutrients in the plantation revealed significant variations between and within rubber stands ($P < 0.05$).

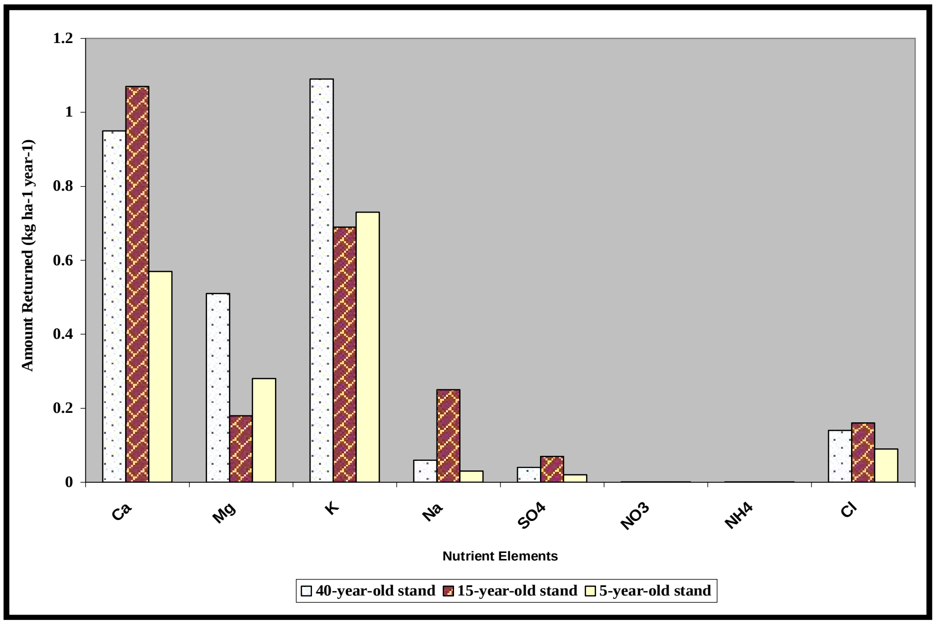


Figure 3: Nutrient return via stem flow (all Stands) in rubber (*Hevea brasiliensis*) plantation agro ecosystem at Remo Rubber Plantation, Ikenne, South west, Nigeria

Nutrient dynamics in stem flow solution are enriched in some elements (Ca^{2+}, Na^{+}, Cl^{-}, and K^{+}) but others are impoverished (total N, NH_4^{+} , -N, and NO_3^{-} - N) as a result of stem bark interactions. The stem bark significantly affect the amount and chemistry of stem flow especially in the 15 year-old rubber stand because their smooth barks allowed more stem flow volume than the 40 year-old stand whose stem bark is coarse due to old age and the 5-yer-old stand whose stem bark is still slender and with smaller basal area which do not support as much stem flow volume as the 15 year-old rubber stand.

Table 3: Seasonal and annual input of nutrients via stem flow (all Stands) in rubber (*Hevea brasiliensis*) plantation agro ecosystem at Remo, 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}							
40 year-old Stem flow	**Dry**	0.12	0.02	0.15	0.01	0.01	< 0.001	< 0.001	0.02
	Wet	0.83	0.49	0.94	0.050.03	< 0.001	< 0.001	0.12	
	Total	0.95	0.51	1.09	0.060.04	< 0.001	< 0.001	0.14	
15 year-old Stem flow	**Dry**	0.24	0.08	0.27	0.03	0.01	< 0.001	< 0.001	0.06
	Wet	0.83	0.10	0.42	0.220.06	< 0.001	< 0.001	0.10	
	Total	1.07	0.18	0.69	0.250.07	< 0.001	< 0.001	0.16	
5 year-old Stem flow	**Dry**	0.06	0.01	0.10	0.01	0.01	< 0.001	< 0.001	0.01
	Wet	0.51	0.27	0.63	0.020.01	< 0.001	< 0.001	0.08	
	Total	0.57	0.28	0.73	0.030.02	< 0.001	< 0.001	0.09	

The 15 year-old stand stem bark also intercept more mineral elements than the two other stands going by the higher nutrient concentrations. Enrichment of stem flow water has been attributed to inputs from mosses, lichen and other organisms living on the surface of boles and branches of trees (Nye, 1961; Yawney *et al.,* 1978; Veneklaas, 1990; Weathers, 2000; Levia, 2003). Other has also attributed the enrichment to the presence of epiphytes (Coxson and Nadkarni, 1995; Lowman and Nadkarni, 1995; Liu et al., 2002). Epiphytes reportedly increase total atmospheric input in tropical montane forests o values 2.5 times higher than for lower elevation forests (Bates and Farmer, 1992).

Conclusion

Going by the amount of nutrients in different rubber age stands, it is concluded that there are significant differences in the composition of nutrients in stem flow in the three age stands. The atmospheric deposition data for the study area show a generally low cycling rate of mineral elements. Atmospheric dust is enriched in Ca^{2+}, Na^{+}, and K^{+}, which is a source of cations to the typically cation-depleted West African soils. The abundance of Ca^{2+}, Na^{+}, Mg^{2+}; and K^{+} can be attributed to pollution from growing urban population and aeolian soil erosion. Generally, NH_4^{+}, NO_3^{-}, and H^{+} are greatly reduced due to absorption by the canopies, whereas base cations and organic acids are leached from foliage.

Inputs of major elements such as Ca^{2+}, Na^{+}, Mg^{2+}, and K^{+} in the different rubber stands are higher in the 15 year-old stand than the 40 year and 5 year-old stands. This in effect show that the rubber stands reached the highest capacity to cycle nutrients effectively and efficiently around the 15 year age bracket after which the ability to function well in nutrient cycling start to decline. Old rubber stands like the 40 year-old have gone past their productive capacity and needs to be felled and new ones planted. Atmospheric deposition of nutrients can vary significantly between years, therefore a long term monitoring programme is desirable where atmospheric deposition monitoring programme can be maintained with relative ease Monitoring of atmospheric deposition is not only relevant to the study of biogeochemical cycle and health of forest ecosystem but it can also be used as an index of changes in land use in these forests. The resultant data from monitoring atmospheric nutrient deposition can also be combined with measurements of nutrient fluxes from other sources to construct a whole agro ecosystem nutrient budget to achieve sustainable management.

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