Hydrology for Disaster Management

Special Publication of the Nigerian Association of Hydrological Sciences, 2012

http://www.unaab.edu.ng

Biogeochemical Consequences of Hydrologic Conditions in Isolated Stands of *Terminalia Cattapa* in the Rainforest Zone of Southern Nigeria

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Abstract

Nutrient cycling is vital to the sustenance and productivity of trees and other plants. Farmers incorporate stands of exotic trees into their farms to provide shade and fruits thereby, contributing to the rural economy. Despite the importance of these isolated trees in the environment, the biogeochemical implications of hydrologic processes of isolated exotics have not been adequately documented in southern Nigeria. This study examined biogeochemical implications of hydrologic processes under isolated stands of *Terminalia cattapa* (T. cattapa) in Orogun, southern Nigeria. Throughfall and stemflow were collected from 15 stands of *T. cattapa* between February 2010 and January 2011; while soil samples were collected underneath the trees. Throughfall and rainfall were collected with funnel-type collectors; stemflow was collected with ¾ mm hose wound round tree trunks; and soil samples collected with a core sampler. Samples collected were analysed in the laboratory using standard methods. Data obtained were statistically analysed with both descriptive and inferential techniques using the SPSS 15.0 version. Annual throughfall and stemflow volumes were 89.2% and 6.5% of the incident rainfall (4325mm). Nitrogen, phosphorus and potassium returned to the soil via throughfall and stemflow varied, with marked similarity between the isolated tree stands and adjoining rainforest used as control. Potassium returned to the soil via throughfall in *T. cattapa* and rainforest were 62.5 kg/ha/yr and 65.4 kg/ha/yr; while the corresponding values for calcium were 30.6 kg/ha/yr and 31.3 kg/ha/yr. More nutrients were returned via throughfall between November and March while peak nutrient returns via stemflow occurred between May and October. Soil nutrients (N, P, K) correlated with throughfall and stemflow at $r \geq 0.23$ and $r \geq 0.45$ respectively. The isolated exotic tree stands were not observed to deplete soil nutrients. Their gradual returns of nutrient elements to the soil through hydrologic processes overtime help to improve soil nutrient status in the rainforest ecosystem.

Key words: Biogeochemical cycling, hydrologic processes, nutrient fluxes, Rainforest ecosystem, Southern Nigeria, *Terminalia cattapa*.

Introduction

Hydrologic deposits through stemflow and throughfall contribute to soil nutrient properties underneath tree stands in the rainforest ecosystem (Parker, 1983; Muoghalu and Oakhumen, 2000). In the process of nutrient cycling, tree stands have been observed to return nutrient elements to the soil through stemflow and throughfall (Chuyong et al., 2004). Nutrient cycles in forests are closely linked to the hydrological cycle because water acts as the main solvent and transporting agent for nutrient elements from the aboveground tree stands to the soil underneath (Bruijnzeel, 2001).

The soils in the environment support the growth of plants. These plants get their moisture and nutrients from the soil, which are utilized for their growth and development. As the plants grow, hydrologic conditions through the washing of nutrients from the leaves and stems of plants by rainfall serve as important sources of nutrient fluxes from the aboveground tree stands to the soils underneath (Newson, 1997; Ward and Robinson, 2000). Dust accumulation on leaves and branches, transported to the soil by throughfall and stemflow is suggested as an important input of mineral nutrients and nitrogen (Muoghalu and Oakhumen, 2000). In the rainforest ecosystems, tree canopies intercept rainfall and redistribute the water to the atmosphere by evaporation and to the ground by throughfall and stemflow. Nutrients returned to the soil through stemflow and throughfall have been observed to help in the maintenance of soil fertility by increasing the quantities of the nutrient elements in the soil (Soulsby and Reynolds, 1994; Muoghalu and Oakhumen, 2000).

In the rainforest zone of southern Nigeria, exotic tree plants such as Indian almond (*T. cattapa)* are planted to produce fruits and shade for resting places within the settlements and surrounding environment. Many of such tree stands are found in isolation (i.e. their canopies are separated from one another) since they are not cultivated in plantations. Although the economic importance of these trees are deemed to be known, no effort has been previously directed to the consideration of their ecological implications in terms of hydrologic contribution to nutrient cycling, and their viability in the environment after the natural plant covers have been cleared in the wetter rainforest ecosystem of southern Nigeria.

Essentially, different studies on nutrient cycling with respect to stemflow and throughfall have been conducted in different parts of the world. Parker (1983) studied throughfall and stemflow in forest nutrient cycle; Soulsby and Reynolds (1994) examined the chemistry of throughfall, stemflow and soil water beneath oak woodland and moorland vegetation in Mid-Wales; while Goller (2005) examined the biogeochemical consequences of hydrologic conditions in a tropical montane rainforest in Ecuador. Also, in the Nigerian rainforest ecosystem, studies by Muoghalu and Oakhumen (2000) were conducted on drier natural rainforest ecosystem; whereas the study by Adedeji (2008) was conducted on plantation ecosystems. From these studies however, the hydrologic contributions of individual tree stands to the soil in nutrient cycling were not effectively ascertained due to close canopy influence. Therefore, the results of such studies cannot provide a rational basis to account for understanding nutrient cycling under isolated tree stands.

The rate at which different plant species immobilize nutrients varies, and results of studies on the more economically important tree plants such as cocoa, teak, rubber, gmelina and oil palm cannot provide a rational basis to account for understanding nutrient cycling under every tree species, as different plant species exert varying effects on the soil (Ndakara, 2012). This emphasizes the need to examine the cycling of nutrients under isolated tree stands in the rainforest ecosystem.

The main objective of this study therefore, was to examine throughfall, stemflow and incident rainfall so as to ascertain the returns of nutrient elements to the soil under isolated stands of *Terminalia cattapa*; and also determine the relationships between the topsoil nutrient properties and nutrients returned in throughfall and stemflow. This is with the view to determine if the isolated exotic tree stands could help to improve soil nutrient status in the rainforest ecosystem, and therefore be integrated in the farmlands to help in the sustenance of soil productivity.

Methodology

Study Area

This study was conducted on the isolated stands of *Terminalia cattapa* (Indian almond) in the moist tropical rainforest of Orogun in Southern Nigeria. Orogun region falls within the humid sub-equatorial climate of Af Koppen's classification, with annual rainfall above 2000mm, and average temperature of about 26ºC (Ndakara, 2006). The topography is a low plain with slope of ≤ 2°. The soils are mainly alfisols and oxisols. The natural vegetation is the moist evergreen tropical rainforest with tree forms ranging in strata from shrubs to exceedingly tall members. This natural vegetation has been affected by man owing to centuries of shifting cultivation and settlement development, such that the originally contiguous ecosystem now feature as island habitats or sacred groves (Ndakara, 2006; 2009), and confined to sacred places where human induced degradation activities are restricted. However, exotic stands of trees such as *Persea gratissima* (Avocado pear), *Mangifera indica* (Mango) and *Terminalia cattapa* (Indian almond) are found cultivated within the settlements and farm areas.

Experimental Design and Samples Collection

The study area was divided into 5 units based on the existing 5 quarters of the clan (Umusu, Unukpo, Imodje, Emonu and Ogwa). The quarters were so used in this study to ensure that every part of the study area was covered. In each quarter, 3 stands of the isolated trees were selected, making a total of 15 tree stands sampled. The selection of the isolated tree stands was based on the condition that they were not subjected to sweeping and burning which expectedly could have impact on the soil properties underneath the trees in the process of nutrient cycling. Also, each tree was so selected such that their canopies were separated from other tree canopies, thereby eliminating relationships with it. The adjoining rainforest in each quarter was divided into quadrats of 10m × 30m and used as control for the study; in addition to the incident rain water collected from the open spaces.

Samples collections were on soil, throughfall, stemflow and incident rainfall. Stemflow samples were collected by intercepting the water running down the tree stems near the ground, with a rubber channel (¾ mm hose) wound round the tree stands, sealed with bitumastic paste and channeled into 5 litter clean gallons; while throughfall and incident rainfall samples were collected with improvised funnel-type collector (constructed of 1 US gallon capacity Clorox bottles and plastic funnels with diameter of 21.2 cm). The funnels were placed in the mouths of the Clorox bottles, and secured to ¼ inch diameter metal stakes with elastic bands. The rainwash samples were collected for all rainfall events between February 2010 and January 2011 into labeled sampling bottles and taken to the laboratory for analysis on the concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sodium (Na), magnesium (Mg) and pH respectively. Soil samples were collected from the 0-15cm and 15-30cm depth of the soil profiles underneath the isolated tree stands. The soil samples were collected by the use of core sampler measuring 4" long and 3" in diameter. The samples were put into labeled polythene bags and taken to the laboratory for analysis on total nitrogen, available phosphorus and exchangeable cations (exchangeable calcium, magnesium, sodium and potassium).

Laboratory Analyses of Samples

Water samples were filtered before analysis through ash-free filter papers with a pore size < 2 µm (Schleicher and Schuell, blue band 589³). In the determination of total N, a segmented Flow Analyser (SANplus, SA 2000/4000, Skalar Analytical BV, The Netherlands) was used. The same equipment was used for the analysis of total P. Detection limits were (0.04 mg / l for total P and 0.05 mg / l for PO_4-P) in rainfall, stemflow and throughfall. Cation concentrations (Na, Ca, Mg and K) were determined by atomic absorption spectrometry

(AAS Atomic Absorption Spectrum – 932, GBC Scientific Equipment pty Ltd. Australia). The calculation of throughfall water and nutrient returns was based on the projected crown area; while stemflow was based on the chemical enrichment as adopted in a study by Levia and Frost (2003). Calculation of stemflow returns was based on the chemical enrichment because stemflow inputs seep into the soil only around a tree bole. The extent of chemical enrichment of stemflow from each test tree during a precipitation event was computed using an enrichment ratio.

Soil samples were analysed for the concentrations of nutrient elements viz: Total nitrogen was determined by first digesting the soil with H_2SO_4, and then the nitrogen content of the digest was determined with an auto-analyzer. In the determination of available phosphorus, available phosphorus extracts were obtained by leaching the soil with Bray P – 1 extracting solution of Hydrochloric acid and Ammonium floride (0.025N Hcl + 0.03N NH_4F). The concentrations of the nutrient cations (Calcium, Sodium, Magnesium and Potassium) in the soil were obtained by leaching the soil with 1N neutral ammonium acetate. The concentrations of calcium, sodium and potassium were determined with a flame photometer while magnesium was determined with an atomic absorption spectrophotometer.

Statistical Analyses of Data

Results of laboratory analyses were subjected to the descriptive and inferential statistics using the **SPSS 15.0** versions. The technique of mean was used to determine the mean values for the concentrations and returns of nutrient elements. Graphs were used to show the monthly volume of rainwash and seasonal variations in the returns of nutrient elements to the soil. Paired-Samples T-Test was employed to determine the differences in nutrient fluxes via throughfall and stemflow between the isolated tree stands and adjoining rainforest. While Pearson's bivariate correlation analysis was employed to ascertain the relationship between topsoil nutrient properties and nutrients returned in throughfall and stemflow.

Results

Volume of Throughfall, Stemflow and Incident Rainfall

Throughfall volumes vary between the isolated tree stands and the adjoining rainforest. The total measured annual volume of throughfall for the Indian almond and the adjoining rainforest are 3857.90 mm and 3641.65 mm. These values accounted for 89.2% and 84.2 % of the measured incident rainfall volume of 4325 mm. These values fall within the range of throughfall values reported for tropical rainforests of south western Amazonia with 89.9% by Germer et al (2006); tropical rainforest of Cameroun with 92.4 – 96.6% by Chunyong et al (2004); and in Nigerian rainforest with 78.8% by Muoghalu and Oakhumen (2000). The throughfall volume varied with the seasons of the year (figs 1 and 2) for both the isolated tree stands and adjoining rainforest, with highest quantity recorded within the peak of the rainy season.

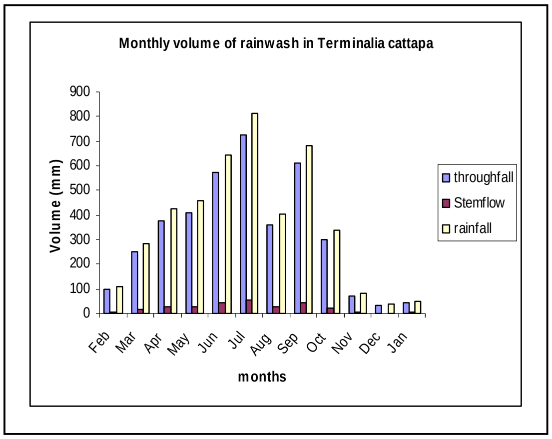


Fig. 1: Volumes of Rainwash in *T.cattapa*

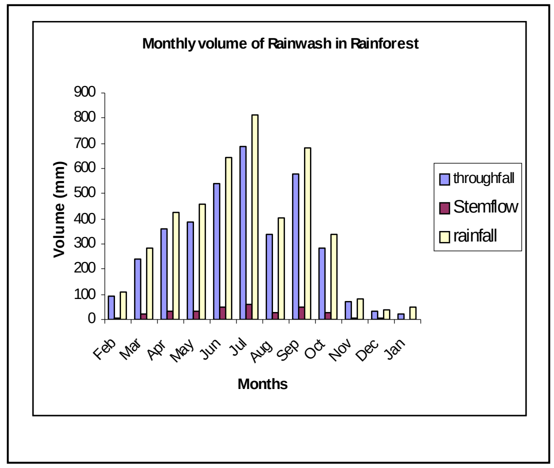


Fig. 2: Volumes of Rainwash in Rainforest

The total measured annual volume of stemflow for the Indian almond and the adjoining rainforest are 281.13 mm and 315.73 mm. These values accounted for 6.5% and 7.3 % respectively of the measured incident rainfall volume of 4325 mm, and they fall within the range of stemflow values reported for tropical rainforest in Nigeria with 5.2% (Muoghalu and Oakhumen, 2000). However, the values differ from findings in studies by Chuyong et al (2004) with stemflow values of 1.5 - 2.2%. Like the throughfall volume, the stemflow volume varies with the seasons of the year also.

Nutrient Concentrations in Throughfall, Stemflow and Incident Rainfall

Generally, rainwash and incident rainfall were observed to contain nutrient elements. However, the concentrations of the nutrient elements varied as observed in the throughfall, stemflow and incident rainfall (Table 1). The order of nutrient concentrations was observed to be Throughfall > stemflow > incident rainfall.

Throughfall has the highest concentrations of the nutrient elements while the incident rainfall has a very low concentration of the nutrient elements. Although some of the nutrient enrichment in rainwash is due to the leaching of nutrients out of the plant tissue, part is due to the capture of airborne (aerosols) by the tree stands.

Table 1: Mean concentrations of nutrient elements in $mg\ l^{-1}$

Nutrient elements	Throughfall		Stemflow		Incident rainfall
	T. cattapa	Rainforest	*T. cattapa*	Rainforest	
Nitrogen	5.99	6.64	0.65	0.71	0.20
Phosphorus	5.06	4.41	0.54	0.54	0.16
Potassium	62.51	65.39	12.33	12.12	2.43
Calcium	30.58	31.27	6.22	5.80	2.09
Sodium	0.89	0.90	0.41	0.43	0.08
Magnesium	21.45	19.63	4.78	4.69	2.16

For the isolated tree stands and adjoining rainforest, the concentrations of K, Ca and Mg in throughfall and stemflow are higher than those of N, P and Na. While the concentration of potassium is highest in the throughfall and stemflow, sodium concentrations were lowest in both the throughfall and stemflow.

Returns of Nutrient Elements via Throughfall, Stemflow and Litterfall

The returns of nutrient elements to the soil under isolated stands of *Persea gratissima* varied in the throughfall, stemflow and litterfall. Generally, stemflow returned the smallest amount of nutrient elements to the soil than the throughfall and litterfall. While the returns of N, P and Ca are highest in litterfall, the returns of K, Na and Mg are highest in throughfall.

Table 2: Mean annual returns of nutrient elements in kg/ha

Nutrient elements	Throughfall		Stemflow	
	T. cattapa	Rainforest	*T. cattapa*	Rainforest
Nitrogen	4.86	6.04	0.39	0.47
Phosphorus	0.66	0.53	0.05	0.08
Potassium	10.55	8.76	0.69	0.67
Calcium	6.84	4.47	0.68	0.28
Sodium	0.46	0.65	0.07	0.14
Magnesium	4.16	2.13	0.83	0.55

Throughfall returned more nutrients to the soil than stemflow (Table 2). While throughfall is a major pathway for potassium returns to the soil, nutrients from stemflow are generally a small fraction (< 15%) of those in throughfall. The returns of nutrient elements to the soil through stemflow and throughfall differ between the isolated tree stands and the adjoining rainforest. However, the observed variation does not significantly differ at the 5% level of confidence (Tables 3 and 4). The returns of P,K,Ca and Mg to the soil via throughfall was higher in the isolated tree stands than in the adjoining rainforest.

Table 3: T-Test Results for Nutrients Returned via Throughfall between *T.cattapa* and adjoining Rainforest

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Almond	4.5883	6	3.82998	1.56358
	Forest	3.7633	6	3.26999	1.33497

Table 4: T-test results for Nutrients returned via Stemflow between *T.cattapa* and adjoining Rainforest

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Almond - Forest	.82500	1.43552	.58605	-.68148	2.33148	1.408	5	.218

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Almond	.4517	6	.33552	.13698
	Forest	.3650	6	.23552	.09615

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Almond - Forest	.08667	.20294	.08285	-.12631	.29964	1.046	5	.343

Seasonal Variations in Nutrient Fluxes

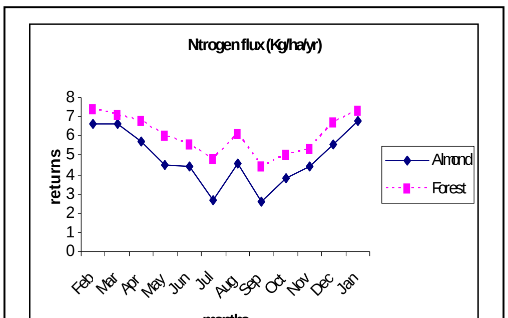
The trend in the returns of nutrient elements to the soil via throughfall and stemflow in the isolated stands of *T. cattapa* varied within the seasons of the year, as well as between the isolated tree stands and the adjoining rainforest (Figures 3-8).

Nutrient fluxes via throughfall are highest in the dry season months. The higher nutrient flux in the dry season could be attributed to the trapped dust particles by the tree stands which are washed down to the soil as throughfall. The dust particles, according to Vitousek and Sanford (1986), contain nutrient elements and serve as source of nutrient return to the soil in nutrient cycling. However, the returns of nutrient elements through stemflow are all lower in the dry season and higher in the rainy season, with observed reduction in the month of August. The higher nutrient flux during the peak of the rainy season could be accounted for by the ability of the heavy and constant rainfall to soak the tree trunk and barks, and therefore wash down more nutrient elements during this period. During the dry season, the reduced amount and frequency of rainfall affects the washing down of nutrient elements to the soil via stemflow (Vitousek and Sanford (1986).

Interrelationships between Nutrient Flux and Soil Nutrient Properties

Cycling of matter or nutrient cycling is an important way in which soils and plants exert reciprocal effects on one another. The isolated stands of *T. cattapa* in the rainforest are closely related with the soils underneath. The nutrient elements which are returned to the soil via throughfall and stemflow help to improve the soil nutrient characteristics under the isolated tree stands.

Table 5 presents the summary of Pearson's bivariate correlations between the topsoil nutrient properties and nutrients returned in throughfall and stemflow. The results as presented show that there are positive correlations between the pairs of nutrient elements between the topsoil and those returned via throughfall and stemflow. Therefore, biogeochemical cycling is enhanced by hydrological processes in isolated stands of exotic tree species thus, help to improve the soil nutrient properties underneath the tree stands.



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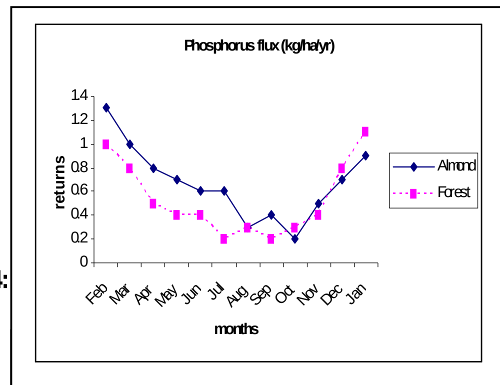

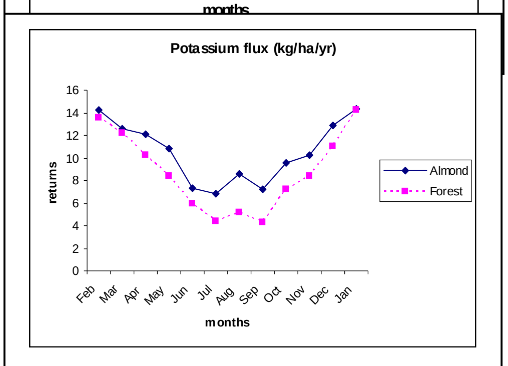

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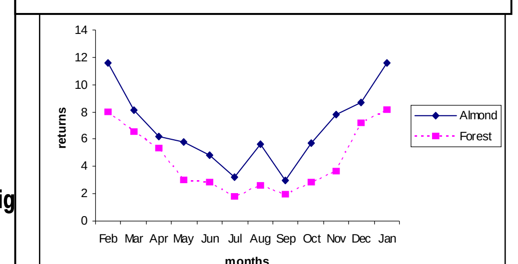

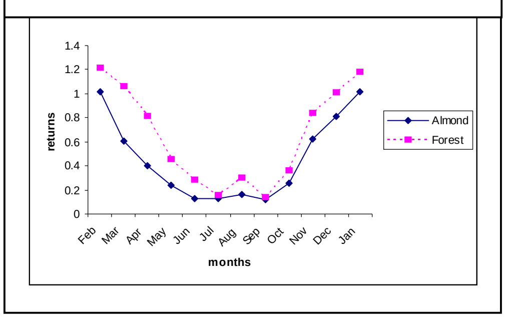

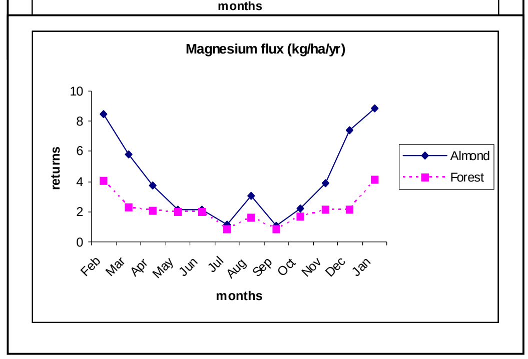

Fig 7: Seasonal variations in Sodium Flux

Fig 8: Seasonal variations in Magnesium Flux

Table 5: Summary of Pearson's Bivariate Correlations between Topsoil Nutrient Properties and Nutrients Returned in Throughfall and Stemflow

Nutrient elements	Sources of returns	Soil Nutrient Elements					
		Nitrogen	Phosphorus	Potassium	Calcium	Sodium	Magnesium
Nitrogen	Throughfall	.602	.324	.517	.558	.326	.238
	Stemflow	.202	.214	.324	.458	.226	.234
Phosphorus	Throughfall	.316	.717	.624	.321	.512	.231
	Stemflow	.216	.417	-.433	.303	.412	.201
Potassium	Throughfall	.568	.582	.723	.702	-.354	.543
	Stemflow	.468	-.482	-.214	.543	-.334	-.523
Calcium	Throughfall	.121	.552	.337	.827	.345	.423
	Stemflow	.111	.402	.122	.134	.435	.233
Sodium	Throughfall	.445	.582	-.438	.418	.810	-.084
	Stemflow	.345	.422	-.723	.442	.460	-.589
Magnesium	Throughfall	.106	.236	.443	.543	-.359	.664
	Stemflow	.116	.231	-.412	.434	-.554	.463

Discussion

Throughfall and stemflow have been observed to return nutrient elements to the soil under the isolated stands of T. cattapa. However, throughfall returns more nutrients to the soil than the stemflow (throughfall > stemflow). Unlike other sources of nutrient returns to the soil such as litterfall, nutrients input to the soil via throughfall and stemflow are immediately available for plants uptake. Rainwash volume varied with the seasons of the year.

Throughfall and stemflow have higher concentrations of dissolved nutrients than the incident rainfall. While some of this enrichment is due to the leaching of materials out of the plant tissue (Parker, 1983; Chuyong et al., 2004), part is due to the capture of airborne particles (aerosols) by the tree plants (Muoghalu and Oakhumen, 2000). Nutrients from stemflow are generally a small fraction (about 15%) of those in throughfall. The highest concentration and returns of all nutrient elements through rainwash to the soil was via throughfall, followed by stemflow and the lowest in incident rainfall. These observations are in line with findings in studies by Muoghalu and Oakhumen (2000) in a Nigerian secondary lowland rainforest, Chuyong et al (2004) in the rainforest ecosystem of Cameroon.

The higher fluxes in these nutrient elements could presumably be due to their high availability in the soil. The order of nutrient concentrations and returns to the soil through stemflow and throughfall is K > Ca > Mg > N > P > Na. This pattern is similar to the observed pattern reported by Chuyong et al (2004). Seasonal variations in the concentrations and returns of nutrient elements to the soil were observed for the throughfall and stemflow. While nutrient return in stemflow is highest during the heavy-rain months (May and October), nutrients returned in throughfall are highest during the early and late rains. The reason for high nutrients return and the observed seasonal returns of nutrient elements via throughfall is that it is likely due to washing off of dry-deposited harmattan dusts. These further corroborated the observed seasonal variations in nutrients returned to the soil via rainwash as reported by Parker (1983), Muoghalu and Oakhumen (2000), and Chuyong et al (2004). Generally, the concentrations and returns of nutrient elements to the soil via throughfall and stemflow varied but do not significantly differ at the 5% level of confidence between the stands of *T. cattapa* and the adjoining rainforest.

Findings on the relationships between the soil nutrient properties and nutrients returned to the soil via throughfall ant stemflow suggest that the greater the amount of nutrient elements returned to the soil through hydrological processes of throughfall and stemflow, the higher the nutrient status of the topsoil under the isolated tree stands. This relationship is to be expected because in the process of nutrient cycling, tree plants depend on soil nutrients for their growth and development while the reciprocal effects return nutrient elements to the soil through rainwash and other processes of nutrients return such as litterfall (Ward and Robinson, 2000; Chuyong et al., 2004). Nutrient elements returned to the soil through hydrological processes were positively correlated with soil nutrient properties. This implies that rainwash enhance the capacity of tree stands to regenerate soil fertility underneath.

Conclusion

This study examined throughfall and stemflow as hydrological processes of nutrient fluxes in isolated stands of T. cattapa in the rainforest ecosystem. The study focused on the concentrations and returns of nutrient elements to the soil under the tree stands through stemflow and throughfall, and therefore determined the relationship between the soil nutrient properties under the tree stands and the nutrient elements returned via throughfall and stemflow. However, the findings of this study revealed that throughfall and stemflow return nutrient elements to the soil, and are therefore important sources of nutrients return to the soil in the process of nutrient cycling. Nutrient elements were leached from the canopies and trunks of tree stands to the soils underneath during the precipitation events. From the results of this study, the isolated exotic stands of T. cattapa were not observed to deplete soil nutrients in the rainforest ecosystem. Their gradual returns of nutrient elements to the soil overtime help to improve soil nutrient status underneath. Therefore integrating stands of the fruit trees in farmlands can help sustain soil productivity as well as ensure sustainable tree stands in the ecosystem in the deforested areas.

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