Biodiversity Journal, 2024,15 (2): 143–155 https://doi.org/10.31396/Biodiv.Jour.2024.15.2.143.155

Characterising Rainwash Nutrient Fluxes and Soil Nutrients under *Anacardium occidentale* L. (Anacardiaceae) and Lowland Rainforest: implications for Ecosystem Management

Ndakara Ofudjaye Emmanuel[1,*] & Atuma Ifeanyi Morrison[2]

[1]Department of Geography and Regional Planning, Delta State University, Abraka, Nigeria
[2]Department of Arts and Humanities, School of General Studies, Delta State Polytechnic, Ogwashi-Uku, Nigeria
*Correspondending author, e-mail: ndascoemma@yahoo.com.

ABSTRACT This study aimed to ascertain the relationship between rainwash nutrient fluxes and soil nutrient properties under *Anacardium occidentale* L. (Anacardiaceae) and lowland rainforest for the purpose of sustainable ecosystem management. Both experimental and quasi experimental research designs were adopted. Samples from rainwash (for 12 months) and soil (from 0–15 cm and 15–30cm) were taken from 12 *A. occidentale* stands and 12 rainforests within 12 stratified quarters. Laboratory analyses of samples involved standard procedures, while data generated where statistically analysed. Results revealed that from *A. occidentale* and rainforest, fluxes of nutrients varied between throughfall (Tf) and stemflow (Sf), and between rainy season and dry season. The monthly nutrient fluxes by rainwash is such that Tf > Sf for both *A. occidentale* and native rainforest. The highest fluxes of nutrients by Tf occurred during dry months, with corresponding Sf fluxes were observed during rainy months. At 0.05 alpha levels, nutrient fluxes between Tf and Sf differed significantly; as well as between soil nutrient contents under *A. occidentale* and rainforest. Rainwash nutrients correlated positively and significantly with soil nutrients. Over time, *A. occidentale* add nutrients to soil through rainwash, therefore its cultivation is recommended for agro-forestry and sustainable ecosystem management.

KEY WORDS Agro-ecology; nutrient fluxes; plant-soil relationships; rainforest ecosystem; rainwash.

Received 04.03.2024; accepted 23.04.2024; published online 28.05.2024

INTRODUCTION

Cycling of nutrient properties is a vital way through which tree plants and soils exert reciprocal effects on one another (Carnol & Bazgir, 2013; Zhang et al., 2013; Kazumichi et al., 2018). In forest ecosystems, plants and soils have been observed to be closely related in terms of the exchange of nutrient properties and moisture, and they influence one another (Komprdová et al., 2016; Ngaiwi et al., 2018). The interrelationship between soil and plants is such that the plants get their nutrients and moisture from the soil in which they grow, through their roots. As the plants grow and develop, dust accumulation on leaves, stem and branches is transported directly to the soil under the plants through rainwash (throughfall and stemflow) which serve as an important source of nutrients addition to soil

(Chuyong et al., 2004; Tobon et al., 2004; Zhang et al., 2014; Abbasian et al., 2015; Purna et al., 2021).

Within typical rainforest, cycling of nutrients are connected to rainwash and water cycle because water serves as the transporting agent that moves nutrient elements from the aboveground standing trees down to soil (Muoghalu, 2003; Ndakara, 2012). Nutrient properties added to soil by rainwash help to maintain soil fertility by increasing the quantities and concentrations of nutrient properties in the soil, while the nutrients fluxed by rainwash are immediately available for plants uptake (Levia & Germer, 2015; Ndakara, 2016; Dawoe et al., 2018; Dunkerley, 2020). Therefore, nutrient elements returned to soil by trees determine their ability to maintain soil underneath their stands and the sustainable management of the ecosystem. Researches have shown that not all species of trees retain nutrients equally, hence they have varying effects on soil nutrients (Gruba & Mulder, 2015; Legout et al., 2016; Zhan et al., 2022). While the capacity of different trees in the maintenance of soils is shown by the high fertility status and closed cycling of nutrient properties within rainforest ecosystems, the contributions of nutrients to soil by each species of trees within the community vary irrespective of the type of ecosystem and species origin (Ndakara & Ofuoku, 2020; Wang et al., 2021).

Several researches have been carried out to investigate the extent of relationships between certain species of trees and soil nutrients underneath their stands. However, studies on nutrient contributions by *A. occidentale* to soil underneath their stands through rainwash have not been effectively carried out within the moist lowland rainforest environment. Although, the studies by Muoghalu & Oakhumen (2000) examined rainwash and their nutrient contents in a secondary lowland forest of Nigeria; Muoghalu (2003) investigated the contributions of rainwash and litterfall to the cycling of nutrients within Nigerian lowland rainforest; Chuyong (2004) studied the addition of nutrients by rainwash to soil in Central African rainforest; Germer et al. (2006) investigated throughfall and trends of rainfall redistribution in south-western Amazonia tropical rainforest; Ndakara (2012) examined the contributions of litterfall, stemflow and throughfall by *Persea gratissima* to soil within Nigerian rainforest environment; Gruba & Mulder (2015) investigated how certain tree species impact on soil cation binding, the exchange capacity of cations, and organic matter; Ndakara (2016) studied the hydrological fluxes of nutrients by *Mangifera indica* to Nigerian rainforest soil; Londe et al. (2016) studied litterfall with reference to forest productivity and ecological functions; Kazumichi et al. (2018) studied how plants and soils interact, and the implications on biodiversity maintenance and forest ecosystem functions; Ngaiwi et al. (2018) carried out a study to investigate how litterfall contributes nutrients to the rainforest soil of Cameroon, with implications on forest productivity; while Ndakara & Ofuoku (2020) characterized the plant biomass and soil properties under non-indigenous trees in Nigeria rainforest, and ascertained the extent of relationships between plants and soil. From these studies presented, the aspect of rainwash nutrient fluxes and the reciprocal interrelationships with the soil under *A. occidentale* in the Nigerian rainforest environment were not investigated.

Therefore, the focus of this research was to quantitatively ascertain the contributions of *A. occidentale* to the soil within the rainforest through rainwash, and determine the extent to which rainwash nutrients correlate with the soil nutrient properties, for the purpose of encouraging agro-forestry and achieving sustainable ecosystem management.

Other objectives of this research were the following: to study the variation of nutrient fluxes of rainwash within a year; differences in mean annual nutrient fluxes due to rainfall scavenging between *A. occidentale* and the rainforest; positive correlations between rainfall nutrients and soil nutrient properties under *A. occidentale* and rainforest. Furthermore, the following were examined: the average annual nutrient flows due to the floods between *A. occidentale* and the rainforest; the annual flows of nutrient properties from *A. occidentale* and rainforest and their diversity between runoff and throughflow; the different nutrient concentrations between *A. occidentale* and rainforest soils; whether there is a significant correlation between rainfall nutrients and soil nutritional properties in *A. occidentale* and rainforest.

MATERIAL AND METHODS

Study area

This study took place in the Orogun region, geographically locate in southern Nigeria between latitude 5°20'N and 5°36'N, and also between longitude 5°30'E and 6°06'E (Fig. 1).

This region situates in the lowland rainforest, and falls within the tropical climatic region with annual rainfall above 2000 mm, and average temperature of about 31.5 °C (Ndakara & Ofuoku, 2020; Ndakara & Ohwo, 2023). The natural forest vegetation comprises the moist evergreen lowland rainforest and riparian vegetation. Due to different anthropogenic disturbances and human impacts, the contiguous vegetal covers have been negatively affected, while relics of the native rainforest are now confined to sacred places. Some indigenous species of rainforest trees commonly found were the *Albizia adianthifolia, Nauclea diderrichii, Ceiba pentandra, Alstonia boonei, Piptadeniastrum africanum* and *Terminalia superba*. According to Byun et al. (2013), Sung et al. (2018) and Yuqi et al. (2023), these species of trees are specific to the native rainforest control plots. However, different species of non-indigenous trees like the *A. occidentale* were grown on farmlands and uncultivated areas to provide fruits and shade for the human inhabitants of the region. The soil orders characteristically fall within the alfisol, ultisols, oxisols and and psalment, following the U.S.D.A. soil classification taxonomy.

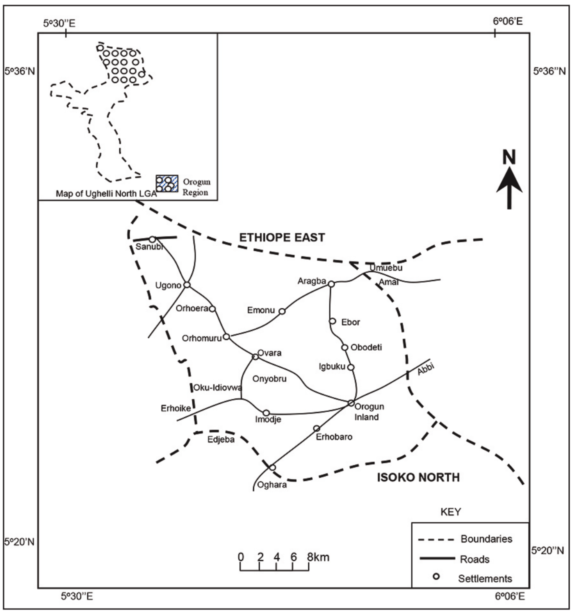

Figure 1. Study area: Orogun Region, Nigeria (modified by Ndakara, 2014).

Methodology

The research designs adopted were both experimental and quasi-experimental approaches. The study area was clearly divided into 12 parts considering the presence of isolated *A. occidentale* trees which were free from anthropogenic disturbances, and mature native rainforest. Samples of rainwash and those of soil were collected from 12 *A. occidentale* stands and 12 mature native rainforest (Rf) control plots dominated with stands of *Ceiba pentandra, Albizia adianthifolia, Nauclea diderrichii, Alstonia boonei, Piptadeniastrum africanum* and *Terminalia superba*, that featured commonly in all the rainforest sites. Collection of rainwash samples took place from January to December, 2023. Total samples taken and used in the study were 96 (Tf = 24, Sf = 24, Topsoil = 24, and Subsoil = 24).

Stemflow (Sf) samples have been obtained by intercepting the water running down the tree stems with rubber hose of ¾ mm size wound round the sampled trees, sealed with bitumastic paste and channeled into clean gallons. Samples of Tf have been obtained through the use of funnel-type collectors of 10 litre volumes stationed some feet above the ground. Rain gauges were set under *A. occidentale*, rainforest and open space to confirm how effective the funnel-type collectors were. Core sampler was used in the collection of soil samples from topsoils (0-15 cm) and subsoils (15-30 cm) depth of sampling spots under *A. occidentale* and rainforest. Laboratory analyses of samples were carried out to determine the concentrations of total nitrogen, available phosphorus, and exchangeable potassium, calcium, sodium and magnesium.

Determination of total nitrogen concentrations in soil has been obtained through auto-analyzer, after digesting with H_2SO_4. Determination of the soil phosphorus concentrations has been obtained with Spectronic 20 spectrophotometer, after colour development with Murphey and Riley reagent. In the determinations of soil Ca, Na and K concentrations flame photometer was used, while magnesium concentration was determined using atomic absorption spectrophotometer. The samples of water were first filtered before analyses were carried out for the concentrations of nutrient properties, which were later converted to nutrient fluxes (nutrients returned). A segmented Flow Analyser was used in determining the concentrations of phosphorus and nitrogen. Total N was digested with alkaline persulfate and ultraviolet so as to convert NH_4 – N and organic N into NO_3 – N; while the concentrations of K, Ca, Na, and Mg were determined by the use of atomic absorption spectrometry. Statistical analysis involved the descriptive, graph, ANOVA, T-test and Pearson's bivariate correlation techniques using the statistical package for the social sciences (SPSS) 22.0 version.

RESULTS AND DISCUSSION

Rainwash fluxes of nutrient properties to soil

The fluxes of nutrient properties varied between Tf and Sf components of the rainwash, between the rainy and dry season months, and also between *A. occidentale* and the native rainforest trees. The monthly pattern of nutrient fluxes by rainwash from *A. occidentale* and the native rainforest could be expressed as Tf > Sf for both *A. occidentale* and the native rainforest trees. The highest fluxes of nutrients by throughfall occurred during the dry season months of January and February, while the least fluxes occurred during rainy season month of September. While the highest nutrient fluxes by stemflow occurred during the rainy months of July and September, the least fluxes of nutrients occurred during the drier months between December and March.

Figures 2-7 present the mean monthly fluxes of nutrient properties by throughfall from *A. occidentale* and rainforest trees. For both stands of *A. occi-*

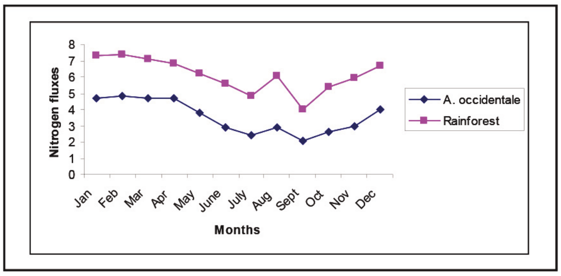

Figure 2. Monthly Tf fluxes of nitrogen (kg/ha).

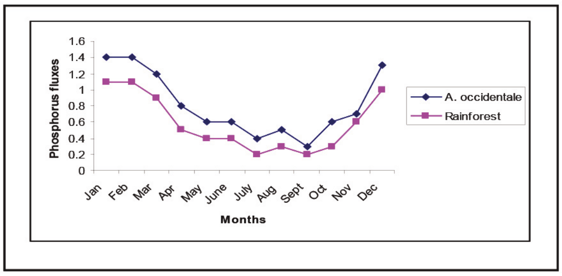

Figure 3. Monthly Tf fluxes of phosphorus (kg/ha).

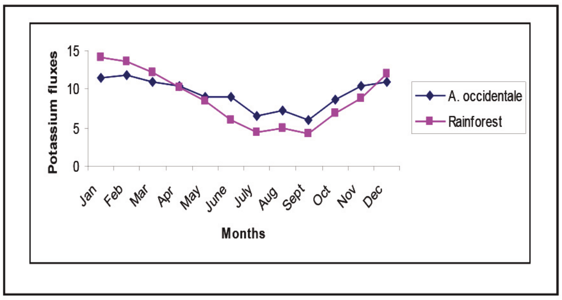

Figure 4. Monthly Tf fluxes of potassium (kg/ha).

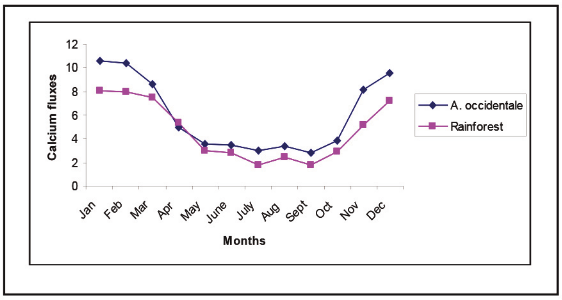

Figure 5. Monthly Tf fluxes of calcium (kg/ha).

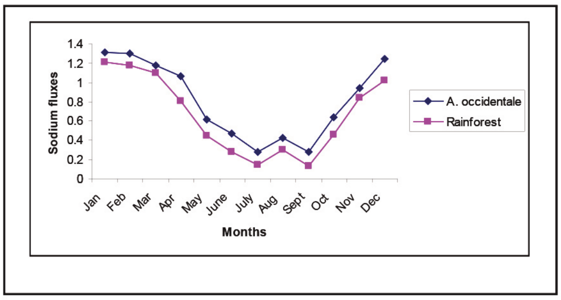

Figure 6. Monthly Tf fluxes of sodium (kg/ha).

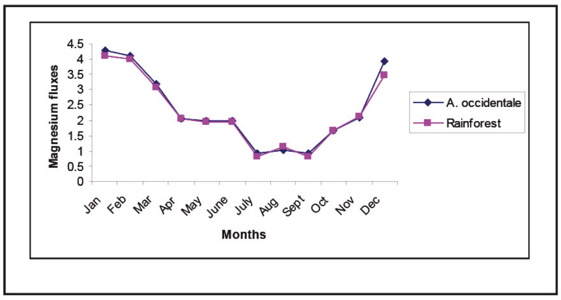

Figure 7. Monthly Tf fluxes of magnesium (kg/ha).

dentale and rainforest trees respectively, the highest monthly fluxes by throughfall for total nitrogen were 4.8 kg/ha and 7.4 kg/ha (in February), for available phosphorus were 1.4 kg/ha and 1.1 within January and February, for exchangeable potassium were 11.8 kg/ha and 14.2 kg/ha (in February and January respectively), for exchangeable calcium were 10.6 kg/ha and 8.1 kg/ha (in January), for exchangeable sodium were 1.31 kg/ha and 1.21 kg/ha within January, and for exchangeable magnesium were 4.27 kg/ha and 4.11 kg/ha (in January). The corresponding lowest monthly fluxes of nitrogen were 2.1 kg/ha and 4.0 kg/ha (in September), of available phosphorus were 0.3 kg/ha and 0.2 kg/ha (in September), of exchangeable potassium were 6.0 kg/ha and 4.2 kg/ha (in September), of exchangeable calcium were 2.8 kg/ha and 1.8 kg/ha within September and July respectively, of exchangeable sodium were 0.28 kg/ha and 0.15 kg/ha within September, and of exchangeable magnesium were 0.92 kg/ha and 0.80 kg/ha within September and July respectively. The monthly fluxes of nutrients from both stands of *A. occidentale* and the native rainforest trees through throughfall show that nutrient input by throughfall is highest during drier months, which could partly be caused by the washing down of captured aerosols from trees. A study conducted by Ndakara (2016) reported higher nutrient fluxes by throughfall during the dry season within humid lowland rainforest.

Figures 8-13 present the mean monthly fluxes of nutrient properties by stemflow from *A. occidentale* and rainforest trees. For the stands of *A. occidentale* and rainforest trees respectively, highest

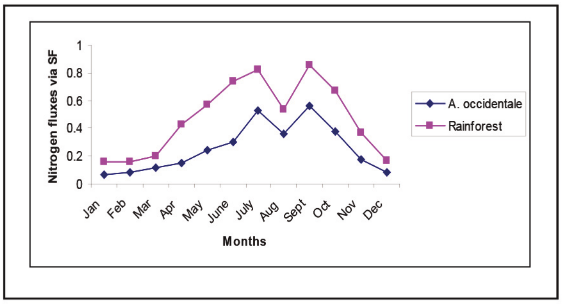

Figure 8. Monthly Sf fluxes of nitrogen (kg/ha).

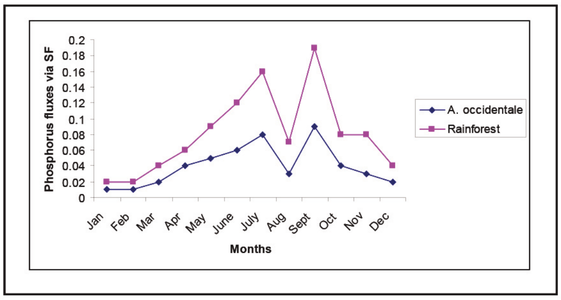

Figure 9. Monthly Sf fluxes of phosphorus (kg/ha).

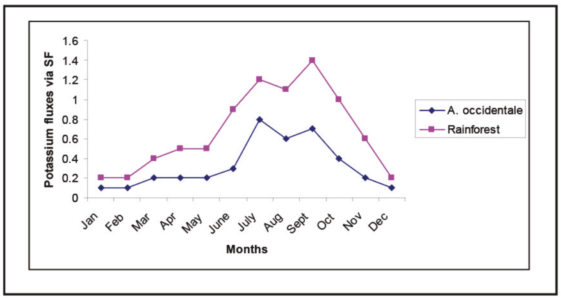

Figure 10. Monthly Sf fluxes of potassium (kg/ha).

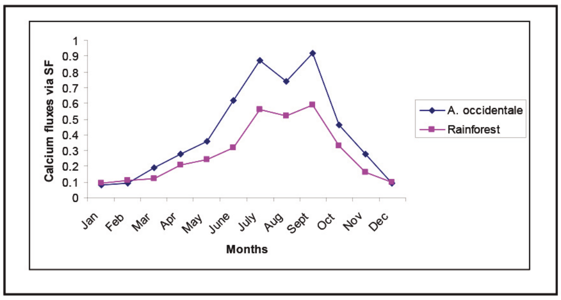

Figure 11. Monthly Sf fluxes of calcium (kg/ha).

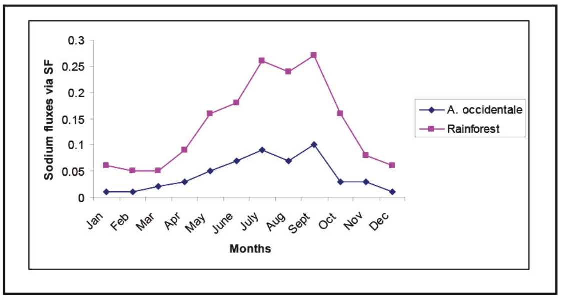

Figure 12. Monthly Sf fluxes of sodium (kg/ha).

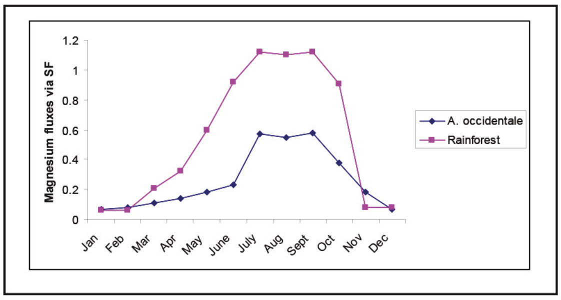

Figure 13. Monthly Sf fluxes of magnesium (kg/ha).

monthly fluxes by stemflow for total nitrogen were 0.56 kg/ha and 0.86 kg/ha (in September), for available phosphorus were 0.09 kg/ha and 0.19 (in September), for exchangeable potassium were 0.8 kg/ha and 1.4 kg/ha within July and September respectively, for exchangeable calcium were 0.92 kg/ha and 0.59 kg/ha within September, for exchangeable sodium were 0.10 kg/ha and 0.27 kg/ha (in September), and for exchangeable magnesium were 0.58 kg/ha and 1.12 kg/ha within September and July months respectively. The corresponding lowest monthly fluxes of nitrogen were 0.07 kg/ha and 0.16 kg/ha (within January and February respectively), of available phosphorus were 0.01 kg/ha and 0.02 kg/ha (within January and February respectively), of exchangeable potassium were 0.1 kg/ha within January, February and December and 0.2 kg/ha within January and February, of exchangeable calcium were 0.08 kg/ha and 0.09 kg/ha (in January), of exchangeable sodium were 0.01 kg/ha (in January and February) and 0.05 kg/ha (in February and March), and of exchangeable magnesium were 0.07 kg/ha (in January and December) and 0.06 kg/ha (in January and February). The monthly nutrient fluxes by stemflow from both stands of *A. occidentale* and rainforest trees shows that nutrients input by stemflow was higher within rainy months, which could partly be attributed to the leaching of nutrients out of the plant tissue through stemflow. Ndakara (2016) reported higher nutrient fluxes by stemflow during rainy season within humid lowland rainforest.

Table 1 shows the values of the $\bar{x}$, S.D and C.V for the rainwash nutrient fluxes by *A. occidentale* and rainforest trees. The values show that nutrients input to soil by throughfall was higher than the cor-

Nutrient Elements	Statistics	Throughfall		Stemflow	
		A. occidentale	Rainforest	*A. occidentale*	Rainforest
N	$\bar{x}$	3.55	6.11	0.25	0.47
	S.D	1.01	1.04	0.17	0.26
	C.V (%)	28.45	17.02	68.00	55.32
P	$\bar{x}$	0.82	0.58	0.04	0.08
	S.D	0.40	0.35	0.03	0.05
	C.V (%)	48.78	60.34	75.00	62.50
K	$\bar{x}$	9.37	8.82	0.33	0.68
	S.D	1.96	3.61	0.25	0.42
	C.V (%)	20.92	40.93	75.76	61.76
Ca	$\bar{x}$	6.04	4.67	0.42	0.28
	S.D	3.15	2.50	0.31	0.19
	C.V (%)	52.15	53.53	73.81	67.86
Na	$\bar{x}$	0.81	0.66	0.04	0.14
	S.D	0.40	0.41	0.03	0.09
	C.V (%)	49.38	62.12	75.00	64.29
Mg	$\bar{x}$	2.35	2.27	0.26	0.55
	S.D	1.23	1.15	0.20	0.46
	C.V (%)	52.34	50.66	76.92	83.64

Table 1. Descriptive statistics for rainwash nutrient fluxes in kg ha^{-1} yr^{-1}. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium; S.D = standard deviation; C.V = coefficient of variation; ha^{-1} = per hectare; yr^{-1} = per year.

responding input by stemflow; while nutrients returned by stemflow were more varied than nutrients returned by throughfall.

For all the nutrient elements, potassium fluxes by throughfall were highest from both *A. occidentale* and rainforest. While potassium flux by stemflow was highest from the rainforest, calcium was highest from *A. occidentale* trees. The lowest nutrient returned by throughfall from *A. occidentale* trees was sodium, while phosphorus was the lowest nutrient returned by throughfall from the native rainforest. The corresponding lowest nutrients returned by stemflow from *A. occidentale* were sodium and phosphorus, while phosphorus was the least nutrient returned by stemflow from the native rainforest. From both stands of *A. occidentale* and rainforest trees, rainwash returned more potassium, calcium, and nitrogen to soil than other nutrient properties.

Apart from nitrogen, all nutrients returned by throughfall were higher from *A. occidentale* than the rainforest. This implied that *A. occidentale* trees have higher capacity of nutrient inputs to soil than the native rainforest through throughfall. Conversely, apart from calcium, all nutrients returned by stemflow to soil were higher from the rainforest thus, implied that rainforest trees have higher capacity of nutrient inputs to soil than the *A. occidentale* trees through stemflow. These findings conform to the results reported by Ndakara (2012). The mean annual nutrient fluxes by rainwash between *A. occidentale* and native rainforest trees were tested with t-test statistics.

Table 2 presents the t-test results for the mean annual nutrient fluxes by rainwash between *A. occidentale* and rainforest. At 0.05 alpha levels, the values of $P < 0.05$ for throughfall fluxes of N, P, Ca

Nutrient Elements	Rainwash	Paired Samples	Paired Difference				T	Df	Sig. (P)
			Mean	S.E.M	Lower (95% CI)	Upper (95% CI)			
N	Throughfall	*A.occidentale/* Rainforest	2.5583	0.1011	-2.7809	-2.3358	25.305	11	0.000
	Stemflow	*A.occidentale/* Rainforest	0.2200	0.0344	-0.2956	-0.1444	6.404	11	0.000
P	Throughfall	*A.occidentale/* Rainforest	0.2333	0.0224	0.1839	0.2828	10.38	11	0.000
	Stemflow	*A.occidentale/* Rainforest	0.0408	0.0081	-0.0587	-0.0230	5.032	11	0.000
K	Throughfall	*A.occidentale/* Rainforest	0.5500	0.5368	-0.6314	1.7314	1.025	11	0.328
	Stemflow	*A.occidentale/* Rainforest	0.3583	0.0609	-0.4923	-0.2244	5.886	11	0.000
Ca	Throughfall	*A.occidentale/* Rainforest	1.3750	0.2818	0.7548	1.9952	4.879	11	0.000
	Stemflow	*A.occidentale/* Rainforest	0.1358	0.0367	0.0550	0.2167	3.698	11	0.004
Na	Throughfall	*A.occidentale/* Rainforest	0.1508	0.0149	0.1179	0.1837	10.091	11	0.000
	Stemflow	*A.occidentale/* Rainforest	0.0950	0.0158	-0.1299	-0.0602	5.999	11	0.000
Mg	Throughfall	*A.occidentale/* Rainforest	0.0833	0.0425	-0.0103	0.1769	1.960	11	0.076
	Stemflow	*A.occidentale/* Rainforest	0.2867	0.0824	-0.4681	-0.1052	3.478	11	0.005

Table 2. Results of t-test statistics for the mean annual nutrient fluxes by rainwash (kg ha^{-1} yr^{-1}) between *A. occidentale* and rainforest. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium; ha^{-1} = per hectare; yr^{-1} = per year (source: SPSS Output, 2024).

and Na between *A. occidentale* and rainforest were significant; the values of P > 0.05 for throughfall fluxes of K and Mg between *A. occidentale* and rainforest were not significant; and the values of P < 0.05 for the mean annual stemflow fluxes of nitrogen, phosphorus, potassium, calcium, sodium and magnesium between *A. occidentale* and rainforest were significant. The observed insignificance in potassium and magnesium fluxes by throughfall showed that both *A. occidentale* and rainforest trees returned about same annual values to the rainforest soil. These findings corroborate findings by Ndakara (2016) where exotic trees were reported to have capacity of returning nutrients to rainforest soil.

The results presented in Table 3 are the t-test outputs for the mean annual nutrient fluxes between throughfall and stemflow from *A. occidentale* and rainforest trees. At 0.05 alpha levels, the values of P < 0.05 for the mean annual fluxes of nutrients between Tf and Sf from *A. occidentale* and rainforest were significant. The levels of significance showed that although throughfall and stemflow return nutrients and contribute to soil nutrient quality underneath the tree stands, there is a wide difference in the amount of nutrient fluxes between the two rainwash sources. This is to be expected because the mean annual nutrient fluxes by throughfall were higher than the corresponding values for stemflow.

Concentrations of nutrients properties in soil under **A. occidentale** *and rainforest*

The concentrations of nutrient properties in soils under stands of *A. occidentale* and rainforest varied. This variation was also observed between the top-

Nutrient Elements	Sites	Paired Samples	Paired Difference				T	Df	Sig. (P)
			Mean	S.E.M	Lower (95% CI)	Upper (95% CI)			
N	*A.occidentale*	Throughfall/ Stemflow	3.2958	0.3376	2.5528	4.0389	9.762	11	0.000
	Rainforest	Throughfall/ Stemflow	5.6352	0.3712	4.8173	6.4510	15.180	11	0.000
P	*A.occidentale*	Throughfall/ Stemflow	0.7767	0.1218	0.5086	1.0447	6.377	11	0.000
	Rainforest	Throughfall/ Stemflow	0.5025	0.1137	0.2523	0.7527	4.421	11	0.001
K	*A.occidentale*	Throughfall/ Stemflow	9.0417	0.6332	7.6479	10.4354	14.279	11	0.000
	Rainforest	Throughfall/ Stemflow	8.1333	1.1577	5.5853	10.6814	7.026	11	0.000
Ca	*A.occidentale*	Throughfall/ Stemflow	5.6267	0.9860	3.4566	7.7968	5.707	11	0.000
	Rainforest	Throughfall/ Stemflow	4.3875	0.7712	2.6901	6.0849	5.689	11	0.000
Na	*A.occidentale*	Throughfall/ Stemflow	0.7692	0.1248	0.4944	1.0439	6.161	11	0.000
	Rainforest	Throughfall/ Stemflow	0.5233	0.1417	0.2115	0.8352	3.694	11	0.004
Mg	*A.occidentale*	Throughfall/ Stemflow	2.0867	0.4077	1.1893	2.9840	5.118	11	0.000
	Rainforest	Throughfall/ Stemflow	1.7167	0.4536	0.7182	2.7151	3.784	11	0.003

Table 3. Results of the t-test analysis for the mean annual nutrient fluxes between throughfall and stemflow (kg ha^{-1} yr^{-1}) from A. occidentale and rainforest. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium; ha^{-1} = per hectare; yr^{-1} = per year.

soil and subsoil profiles under stands of *A. occidentale* and rainforest.

Table 4 presents the descriptive statistical results for nutrient concentrations in soils under the stands of *A. occidentale* and native rainforest. The $\bar{x}$, S.D and S.E.M values revealed that soils under rainforest have contained more nutrients than soils under *A. occidentale*. Higher nutrient contents of rainforest soils could be due to higher litterfall which support rapid built up of organic carbon and organic matter, owing to community of trees contained in the ecosystem, in comparison with the isolated stands of *A. occidentale*. Higher nutrient content of rainforest soil was reported in the research carried out by Ndakara and Ofuoku (2020). Nutrient concentrations were generally higher in the topsoils than the subsoils. This could be as a result that rainwash nutrient fluxes and other sources by which nutrients are added to the soil take place within the topsoil layer before nutrients are leached to the subsoil. In both topsoil and subsoil, calcium contents were highest under the *A. occidentale* trees and native rainforest.

Table 5 presents the paired t-test results for nutrient concentrations in soils between *A. occidentale* and rainforest. At 0.05 alpha levels, values of $P < 0.05$ for the concentrations of both topsoil and subsoil nitrogen, potassium, calcium, sodium and magnesium under *A. occidentale* and rainforest trees were significant; while values of $P > 0.05$ for phosphorus concentrations in both topsoil and subsoil under *A. occidentale* and rainforest was not significant. Findings here showed that soil nutrient properties differ strikingly in concentrations between *A. occidentale* and rainforest; while similarities in phosphorus concentrations were

Nutrient Elements	Statistics	Topsoil		Subsoil	
		A. occidentale	Rainforest	*A. occidentale*	Rainforest
N (%)	x̄	0.48	0.61	0.20	0.29
	S.D	0.05	0.13	0.03	0.05
	S.E.M	±0.01	±0.04	±0.01	±0.01
P (mg/kg)	x̄	12.76	14.74	7.05	7.85
	S.D	2.52	1.92	1.16	2.20
	S.E.M	±0.73	±0.55	±0.33	±0.63
K (mg/kg)	x̄	62.33	116.75	17.58	31.08
	S.D	4.76	29.15	1.98	11.99
	S.E.M	±1.37	±8.42	±0.57	±3.46
Ca (mg/kg)	x̄	768.33	1667.08	357.75	518.00
	S.D	41.78	390.90	16.74	151.70
	S.E.M	±12.06	±112.84	±4.83	±43.79
Na (mg/kg)	x̄	55.25	87.67	19.50	28.33
	S.D	4.86	16.29	2.28	2.96
	S.E.M	±1.40	±4.70	±0.66	±0.86
Mg (mg/kg)	x̄	253.67	471.75	101.50	182.25
	S.D	35.79	49.44	10.33	68.50
	S.E.M	±10.33	±14.27	±2.98	±19.77

Table 4. Descriptive statistical results for the concentrations of soil nutrient elements under *A. occidentale* and rainforest. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium; S.D = standard deviation; S.E.M = standard error of mean.

observed in soils under the *A. occidentale* and rainforest.

Relationship between rainwash nutrient fluxes and soil nutrient properties under* A. occidentale *and rainforest

Rainwash fluxes add nutrients to soil thereby improving the fertility status of soils under trees. The limit to which rainwash nutrients and soil nutrients compares, determines their levels of relationships, while the interdependence on these nutrient elements between the plants and soils explains their levels of interrelationships.

Table 6 presents the correlation results between rainwash nutrients and soil nutrients under *A. occidentale* and rainforest. Rainwash nutrient fluxes are correlated positively and significantly with soil nutrients. Nutrient fluxes by throughfall are correlated more with soil properties under *A. occidentale* and rainforest than the stemflow nutrient fluxes. Total nitrogen flux by throughfall is correlated with potassium, calcium and sodium for both *A. occidentale* and rainforest. While phosphorus is correlated with potassium, calcium and sodium under rainforest, it is correlated with potassium only under *A. occidentale*. Also, while potassium is correlated with calcium and magnesium under rainforest, it is correlated with calcium and sodium under *A. occidentale*. Throughfall calcium flux is correlated with soil sodium under *A. occidentale*.

Stemflow nutrient fluxes are correlated positively and significantly with soil nutrients. Stemflow nitrogen is correlated with soil calcium under rainforest, and also with soil sodium under *A. occidentale* and rainforest. Phosphorus flux is correlated

Nutrient Elements	Soil Layers	Paired Samples	Paired Difference				T	Df	Sig. (P)
			Mean	S.E.M	Lower (95% CI)	Upper (95% CI)			
N (%)	Topsoil	*A.occidentale* / Rainforest	0.1258	±0.0418	0.2179	0.0338	3.010	11	0.012
	Subsoil	*A.occidentale* / Rainforest	0.0792	±0.0151	0.1124	0.0459	5.243	11	0.000
P (mg/kg)	Topsoil	*A.occidentale* / Rainforest	1.9842	±1.0482	4.2913	0.3229	1.893	11	0.085
	Subsoil	*A.occidentale* / Rainforest	0.8058	±0.8285	2.6294	1.0177	0.973	11	0.352
K (mg/kg)	Topsoil	*A.occidentale* / Rainforest	54.4167	±8.5701	73.28	35.55	6.350	11	0.000
	Subsoil	*A.occidentale* / Rainforest	13.5000	±3.3246	20.8174	6.1826	4.061	11	0.002
Ca (mg/kg)	Topsoil	*A.occidentale* / Rainforest	898.7500	±109.9520	1144.75	656.7470	8.174	11	0.000
	Subsoil	*A.occidentale* / Rainforest	160.250	±44.5057	258.206	62.2936	3.601	11	0.004
Na (mg/kg)	Topsoil	*A.occidentale* / Rainforest	32.4167	±5.1939	43.8484	20.9850	6.241	11	0.000
	Subsoil	*A.occidentale* / Rainforest	8.8333	±1.1135	11.2942	6.3825	7.933	11	0.000
Mg (mg/kg)	Topsoil	*A.occidentale* / Rainforest	218.083	±16.7148	254.872	181.294	13.047	11	0.000
	Subsoil	*A.occidentale* / Rainforest	80.7500	±19.5855	123.857	37.6426	4.123	11	0.002

Table 5. T-test results for the concentrations of soil nutrients between *A. occidentale* and rainforest. N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium; S.D = standard deviation; S.E.M = standard error of mean.

Sources	Sites	Throughfall nutrient elements	Soil Nutrient Properties					
			N	P	K	Ca	Na	Mg
Throughfall	*A. occidentale*	N	0.680*	0.364	0.523*	0.531*	0.518*	0.302
	Rainforest		0.721*	0.382	0.626*	0.482*	0.436*	0.223
	A. occidentale	P	0.364	0.615*	0.744*	0.364	0.152	0.243
	Rainforest		0.382	0.713*	0.914*	0.465*	0.459*	0.316
	A. occidentale	K	0.523*	0.744*	0.755*	0.458*	-0.457*	0.223
	Rainforest		0.626*	0.914*	0.834*	0.448*	-0.298	0.454*
	A. occidentale	Ca	0.531*	0.364	0.458*	0.845*	0.512*	0.332
	Rainforest		0.482*	0.465*	0.448*	0.924*	0.330	0.327
	A. occidentale	Na	0.518*	0.152	-0.457*	0.512*	0.898*	-0.102
	Rainforest		0.436*	0.459*	-0.298	0.330	0.741*	-0.132
	A. occidentale	Mg	0.302	0.243	0.223	0.332	-0.102	0.765*
	Rainforest		0.223	0.316	0.454*	0.327	-0.132	0.902*
Stemflow	*A. occidentale*	N	0.370	0.244	0.224	0.372	0.423*	0.132
	Rainforest		0.311	0.263	0.313	0.436*	0.526*	0.231
	A. occidentale	P	0.244	0.347	-0.402	0.328	0.141	0.236
	Rainforest		0.263	0.504*	-0.562*	0.423*	0.436*	0.321
	A. occidentale	K	0.224	-0.402	-0.523*	0.316	-0.437*	-0.214
	Rainforest		0.313	-0.562*	-0.551*	0.424*	-0.257	-0.341
	A. occidentale	Ca	0.372	0.328	0.316	0.546*	0.534*	0.436*
	Rainforest		0.436*	0.423*	0.424*	0.174	0.324	0.248
	A. occidentale	Na	0.423*	0.141	-0.437*	0.534*	0.568*	-0.415*
	Rainforest		0.526*	0.436*	-0.257	0.324	0.667*	-0.649*
	A. occidentale	Mg	0.132	0.236	-0.214	0.436*	-0.415*	0.576*
	Rainforest		0.231	0.321	-0.341	0.248	-0.649*	0.659*

Table 6. Correlations between rainwash nutrients and soil nutrients. * = Significant at 0.05 alpha level.
N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; Na = sodium; Mg = magnesium.

with potassium, calcium and sodium under rainforest. Potassium flux is correlated with calcium under rainforest and Na in soil under *A. occidentale*. Calcium flux is correlated with soil sodium and magnesium under *A. occidentale*, while sodium flux is correlated with soil magnesium under *A. occidentale* and rainforest. These correlation results are similar to the findings reported in studies by Ndakara (2012) and Ndakara (2016), where nutrient fluxes by non-indigenous trees species are correlated positively and significantly with soil nutrient properties in the rainforest environment.

CONCLUSIONS

Rainwash fluxes from *A. occidentale* add nutrients to soil thereby improving the fertility status of soils under them. The limit to which rainwash nutrients and soil nutrients compares, determines their levels of relationships, while the interdependence on these nutrient elements between the plants and soils explains their levels of interrelationships.

Rainwash nutrients from *A. occidentale* are correlated positively and significantly with soil nutrients. Therefore, the observed level of correlations between the nutrient properties of rainwash from *A. occidentale* and rainforest and the soil properties under their stands indicate that *A. occidentale* trees contribute to soil within the rainforest environment.

Over time, *A. occidentale* add nutrients to soil through rainwash, therefore its cultivation is recommended for agro-forestry and sustainable ecosystem management.

REFERENCES

Abbasian P., Attarod P., Sadeghi S.M.M., Van Stan J.T. & Hojjati S.M., 2015. Throughfall nutrients in a degraded indigenous *Fagus orientalis* forest and a *Picea abies* plantation in the North of Iran. Forest Systems, 24: 2171–9845. http://dx.doi.org/10.5424/fs/2015243-06764

Berger T.W., Untersteiner H., Schume H. & Jost G., 2008. Throughfall fluxes in a secondary spruce (*Picea abies*), a beech (*Fagus sylvatica*) and a mixed spruce-beech stand. Forest Ecology and Management, 255: 605–618. http://dx.doi.org/10.1016/j.foreco.2007.09.030

Byun G.J., Cheon K.I. & Oh S.H., Lee Y.M., Jang J.W. & Joo S.H., 2013. Vegetation structure of *Pedicularis ishidoyana* Koidz. & Ohwi in south Korea natural habitats. Korean Journal of Plant Resources, 26: 214–226. http://dx.doi.org/10.7732/kjpr.2013.26.2.214

Carnol M. & Bazgir M., 2013. Nutrient return to the forest floor through litter and throughfall under 7 forest species after conversion from Norway spruce. Forest Ecology and Management, 309: 66–75.

Chuyong G.B., Newbery D.M. & Songwe N.C., 2004. Rainfall input, throughfall and stemflow of nutrients in a central African rain forest dominated by ectomycorrhizal trees. Biogeochemistry, 67: 73–91. https://doi.org/10.1023/B:BIOG.0000015316.90198.cf

Crockford R.H. & Richardson D.P., 2000. Partitioning of rainfall into throughfall, stemflow and interception effect of forest type, ground cover and climate. Hydrological Process, 14: 2903–2920. https://doi.org/10.1002/1099-1085(200011/12)14:16/17<2903::AID-HYP126>3.3.CO;2-Y

Dawoe E.K., Barnes V.R. & Oppong S.K., 2018. Spatiotemporal dynamics of gross rainfall partitioning and nutrient fluxes in shaded-cocoa (*Theobroma cocoa*) systems in a tropical semi-deciduous forest. Agroforestry Systems, 92: 397–413. http://dx.doi.org/10.1007/s10457-017-0108-3

Dunkerley D., 2020. A review of the effects of throughfall and stemflow on soil properties and soil erosion. In: Van Stan J.T., Gutmann E. & Friesen J. (Eds.), Precipitation Partitioning by Vegetation. Springer International Publishing; Cham, Switzerland, pp. 183–214. https://doi.org/10.1007/978-3-030-29702-2_12

Germer S., Elsenbeer H. & Moraes J.M., 2006. Throughfall and temporary trends of rainfall redistribution in an open tropical rainforest, south-western Amazonia. Hydrology Earth Systems Science, 10: 383–393. https://doi.org/10.5194/hess-10-383-2006, 2006.

Gruba P. & Mulder J., 2015. Tree species affect cation exchange capacity (CEC) and cation binding properties of organic matter in acid forest soil. Science of the total Environment 511: 655–662. https://doi.org/10.1016/j.scitotenv.2015.01.013

Kazumichi F., Makoto S., Kaoru K., Tomoaki I., Kanehiro K. & Benjamin L.T., 2018. Plant–soil interactions maintain biodiversity and functions of tropical forest ecosystems. Ecological Research, 33: 149–160. https://doi.org/10.1007/s11284-017-1511-y

Komprdová K., Komprda J., Menšík L., Vaňková L., Kulhavy J. & Nizzetto L., 2016. The influence of tree species composition on the storage and mobility of semivolatile organic compounds in forest soils. Science of the Total Environment, 553: 532–540. https://doi.org/10.1016/j.scitotenv.2016.02.132

Legout A., Van der Heijden G., Jaffrain J., Boudot J.P. & Ranger J., 2016. Tree species effects on solution chemistry and major element fluxes: A case study in the Morvan (Breuil, France). Forest Ecology and Management, 378: 244–258. https://doi.org/10.1016/j.foreco.2016.07.003

Londe V., De Sousa H.C. & Kozovits A.R., 2016. Litterfall as an indicator of productivity and recovery of ecological functions in a rehabilitated riparian forest at Das Velhas River, Southeast Brazil. Tropical Ecology, 57: 355–360.

Muoghalu J.I., 2003. Contributions of throughfall, stemflow and litterfall to nutrient cycling in a secondary lowland rain forest in Ile-Ife, Nigeria. Journal of Tropical Forest Science, 15: 399–410.

Muoghalu J.I. & Oakhumen A., 2000. Nutrient content of incident rainfall, throughfall and stemflow in a Nigerian secondary lowland forest. Applied Vegetation Science, 3: 181–188.

Ndakara O.E., 2012. Throughfall, Stemflow and Litterfall Nutrient Flux in Isolated Stands of *Persea gratissima* in a Moist Tropical Rainforest Region, Southern Nigeria. Journal of Physical and Environmental Science research, 1: 5–14. https://doi.org/10.2307/1478996

Ndakara O.E., 2016. Hydrological Nutrient Flux in Isolated Exotic Stands of Mangifera indica Linn: Implications for sustainable Rainforest Ecosystem Management in South-Southern Nigeria. Nigerian Journal of Science and Environment, 14: 125–131.

Ndakara O.E. & Ofuoku U.A., 2020. Characterizing plant biomass and soil parameters under exotic trees within rainforest environment in southern Nigeria. AIMS Environmental Science, 7: 611–626. https://doi.org/10.3934/environsci.2020039

Ndakara O.E & Ohwo O. 2023. Seasonality Assessment of Abattoir Waste Impact on Water Quality of Anwai River in Nigeria. Biodiversity Journal, 14: 405–413. https://doi.org/10.31396/Biodiv.Jour.2023.14.3.405.413

Ngaiwi E.M., Molua E.L. & Egbe A.E., 2018. Litterfall and nutrient returns in the rainforest of south western Cameroon: Some implications for Tropical forest productivity. Environmet and Natural Resources Research, 8: 25–32. https://doi.org/10.5539/enrr.v8n3p25

Purna J., Sabyasachi D. & Nagendra P.T., 2021. Throughfall and stemflow nutrient flux in deodar and oak forests, Garhwal Himalaya, India. Water Supply, 21: 1649–1656. https://doi.org/10.2166/ws.2021.009

Sung C.Y., Shin H.T, Choi S.H. & Song H.-S., 2018. Predicting potential habitat for Hanbusaya asiatica in the North and South Korean border region using MaxEnt. Korean Journal of Environment and Ecology, 32: 469–477. https://doi.org/10.13047/KJEE.2018.32.5.469

Tobon C., Sevink J. & Verstraten J.M., 2004. Solute fluxes in throughfall and stemflow in four forest ecosystems in northwest Amazonia. Biogeochemistry, 70: 1–25.

Yuqi W., Lee S.J., Shin D.B. et al., 2023. Vegetation characteristics and assessment of habitat suitability for *Pedicularis ishidoyana* Koidz. & Ohwi (Scrophulariaceae) community. Journal of Asian-Pacific Biodiversity, 16: 605–614. https://doi.org/10.1016/j.japb.2023.05.007

Zhan C., Yihao W., Ruisi C., Xiuya N. & Jixin C., 2022. Effects of Forest Type on Nutrient Fluxes in Throughfall, Stemflow, and Litter Leachate within Acid-Polluted Locations in Southwest China. International journal of Environmental Research and Public Health, 19: 2810. https://doi.org/10.3390/ijerph19052810

Zhang Y.F., Wang X.P., Hu R., Pan Y. & Zhang H., 2013. Stemflow in two xerophytic shrubs and its significance to soil water and nutrient enrichment. Ecological Research, 28: 567–579. https://doi.org/10.1007/s11284-013-1046-9

Zhang Y., Wang X., Pan Y. & Paradelo Pérez M., 2015. Rainfall partitioning into throughfall, stemflow and interception loss by two xerophytic shrubs within a rain-fed re-vegetated desert ecosystem, northwestern China. Journal of Hydrology, 527: 1084–1085. https://doi.org/10.1016/j.jhydrol.2015.05.060

Zhang Y.F., Wang X.P., Pan Y.X. & Hu R., 2016. Variations of nutrients in gross rainfall, stemflow, and throughfall within revegetated desert ecosystems. Water, Air & Soil Pollution, 227*:* 183. https://doi.org/10.1007/s11270-016-2878-z

Zhang J.Q., Zhang C.L., Ma X.J., Zhou N., Wang H. & Rissler P.S., 2014. Dust fall and biological soil crust distribution as indicators of the aeolian environment in China's Shapotou railway protective system. Catena, 114: 107–118. https://doi.org/10.1016/j.catena.2013.11.004