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PRECIPITATION PATHWAYS A CHANNEL OF NUTRIENT CYCLING IN AN *Entandrophragma cylindricum* (Sprague) Sprague PLANTATION IN ONNE, RIVERS STATE, NIGERIA

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ABSTRACT

Field experiment was conducted in 2011 at Forestry Research Institute of Nigeria (FRIN), Swamp Forest Research Station, Onne, Rivers State Nigeria, to study nutrient cycling through precipitation pathways in Entandrophragma cylindricum plantation. The experiment was 3 x 12 factorial in a Randomized Complete Block Design (RCBD) with three replications. The treatments were Time in 12 levels (months of the year) and Precipitation pathways in 3 levels (stemflow, throughfall and rainfall). In the precipitation pathways, results of throughfall, stemflow and rainfall were 7.31, 7.38 and 6.56 for pH; 56.00, 88.67 and 39.67 mg L^{-1} for Nitrogen; 7.93, 8.34 and 7.70 mg L^{-1} for Phosphorus; 6.51, 2.59 and 0.92 mg L^{-1} for Potassium; 19.10, 22.93 and 14.45 mg L^{-1} for Magnesium; 63.02, 75.34 and 49.49 mg L^{-1} for Chlorine; 0.58, 0.88 and 0.48 mg L^{-1} for Lead; 0.07, 0.12 and 0.05 mg L^{-1} for Cadmium respectively. Stemflow and rainfall gave significantly the highest and the least nutrient contents. Nutrient released in the precipitation pathways were in the following significant order: stemflow > throughfall > rainfall. The study showed that precipitation pathways can be channels through which nutrients are released into the soil.

Keywords: Precipitation pathways, stemflow, throughfall, rainfall, nutrient elements

INTRODUCTION

Rainfall is one of the vital sources of nutrient inputs in forest ecosystems. Rain water constitutes an important pathway for nutrient transfer to the forest floor. Some elements or compounds are easily leached from plant tissues (for example base cations) into rain water as precipitation passes through the canopy, while other substances are taken up in return (for example protons and ammonium) (De Schrijver *et al*., 2007; Fan and Hong, 2001). The chemical composition of the rain water is a result of the interaction of meteorological factors, distance from the sea, dry depositions and leaching of the canopies (Andre *et al*., 2008).

Bulk precipitation can be partitioned into interception loss, throughfall, and stemflow as it passes through the forest canopy. The latter two fractions both reach the ground surface as understory rainfall (Su *et al.*, 2016; Sheng and Cai, 2019). Interception loss is defined as the fraction of rainfall intercepted by the canopy and then evaporates back into the atmosphere. Stemflow is the flow of intercepted water down the trunk or stem of a plant (Williams, 2004). The redirection of water by this process causes the ground area around the plant stem to receive additional moisture (Pidwirny, 2006). Throughfall is the portion of the precipitation that reaches the ground directly through the gaps in the canopy and drips from leaves, twigs and stems. Throughfall describes the process of precipitation passing through the plant canopy (Johnson and Lehmann, 2006). Throughfall can be divided into free throughfall and canopy drip. It is the sum of free throughfall and canopy drip (Levia *et al.*, 2019). Free throughfall is the raindrops that reach the ground surface through the gaps in the canopy leaves and branches without hitting the canopy surface. Canopy drip is the water drip from the canopy surfaces and it occurs when the canopy surface rain-water exceeds its storage capacity. It can also occur when the equilibrium status of the tree surface water storage decreases due to the impact ejection from drip or mechanically from wind blowing the tree (Williams, 2004).

Throughfall and stemflow are controlled by such factors as species composition, canopy structure, leaf shape and stem density, type of precipitation, intensity of the precipitation and duration of the precipitation event (Pidwirny, 2009; Williams, 2004). The amount of precipitation passing through varies greatly with vegetation type (Pidwirny, 2009; Williams, 2004). Rates of throughfall are higher in areas of forest where the leaves are broad-leaved, because the flat leaves allow water to collect. Rates of throughfall are lower in coniferous forests, as conifers can only hold individual droplets of water on their needles. Similarly, deciduous trees have more stemflow than coniferous vegetation (Pidwirny, 2009).

Throughfall is the major component of understory rainfall, making this component a direct nutrient source for forest plants and microorganisms. Throughfall is also a key regulator of the biogeochemical cycle of the Earth's surface (Gautam *et al*., 2017; Levia and Frost, 2006; Su *et al*., 2019). As reported by Hansen (1996), solute concentrations of throughfall are closely linked to distance from the nearest tree stem, with closer distances being associated with higher solute concentration. While stemflow volume is typically much less than throughfall, it is still an important point-scale water flux (Swaffer *et al*., 2014; Wang *et al.*, 2011). Stemflow can directly change the physicochemical properties of the root zone and accelerate the redistribution of nutrients in forest ecosystems. Hence, stemflow is recognized as a key factor regulating hydrochemical characteristics (Dunkerley 2014; Germer *et al*., 2010; Levia and Germer, 2015).The objective of this paper was to estimate nutrient cycling contents in three precipitation pathways overtime at *E. cylindricum* plantation.

MATERIALS AND METHODS

Study Area

The study was carried out at Forestry Research Institute of Nigeria, swamp Forest Research Station, Onne, Rivers State, Nigeria. Onne is a village located about 7km off Port Harcourt, Rivers State capital. It lies on latitude 4°42'5.86" - 4°42'2.59"N and Longitude $7^{o}10^{'}36.57^{''}$ - 7°10'42.65"E with an elevation of 40 meters above sea level (Anegbeh, 1997). The climate is characterized by long wet season and short dry season. The wet season starts from April and ends in October while the dry season starts from November and ends in March (Anegbeh, 1997). Jagap *et al.* (1999) reported that the climate of the area is typical of the humid rainforest. The mean annual rainfall is 2,400 mm in a monomodal distribution falling in one season (March - November). Temperature varies from 28 ^{o}C in February and March (warmest months) to 25 ^{o}C in July (coolest month). Relative humidity varies from 70% in February (driest month) to 84% in July (rainy month) (Anegbeh, 1997). Sunshine also varies from 2 hours per day (September) to 6 hours per day (February) (Anegbeh, 1997).

Nutrient Cycling Through Precipitation Pathways at Onne Rivers State Nigeria

A 3x12 factorial experiment in a Randomized Complete Block Design with three replications/blocks was undertaken from January to December, 2011 (12 months), to study nutrient cycling contents in three precipitation pathways overtime at the *E. cylindricum* plantation in the Swamp Forest Research Station, Forestry Research Institute of Nigeria (FRIN), Onne, Rivers State, Nigeria. Each of the experimental blocks measured 10 x 20 m. The first factor, the precipitation pathways comprised rainfall (incipient precipitation), throughfall and stemflow and the second factor namely Time which consisted of 12 months.

The study of throughfall was carried out in each of the 10 x 20 m blocks using nine plastic collectors raised 1meter above the ground and having a 40cm diameter plastic funnel. The plastic collectors were randomly positioned underneath the canopies of *E. cylindricum* stands. Rainfall was also sampled with plastic collectors but in an open field adjacent to the plantation. Stemflow was studied using a hose of 2cm in diameter, attached to the stem of the tree and connected to an enclosed plastic collector. Nine plastic collectors were used and were randomly positioned.

Collection of each of the precipitation (stemflow, throughfall and rainfall) volumes took place every day that rainfall occurred. At each collection, the water was measured with a measuring cylinder. The water collected per precipitation pathways was stored in a deep freezer at FRIN, Onne and later sent to the Soils Laboratory of National Root Crop Research Institute (NRCRI), Umudike for chemical analysis.

Nutrient Analysis of Rainfall (Incipient Precipitation), Throughfall and Stemflow
Hydrogen ion concentration (pH)
The hydrogen ion concentration (pH) was measured electronically on a direct reading pH meter using a glass electrode with a saturated potassium chloride-calomel reference electrode of Dewis and Freita, (1970). The pH meter was calibrated with standard pH buffer solutions of pH 4.0, pH 7.0 and pH 9.0. Sample of 50 mL water was pipette into a 100 mL clean beaker and the electrode was dipped into the beaker.

Nitrogen (N)
Nitrogen contents in the various precipitation pathways were determined by the semi-micro distillation method—the Kjedahl method (Jackson, 1962). Sample of 100 mL of water was distilled with the Markhan's distillation apparatus. Sample of 50 mL distillate was collected over 10 mL of 4% H_2BO_3 using Ma-zua-zaga indicator. The distillate was titrated with 0.02 N H_2SO_4.

Phosphorus (P)
Phosphorus was extracted in Bray and Kurtz, No. 1 solution described by Olsen and Sommers (1982) and its concentration measured by the Vanado-molybilate blue colour method of Murphy and Riley (1962).

Potassium (K) and Sodium (Na)
These elements were determined by direct reading with the flame emission photometer according to Black (1965).

Calcium (Ca) and Magnesiun (Mg)
The ethylene diamine tetracetic acid (EDTA) versonate complexometric titration method of Allison (1973) was used to determine Ca contents in each precipitation pathway.

Chlorine (Cl)
Chlorine was determined titrimetrically according to Dewis and Freitas (1970). 10mL water sample was pipette into a 150mL conical flask. Three (3) drops of potassium chromate was added into the flask as an indicator. The water sample was titrated with 0.02N $AgNO_3$ to a reddish brown colour end point.

Iron (Fe)
Iron (Fe) was analysed using the atomic absorption spectrophotometer (AAS) with UNICAM 929 spectrophotometer equipment according to the procedures of Allison (1973).

Organic Carbon (OC)
Organic Carbon was determined by the wet oxidation method (Black, 1965) as modified and described by Juo (1979). Organic carbon was oxidized by potassium dichromate in the presence of concentrated sulphuric acid and then titrated with ferrous ammonium sulphate.

Lead (Pb) and Cadmium (Cd)
Lead (Pb) and Cadmium were determined in water sample using the methods of AOAC (1990) and APHA (1995). Water sample of 500 mL each of Pb and Cd were individually placed in a 500 mL beaker. Each sample of Pb and Cd was heated in a water bath at 100 ^oC to concentrate the sample to 40 mL. Solution of 5 mL 1.0M HCl was then added to the concentrated water and brought to 50 mL with distilled water in 50 mL volumetric flask. The levels of Pb and Cd were determined using the atomic absorption spectrophotometer (AOAC, 1990; APHA, 1995).

Statistical Analysis
The data obtained from the precipitation study were statistically analyzed using Fisher's Least Significant Difference (F-LSD) at $P \leq 0.05$ to determine significant difference between treatment means according to the procedures of Steel and Torrie (1980) and Alika (2006).

RESULT

Nutrient Cycling Through Precipitation Pathways: Rainfall, Throughfall And Stemflow

pH in water.

Table 1 shows that stemflow in January, 2011 had the highest pH value (8.13). In December 2011, rainfall gave significantly ($P \leq 0.05$) the least (6.56) pH value. Generally, the pH values of the various precipitation pathways in January, July, October and September 2011 were significantly ($P \leq 0.05$) higher than those of the rest of the study periods. January 2011 and December 2011 had significantly ($P \leq 0.05$) the highest (7.84) and least (6.65) pH values in the overall precipitation pathways. The pH results of May, August and November were statistically similar.Table 1 further shows that stemflow and rainfall gave significantly the highest (7.38) and least (6.56) pH values respectively. The order of the overall results of the pH values of the precipitation pathways were significantly as follows: Stemflow > throughfall >Rainfall.

Table 1: Mean pH value in *E. cylindricum* plantation at Onne, Rivers State, Nigeria in 2011

Time (T) (Month)	Precipitation Pathways			Mean (Time)
	Throughfall	Stemflow	Rainfall	
January	7.93	8.13	7.47	7.84
February	7.26	7.45	6.31	7.01
March	7.16	7.25	6.79	7.07
April	6.75	7.24	6.96	6.91
May	6.96	7.09	6.67	6.91
June	7.11	7.03	6.82	6.99
July	7.52	7.76	6.81	7.36
August	6.88	6.68	7.15	6.90
September	7.69	7.64	6.11	7.15
October	7.76	7.63	6.26	7.22
November	7.54	7.34	5.98	6.95
December	7.21	7.30	5.43	6.65
Mean	**7.31**	**7.38**	**6.56**	
		F-LSD (0.05)		
Precipitation pathways (P)		0.04		
Time (T)		0.08		
Interaction P x T		0.02		

Nitrogen (N)

Table 2 shows the N values of the Precipitation pathways. Stemflow and rainfall gave significantly ($P \leq 0.05$) the highest and least N contents respectively. The overall results of N contents in the precipitation pathways were in the following order of magnitude: Stemflow > Throughfall > Rainfall. In respect of the overall N contents overtime in all the precipitation pathways, September 2011, followed by February 2011 had significantly ($P \leq 0.05$) the highest N contents. January, June and July 2011 had statistically similar N contents which were higher ($p \leq 0.05$) than those of March, April, May, August, November and December 2011. August, 2011 however, gave significantly ($P \leq 0.05$) the least N contents in the overall precipitation pathways. Stemflow in September, 2011 gave significantly ($P \leq 0.05$) the highest (140 mg L^{-1}) N content. The statistically similar ($P \leq 0.05$) throughfall N contents (28 mg L^{-1}) in March, April and August, 2011 and also similar ($P \leq 0.05$) rainfall N contents (28 mg L^{-1}) in February, April, May, June, August, October, November, and December, 2011 had statistically the least values.

Phosphorus (P)

Table 2 further shows the P values of the precipitation pathways overtime. Stemflow and rainfall gave significantly ($P \leq 0.05$) the highest (8.34 mg L^{-1}) and least (7.70 mg L^{-1}) P contents respectively. The overall results of P contents in the precipitation pathways are in the following significant order of magnitude: Stemflow > Throughfall > Rainfall. Regarding Time, August and March, 2011 had higher P values than February, April, May and June, 2011. Both months gave statistically similar P contents as January, July, September, October and November, 2011. January, July and September, 2011 had higher (P ≤ 0.05) P contents than February, April, May, 2011. Generally, P contents were lower during the early rainy season months of April, May and June. Concerning Precipitation pathways (P) x Time (T), stemflow, followed by throughfall gave significantly the highest P contents. The statistically similar P contents of Rainfall in January – December 2011, of Throughfall in February – November, 2011 and of Stemflow in January, February, April and June, 2011 had the least (P ≤ 0.05) values. Generally, P contents increased in November and December, 2011 in the three precipitation pathways.

Table 2: Mean Nitrogen (N) and Phosphorus (P) Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria in 2011

Time Month)	Nitrogen ($mg L^{-1}$) Precipitation Pathways			Mean	Phosphorus ($mg L^{-1}$) Precipitation Pathways			Mean
	Throughfall	**Stemflow**	**Rainfall**		**Throughfall**	**Stemflow**	**Rainfall**	
January	56.00	84.00	56.00	65.33	8.80	7.76	7.52	8.03
February	84.00	112.00	28.00	74.67	7.60	7.84	7.52	7.65
March	28.00	56.00	56.00	46.67	7.68	8.80	7.92	8.13
April	28.00	112.00	28.00	56.00	7.04	8.16	7.68	7.63
May	56.00	84.00	28.00	56.00	7.92	7.36	7.68	7.65
June	56.00	112.00	28.00	65.33	7.92	8.00	7.36	7.76
July	56.00	84.00	56.00	65.33	7.84	8.32	7.92	8.03
August	28.00	56.00	28.00	37.33	8.08	8.56	7.92	8.19
September	112.00	140.00	84.00	112.00	7.76	8.72	7.60	8.03
October	56.00	56.00	28.00	46.67	7.84	8.16	7.68	7.89
November	56.00	84.00	28.00	56.00	7.68	8.48	7.52	7.89
December	56.00	84.00	28.00	56.00	8.96	9.92	8.08	8.99
Mean	**56.00**	**88.67**	**39.67**		**7.93**	**8.34**	**7.70**	

	F-LSD (0.05)	
	N ($mg L^{-1}$)	**P ($mg L^{-1}$)**
Precipitation Pathways (P)	1.61	0.18
Time (T)	3.21	0.36
P x T Interaction	5.66	0.62

Potassium (K)

Table 3 shows the K values of the precipitation pathways overtime. Stemflow and rainfall gave significantly the highest (6.51 $mg L^{-1}$) and least (0.92 $mg L^{-1}$) K contents respectively. The overall results of K contents in the precipitation pathways are in the following significant order of magnitude: Stemflow > Throughfall > Rainfall. Potassium contents overtime in all the precipitation pathways shows that November and March, 2011 gave significantly the highest (6.43 $mg L^{-1}$) and least (1.00 $mg L^{-1}$) K contents. December, July and August had statistically similar K contents that were significantly higher than those of March, April and June. Generally, the late rainy season months of September and October, 2011 and the early dry season months of November and December, 2011 had respectively higher (P ≤ 0.05) K contents than the early rainy and late dry season months/periods. A precipitation pathway (P) x Time (T) result shows that throughfall in November, September and October 2011 had the highest (P ≤ 0.05) K contents. Rainfall had significantly (P ≤ 0.05) the least K values and statistically similar values in February, March, April, September, October, November, and December, 2011.

Magnesium (Mg)

Table 3 also shows the Mg contents of the precipitation pathways overtime. Stemflow and rainfall gave significantly (P≤0.05) the highest (22.94 mg L^{-1}) and least (14.45 mg L^{-1}) Mg contents respectively. The order of the overall results of the Mg contents of the Precipitation pathways were significantly as follows: Stemflow > Throughfall > Rainfall. In reference to Time, April and November, 2011 had significantly (P ≤ 0.05) the highest (26.74 mg L^{-1}) and least (13.78 mg L^{-1}) Mg contents. However, the statistically similar Mg contents in January, 2011 (21.88 mg L^{-1}) and February, 2011 (21.88 mg L^{-1}) were significantly higher than those of March and May to December, 2011. Throughfall in April, 2011 had the highest (p ≤ 0.05) Mg content while Rainfall in October and November, 2011 gave significantly the least Mg contents. Generally, Stemflow had higher Mg contents overtime.

Table 3: Mean Potassium (K) and Magnesium (Mg) Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria in 2011

Time Month)	Potassium (mg L^{-1}) Precipitation Pathways			Mean	Magnesium (mg L^{-1}) Precipitation Pathways			Mean
	Throughfall	Stemflow	Rainfall		Throughfall	Stemflow	Rainfall	
January	4.70	5.20	1.20	3.70	19.48	24.31	21.80	21.86
February	4.70	5.10	0.40	3.40	21.88	29.17	14.59	21.88
March	1.10	1.10	0.80	1.00	14.59	17.02	14.59	15.40
April	3.20	1.30	0.40	1.63	36.47	31.60	12.16	26.74
May	9.90	2.80	1.60	4.77	19.45	26.74	14.59	20.26
June	2.60	2.60	1.30	2.17	17.02	21.88	14.89	17.03
July	3.50	2.90	1.40	2.60	19.45	21.88	14.59	18.64
August	3.00	2.90	1.40	2.43	17.62	21.88	17.62	19.04
September	13.20	1.00	0.70	4.97	17.02	24.59	12.16	17.92
October	11.40	0.80	0.70	4.30	12.16	19.72	9.72	13.87
November	16.70	1.90	0.70	6.43	17.02	14.59	9.02	13.78
December	4.10	3.50	0.40	2.67	17.02	21.88	17.02	18.64
Mean	**6.51**	**2.59**	**0.92**		**19.10**	**22.94**	**14.45**	

F-LSD (0.05)	K (mg L^{-1})	Mg (mg L^{-1})
Precipitation Pathways (P)	0.12	0.01
Time (T)	0.25	0.02
P x T Interaction	0.43	0.03

Sodium (Na)

Table 4 shows the Na values of the precipitation pathways overtime. Stemflow and rainfall gave significantly the highest (4.12 mg L^{-}1) and least (1.61 mg L^{-}1) Na contents respectively. The order of the overall results of the Na contents of the precipitation pathways were significantly as follows: Stemflow > Throughfall > Rainfall. September, 2011, followed by October, 2011 gave significantly the highest Na contents in all the precipitation pathways (Rainfall, Throughfall, Stemflow). April, 2011 had the least (1.20 mg L^{-}1) Na contents. The Na contents of the precipitation pathways in May and November, 2011 were significantly higher than those of January, February, March, June, July, August, and December, 2011. February, June and July, 2011 had significantly the highest (2.11 mg L^{-1}, 2.27 mg $L^{-1}$and 2.20 mg L^{-1} respectively) Na contents in the precipitation. Rainfall in April, 2011 had the least (P ≤ 0.05) Na values.

Calcium (Ca)

Table 4 also shows the Ca values of the precipitation pathways overtime. Stemflow and Rainfall respectively gave significantly the highest and least Ca contents. The overall results of Ca contents in the precipitation pathways are in the following order of magnitude: Stemflow > Throughfall > Rainfall. In respect of Time, April and September, 2011 had significantly (P ≤ 0.05) the highest and least Ca contents. In the interaction of Precipitation pathways (P) x Time (T), Throughfall and Stemflow gave significantly (P ≤ 0.05) the highest Ca contents in April, 2011. Rainfall in November and December, 2011 had statistically similar least Ca values.

Table 4: Mean Sodium (Na) and Calcium (Ca) Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria 2011

Time Month)	Sodium (mg L^{-1}) Precipitation Pathways			Mean	Calcium (mg L^{-1}) Precipitation Pathways			Mean
	Throughfall	**Stemflow**	**Rainfall**		**Throughfall**	**Stemflow**	**Rainfall**	
January	3.40	3.10	1.30	2.60	52.10	96.19	36.07	61.45
February	2.20	3.40	0.80	2.13	64.14	68.14	52.10	52.10
March	1.90	1.60	1.40	1.63	56.11	64.13	48.10	56.11
April	1.30	1.60	0.70	1.20	76.15	72.14	56.11	68.13
May	2.00	5.90	1.90	3.27	60.12	60.12	44.09	54.78
June	1.90	3.40	1.50	2.27	48.10	48.10	36.07	44.09
July	1.80	3.10	1.70	2.20	48.10	53.10	48.10	49.43
August	3.60	3.70	1.60	2.97	52.10	52.10	36.07	46.76
September	3.20	9.60	2.60	5.13	36.07	32.06	32.06	33.40
October	2.80	7.40	2.30	4.17	48.10	48.06	44.09	46.75
November	3.80	3.40	2.50	3.23	36.07	48.10	32.10	38.76
December	3.00	3.80	1.00	2.60	48.10	52.10	32.06	44.09
Mean	**2.58**	**4.17**	**1.61**		**52.10**	**57.78**	**41.42**	

F-LSD (0.05)	Na (mg L^{-1})	Ca (mg L^{-1})
Precipitation Pathways (P)	0.09	0.01
Time (T)	0.17	0.03
P x T Interaction	0.04	0.05

Chlorine (Cl)

Table 5 shows the Cl values of the precipitation pathways overtime. Stemflow and Rainfall precipitation pathways gave significantly ($P \leq 0.05$) the highest and least Cl contents. The overall results of Cl contents in the Precipitation pathways are in the following significant order of magnitude: Stemflows > Throughfall > Rainfall. August and February, 2011 gave significantly ($P \leq 0.05$) the highest (85.68 mg L^{-1}) and least (42.27 mg L^{-1}) Cl contents. Chlorine contents increases overtime from January to December, 2011. The Precipitation pathways (P) x Time (T) treatment interaction indicated that, Stemflow in August, followed by December, 2011 had significantly ($P \leq 0.05$) the highest Cl contents.

Iron (Fe)

Table 5 shows the Fe values of the precipitation pathways overtime. Stemflow and rainfall gave significantly ($P \leq 0.05$) the highest (14.64 mg L^{-1}) and least (4.05 mg L^{-1}) Fe contents. The overall results of Fe contents in the Precipitation pathways are in the following significant order of magnitude: Stemflow > Throughfall > Rainfall. Regarding Time, except January, 2011, March, 2011 had significantly the highest Fe content than the other months in 2011. July, August and October, 2011 gave the least ($P \leq 0.05$) Fe values. Generally, the late dry season months of January, February and March, 2011 had significantly higher Fe contents than the rainy season (April – October, 2011) and early dry season months (November and December, 2011). Precipitation (P) x Time (T) treatment interactions showed that, Stemflow in January 2011 and Rainfall in August 2011 gave significantly ($P \leq 0.05$) the highest and least Fe contents.

Table 5: Mean Chlorine (Cl) and Iron (Fe) Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria 2011

Time (Month)	Cl ($mg\ L^{-1}$) Precipitation Pathways			Mean	Fe ($mg\ L^{-1}$) Precipitation Pathways			Mean
	Throughfall	**Stemflow**	**Rainfall**		**Throughfall**	**Stemflow**	**Rainfall**	
January	53.18	62.04	35.45	50.22	15.50	23.50	4.34	14.45
February	35.45	62.04	44.32	47.27	15.10	15.40	6.23	12.24
March	53.18	70.91	44.32	56.14	17.40	18.60	13.50	16.50
April	44.32	53.18	44.32	50.23	12.50	13.40	3.55	9.82
May	44.32	62.04	44.32	50.23	14.30	17.40	3.86	11.85
June	62.04	70.91	62.04	74.82	10.60	19.30	4.70	11.53
July	62.04	70.91	53.18	62.04	6.28	12.40	2.28	6.99
August	88.63	115.22	53.18	85.68	9.28	10.20	0.96	6.99
September	62.04	62.04	35.45	53.18	12.10	14.38	1.58	9.35
October	62.04	70.91	53.18	62.04	5.48	8.70	1.06	5.08
November	70.90	97.50	62.04	76.81	11.20	12.25	2.66	8.70
December	79.77	106.36	62.04	82.72	14.60	15.10	3.87	11.19
Mean	**63.02**	**75.34**	**49.49**		**12.03**	**14.64**	**4.05**	

F-LSD (0.05)	Cl ($mg\ L^{-1}$)	Fe ($mg\ L^{-1}$)
Precipitation Pathways (P)	1.61	0.18
Time (T)	3.21	0.36
P x T Interaction	5.66	0.62

Organic Carbon (OC)

Table 6 shows the Organic carbon contents of the precipitation pathways overtime. The OC content result of the precipitation pathways are significantly in the following order: Stemflow > Throughfall > Rainfall. The statistically similar OC contents of February and September, 2011 were significantly higher than those of the other months, namely: January, March – August, October – December, 2011. June, 2011 had the least ($P \leq 0.05$) Org. C content. Precipitation pathways (P) x Time (T) treatment interactions revealed that, Stemflow in May and September, 2011, Throughfall in January – March 2011 had significantly the highest OC while Rainfall in January – December 2011 had the least OC.

Organic Matter (OM)

The organic matter (OM) contents of the precipitation pathways overtime are also presented in Table 6. The OM contents are significantly in the following order Stemflow > Throughfall > Rainfall. February and September 2011 had statistically similar OM contents that were significantly ($P \leq 0.05$) higher than those of the other months. June, 2011 had the least (($P \leq 0.05$) OM content. Stemflow in May and September, 2011 had the highest OM contents with reference to Precipitation pathways (P) x Time (T) interactions. Generally, Rainfall in June and July, 2011 had significantly ($P \leq 0.05$) lower OM than Stemflow in January – December, 2011 and Throughfall in January – July, 2011 and in September – December, 2011.

Table 6: Mean Organic carbon and Organic matter Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria 2011

Time Month)	Organic carbon (%) Precipitation Pathways			Mean	Organic matter (%) Precipitation Pathways			Mean
	Throughfall	Stemflow	Rainfall		Throughfall	Stemflow	Rainfall	
January	0.08	0.06	0.05	0.06	0.14	0.10	0.09	0.11
February	0.08	0.08	0.06	0.07	0.14	0.14	0.10	0.13
March	0.08	0.06	0.05	0.06	0.10	0.14	0.09	0.11
April	0.06	0.07	0.04	0.06	0.10	0.12	0.07	0.10
May	0.06	0.09	0.04	0.06	0.10	0.16	0.07	0.11
June	0.06	0.06	0.03	0.04	0.05	0.10	0.05	0.07
July	0.05	0.06	0.03	0.05	0.09	0.10	0.05	0.08
August	0.04	0.06	0.04	0.05	0.07	0.10	0.07	0.08
September	0.07	0.09	0.05	0.07	0.12	0.16	0.09	0.12
October	0.05	0.06	0.04	0.05	0.09	0.10	0.07	0.09
November	0.05	0.06	0.04	0.05	0.09	0.10	0.07	0.09
December	0.05	0.05	0.04	0.05	0.09	0.09	0.07	0.08
Mean	**0.06**	**0.07**	**0.04**		**0.10**	**0.12**	**0.07**	

F-LSD (0.05)	Organic carbon (%)	Organic matter (%)
Precipitation Pathways (P)	0.01	0.01
Time (T)	0.01	0.01
P x T Interaction	0.02	0.02

Lead (Pb)

Table 7 shows the Pb contents of the Precipitation pathways overtime. Stemflow and Rainfall gave significantly the highest (0.80 mg L^{-1}) and least (0.48 mg L^{-1}) Pb contents. The order of the Pb contents of the Precipitation pathway is significantly as follows: Stemflow > Throughfall > Rainfall. December and July 2011 gave significantly the highest (4.25 mg L^{-1}) and least (0.20 mg L^{-1}) Pb contents respectively. The dry season months of January, March, November and December, 2011 generally had significantly higher Pb values than the rainy season months of April – October, 2011. Precipitation pathways (P) x Time (T) treatment interactions showed that, Stemflow in December, 2011 had significantly ($P \leq 0.05$) the highest Pb contents. Throughfall, Stemflow and Rainfall in July, 2011 had statistically similar Pb contents which gave significantly the least Precipitation x Time treatment interaction Pb values.

Cadmium (Cd)

Table 7 further shows the Cd contents of the Precipitation pathways overtime. Stemflow and rainfall gave significantly ($P \leq 0.05$) the highest (0.12 mg L^{-1}) and least (0.05 mg L^{-1}) Cd contents. The overall results of Cd contents in the precipitation pathways are in the following significant order of magnitude: Stemflow > Throughfall > Rainfall. December, January and March, 2011 had significantly higher Cd contents than the other months (February, April – November, 2011). October, 2011, however, gave the least (0.01 mg L^{-1}) Cd contents. Precipitation pathways (P) x Time (T) treatment interactions revealed that, Stemflow in January, 2011 had the highest (0.17 mg L^{-1}) Cd content. However,

Throughfall in July (0.00 mg L^{-1}), August (0.00 mg L^{-}1) and October (0.04 mg $L^{-1)}$, 2011, Stemflow in October (0.00 mg L^{-1}), 2011 and Rainfall in April (0.01 mg L^{-1}), June (0.01 mg L^{-1}) and September – November (0.01 mg L^{-1}), 2011 gave significantly the least Cd values.

Table 7 Mean Lead (Pb) and Cadmium (Cd) Contents in Precipitation Pathways Overtime in *E. cylindricum* Plantation at Onne, Nigeria 2011

Time (Month)	Pb ($mg\ L^{-1}$) Precipitation Pathways			Mean	Cd ($mg\ L^{-1}$) Precipitation Pathways			Mean
	Throughfall	Stemflow	Rainfall		Throughfall	Stemflow	Rainfall	
January	2.58	2.94	2.46	2.66	0.12	0.17	0.11	0.13
February	2.22	2.16	2.28	2.22	0.08	0.09	0.08	0.08
March	1.39	2.25	1.44	1.86	0.11	0.17	0.09	0.12
April	1.98	2.37	1.08	1.81	0.08	0.15	0.01	0.08
May	1.50	3.03	1.32	1.95	0.08	0.08	0.07	0.07
June	1.68	2.28	1.26	1.74	0.01	0.12	0.01	0.04
July	0.30	0.33	0.24	0.29	0.00	0.06	0.05	0.06
August	0.96	1.41	0.75	1.04	0.00	0.11	0.08	0.10
September	1.02	1.32	0.75	1.03	0.04	0.08	0.01	0.04
October	1.02	1.26	0.63	0.97	0.00	0.00	0.01	0.01
November	2.43	2.91	1.95	2.43	0.04	0.06	0.01	0.03
December	3.12	6.66	2.97	4.25	0.14	0.26	0.10	0.14
Mean	**0.58**	**0.88**	**0.48**		**0.07**	**0.12**	**0.05**	

	F-LSD (0.05) Pb ($mg\ L^{-1}$)	F-LSD (0.05) Cd ($mg\ L^{-1}$)
Precipitation Pathways (P)	0.01	0.01
Time (T)	0.03	0.01
P x T Interaction	0.05	0.02

DISCUSSION

Nutrient Cycling Through Precipitation Pathways

The nitrogen (N) contents in Stemflow in *E. cylindricum* plantation ranged from 56.00 to 112.00 mg L^{-1}. This range is higher than the dissolved nitrogen concentrations reported for several temperate species which ranged from 0.27 to 1.39 mg L^{-1} (Johnson and Lehmann, 2006; Chang and Matzner, 2000) and from 0.21 to 1.04 mg L^{-1} for a variety of tropical forest and fruit tree species (Schroth *et. al.*, 2001). The *E. cylindricum* phosphorus (P) contents (8.34 mg L^{-1}) in stemflow were higher than that recorded by Schroth *et al.*, (2001) which ranged from 10 to 14 mg L^{-1}. The concentration of micronutrients in the precipitation pathways of *E. cylindricum* are similar to those in tree-based land use systems and spontaneous tree vegetation of Central America (Cantu and Gonzalez, 2001) where Pine and Oak precipitation pathways were enriched with copper (Cu), Iron (Fe), Manganese (Mn) and zinc (Zn). The higher nutrient concentrations recorded in the various precipitation pathways of *E. cylindricum* could be as a result of greater rain-water-based leachability of bark tissue in stemflow and foliar leaching of nutrients in throughfall. Thus, the chemical composition of precipitation intercepted by the canopy is enhanced by wash-off of dry deposition collected by the canopy and foliar leaching of nutrients into rainwater (Chen *et al*., 2010; Fan and Hong, 2001). The extent to which dry deposition and foliar leaching enhance the nutrient status of intercepted precipitation is a function of leaf and canopy morphology and nutrient status, as well as regional climate and environmental conditions (Johnson and Lehmann, 2006). The presence of heavy metals in the precipitation pathways in *E. cylindricum* plantation at the study site could be as a result of industrial activities at Onne, Rivers State, Nigeria. The higher pH value of stemflow than that of the rainfall is in accordance with the findings of Dawoe *et al.* (2018) in a shaded-cocoa system in semi-deciduous tropical forest. This increase in pH of stemflow and throughfall can be ascribed to canopy interaction with precipitation. Canopy interaction with precipitation neutralizes the pH of the water due to absorption of hydrogen ions by the surface of the vegetation. In addition, the rate at which water passes through the leaves, branches, trunk and bark carries basic cations, which results in increasing the pH of the aqueous solution (Momolli *et al*., 2019). However, this result differs from that of Crockford *et. al.* (1996) where the pH values of stemflow of *Eucalyptus spp* and *Pinus spp* were less than those of rainfall. However, Crockford *et. al.* (1996) stated that the pH values of *Eucalyptus melliodora* in stemflow and rainfall were statistically similar.

Stemflow generally had significantly higher macro and micro-nutrient concentrations in *E. cylindricum* plantation at Onne, Nigeria than throughfall and rainfall. This feature corresponds to the trends reported by Tan *et al.* (2018), Johnson and Lehmann, (2006), Levia and Herwitz, (2000); Okamoto *et al.* (2000); Houbao *et al.* (1999). However, it differs from the results of Crockford *et al.* (1996); Tobon *et. al.* (2004) where throughfall had the major contribution in the nutrient input. Kellman and Roulet (2008) reported that stemflow and throughfall had statistically similar concentration of macro and micro-nutrients which were significantly higher than those of rainfall. Levia and Herwitz (2000) explained that a longer canopy residence time which occurs more in stemflow than in throughfall and greater leachability of bark tissues contribute to chemical concentration gradients of water fluxes in the following significant order: stemflow > throughfall > rainfall.

CONCLUSION

This study has shown that pH and Organic matter contents of water in throughfall and stemflow can increase due to canopy interaction. It was also revealed that precipitation in the form of incident rainfall, stemflow and throughfall contained dissolved nutrient elements (Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Sodium and organic Carbon) which will help in improving the nutrient status of the soil in plantations and agroforestry systems and they are vital sources of nutrients for recycling.

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