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PRECIPITATION PATHWAYS ASUSTAINABLE CHANNEL OF NUTRIENT CYCLING IN AN *Acacia auriculiformis* PLANTATION IN UMUAHIA, ABIA STATE, NIGERIA

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ABSTRACT

Acacia auriculiformis a useful agroforestry plant, that fixes nitrogen after nodulating with a range of Rhizobium and Bradyrhizobium strains has great attributes to improve the nutrient status of the soil. This study therefore investigated the potentials of *A. auriculiformis* in nutrient cycling through precipitation pathways, a rapid channel of nutrient inputs.The experiment was 3 x 8 factorial in a Randomized Complete Block Design (RCBD) with three replications in *Acacia auriculiformis* plantation. The treatments were Time in 8 levels (months of the year) and Precipitation pathways in 3 levels (Stem flow, Through fall and Rainfall). The water collected per precipitation pathways was stored in a deep freezer at FRIN, Umuahia and later sent to the Soils Laboratory of National Root Crop Research Institute (NRCRI), Umudike for chemical analysis. In the precipitation pathways, results of Throughfall, Stemflow and Rainfall were 143.30, 197.60 and 101.90 mg L^{-1} for Nitrogen; 4.14, 4.05 and 3.04 mg L^{-1} for Phosphorus; 2.28, 3.02, and 1.44 mg L^{-1} for Potassium; 25.69, 23.42, 34.53 mg L^{-1} for Calcium; 2.95, 3.85 and 2.99 mg $L^{-1}$for Sodium; 12.08, 12.27 and 13.17 mg L^{-1} for Magnesium. Stemflow and Throughfall had significantly higher nutrient contents than Rainfall. The study has shown that *Acacia auriculiformis* can contribute significantly to a sustainable forest and agroforestry ecosystems based on the nutrient contents in its Stemflow and Throughfall solutions.

Keywords: Precipitation pathways, *Acacia auriculiformis,* Stemflow, Throughfall, nutrient

Introduction

Rainfall that falls on the canopy of trees can be partitioned into: Canopy evaporation, Stemflow and Throughfall. Canopy evaporation is when part of the interceptedrain directly evaporates into the atmosphere. Stemflow, is regarded as aportion of the rain that comes in contact with canopy which flows throughthe stem, before finally reaching the ground while Throughfall, is the rain that reaches the ground through gaps in the canopy or viawater that drips from leaves (Venkatraman and Ashwath, 2016). Stemflow and throughfall reach the ground surface as understory rainfall(Su*et al*., 2016; Sheng and Cai 2019).

Rainfall is one of the vital sources of nutrient inputs in forest ecosystems.Rainwater constitutes an important pathway for nutrient transfer to the forest floor. Incident rainfall carries some amount of nutrients, irrespective of this, significant amounts are added and transferred fromabove-ground plant parts to the forest floor as the rainwater passes through thecanopy (Dawoe *et al*., 2018). As precipitation passes through the forest canopy, it washes off particles and gases deposited on the vegetation surface during dry periods and fog events, mobilizes plant secretions, changes the vegetation canopy's original chemical form, and acts as a medium for the transfer of nutrients to soil. Some elements or compounds are easily leached from plant tissues (for examplebase cations) and precipitation is therefore enriched with these substances during its passage through the canopy, while other substances are taken up in return (for instance, protons, ammonium)(Fan and Hong, 2001; De Schtijver *et al*., 2007).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 (Levia and Frost, 2006; Gautam *et al*., 2017; Su*et al*., 2019a).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 (Germer *et al*., 2010; Dunkerley, 2014; Levia and Germer, 2015).

The chemical composition of the water from the stemflow and throughfall is a result of the interaction ofmeteorological factors, distance from the sea, dry depositions and leaching of the canopies (Andre *et al*., 2008).

In nutrient-limited areas, precipitation can be the sole source of nutrient inputs, and can influence the growth and succession of forest communities (Navar *et al*., 2009; Lu *et al*., 2017; Dawoe *et al*., 2018) and the basis of forest nutrient cycling. Compared to the rate of mineralizationfrom decomposing litter, fluxes of nutrients as throughfall and stemfloware much more rapid. The elements are largely in dissolved inorganic forms whichcan be taken up immediately by trees (Zhang *et al*., 2016).

Acacia auriculiformis A.Cunn. ex Benth, an evergreen plant commonly known as ear-pod wattle plant, belonging to the legume family, Fabaceae (PROTA, 2016).It can grow up to 20m in height and 50cm in diameter (Fern, 2014). It is a useful agroforestry plant, that fixes nitrogen after nodulating with a range of Rhizobium and Bradyrhizobium strains. It also has associations with both ecto- and endo-mycorrhizal fungi (Galiana, 1990).

Incorporating *A. auriculiformis* into our farming system through agroforestry will not onlyimprove soil fertility by nitrogen fixation through rhizobium association but also through precipitation pathways, a rapid channel of nutrient inputs. The objective of this paper was to determine the nutrient contents in three precipitation pathways overtime at *A. auriculiformis* plantation.

Materials and Methods

The study was carried out in the *Acacia oricuformis* stand of Humid Forest Research Station, Forestry Research Institute of Nigeria (FRIN), Umuahia, Abia State, Nigeria. Umuahia lies on latitude 5^{o} 30' 51.73"N and longitude 7^{o} 31' 46.77"E. It is situated on the coastal plain geographical zone of South-Eastern Nigeria (Ujoh *et al*., 2011) and is dominated by a tropical rainforest vegetation (Ochege and Okpala-Okaka, 2017). It has two major seasons, dry season and rainy season. It has an annual mean rainfall of 2, 278mm, with eight months of precipitation, which starts from early March to late October. The dry season is characterized with a period of short spell of dry/cool season referred to as harmattan (Ujoh *et al*., 2011; Ochege and Okpala-Okaka, 2017).The mean annual maximum temperature is 31°C with little daily variations. Mean daily insolation is 4.8 h (Ochege and Okpala-Okaka, 2017), while the mean relative humidity varies from 60 to 90% (Kalu *et al*., 2012).

A 3x8 factorial experiment in a randomized complete block design with three replications was undertaken from April to November, 2013 (8 months), to study nutrient cycling contents in three precipitation pathways overtime at the *A. auriculiformis* stand in the Humid Forest Research Station, FRIN, Umuahia, Abia State, Nigeria. Each of the experimental blocks measured 6 x 18m. The first factor, the precipitation pathways comprised rainfall (incipient precipitation), throughfall and stemflow. The second factor, namely, Time, consisted of 8 months.

The study of throughfall was carried out in each of the 6 x 18m 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 *A .auriculiformis* 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, Umuahia and later sent to the Soils Laboratory of National Root Crop Research Institute (NRCRI), Umudike for chemical analysis.

Nitrogen (N)

Nitrogen contents in the various precipitation pathways were determined by the semi-micro distillation method—the Kjedahl method (Jackson, 1962). 100ml of water sample was distilled with the Markhan's distillation apparatus. 50ml distillate was collected over 10ml 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 determined spectrophotometrically (Mackereth *et. al.*, 1978).

Potassium (K) and Sodium (Na)

These were determined by direct reading with the flame emission photometer (Black, 1965).

Calcium (Ca) and Magnesium (Mg)

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

Result and Discussion

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Result

Nitrogen (N)

Table 1reveals the N values of the Precipitation pathways. Stemflow and rainfall gave significantly ($p = 0.05$) 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 (197.60 mg L^{-1}) > Throughfall (143.30 mg L^{-1})> Rainfall (101.90 mg L^{-1}).

In terms of the overall N contents overtime in all the precipitation pathways, April ((154.40 mg L^{-1}), May (154.20 mg L^{-1}), September (153.60 mg L^{-1})and October (156.00 mg L^{-1}) had statistically similar N contents which were higher than those of June (137.90 mg L^{-1}), August (138.40 mg L^{-1}), and November (131.40 mg L^{-1}). The trend showed that there was a decreased from June to August followed by an increase in September and October.

The N contents in Rainfall in the months of May (70.40mg l^{-1}), June (90.20mg L^{-1}) and November (77.00 mg L^{-1}) were significantly lower than those of Stemflow (164.10 – 231.00mg L^{-1}) and Throughfall (119.80 – 202.40mg L^{-1}) in all the months.

Phosphorus (P)

Table 1 further shows the Phosphorus values of the precipitation pathways overtime. Stemflow (4.05 mg L^{-1}) and Throughfall (4.14 mg L^{-1}) gave statistically similar Phosphorus values which were significantly ($p = 0.05$) higher than the Phosphorus value in rainfall (3.04 mg L^{-1}). Phosphorus contents overtime indicated that the months of April (4.69 mg L^{-1}), May (4.46 mg L^{-1}) and June (5.07 mg L^{-1}) gave significantly ($p = 0.05$) higher Phosphorus values than the months of July – November which ranges between (2.56– 4.07 mg L^{-1}).

The statistical similar Phosphorus values of Stemflow in June (6.79 mg L^{-1}) and Throughfall in August (6.44 mg L^{-1}) gave significantly ($p = 0.05$) the highest Phosphorus value in all precipitation pathways. However, Phosphorus contents in the three precipitation pathways are the same in the months of October and November.

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Table 1: Mean Nitrogen and Phosphorus Contents in Precipitation Pathways Overtime in *A. auriculiformis* Plantation at Umuahia, Nigeria in 2013

Time	N (mg l^{-1}) Precipitation Pathways				P (mg l^{-1}) Precipitation Pathways			
Month)	Throughfall	Stemflow	Rainfall	Mean	Throughfall	Stemflow	Rainfall	Mean
April	154.00	231.00	90.20	158.40	6.44	5.02	2.63	4.69
May	180.30	211.80	70.40	154.20	5.70	4.86	2.81	4.46
June	128.80	194.70	90.20	137.90	4.83	6.79	3.60	5.07
July	123.20	191.10	107.80	140.70	2.71	4.49	5.02	4.07
August	129.40	165.40	120.60	138.40	3.08	3.20	2.64	2.97
September	202.40	164.10	124.40	153.60	4.84	2.95	2.71	3.50
October	m119.80	213.90	134.40	156.00	2.62	2.63	2.44	2.56
November	198.10	209.10	77.00	131.40	2.87	2.45	2.44	2.59
Mean	143.30	197.60	101.90	147.6	4.14	4.05	3.04	3.74

F-LSD (0.05)	N (mg l^{-1})	P (mg l^{-1})
Precipitation Pathways (P)	9.41	0.22
Time (T)	15.36	0.36
P x T Interaction	26.61	0.63

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Potassium (K)

Table 2 shows the K values of the precipitation pathways overtime. Stemflow and rainfall gave significantly (P = 0.05) the highest (3.02 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. K contents overtime in all the precipitation pathways shows that April and October gave significantly the highest (3.68 mg L^{-1}) and least (1.43 mg L^{-1}) K contents. July, August, September and October had statistically similar K contents (1.72 mg L^{-1}, 1.92 mg L^{-1}, 1.88 mg L^{-1} and 1.87 mg L^{-1} respectively). Generally, K values decreased from April – November.

The precipitation pathways (P) x Time (T) interaction showed that Stemflow in April had significantly (P =0.05) the highest (3.68 mg L^{-1}) K contents. The statistically similar K contents in Rainfall in July (0.88 mg L^{-1}), September (1.16 mg L^{-1}), October (1.03 mg L^{-1}) and November (1.27 mg L^{-1}) gave significantly (P = 0.05) the least values.

Calcium (Ca)

Table 2also shows the Ca values of the precipitation pathways overtime. Throughfall and Stemflow gave significantly(P = 0.05) the highest (34.53 mg L^{-1}) and the least (23.42 mg L^{-1}) Ca contents respectively. The overall results of Ca contents in the precipitation pathways are in the following order of magnitude: Throughfall > Rainfall > Stemflow. The statistical similar Ca contents in the precipitation pathways in July (30.29 mg L^{-1}), August (32.57 mg L^{-1}), September (30.27 mg L^{-1}) and November (32.15 mg L^{-1}) were significantly higher than the Ca contents in April (24.83 mg L^{-1}), May (21.85 mg L^{-1}) and June (23.23 mg L^{-1}).

In the Precipitation pathways and Time interaction, Throughfall in August and September and Rainfall in November gave significantly the highest Ca contents. While Stemflow in May (17.29 mg L^{-1}), June (19.00 mg L^{-1})and October (17.19 mg L^{-1}) and Rainfall in April (17.17 mg L^{-1}), May (18.11 mg L^{-1}), June (21.90 mg L^{-1}) and September (21.19 mg L^{-1}) gave significantly the least.

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Table 2 : Mean Potassium (K) and Calcium (Ca) Contents in Precipitation Pathways Overtime in A. auriculiformisPlantation at Umuahia, Nigeria in 2013

Time	K (mg l^{-1}) Precipitation Pathways				Ca (mg l^{-1}) Precipitation Pathways			
Month)	Throughfall	Stemflow	Rainfall	Mean	Throughfall	Stemflow	Rainfall	Mean
April	3.85	4.84	2.36	3.68	35.31	22.00	17.17	24.83
May	3.01	4.11	1.81	2.97	30.16	17.29	18.11	21.85
June	1.81	3.90	1.72	2.48	28.78	19.00	21.90	23.23
July	1.76	2.52	0.88	1.72	22.04	37.91	30.91	30.29
August	1.93	2.56	1.29	1.92	44.11	27.66	25.95	32.57
September	2.20	2.27	1.16	1.88	46.20	24.90	21.19	30.77
October	1.55	1.72	1.03	1.43	38.63	17.19	25.13	27.31
November	2.10	2.24	1.27	1.87	31.00	21.35	44.11	32.15
Mean	2.28	3.02	1.44	2.25	25.69	23.42	34.53	27.88

F-LSD (0.05)	K (mg l^{-1})	Ca (mg l^{-1})
Precipitation Pathways (P)	0.14	1.58
Time (T)	0.23	2.57
P x T Interaction	0.40	4.46

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Sodium (Na)

Table 3 shows the Na values of the precipitation pathways overtime. Stemflow gave significantly the highest (3.85 mg L^{-1}) Na contents. Throughfall (2.95 mg L^{-1}) and Rainfall (2.99 mg L^{-1}) had similar Na contents.

In terms of Time, the similar Na contents of April(3.57 mg L^{-1}), May (3.57 mg L^{-1}), July (3.66 mg L^{-1}) and August (3.52 mg L^{-1})were higher than that of June (3.14 mg L^{-1}), September (3.04 mg L^{-1}), October (3.05 mg L^{-1}) and November (2.56 mg L^{-1}). The precipitation pathways and Time interaction showed that The Stemflow of May and July gave significantly the highest (4.75 mg $L^{-1}$and 4.00mg L^{-1}respectively) Na value. The constant Na contents in throughfall from June to October is similar to that of Rainfall from September to November.

Magnesium (Mg)

Table 3 further shows that Rainfall gave significantly the highest Mg contents. Stemflow and Throughfall had similar Mg values. Mg contents overtime in all the precipitation pathways shows that August and November gave significantly the highest (16.25 mg $L^{-1}$and 16.82 mg L^{-1}respectively). The Mg contents in the precipitation pathways decreased from August

The Precipitation pathways and Time interaction showed that Throughfall in August and Rainfall in November had similar Mg contents (26.75 mg L^{-1}) and gave significantly the highest Mg value. The Stemflow in May and June and Rainfall in August had similar Mg contents which gave significantly the least values (5.29 mg L^{-1}, 4.88 mg L^{-1} and 5.24 mg L^{-1} respectively).

Table 3: Mean Sodium (Na) and Magnesium (Mg) Contents in Precipitation Pathways Overtime in *A. auriculiformis* Plantation at Umuahia, Nigeria in 2013

	Na ($mg\ l^{-1}$)				Mg ($mg\ l^{-1}$)			
Time	Precipitation Pathways				Precipitation Pathways			
Month)	Throughfall	Stemflow	Rainfall	Mean	Throughfall	Stemflow	Rainfall	Mean
April	4.18	3.52	3.01	3.57	10.69	13.38	13.05	12.37
May	3.54	4.75	2.42	3.57	13.05	5.29	12.28	10.21
June	2.62	4.00	2.79	3.14	12.24	4.88	10.44	9.18
July	2.53	4.83	3.63	3.66	10.69	22.98	10.70	14.79
August	2.54	4.04	3.88	3.52	26.75	16.76	5.24	16.25
September	2.85	3.72	2.54	3.04	13.42	12.61	10.28	12.10
October	2.90	3.34	2.92	3.05	7.81	9.28	7.91	8.34
November	2.32	2.61	2.75	2.56	10.72	12.97	26.75	16.82
Mean	2.95	3.85	2.99	3.26	12.08	12.27	13.17	12.51

F-LSD (0.05)

	Na ($mg\ l^{-1}$)	Mg ($mg\ l^{-1}$)
Preciptation Pathways (P)	0.19 0.78	
Time (T)	0.30	1.28
P x T Interaction	0.53	2.21

Discussion

The nitrogen (N) contents in *Acacia auriculiformis* Stemflow and Throughfall solution ranged from 119.80 to 231.00 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}(Chang and Matzner, 2000; Johnson and Lehmann, 2006) and from 0.21 to 1.04 mg L^{-1} for a variety of tropical forest and fruit tree species (Schroth *et. al.*, 2001). However, it is in line with the findings of Koyejo *et al*., (2020) who reported a range of 56.00 to 112.00 mg L^{-1} for *E. cylindricum* at Onne, Nigeria.

The*Acacia auriculiformis*phosphorus (P) contents in Stemflow(2.45 to 6.79 mg L^{-1}) islower than that recorded by Koyejo *et al.* (2020) for *E. cylindricum* (7.36 – 8.92 mg L^{-1}) and Schroth *et al.*, (2001) for tropical forest trees (10 to 14 mg l^{-1}). The mean K contents in *Acacia auriculiformis* Stemflow (3.02 mg L^{-1}) was lower than that reported for *Eucalyptus dumnii* Stemflow (17.55 mg L^{-1}) in southern Brazil but the K contents in Throughfall (2.28 mg L^{-1}) of *A. auriculiformis* was higher than that of *E. dumnii* (1.28 mg L^{-1}) (Momolli *et al*., 2019). *A. auriculiformis* mean Ca concentration in Stemflow (23.42 mg L^{-1}) and Throughfall (25.69 mg L^{-1}) were higher than those of *E. dumnii* (2.73 mg L^{-1}) and (0.71 mg L^{-1}) respectively (Momolli *et al*., 2019)

The higher ions concentration found in Stemflow and Throughfall than that of Rainfall corresponds with the findings ofJohnson and Lehmann, (2006); Zhang *et al*., (2016), Tan *et al.* (2018), Su *et al.*, (2019b), Koyejo *et al.*, (2020), where ions concentration in Stemflow and Throughfall were higher than Rainfall. Stemflow was found to have more nutrient concentrations than Throughfall. This was also reported by Su*et al*., 2019b, where some nutrient elements were higher in Stemflow than Throughfall.However, the least Ca concentration in Stemflow when compared to Throughfall and Rainfall could be as a result of absorption of Ca from the precipitation flowing along the trunk surface by epiphyticbryophytes (mosses and lichens) growing abundantlyon the stems and boles of forest trees due to the moist conditions that prevail under forest canopies (Dawoe *et al.*, 2018).

It is a prevalent occurrence for the concentrations of nutrient elements to increase after precipitation passes through the tree canopy (Tan *et al*., 2018).The interaction between rainfall and the canopy can change the concentration of nutrient elements in the precipitation as it passes through the canopy (Germer *et al.*, 2007). This increase in nutrient concentration of Stemflow and Throughfall could be due to adequately long residence times of the intercepted precipitation on the surfaces of thetree branch (Tan *et al.*, 2018).This results in greater leachability of bark tissue in Stemflow and foliar leaching of nutrients in Throughfall (Zhang *et al*., 2016).

Theextent to which individual nutrients are leachedappears to be dependent on the mineral nutrient statusof the plant and the balance that exists among elements (Dawoe *et al.*, 2018).

Three processes govern the chemistry of throughfall which are; concentration due to the evaporation from the wet canopy, washout of the dry deposition for example, dusts, vegetal and animal debris,decomposition over the vegetation (Germer *et al*., 2007, Su*et al*., 2019;Corti *et* *al*., 2019) and leaching of the nutrients in internal plant parts (Tan *et al*., 2018).

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 high nutrient concentration recorded in most of the nutrient elements at the beginning of the raining season corresponds with the findings of Zhang *et al*., (2016) who reported high ions concentration during the first rainfall event and subsequent decrease as the rainfall depth increases. Ion concentrations in Stemflow and Throughfall strongly depends on the first flush effect, rainfall depth, and the antecedent dry period before a rainfall event occurring (Zhang *et al*., 2016).

Conclusion

The study has revealed that precipitation in the form of Rainfall, Stemflow and Throughfall contained dissolved nutrient elements (Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, and Sodium). It was further revealed that Stemflow and Throughfall contain more concentration of nutrients than Rainfall. Therefore, *Acacia auriculiformis* can contribute significantly to a sustainable forest and agroforestry ecosystems based on the nutrient concentration in its Stemflow and Throughfall solution.This serve as an important channel for nutrient recycling.

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