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Litterfall nutrients and the soil nutrients under three indigenous tree species in the Nigerian rainforest Region

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Abstract

The study was conducted in the 3 senatorial districts in Delta State (Delta North, Delta Central and Delta South). From each senatorial district, 5 stands of each indigenous species of tree were selected, while 5 rainforest control plots were established from neighbouring rainforest cover of ≥ 80 years in age. Thus, samples of litterfall and soil were gathered from 15 trees, each from the indigenous species and the control plots, respectively. Two soil layers of 0-15cm and 15-30cm depth were determined under the trees, from where soil samples were collected, using a core sampler, while litterfall was gathered from March 2019 to February 2020 using litter traps. Standard laboratory procedures were adopted to analyse the samples collected. Descriptive, ANOVA and correlation statistics were employed to analyse the data using the 15.0 version of SPSS. The research statistically correlates litterfall nutrients with soil nutrients under isolated indigenous stands of *Terminalia superba, Irvingia gabonensis* and *Newbouldia laevis* trees in the Nigerian rainforest region. Results show that soil nutrients, litterfall nutrient contents and returns significantly differed among the tree species at a 5% confidence level, while soil nutrients correlated with litterfall nutrients positively. Since the isolated indigenous trees can add nutrients to rainforest soil, thereby improving its nutrients and sustaining its productivity, their incorporation into the agro-forestry practice as farm trees by farmers is recommended. This has implications for forest and environmental conservation.

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Introduction

Tree stands and soils under them are interrelated in terms of the exchange of nutrients. Litterfall nutrient elements returned to the soil help to enhance soil fertility status by adding to the amount of nutrients present in the soil (Londe *et al.* 2016; Krishna and Mahesh, 2017; Ndakara, 2019). Based on this, Augusto *et al.* (2017) have argued against the practice of examining vegetation and soil as separate entities because vegetation and soil operate separately but are strongly dependent on open systems. In other words, if their components are studied separately, the changes which take place within the soils under trees and those changes which occur in their physiognomy during their life span cannot be fully understood (Kazumichi *et al.*, 2018; Eguakun and Job, 2018).

The plant cover has always served as an index of soil status (Ndakara and Ofuoku, 2020). Therefore, the productivity of the forest ecosystem relies much on the litter quality, which influences nutrients uptake and returns. In nutrient cycling, litterfall nutrients return to soil varies according to the floristic compositions of the plant cover (Pypker *et al.*, 2005). The amount of nutrients returned by trees to soils will, however, vary according to the tree type and the species in question, while varying tree species will exert varying influences on the nutrient properties of rainforest soils (Oziegbe *et al.,* 2011). Indeed, a review of different studies by Krishna and Mahesh (2017) has revealed that not every tree species can significantly improve soil organic matter, exchangeable cations and build-up of extractable micronutrients under their canopies.

Several researchers have investigated relationships between litterfall nutrients and soil nutrients underneath plants. A study by Lanuza *et al.* (2018) on litterfall nutrients dynamics in a tropical forest showed that combined changes in the composition of vegetation and litterfall nutrients accounted for variation in the phosphorus (P) and nitrogen (N) content of the soil. A study carried out by Ngaiwi *et al.* (2018) on Litterfall nutrients return in rainforest cover of South-western Cameroon observed seasonal variations in litter-fall, while litterfall nutrients return to soil varied in concentrations. In Cote d'Ivoire, findings in a study by Bernhard-Reversat (1977) show that aboveground biomass and storage are higher in the natural rainforest than in the monocultural plantation of 38-year old plantation of *Terminalia ivorensis*. Higher nutrient content was also found in the natural forest than in the monocultural plantations. Loumeto (2003) investigated litterfall and nutrients return in rainforest within the Chaillu area, Southwest Congo. Findings from the study showed that the amounts of the litter as biomass and nutrients input were higher in the secondary forest than in the primary forest. This amount is low compared with other tropical areas in Africa due to a long dry season in the Congo. Research by Oziegbe *et al.* (2011) on litterfall within the secondary rainforest of Ile-Ife in Nigeria showed a significant monthly variation in litterfall. The study also revealed that litterfall is an essential channel for nutrient cycling between plants and soils.

From the different researches conducted on the relationships between litterfall nutrients and soil nutrients, the contributions of individual species of tree to the soil have not been adequately carried out because of close canopy influence from other tree species. Also, different tree species selectively immobilize nutrients; hence their influences on soil nutrients vary (Ekanade, 2007; Ndakara, 2018). This study is, therefore, aimed at statistical correlates between litterfall and soil nutrients under isolated indigenous trees in the rainforest region. Upon these, the following hypotheses were tested: (i) Significant differences exist in litterfall nutrients concentrations and returns by the indigenous isolated and neighbouring rainforest trees. (ii) Significant differences exist in soil nutrient properties under the isolated indigenous and adjoining rainforest trees. (iii) Litterfall nutrients returned correlated positively with the soil nutrients under trees.

Materials and methods

This research took place in Delta State. The state was divided into 3 subregions according to the existing senatorial districts Delta North, Delta central and Delta South, as adopted by Ndakara and Eyefia (2021). The isolated indigenous trees (*Terminalia superba, Irvingia gabonensis* and *Newbouldia laevis*) selected in this study have no specific distribution pattern; thus, only isolated stands of the three indigenous species selected were sampled to account for their contributions to the rainforest soil, and as well determine the relationships between soil nutrients and nutrients returned by isolated indigenous trees within the rainforest region. From each senatorial district, 5 stands of each isolated indigenous species were selected, while 5 rainforest control plots measuring 900m², divided into quadrats of 300m² were established from the neighbouring rainforest cover of ≥ 80 years in age. Thus, litterfall and soil samples were gathered from 15 stands of each species of the indigenous trees and the control plots, respectively, making the total sample sites investigated 60.

The samples collected for this study were soil and litterfall. Samples of soil were collected from 2 soil layers (0-15cm and 15-30cm) using a core sampler, while litterfall was taken from March 2019 to February 2020 using litter traps. Samples were put into labeled polythene bags and moved to the laboratory for analysis on nitrogen (N), phosphorus (P) and potassium (K).

Concentrations of N and P in litterfall were ascertained by the digestion system using auto analyzer; while Exchangeable potassium in litterfall was determined by digesting the litter samples in HNO_3 / H_2O_2 on a block at 105°C and analysed with Spectrometry as adopted by Adedeji (2008). The concentrations (mg/g) of litterfall nutrients were converted to nutrients returned (kg/ha).

For soil samples, total N was obtained by digesting soil samples with concentrated H_2SO_4, while an auto-analyzer was used to determine its content. Available P was determined through leaching with Bray P-1 extracting solution, while a spectrophotometer was used to ascertain the concentration after colour development using Murphey and Riley reagent. Exchangeable potassium content was ascertained with the use of a flame photometer, after the soil sample was leached with 1N neutral ammonium acetate.

Statistical analysis of data employed the descriptive, ANOVA and correlation techniques using 5.0 version of SPSS. The descriptive statistical technique was employed to ascertain the mean, standard deviation (SD) and the coefficient of variation (CV) values of soil data sets. The ANOVA statistical technique was employed to comparatively test the means of soil nutrients, litterfall nutrient contents and litterfall nutrients returned, while soil nutrients were correlated with litterfall nutrients.

Results discussion

Nutrient contents and returns to soil by litter-fall

Litterfall nutrient contents and returns to soil varied amongst the isolated indigenous and rainforest trees. This variation is probably because of differences in the compositions of tree species, as indicated in studies by Muoghalu *et al.* (1993), Ndakara (2011), Oziegbe *et al.* (2011), Lanuza *et al.* (2018) and Ngaiwi *et al.* (2018). Table 1 shows the nutrient contents and returns to soils under tree stands. Apart from potassium with concentrations of 4.88 mg/g, 3.75 mg/g, 3.44 mg/g and 3.70 mg/g for *Terminalia superba*, *Irvingia gabonensis, Newbouldia laevis and* Adjoining rainforest, respectively, nutrients concentrations in rainforest litter were higher than nutrients concentrations in isolated tree litter.

Generally, potassium and nitrogen concentrations are higher than phosphorus concentrations. Nitrogen concentrations for *Terminalia superba*, *Irvingia gabonensis, Newbouldia laevis and* adjoining rainforest are 5.88 mg/g, 4.79 mg/g, 4.52 mg/g and 10.69 mg/g, respectively. Thus, this corroborates results reported in studies by Kitayama *et al.* (2015), which showed that potassium and nitrogen concentrations (6.5 mg/g and 19 mg/g, respectively) were more than phosphorus concentrations (0.7 mg/g).

Table 1. Mean concentrations and the returns of nutrients in litterfall.

	Nutrient Elements	Sites			
		Terminalia superba	*Irvingia gabonensis*	*Newbouldia laevis*	Adjoining rainforest
concentrations (mg/g)	Nitrogen	5.88	4.79	4.52	10.69
	Phosphorus	0.67	0.61	0.71	0.73
	Potassium	4.88	3.75	3.44	3.70
nutrient returns (kg/ha)	Nitrogen	5.74	3.44	2.43	9.09
	Phosphorus	0.66	0.46	0.43	0.61
	Potassium	4.93	2.65	2.15	3.40

Also, apart from nitrogen returned which is highest in the rainforest with a value of 9.09, potassium and phosphorus returned are highest in *Terminalia superba,* returning 0.66 kg/ha and 4.93 kg/ha, respectively. The returned potassium and nitrogen are generally more than phosphorus returned, thus, corroborating findings reported by Muoghalu *et al.* (1993) and Ndakara (2012), where potassium and nitrogen returns (4.5 kg/ha and 6.6 kg/ha, respectively) are more than phosphorus returns (4.0 kg/ha). The higher flux in these nutrient elements could presumably be due to their high availability in these soils. The order of litterfall nutrients returned by the isolated indigenous and neighbouring rainforest trees is nitrogen > potassium > phosphorus. This order tallies with the observed order reported by Muoghalu *et al.* (1993) and Perez *et al.* (2003).

Table 2. Results of ANOVA for Nutrients Returned by Litterfall to soils from *Terminalia superba, Irvingia gabonensis, Newbouldia laevis* and neighbouring Rainforest Trees.

Nutrient Element	Groups	Sum of squares	d/f	Mean square	F	Sig.
Nitrogen	Between	312.295	3	104.099	6.588	.001
	Within	695.387	44	15.804		
	Total	1007.682	47			
Phosphorus	Between	.448	3	.150	1.097	.360
	Within	6.003	44	.136		
	Total	6.451	47			
Potassium	Between	72.859	3	24.287	3.284	.041
	Within	325.471	44	7.397		
	Total	378.330	47			

Table 2 shows the results of ANOVA for litterfall nutrients returned by the isolated indigenous and neighbouring rainforest trees. The variations in potassium and nitrogen returns via litterfall are significant at the 5% levels, at 0.001 and 0.041, respectively. Therefore, the stated hypothesis that "significant differences exist in litterfall nutrients concentrations and returns by the indigenous isolated and neighbouring rainforest trees" is accepted. The concentrations and returns of nutrients by the trees are not the same. Different tree species immobilize nutrients as well as return nutrients at different levels.

Soil nutrient elements

Soil nutrients varied between the topsoil and subsoil layers, as well as under the isolated indigenous and neighbouring rainforest trees.

Table 3. Descriptive statistical analysis of soil nutrient properties under isolated indigenous and neighbouring rainforest trees.

Layer of soil	Soil Properties	Statistics	*Newbouldia laevis*	*Irvingia gabonensis*	*Terminalia superba*	Neighbouring Rainforest
Topsoil Layer	Total N. (%)	Mean	0.46	0.49	0.54	0.60
		S.D	0.08	0.06	0.06	0.13
		C.V (%)	17.39	12.24	11.11	21.67
	Available P. (mg/kg)	Mean	11.77	12.10	13.88	14.87
		S.D	4.27	2.63	1.94	1.83
		C.V (%)	36.28	21.74	13.98	12.31
	Exchangeable K. (mg/kg)	Mean	60.74	61.74	116.48	57.81
		S.D	4.44	5.70	26.70	5.68
		C.V (%)	7.31	9.23	22.92	9.83
Subsoil Layer	Total N. (%)	Mean	0.20	0.21	0.24	0.28
		S.D	0.06	0.04	0.04	0.05
		C.V (%)	30.00	19.00	16.67	17.86
	Available P. (mg/kg)	Mean	6.23	6.80	7.62	7.69
		S.D	1.17	1.16	0.72	2.08
		C.V (%)	18.78	17.06	9.45	27.40
	Exchangeable K. (mg/kg)	Mean	18.21	16.41	19.61	29.41
		S.D	2.49	2.40	3.01	11.02
		C.V (%)	13.67	14.63	15.35	37.47

Table 3 presents the descriptive statistical analysis of soil nutrient properties under isolated indigenous and neighbouring rainforest trees. The concentrations of total N., available P. and exchangeable K. are higher in the topsoil layer. Apart from exchangeable K. under *Terminalia superba* with the concentration of 116.48 mg/kg, nutrients are higher under the neighbouring rainforest than under isolated trees. While available P. was highest in topsoil under the neighbouring rainforest (14.87 mg/kg), *Newbouldia laevis* recorded its lowest value (11.77mg/kg).

Within the subsoil layer, available phosphorus was highest under rainforest (7.69 mg/kg) while the lowest concentration was observed under *Newbouldia laevis* (6.23 mg/kg).

Table 4. ANOVA results for soil characteristics under isolated indigenous and neighbouring rainforest trees.

Soil Layer	Soil properties	Groups	Sum of squares	d/f	Mean square	F	Table F
Topsoil	Total N.	Between	0.176	3	0.058	9.339	2.84
		Within	0.348	56	0.006		
		Total	0.524	59			
	Available P.	Between	97.008	3	32.335	4.043	2.84
		Within	447.685	56	7.994		
		Total	544.693	59			
	Exchangeable K.	Between	35882.983	3	11960.983	60.071	2.84
		Within	11150.000	56	199.107		
		Total	47032.983	59			
Subsoil	Total N.	Between	0.063	3	0.020	12.239	2.84
		Within	0.094	56	0.003		
		Total	0.157	59			
	Available P.	Between	20.227	3	6.740	3.626	2.84
		Within	104.152	56	1.862		
		Total	124.379	59			
	Exchangeable K.	Between	1522.202	3	507.401	14.286	2.84
		Within	1989.201	56	35.521		
		Total	3511.403	59			

*Significant at F > critical table F (2.84) at the 0.05 level.

From Table 4, the ANOVA results show that significant variations exist in soil nutrient elements under isolated indigenous and the neighbouring rainforest trees at 5% levels, for both soil layers. The topsoil F-values for N, P and K are 9.339, 4.043 and 60.071, with corresponding table F-values of 2.84, respectively. In like manner, the subsoil F-values for N, P and K are 012.239, 3.626 and 14.286, with corresponding table F-values of 2.84, respectively. Therefore, the stated hypothesis that "significant differences exist in soil nutrient elements under isolated indigenous and the neighbouring rainforest trees" is accepted. Nutrient status differs significantly under the different tree species.

Table 5. Correlations between Litterfall Nutrients Returned and Soil Nutrients under Isolated Indigenous and Neighbouring Rainforest Trees.

Litterfall sources	Litterfall nutrients returned	Soil Nutrient Elements		
		Nitrogen	Phosphorus	Potassium
Terminalia superba	Nitrogen	.937	.603	-.167
Irvingia gabonensis		.883	.474	-.044
Newbouldia laevis		.815	.541	-.019
Rainforest		.922	.596	-.005
Terminalia superba	Phosphorus	.669	.869	-.450
Irvingia gabonensis		.301	.809	-.691
Newbouldia laevis		.471	.909	-.586
Rainforest		.422	.926	-.992
Terminalia superba	Potassium	-.398	-.835	.902
Irvingia gabonensis		-.982	-.905	.903
Newbouldia laevis		-.827	-.952	.868
Rainforest		-.812	-.911	.895

Relationships between litterfall nutrients returned and soil nutrients under trees

Litterfall contributes to soil nutrients by returning nutrient elements from the aboveground tree stands to soil.

Results in Table 5 show that nutrient elements returned to the soil via litterfall correlated positively with the soil nutrients underneath the isolated indigenous and neighbouring rainforest trees. High positive correlations were observed between nitrogen and phosphorus, ranging from 0.301 to 0.93 under all the trees and the rainforest. The highest correlation at 0.603 between nitrogen and phosphorus was recorded under *Terminalia superba,* while the highest observed correlation at 0.669 between phosphorus and nitrogen was recorded under *Terminalia superba* as well. Therefore, the hypothesis which states that "litterfall nutrients returned correlated positively with soil nutrients under tree stands" is accepted. This result is similar to the findings reported in a study by Kazumichi *et al.* (2018). Generally, the observed levels of correlation between nutrients returned in litterfall and the nutrient elements in soil show that litterfall contributes to soil nutrients. Therefore, relationships exist between nutrients returned in litterfall and the nutrient elements in the soil underneath trees. This indicates the natural nutrient recycling process and aligns with the findings reported by Lanuza *et al.* (2018).

Conclusion

Litterfall nutrients returned varied amongst the isolated indigenous and neighbouring rainforest trees and correlated positively with the soil nutrient properties under the trees. Soil nutrient elements varied under the isolated indigenous species and the neighbouring rainforest trees, respectively. Since the isolated indigenous trees can return nutrients to the soil, making them capable of adding values to soil fertility status and sustaining the productivity of soils within the rainforest environment, they are, therefore, recommended to be incorporated into the agro-forestry practices within the rainforest ecosystem. Agro-forestry practices need to be encouraged among farmers. This has implications for forest and environmental conservation and, by extension, species conservation, which has the capacity to preserve the tree species, thereby preventing their extinction and protecting the environment. These agro-forestry practices prevent the usage of inorganic fertilizers that are not environmentally friendly.

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