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Leaf Litter Production and Nutrient Return in Coffee (*Coffea canephora*) Plantations of Different Ages in Ibadan, Nigeria

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Authors' contributions

This work was carried out in collaboration among all Authors. Author CII designed the study, monitored and supervised the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NT and CEO managed analysis of the study and conducted literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the role of leaf litter and its nutrient input on soil fertility levels in coffee plantations of different ages in Ibadan, Nigeria. Four coffee plantations of 11, 19, 24 and 51 years were selected for the study. Each plantation was divided into four blocks where leaf litter, soil and plant samples were collected and analyzed for nutrient .Results indicated that mean total leaf litter input in these plantations ranged from 2.50 - 3.5 $tha^{-1}yr^{-1}$ with a minimum in the 11 year old plantation and maximum in the 51 year plantation. Nitrogen input from leaf litter across the coffee plantations ranged from 27.60 – 60.07 $kgNha^{-1}year^{-1}$, which was insufficient to meet the nitrogen need of coffee trees. This was reflected by the low nitrogen content of soils of the coffee plantation (0.2 g/kg - 0.8 g/kg) which was below the soil critical nitrogen level of 0.9 g/kg recommended for coffee production. Phosphorus input from the leaf litter in the different plantations was also low 0.38 - 1.73 $kgPha^{-1}$ as evident from the low phosphorus content of the soil 4.49 - 5.94 mg/kg. This was also reflected in the low leaf phosphorus content of 0.14 - 0.23 g/kg. The potassium content of the

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leaf litter was also insufficient 17- 55.8 kg Kha^{-1}. Calcium, magnesium, iron, and zinc were sufficient. Coffee leaf litter contributes considerable amount of nutrient to natural soil fertility management of coffee plantations but this is inadequate to meet the nutrient requirement of coffee. There is therefore need for application of fertilizer to supply limiting nutrients.

Keywords: Soil fertility management; leaf litter; limiting nutrient; plant productivity.

1. INTRODUCTION

Coffee is a cash crop with great economic potential as a foreign exchange earner. In Nigeria, about 96% of the coffee grown is low land *Coffea canepora* [1], with production of *Coffea arabica* limited to the highland of Mambilla and Jos Plateau. In Nigeria, highland for production of *coffea arabica* is limited, but large expanse of low land is available for production of *Coffea robusta.* This creates great potential for expansion of lowland *Coffea canephora* production. Despite this potential, very little coffee beans is produced and marketed in Nigeria.

Coffee bean production in Nigeria is on the decline with a production of 1,849 tonnes of coffee green beans in 2018 as against 5,340 metric tonnes in 2006 [2]. This is because of a number of reasons, among which the poor nutrient status of the soil is prime. African soils are low in inherent fertility when compared with other parts of the world. This is due to the presence of low activity kaolinite clay which requires fertilizer application. Coffee farmers in Nigeria use little or no fertilizer, with reasons ranging from ignorance on the need for fertilizer, unavailability and high cost of fertilizer where available among other reasons. Coffee production in Nigeria is therefore largely dependent on the natural endowment of the soil and on litterfall. This has led to nutrient mining through harvesting of coffee berries, hence deficiency of some nutrients thus the need for nutrient replenishment.

Litterfall is an important component of nutrient cycling. It recycles nutrient within the plant soil component and regulates soil fertility and plant productivity [3]. This is because a portion of nutrient taken up by trees are returned back to the soil as litter fall [4] thus reducing nutrient loss through erosion and leaching. Organic matter and nutrient released from the decomposing litter is however dependent on abiotic factors, the initial quality of the litter [4, 5] and on soil fertility [6]. The quantity of litter input in the ecosystems is also affected by tree specie, age of the tree, climate, season, management practices [7, 8] and elevation [9]. *Coffea arabica* produced 2.21 $tonsha^{-1}yr^{-1}$ of leaf litter in a 10 year old organic *Coffea arabica* plantation, with leaf litter containing 54.15 $kgNha^{-1}yr^{-1}$ [10]. [11, 12] Also reported 28 – 35 $kgNha^{-1}yr^{-1}$ in coffee leaf litter. [13, 14] in the rainforest of Western Nigeria recorded 6-8.5 tonnes ha^{-1} and 5.83- 7.3 tonnes ha^{-1} of leaf litter in cocoa and kola plantations respectively. while, [15] reported litter fall of 6-7 tonnes ha^{-1} in cocoa plantation with this litter contributing 88 $kgNha^{-1}yr^{-1}$, 6 $kgPha^{-1}yr^{-1}$ and 82 $kgha^{-1}yr^{-1}$.

Coffee trees generate leaf litter with peak litter fall in the dry season. There is need to study leaf litter production and its contribution to soil nutrient status of coffee plantations. This would ensure better understanding of nutrient recycling in coffee plantations and appropriate soil and fertilizer management for optimum productivity under coffee plantations in Nigeria.

1.1 The Objectives of this Study are to

i. Determine the amount of leaf litter in coffee plantations of different ages.
ii. Determine nutrient content of leaf litter generated in coffee plantations of different ages.
iii. Assess soil fertility levels of coffee plantations of different ages.

2. MATERIALS AND METHODS

2.1 Study Location

The study was conducted at Cocoa Research Institute of Nigeria (CRIN) in Ibadan, Nigeria (lat $07^{0}10^{1}$ N and long $03^{0}51^{1}$E) and altitude of 122 m above sea level. Ibadan is located in the forest ecological zone with a bimodal rainfall pattern and a mean annual rainfall of 1300 mm. The wet season lasts from March to October or early November with two weeks of dry spell in August, while the dry season runs from early November to March. The maximum temperature ranges from 26°C to 35°C and the minimum temperature is 30.1°C.The soil is classified as an alfisol.

2.2 Experimental Layout

Four coffee plantations of ages 11, 19, 24 and 51 years with plant density of 2,053, 1,915, 1,741 and 1,895 plants ha^{-1} respectively was used for the study. The coffee trees were spaced 3 m X 3 m apart with each coffee plantation not less than two hectares. The mean plant height of the trees in the 11, 19, 24, and 51 year old coffee plantation was 1.48 m, 1.50 m 1.67 m and 1.63 m respectively, while the mean circumference of the coffee trees was 31.7±3.1 cm, 40.8±2.4 cm, 45.5±3.0 cm and 35±2.6 cm for the 11, 19, 24 and 25 year old plantation respectively.

Each plantation was divided into four blocks. Leaf litter was collected for one year using 1m X 1m litter traps which were placed 10 m apart from each other. Seven such spots were demarcated per block. The litter traps with a 1 mm mesh size, were suspended 40 cm above the ground and placed at a distance of 1 m from the trunk of the tree. Soil auger was used to collect soil samples at 0-20 cm and 20-40 cm soil depth under the canopy of the trees from which leaf litter was collected. The 4^{th} pair of leaves was collected from the tip of a growing coffee branch for coffee plant nutrient analysis.

2.3 Leaf and Soil Analysis

The 4^{th} pair of leaves from the coffee tree and coffee leaf litter samples collected were cleaned to remove soil particles, oven dried at 60°C for 72 hours and the leaf litter weighed. Leaves from the coffee plant and representative leaf sample from the leaf litter were milled and analyzed for organic carbon, total N, P, K, Ca, Mg, Na, Mn, Fe, Cu and Zn.

Soil samples for analysis were air dried, passed through a 2 mm sieve and analyzed for some of its physical and chemical properties using standard procedures. Dichromate wet oxidation method as described by [16] was used to determine soil organic carbon content. Soil pH was determined in soil water solution of 1:1 ratio [17]. Particle size analysis was determined by hydrometer method [18], total nitrogen by Kjeldahl method, available phosphorous by Bray-1 method [19] and exchangeable acidity by filtration titration method. Ammonium acetate was used to extract exchangeable bases (K, Ca, Mg, and Na). Potassium and Na in the filtrate were read using a flame photometer, while Ca and Mg were read using an Atomic absorption spectrophotometer. Cation exchange Capacity (CEC) was determined by summation of all cation and effective cation exchange capacity (ECEC) determined by sum mation of exchangeable bases and acids. Soil and coffee plant leaf samples were compared across plantations using the soil and foliar critical levels.

Data collected on coffee leaf litter weight, nutrient content of the leaf litter and nutrient content of coffee plant leaf was subjected to analysis of variance (ANOVA). Where differences were significant, at 5% level of probability. Least significant differences (LSD) was used for mean separation [20].

3. RESULTS AND DISCUSSION

3.1 Quantity of Leaf Litter

Mean leaf litter production across coffee plantation of different ages ranged between 2.50 – 3.51 $tonsha^{-1}yr^{-1}$ (Table 1) with the 51 year old coffee plantation producing the highest mean leaf litter quantity (3.51 tons $ha^{-1}yr^{-1}$) and 11 year old coffee plantation producing the lowest (2.50 $tonsha^{-1}yr^{-1}$).

Table 1. Weight of coffee leaf litter (tons $ha^{-1}yr^{-1}$) in coffee plantations of different age

Age of plantation (years)	Mean litter weight	Range of litter weight
11	2.50	2.40 – 2.60
19	3.04	3.03 – 3.05
24	2.71	2.50 – 2.90
51	3.51	3.40 – 3.61
LSD (.05)	0.17	

Similar observation was made by [10] who reported that *Coffea arabica* produced 2.21 $tonsha^{-1}yr^{-1}$ of leaf litter in a 10 year old organic *Coffea arabica* plantation. Leaf litter produced by coffee was however low when compared to other tree crops in Ibadan. [13, 14] observed that cocoa and kola plantations produced 6 - 8 tons ha^{-1} and 5.83 – 7.38 $tonsha^{-1}$ of leaf litter respectively.

Coffee leaf litter weight was higher in the 19 year old coffee plantation than in the 11 year old coffee plantation. The 19 year old coffee plantation had 22 % higher leaf litter than the 11 year old coffee plantation. This is in agreement with [7] who reported that leaf litter production increased with increasing age of trees. This could be as a result of increased vegetative biomass of the coffee trees with increasing age of the coffee tree. The 24 year old coffee plantation however had 13% lower leaf litter than the 19 year old coffee plantation. The decrease in leaf litter quantity in the 24 year old coffee plantation compared with the 19 years old coffee plantation could be attributed to the fact that at this stage in the productive life of the coffee tree, more nutrients were channeled to berry production at the expense of leaf production, hence decrease in leaf litter. Increasing age of coffee plantation from 24 to 51 years gave a corresponding increase in leaf litter quantity of 30 %. This trend in leaf litter accumulation could be as a result of increasing coffee litter biomass with increasing age of coffee plantation. This coupled with the fact that the coffee trees had exceeded the maximum coffee berry production stage, resulted to diversion of nutrients to leaf production, hence higher leaf biomass.

3.2 Primary Macronutrient and their Nutrient Dynamics

Nitrogen in the leaf litter was 27.60 – 60.07 $kgNha^{-1}yr^{-1}$(Table 2).

This was in agreement with [11,12] who reported 28 – 35 $kgNha^{-1}yr^{-1}$ in coffee leaf litter, while [10] reported that *Coffea arabica* leaf litter contained 54.15 $kgNha^{-1}yr^{-1}$ in 10 year old organic coffee. [21] also reported that leaves and branches from the coffee plant returned 41 $kgNha^{-1}yr^{-1}$, to the soil. Nitrogen in the leaf litter was low. This low nitrogen content of the leaf litter was reflected in the low total nitrogen content of the soils of the various coffee plantations (0.2 – 0.8 g/kg) (Table 3).

This is below the soil critical nitrogen level of 0.9 g/kg required for coffee production [22].This is also reflected in the low soil organic carbon content in the coffee plantations (2.00-7.8 g/kg) which was below the 10 g/kg, required [23]. This nitrogen inadequacy in the soil could also be attributed to the fact that fast growing high yielding coffee takes up 135 $kgNha^{-1}$ [24] and nitrogen in the leaf litter 27.60 – 60.01 was grossly inadequate to replenish the nitrogen removed by the coffee berries. This coupled with the fact that N and K deficiency limits coffee berry yield [25], necessitates good management practices that ensures buildup of N in the soil.

The influence of age of coffee plantation on nitrogen content of the leaf litter was significant (P =.05). Nitrogen content of the leaf litter increased from 11 years old plantation to 24 year old coffee plantation. This is as a result of increase quantity of the leaf litter, by the 24 year old coffee plantation when compared with the 11 year old coffee plantation and thus a corresponding increase in nitrogen content. Nitrogen content of the leaf litter however decreased with increasing age of coffee plantation from 24 years to 51 years. This higher nitrogen concentration in the leaf litter of the 24 year old coffee plantation when compared with the 51 year old plantation could be due to the fact that the 24 year old coffee was still at its productive stage hence though had lower leaf litter quantity, it still had higher quantity of nitrogen in the litter. Leaf litter from the 24 years old coffee plantation had the highest nitrogen content, while leaf litter from 11 year old coffee plantation had the lowest nitrogen content.

Phosphorus content of the leaf litter was low across coffee plantations of different ages with values of 0.38 - 1.73 $kgPha^{-1}yr^{-1}$ (Table 2). [21] Reported that leaves and branches from the coffee plant returned 3 $kgPha^{-1}year^{-1}$ to the soil. Similarly, [10] reported that leaf litter of Arabica coffee contained 3.60 kg. This low P in the leaf litter was indicative of the low soil available phosphorus content of soils of coffee plantations which ranged from 4.49 - 5.99 mg/kg (Table 2). This was below the soil critical value of 6 mg/kg required for coffee production [22]. This was also further corroborated by the low leaf phosphorus content in the coffee trees.

(0.11 – 0.23 g/kg) (Fig. 1) which was well below the leaf critical value of 0.7 g/kg required for coffee productivity [22]. This low soil available P could be attributed to the fact that phosphorus content of the leaf litter was low and inadequate to replenish the 7 kg $P_20_5ha^{-1}$ (3 $kgPha^{-1}$) removed by robusta coffee beans [26]. This was also below 30 kg $P_20_5ha^{-1}$(13.2 $kgPha^{-1}$) required for good yield of robusta coffee beans [27]. There was therefore phosphorus deficiency thus need for phosphorus fertilization to enhance productivity of coffee.

Phosphorus content of the leaf litter was influenced significantly (P =.05) influenced by age of coffee plantation (Table 2) and followed the trend of leaf litter quantity. The 51 year old coffee plantation had the highest phosphorus content while the 11 years old coffee plantation had the lowest. This could be attributed to the fact that the 51 year old coffee plantation produced highest leaf litter hence had more phosphorus, while the 11 year old coffee plantation produced the lowest.

Mean potassium content of leaf litter ranged between 17- 55.8 $kgKha^{-1}yr^{-1}$ (Table 2). Similar observation was made by [21] who reported that coffee litter returned 10 $kgKha^{-1}yr^{-1}$ to the soil, while [25] observed that coffee leaf litter contained 27.5 $kgKha^{-1}yr^{-1}$. This low K content of the leaf litter was reflected in the low soil exchangeable potassium content of 0.20-0.40 cmol/kg soil (Table 3), which was below the soil potassium critical level of 0.4 cmol/kg [22]. This is in agreement with finding of [28] who reported potassium deficiency in soils of coffee plantations of different ages. The potassium content in the leaf litter was therefore unable to meet 145 kg K_2O ha^{-1} required for high yielding coffee [24].

This low K can be attributed to loss of potassium during harvesting of coffee berries. [29] using tracer technique observed that coffee beans were the main sink for nitrogen and potassium, while [24] reported that robusta coffee removes 89 kgK_20 (73.87 K) ha^{-1} and the amount of nutrient required to build the coffee berries are twice the quantity removed by the coffee berries. Hence harvesting coffee berries without appropriate nutrient replenishment as done in these coffee plantation studied, led to loss of potassium from the coffee plantation, which potassium from the leaf litter is unable to replenish.

3.3 Secondary Macronutrient and their Nutrient Dynamics

Calcium content of the leaf litter of the coffee plantations was high and ranged between 40.24 - 58.05 $kgha^{-1}yr^{-1}$ (Table 2). This is in agreement with [10] who reported that coffee leaf litter contained 40.2 kgCa $ha^{-1}yr^{-1}$, while [19] reported that litter from the coffee plant returned 39 kgCa ha^{-1} yr^{-1} to the soil. Leaf litter generated in the 24 and 51 year old coffee plantation had higher calcium content than 11 and 19 year old coffee plantations. The amount of calcium in the leaf litter was sufficient to meet calcium requirement of coffee. This accounted for the high soil exchangeable calcium content of the soil 6.68 – 14.72 cmol/kg soil (Table 3). This was well above the soil calcium critical level of 0.89 cmol/kg soil required by coffee [22]. This was also reflected in the high leaf calcium content of 11.20 – 19.30 cmol/kg (Fig. 2), which was also above the foliar critical level of 3.7 g/kg required for coffee production.

This is an indication of calcium sufficiency across the coffee plantation irrespective of age. Magnesium content of the leaf litter was also high (10.02 – 14.51 $kgMgha^{-1}yr^{-1}$) across the coffee plantations irrespective ages (Table 2). This finding was in agreement with [21] who reported that coffee plant returned 11 $kgMgha^{-1}$ yr^{-1} to the soil, while [10] reported that coffee leaf litter contained 4.64 kg Mg $ha^{-1}yr^{-1}$ .Magnesium content of leaf litter followed the trend of Ca content with the 24 and 51 year old coffee plantation had higher calcium content than 11 and 19 year old coffee plantations. The high magnesium content of the leaf litter was reflected in the leaf magnesium content of coffee tree which was (3.5 – 4.60 g /kg). This was well above the plant critical level of 1.3 g/kg required by coffee (Fig 2) [22]. Similarly, soil exchangeable magnesium content was high (1.05 – 2.00 cmol/kg) (Table 3) and above the soil critical magnesium value of 0.8 cmol/kg soil required by coffee [22].

3.4 Micronutrients and their Nutrient Dynamics

Sodium content of cashew leaf litter ranged between 17.88 - 58.57 kg Na $ha^{-1}yr^{-1}$ (Table 2). And decreased with increasing age of cashew plantation from 11 years to 24 years. Further increase in age of coffee plantation from 24 to 51 years resulted in decrease in leaf sodium content of the leaf litter. Leaf litter from the 11 year old

Table 2. Nutrient content ($kg^{-1}ha^{-1}yr^{-1}$) of leaf litter in coffee plantations of different ages in Ibadan, Nigeria

Age of plantation	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn
11 Years	39.22	0.38	55.8	40.24	10.02	58.57	0.50	0.056	0.05	0.17
19 Years	27.60	1.24	20.81	42.45	10.03b	21.21	1.86	0.057	0.15	0.48
24 Years	60.07	0.66	17.00	58.05	14.51	17.88	1.19	0.016	0.15	1.15
51 Years	27.81	1.73	21.41	578.3	14.40	22.55	3.41	0.061	0.23	1.40
LSD(.05)	1.00	0.098	1.95	1.30	1.91	1.54	0.17	0.01	0.003	0.21

Table 3. Physical and chemical properties of soils of coffee plantations of different ages in Ibadan, Nigeria

	Age of coffee plantation							
	11 years		**19 years**		**24 years**		**51 years**	
Parameters	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm
pH	6.70	6.60	6.13	6.00	5.95	5.70	5.75	5.85
Organic C	7.65	5.20	7.80	6.80	2.80	1.10	4.10	2.00
N(g/kg)	0.80	0.50	0.80	0.80	0.30	0.20	0.50	0.30
P(mg/kg	5.94	4.49	5.99	5.29	5.31	5.95	5.94	4.49
K^+(cmol/kg)	0.20	0.22	0.33	0.26	0.34	0.29	0.30	0.32
Ca^{2+}(cmol/kg)	13.86	8.88	14.72	11.75	6.68	14.21	10.59	8.02
Mg^{2+}(cmol/kg)	2.00	1.41	1.88	1.05	1.05	1.24	1.38	1.33
Na^+(cmol/kg)	0.55	0.49	1.03	0.82	0.62	0.60	1.12	0.60
Ca:Mg^{2+}(cmol/kg)	6.98	6.30	7.83	11.19	6.36	11.46	7.84	6.03
Mg2+:K+(cmol/kg)	10.00	6.55	5.70	4.03	3.09	4.28	4.60	4.16
Ex.bases(cmol/kg)	16.81	11.00	18.08	13.93	8.75	15.85	13.51	10.27
Ex.acidity (cmol/kg)	0.20	0.13	0.17	0.10	0.10	0.15	0.19	0.13
ECEC (cmol/kg)	17.01	11.13	18.25	14.03	8.85	16.00	13.60	10.40
Base Sat (%)	98.82	99.7	99.07	99.29	98.87	99.06	99.34	98.80
Zn^{2+} (mg/kg	4.54	4.60	12.15	10.28	6.25	5.10	5.50	5.83
Cu(mg/kg)	0.72	0.55	1.28	1.44	1.50	1.00	0.86	1.23
Mn(mg/kg)	135.58	77.80	188.40	148.79	176.20	111.70	129.60	146.19
Fe(mg/kg)	7.24	12.80	8.62	8.29	10.20	11.20	8.98	10.02
Sand(g/kg)	785.20	615.20	805.20	825.20	665.20	695.20	785.20	675.20
Silt(g/kg)	82.80	212.80	128.50	37.80	202.80	132.80	92.80	21.00
Clay (g/kg)	132.00	172.00	66.30	137.00	132.00	172.0	122.0	172.00
extural Class	Sandy clay loam	Sandy loam	Loamy sand	Sandy loam	Sandy clay loam	Sandy loam	Sandy loam	Sandy loam

coffee plantation had the highest sodium content, while leaf litter from the 24 year old coffee plantation had the lowest. Sodium content of the leaf of coffee tree was also significantly (P =.05) influenced by age of cashew plantation (Fig. 2) and ranged between 14.90- 31.20 g/kg. The leaf of the 24 year old coffee tree had the highest leaf sodium content, while the 11 year old coffee tree had the least. Soil exchangeable sodium content of the soil across the coffee plantation of different ages also ranged between 0.49 - 1.12 cmol/kg soil (Table 3).

Iron content of the leaf litter ranged between 0.50 - 3.41 $kgha^{-1}yr^{-1}$ with iron content of the leaf litter increasing with increasing age of coffee plantation (Table 2). Leaf litter from the 51 year old plantation had the highest iron content, while that from 11 year old plantation had the least Soil iron content ranged between 7.24- 11.2 mg/kg (Table 3). This was within 2- 20 mg/kg Fe recommended for coffee [22]. Manganese content of the leaf litter ranged between 0.17- 1.40 $kgha^{-1}yr^{-1}$ (Table 2). Manganese content of leaf litter followed similar trend as iron, with leaf litter from the 51 year old cashew plantation having the highest manganese content and leaf litter from 11 year old coffee plantation having the lowest. Soil manganese content ranged between 77.8 – 176.2 mg/kg (Table 3).

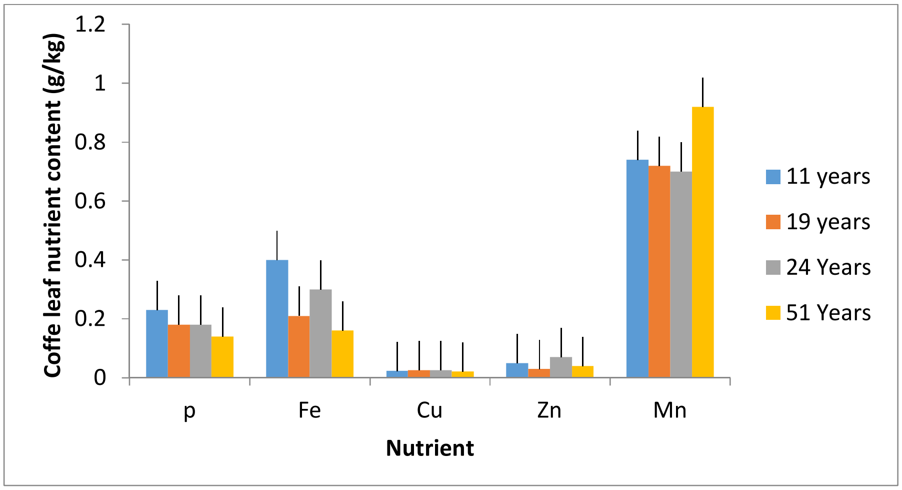

Fig. 1. Amount of P, Fe, Cu, Zn and Mn (g/kg) in leaf of coffee tree in coffee plantation of different ages

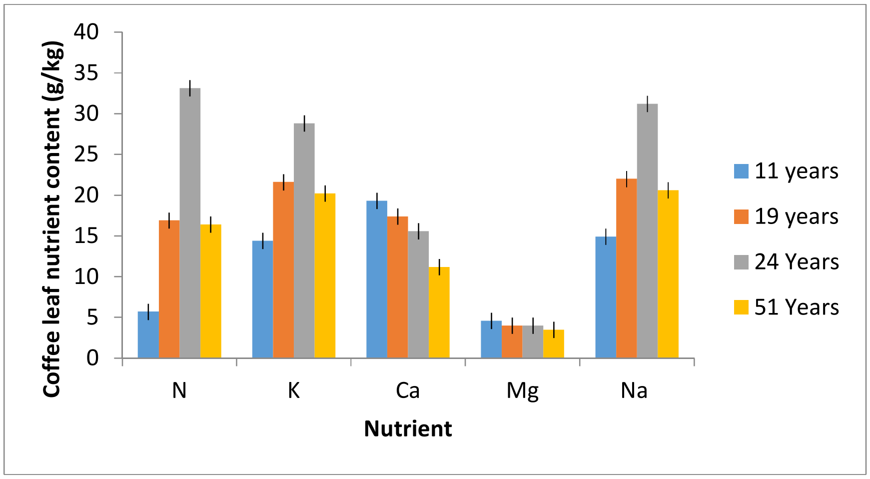

Fig. 2. Amount of N, K, Ca, Mg and Na (g/kg) in leaf of coffee tree in coffee plantation of different ages

Table 4. Simple correlation coefficient between leaf litter nutrient content and soil nutrient content in coffee plantation in Ibadan

	Soil calcium	Soil copper	Soil iron	Soil potassium	Soil magnesium	Soil manganese	Soil nitrogen	Soil sodium	Soil phosphorus	Soil zinc
Leaf litter calcium	0.6114**	0.2044	0.6440*	0.7623**	0.3123	0.0339	0.8144**	0.0147	0.5532*	0.2941
Leaf litter copper	0.0027	0.0063	0.0564	0.1466	0.0068	0.1439	0.1200	0.1019	0.0519	0.5724*
Leaf litter iron	0.7887**	0.7838**	0.3380	0.1499	0.3847	0.4871	0.4141	0.0000	0.5457*	0.7492**
Leaf litter potassium	0.1133	0.0099	0.0027	0.4000	0.0323	0.0661	0.0215	0.0470	0.7612**	0.1668
Leaf litter magnesium	0.0002	0.2537	0.0161	0.0835	0.0000	0.7325**	0.0867	0.6646*	0.2305	0.1424
Leaf litter manganese	0.0090	0.3749	0.0234	0.0344	0.0004	0.7023*	0.0969	0.1154	0.4850	0.4161
Leaf litter nitrogen	0.0143	0.0944	0.1327	0.6264*	0.0267	0.4520	0.6182*	0.0112	0.1462	0.1937
Leaf litter sodium	0.0864	0.0073	0.0123	0.0000	0.0321	0.0704	0.0347	0.0395	0.4465	0.1560
Leaf litter phosphorus	0.8721**	0.8914**	0.4222	0.1147	0.6764*	0.7779**	0.4850	0.0000	0.4153	0.3574
Leaf litter zinc	0.2933	0.4529	0.0744	0.0138	0.0784	0.9962**	0.1211	0.0012	0.8834**	0.6845*

** Significant at 0.05 **significant at 0.01*

Copper and zinc content of leaf litter was 0.02 – 0.06 kgha^{-1}yr^{-1} and 0.05 -0.23 kgha^{-1}yr^{-1} respectively (Table 2) and was influenced by age of coffee plantation. Leaf litter from the 51 year old cashew plantation had the highest copper and zinc content while the 24 year old coffee plantation having higher leaf copper and zinc content when compared with coffee plantations of all other ages. Soil copper and zinc content ranged between 0.55-1.50 mg/kg and 4.54-12.15 mg/kg respectively (Table 3). The copper and zinc content across 0-40cm soil depth fell within the 0.3 – 10 mg/kg and 2 – 10 mg/kg recommended for copper and zinc respectively [30].

3.5 Correlation Coefficient between Leaf Litter Nutrient Content and Soil Nutrient Content

The correlation coefficients of leaf litter nutrient content and soil nutrient content is shown in Table 4. Leaf litter nitrogen was positively and significantly related to soil nitrogen (r=0.6182*) and soil potassium (r=0.6264*). There was also a significant and positive correlation between leaf litter phosphorus and soil calcium (r=0.8721**), soil copper (r=0.8914**), soil magnesium (r=0.6764*) and soil manganese (r=0.7779**). There was a positive correlation between leaf litter potassium and soil potassium with r value of (r=0.400), but the correlation was however not significant. There was also a significant and positive relationship between leaf litter potassium and soil phosphorus (r=0.7612**). Significant and positive correlation was observed between leaf litter calcium and soil calcium (r=0.6114**), soil iron (r=0.6440*), soil potassium (r=0.7623**) soil nitrogen (r=0.8144**), soil phosphorus (r=0.5532*). Positive and significant relationship was also observed between leaf litter zinc and soil zinc (r=0.6845*), soil phosphorus (r=0.8834*), soil manganese (r=0.9962**). The significant and positive correlation between leaf litter nitrogen and soil nitrogen; leaf litter calcium and soil calcium; leaf litter zinc and soil zinc is an indication that N, Ca and Zn content of the leaf litter directly influenced N, Ca and Zn content of the soil. Therefore an increase in N, Ca and Zn content of leaf litter resulted to an increase in soil N, Ca and Zn. Soil P litter content was positively but not significantly correlated with soil P. This can be attributed to the low P content of the leaf litter (0.38-1.73 kg P/ha) which was reflected in the soil P content.

4. CONCLUSION

Leaf litter produced across the coffee plantations of different ages ranged from 2.50 to 3.51 tons ha^{-1}yr^{-1} and contained 27.60 – 60.07 kgN ha^{-1}yr$^{-1,}$ 0.38 – 1.73 kgP ha^{-1}yr^{-1} and 17.00 – 55.80 kgK ha^{-1}yr^{-1} respectively. Nitrogen, phosphorus and potassium content of the leaf litter were insufficient to meet the nutrient demand of coffee trees, while calcium, magnesium, iron and zinc content of the leaf litter was adequate. Nitrogen, potassium, calcium, sodium, Iron and manganese content of the leaf litter varied with age of the coffee plantation, while the 24 year old coffee plantation had higher nitrogen, potassium and sodium than all other plantations. There is therefore need for nutrient supplementation as fertilizer to supply limiting nutrients and enhance productivity of coffee plantations.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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