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Research Article

Properties of Arboreal Ant and Ground-Termite Nests in relation to Their Nesting Sites and Location in a Tropical-Derived Savanna

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Ecosystem engineers such as ants and termites play an important role in the fertility of tropical soils. Physicochemical analyses were thus carried out on some arboreal ant nests collected from mango (*Mangifera indica*), bush mango (*Irvingia gabonensis*), kola (*Cola nitida*), newbouldia plant (*Newbouldia laevis*), and oil bean plant (*Pentaclethra macrophylla*) and on ground nest of termite, *Odontotermes sudanensis* Sjost. (Isoptera: Termitidae) in Nigeria. Arboreal nests, particularly those of *M. indica*, were significantly richer in the chemical constituents sampled, compared to those of ground-termite nests or adjacent unaffected soils. Available water capacity of nests from *M. indica* (60.0%) was significantly higher than those of other sites or locations sampled. While biogenic structures were sandy-loamy in texture, their corresponding adjacent soils were either sandy or sandy-loamy. Soils worked by ants and termites had greater proportions of silt-sized (17.9 versus 9.7) and clay-sized (19.2 versus 9.3) to the detriment of coarse-sized particles (51.2 versus 60.9) and fine-sand-sized particles (11.7 versus 20.1) relative to the adjacent soils. Generally, biogenic structures were about 348% richer in P than their corresponding adjacent soils; an attribute, which holds a strong promise in bioremediation and biofortification of soils especially during amendment.

1. Introduction

Tropical-derived savannah ecosystems are often dominated with patches of arboreal ant and epigeous termite nests ($\approx$5 mounds/m^2). Ants are ubiquitous, diverse, and abundant in tropical ecosystems and represent up to 80% of animal biomass [1]. Tree crops are of great economic significance in the forests of Nigeria, and the ants which inhabit those trees profoundly affect the ecosystem dynamics through the modification, maintenance, and/or creation of habitats for other organisms in the forest ecosystem [2].

Ecosystem engineers such as ants and termites play an important role in the fertility of tropical soils. Physicochemical analyses were thus carried out on some arboreal ant nests collected from mango (*Mangifera indica*), bush mango (*Irvingia gabonensis*), kola (*Cola nitida*), newbouldia plant (*Newbouldia laevis*), and oil bean plant (*Pentaclethra macrophylla*) and on ground nest of termite, *Odontotermes sudanensis* Sjost. (Isoptera: Termitidae) in Nigeria. Arboreal nests, particularly those of *M. indica*, were significantly richer in the chemical constituents sampled, compared to those of ground-termite nests or adjacent unaffected soils. Available water capacity of nests from *M. indica* (60.0%) was significantly higher than those of other sites or locations sampled. While biogenic structures were sandy-loamy in texture, their corresponding adjacent soils were either sandy or sandy-loamy. Soils worked by ants and termites had greater proportions of silt-sized (17.9 versus 9.7) and clay-sized (19.2 versus 9.3) to the detriment of coarse-sized particles (51.2 versus 60.9) and fine-sand-sized particles (11.7 versus 20.1) relative to the adjacent soils. Generally, biogenic structures were about 348% richer in P than their corresponding adjacent soils; an attribute, which holds a strong promise in bioremediation and biofortification of soils especially during amendment.

Ants and termites as decomposers have been reported as the basis for soil formation [3]. Some of the outcome of this decomposition is nutrient release to the soil worked upon by these organisms. Extensive works have been done on the nutrient recycling, soil formation, and soil structural modification by these animals. Lee and Foster [4] observed that the activities of ants and termites together with their abiotic physical and chemical processes regulate the soil fertility and counteract the physical and chemical processes of soil degradation. Leprun and Roy-Noël [5], Boyer [6], and Mahaney et al. [7] reported a remarkable increase in the mineralogical properties of mounds built by ants and termites. Jouquet et al. [8] and Holt and Lepage [9] found enrichment in mineral nutrients (e.g., NH_4^+, NO_3^-) and exchangeable cations (e.g., Ca^{2+}, Mg^{2+}, K^+, and Na^+) on biogenic (nest) structures of termites as compared to that of the surrounding soils. Konaté et al. [10], Macmahon et al. [11], Kristiansen et al. [12] and Jouquet et al. [13] also observed that through the impact on soil by termites, their biogenic structures can constitute patches in the landscape where the availability of soil nutrients for plants is improved. Nests of the harvester ant *Pogonomyrmex barbatus* typically contain higher concentrations of organic matter, nitrogen, and phosphorus than surrounding soils [14]. Comparative studies by Jouquet et al. [15] on nests made by ants and termites revealed some changes in their soil nutrient properties. They suggested that these changes could be due to greater litter associated with ant nest relative to termite nests, which also could be responsible for changes in the morphology and performance of plants and the composition of plant communities in any agroecology.

Very special biogenic structures created by ants are the so-called ant gardens [2]. Jouquet et al. [2] also indicated that a clear agreement has been established between plant preferences for soil altered by termite activity and termite preferences for plant species growing on their own nests. Ants also have been reported to be capable of building nests of carton materials constructed around epiphytic roots thereby developing aggregation of artificial soil [16, 17]. Buckley [18] noted that direct positive effect of the engineering activity of ants lies in the development of a mutualistic relationships between the ants and the epiphytes, whereby the ants profit from the roots forming an integral part of the nest and increasing its structural stability and an abundant food source close to the nest. It could therefore be suggested that these soil engineers indirectly invade their own availability through the increase in colony fitness (i.e., better nourishment of nymphs, higher alate production, and survival) [2].

While the biogenic structures of these organisms have been shown to influence soil quality, microorganism activities, and plants, very little information is available about the differences in the nutrient status of the nest soils based on their nesting sites, biota, and soil locations. We therefore wanted to test the hypotheses that nest substrate (sites) does not influence nest soil properties and that nest soil properties are not a reflection of the initial soil properties when it was unaffected by soil engineers. The aims of this study therefore were to determine the physicochemical properties of the biogenic structures in relation to their nesting sites and biota nests and to compare the characteristics of these nests and their adjacent surface soil. Particle-size analyses of soils were used to assess the physical properties of the soils. The chemical properties of the soils were determined by estimating their C, N, organic matter, base saturation, cation exchange capacity (CEC), exchangeable bases, and P-contents, as well as their pH in both water and in KCl. To determine the availability of the chemical nutrients to plants and thus assess the relative importance of the various soil characteristics in the ecosystem, we also estimated the available water capacity (AWC) and the dispersion ratios (DR) of the various soils, in addition to the dispersibilities of their clay and silt fractions in both calgon and water. The specific objectives of this study thus were to

(i) determine the effect of different tree hosts on the physiochemical properties of nests they inhabit,

(ii) compare the physiochemical properties of biogenic structures with that of their adjacent unmodified soils,

(iii) ascertain the interaction effects of the nesting sites and soil location on the physiochemical properties of their soils.

2. Materials and Methods

2.1. Study Site and Species Studied. Field samples of arboreal-ant and ground-termite nests were collected at Orba Nsukka in Udenu Local Government Area of Enugu State in South-east Nigeria (06° 52′N, 07° 24′E; altitude 442 m above mean sea level). Nsukka is situated in a derived savannah belt with some relics of rainforest distributed in patches [19]. The soil is well-drained reddish-brown Typic Paleustult [20]. The annual bimodal rainfall is 1800 mm and spans from April to November of each year [21], with peaks around July and September. The mean monthly temperatures vary between 25°C and 32°C [22]. The study site is a grassy humid savannah with sparse shrub vegetations intermingled with palm trees and some other tree plants forming patches of thickets.

2.2. Field Sample Collection. Six biogenic structures (comprising five from different trees and one from ground soil termite nest—termitarium) were sampled for this study. The five trees were mango (*Mangifera indica*), bush mango (*Irvingia gabonensis*), kola (*Cola nitida*), newbouldia (*Newbouldia laevis*), and oil bean plant (*Pentaclethra macrophylla*). Biogenic structures (nests) collected from ants and termite nests and the adjacent surface soils (control) were regarded as two soil locations. This is to be able to compare the constituents of nest and unmodified surface soil. Ant arboreal nests were built by *Camponotus acvapimensis* Mayr. (Hymenoptera: Formicidae), while the termite nest was built by *Odontotermes sudanensis* Sjost. (Isoptera: Termitidae). Each ant arboreal nest sample was collected from two trees of the same tree species and about the same age and height to represent the two replications of each treatment. Ground-termite nest samples were taken in pairs from the same soil type (Typic Paleustult) also. Termite mounds were collected and excavated from 0 to 10 cm depth from actively forming nests from the open field. Adjacent soils (without any visible termite—or ant—activity) were sampled at the same depth

(0–10 cm depth) and 6 m away from each habitat tree and termite mound. Sampling from adjacent unaffected soils was conducted in pairs from their surrounding environment. Nest samples were randomly collected from actively forming mound samples.

The entire arboreal carton ant nests were pried from their host trees, placed in plastic bags and taken to the laboratory for analysis. The nests were dissected by segmental shaving after being air-dried for seven days to remove the ants. The corresponding termite nests collected were also placed inside plastic bags and taken to the same laboratory after being air-dried for seven days. All samples were sieved with 2 mm mesh and used for laboratory analysis. Each laboratory result was read in triplicate for each sample.

2.3. Laboratory Analysis. The particle-size analyses of soils, termite, and carton nests were determined by the hydrometer method as described by Gee and Bauder [23] using sodium hexametaphosphate (Calgon) dispersant while dieonised water was used separately to disperse soil mechanically only after soaking for 24 hours and distilled water separately as dispersants. The percentage clay-sized and silt-sized particles obtained using calgon were regarded as the total clay and total silt while those obtained with water alone were assumed to be water dispersible clay and silt.

Soil pH for soils and ant/termite affected soil in both 1 : 2.5 soil: 0.1 M KCl suspension and in a soil/water suspension ratio using a Beckman Zeromatic pH meter were determined. The soil organic carbon was determined by a modified acid dichromate oxidation procedure according to Walkey and Black [24] as described by Nelson and Sommers [25]. The percentage organic matter was calculated by multiplying values obtained by "Van Benmelin" factor of 1.724. The exchangeable cations and acidity were determined by the method described by Thomas [26]. The cation exchange capacity (CEC) was calculated as the total of all the exchangeable cations.

Total (Kjeldahl) nitrogen was measured with a block digester [27] and distilled using NaOH. Available P was determined using Bray and Kurtz [28] method. AWC was calculated by Klute [29] method.

Dispersion ratio (DR) was calculated as (WDSi + WDC)/(Tsilt + Tclay), where WDSi is the water dispersible silt, WDC is the water dispersible clay, Tsilt is the total silt and Tclay is the total clay.

The laboratory analyses results were read in triplicates (three times) for each sample.

2.4. Data Analysis. Treatments comprised factorial combinations of six nesting sites of ants and termites nests and two soil locations (adjacent soils and biogenic structures) arranged in a completely randomized design (CRD). These treatment combinations were each replicated two times. The laboratory results were read in triplicates (three times) for each sample making a total of six replications on the whole. Treatment effects were tested through analysis of variance (ANOVA) and differences between means were tested with Duncan's New Multiple Range Test (DNMRT). Differences were only considered significant when P values were lower than or equal to 0.05. Percent values were subjected to angular (inverse sine) transformation ($\arcsin \sqrt{x}$), before analyses of variance were carried out on them.

3. Results

The AWC of ant nests from *Cola, Irvingia*, *Newbouldia,* and termitaria did not differ ($P > 0.05$) with one another statistically, but were significantly ($F = 4.08$; d.f. $= 5$; $P < 0.05$) lower than the AWC of ant nests collected from *Mangifera* (Table 1). The AWC of *M. indica* hosted nests (60%) was significantly higher than the AWC obtained from *C. nitida* (42.3%), *I. gabonensis* (30.4%), *N. leavis* (43.3%), termitaria (44.6%), and *P. macrophylla* (46.7%). Differences amongst the nesting site effects on dispersion ratios (DRs) of nest soils, calgon and water dispersible clay, clay + silt, and silt were not significant. However, there were evident trends of higher calgon dispersible clay + silt and silt and water dispersible clay and clay-silt on arboreal ant nests than on epigeous termite ground mounds. Similarly the AWC (53.8%), calgon dispersible clay (19.2%), clay + silt (36.5%), and silt (15.9%) and water dispersible clay (22.1%), clay + silt (32.8%), and silt (7.7%) were found to be significantly higher on biogenic structures compared to their corresponding adjacent surface soil values of 36.0%, 9.3%, 19.4%, 8.8%, 9.5%, 12.7%, and 3.3%, respectively (Table 2). Although the differences produced by the effect of soil location amongst the dispersion ratio (DR) were not statistically significant, the DR of the biogenic structure was relatively higher compared with those of their adjacent soils.

Except for the total dispersible silt which differed significantly when the effect of the nesting sites was combined with the soil types, the AWC, DR, and other calgon or water dispersible soil fractions did not show such statistical differences ($P > 0.05$) under comparable combined treatment effects (Table 3). This is such that ant nests of biogenic structure on *I. gabonensis* contained significantly ($F = 3.75$; d.f. $= 5$; $P < 0.013$) higher calgon dispersible silt (28.6) than other nest structures or adjacent soil, while the adjacent soil around *C. nitida* (5.6), *I. gabonensis* (6.6), *M. indica* (13.6), *N. leavis* (8.5), *P. macrophylla* (9.6), and the termitaria contained significantly ($F = 3.75$; d.f. $= 5$; $P < 0.013$) lower calgon dispersible silt than other soils. However, there were glaring trends of numerically higher AWC, DR, and soil dispersibilities amongst the nest structures collected from any of the substrates than their corresponding adjacent soils.

The percent C and N, SOM, base saturation, exchangeable bases, and pH values differed significantly amongst the various soil engineering host substrates (Table 4). The carbon contents of kola (7.32%), bush mango (9.14%), mango (6.98%), newbouldia (7.01%), and oil bean (8.27%) were significantly ($F = 11.94$; d.f. $= 5$; $P < 0.001$) higher than the C content of termitarium (1.23%). The same trend also followed in Mg^{2+}. N was significantly ($F = 15.28$; d.f. $= 5$; $P < 0.001$) higher in oil bean compared to samples, while Ca^{2+} was higher in Kola (5.15 meq/100 g sample) and newbouldia (6.0 meq/100 g sample) compared to others.

Table 1: Main effects of soil engineers nesting substrates (sites) on the mean available water capacity (AWC), dispersion ratio (DR), and calgon and water dispersibilities of the biogenetic structure's clay, clay and silt, and silt.

Soil engineer	Nesting Site	AWC[1] (%)	DR	Calgon dispersed			Water dispersed		
				Clay	Clay + silt	Silt	Clay	Clay + silt	Silt
Ant	*C. nitida*	42.3_{ab}	0.72_a	12.5_a	23.5_a	10.6_a	15.2_a	17.8_a	2.5_a
Ant	*I. gabonensis*	30.4_a	0.71_a	16.0_a	34.0_a	17.6_a	20.7_a	24.8_a	4.1_a
Ant	*M. indica*	60.0_c	0.76_a	17.5_a	35.0_a	14.5_a	16.2_a	24.8_a	8.8_a
Ant	*N. leavis*	43.3_{ab}	0.70_a	10.5_a	25.0_a	11.1_a	10.4_a	19.8_a	5.6_a
Ant	*P. macrophylla*	46.7_b	1.16_a	15.5_a	27.5_a	11.6_a	21.7_a	33.7_a	7.1_a
Termite	Ground	44.6_{ab}	0.71_a	13.5_a	22.5_a	8.6_a	10.7_a	15.8_a	5.1_a
	F-value	4.08	2.11	2.10	0.94	1.16	0.91	0.93	1.60
	d.f.	5	5	5	5	5	5	5	5
	P value	0.005	0.087	0.088	0.469	0.348	0.485	0.471	0.201

AWC: available water capacity and DR: dispersion ratio.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significantly different.

Table 2: Main effect of soil locations on the mean available water capacity (AWC), dispersion ratio (DR), calgon and water dispersed clay, clay/silt, and silt of different soil locations.

Soil location	AWC[1] (%)	DR	Calgon dispersed			Water dispersed		
			Clay	Clay + silt	Silt	Clay	Clay + silt	Silt
Adjacent soil	36.0_a	0.69_a	9.3_a	19.4_a	8.8_a	9.5_a	12.7_a	3.3_a
Biogenic structures	53.8_b	0.89_a	19.2_b	36.5_b	15.9_b	22.1_b	32.8_i	7.7_a
t-value	961.23	6.07	39.68	108.0	87.6	287.41	164.28	480.00
d.f.	1	1	1	1	1	1	1	1
P value	<0.001	0.220	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

AWC: available water capacity and DR: dispersion ratio.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significantly different.

Table 3: Interaction effects of soil engineers' nesting substrates (sites) and soil locations on the values of some soil properties of biogenic structures and their adjacent soils.

Soil engineer	Nesting site	Soil location	AWC[1] (%)	DR	Calgon dispersed			Water dispersed		
					Clay	Clay + silt	Silt	Clay	Clay + silt	Silt
Ant	*C. nitida*	Adj. soil	30.3_a	0.65_a	6.5_a	12.0_a	5.6_a	7.2_a	7.8_a	0.56_a
		B. structure	54.2_a	0.68_a	19.6_a	13.0_a	15.6_b	23.2_a	27.8_a	4.56_a
Ant	*I. gabonensis*	Adj. soil	31.0_a	0.68_a	6.5_a	13.0_a	6.6_a	7.2_a	8.8_a	1.56_a
		B. structure	29.7_a	0.74_a	26.5_a	55.0_a	28.6_c	34.2_a	40.8_a	6.56_a
Ant	*M. indica*	Adj. soil	40.0_a	0.75_a	14.5_a	33.0_a	13.6_{ab}	15.2_a	20.8_a	6.06_a
		B. structure	83.9_a	0.75_a	21.5_a	37.0_a	15.5_b	17.2_a	28.8_a	11.56_a
Ant	*N. leavis*	Adj. Soil	36.2_a	0.63_a	6.5_a	15.0_a	8.6_a	7.2_a	8.8_a	1.56_a
		B. structure	50.9_a	0.77_a	16.6_a	35.0_a	13.6_{ab}	13.7_a	30.8_a	9.56_a
Ant	*P. macrophylla*	Adj. soil	39.9_a	0.73_a	13.5_a	23.0_a	9.6_{ab}	11.2_a	16.7_a	5.56_a
		B. structure	53.5_a	1.60_a	18.5_a	32.0_a	13.6_{ab}	32.2_a	50.8_a	8.56_a
Termite	Ground	Adj. soil	38.4_a	0.72_a	11.5_a	20.0_a	8.6_{ab}	9.2_a	13.8_a	4.56_a
		B. structure	50.8_a	0.70_a	16.5_a	25.0_a	8.6_{ab}	12.2_a	17.8_a	5.56_a
		F-value	0.92	2.44	0.68	2.62	3.75	0.55	0.89	2.14
		d.f.	5	5	5	5	5	5	5	5
		P value	0.489	0.066	0.641	0.053	0.013	0.737	0.502	0.099

AWC: available water capacity; DR: dispersion ratio; B. structure: biogenic structure; Adj. soil: adjacent soil.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significant different.

Table 4: Main effects of soil engineers' nesting substrate (site) on the mean values of some physicochemical properties of their biogenic structures.

Soil engineer	Nesting site	C[1] (%)	N[1] (%)	SOM[1] (%)	Base[1] Sat. (%)	CEC	Exchangeable bases				pH value		P (mg/kg)	Particle size (%)[1]				Textural class
							Ca^{2+}	Mg^{2+}	K^+	Na^+	H_2O	KCl		Clay	Silt	Fine sand	C. Sand	
Ant	*C. nitida*	7.32_b	0.37_{ab}	12.6_b	40.9_c	27.9_a	5.15 + I	5.20_e	0.59_a	0.51_a	6.38_{ab}	6.33_b	53.9_c	12.5_a	11.0_a	17.0_a	59.5_a	SL
Ant	*I. gabonensis*	9.14_b	0.88_b	15.8_{bc}	36.3_{bc}	45.3_a	2.80_a	5.75_f	1.74_b	0.51_a	6.75_{ab}	6.30_b	54.2_c	16.0_a	18.0_a	11.5_a	54.5_a	SL
Ant	*M. indica*	6.98_b	0.46_{ab}	12.0_b	22.7_{ab}	39.2_a	2.15_a	1.95_{bc}	1.69_b	0.46_a	6.28_a	5.68_a	43.0_b	17.5_a	15.0_a	10.2_a	57.2_a	SL
Ant	*N. leavis*	7.01_b	0.41_{ab}	16.5_c	36.2_b	45.5_a	6.08_b	4.50_d	1.03_a	0.54_a	7.28_b	6.35_b	47.0_b	10.5_a	13.5_a	16.8_a	55.5_a	SL
Ant	*P. macrophylla*	8.27_b	1.28_b	14.4_b	20.0_a	36.1_a	2.15_a	2.30_c	1.78_b	0.49_a	6.80_b	6.18_b	42.8_b	15.5_a	12.0_a	19.1_a	53.2_a	SL
Termite	Ground	1.23_a	0.19_a	2.5_a	20.9_a	36.2_a	1.45_a	1.00_a	0.20_a	0.45_a	6.60_{ab}	5.63_a	23.6_a	13.5_a	9.0_a	20.5_a	56.5_a	SL
	F-value	11.94	15.28	9.66	3.83	1.86	38.48	20.05	47.66	2.14	12.99	8.49	5.28	0.92	2.62	0.68	0.55	
	d.f.	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
	P value	<0.001	<0.001	<0.001	0.012	0.142	<0.001	<0.001	<0.001	0.098	<0.001	<0.001	0.002	0.489	0.053	0.641	0.731	

SOM: soil organic matter and SL: sandy loam; C. Sand: coarse sand; P: phosphorus. C: carbon; N: nitrogen; CEC: cation exchange capacity.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significantly different.

K^+ was significantly higher ($F = 47.66$; d.f. $= 5$; $P < 0.001$) in *Irvingia* (1.74 meq/100 g sample), mango (1.69 meq/100 g sample), and oil bean (1.78 meq/100 g samples) relative to other soil engineer nests. The soil pH in H_2O was lower in kola (6.38), *Irvingia* (6.75), mango (6.28), and termitaria (6.60) compared to other nesting sites. Although SOM, the base saturation, CEC, P, and particle-size distributions did not differ between ant and termite nests, there were clear trends of numerically higher values in the ant nests compared to the termite nests. Based on Black [30] classifications, the values of organic C obtained amongst the ant nests were high (between 6.98 and 9.14%) compared to termite nests (1.23%). Similarly, SOM content of *N. leavis* was significantly higher ($F = 9.66$; d.f. $= 5$; $P < 0.001$) than other nests, except those from *I. gabonensis* (15.8%). Base saturation of *C. nitida* was significantly ($F = 3.85$; d.f. $= 5$; $P < 0.012$) higher than those of other nests, except those of Irvingia (36.3%). The N-contents of between 0.37 and 1.28% obtained amongst ant nests were classified as very high compared to 0.19% obtained from termite nests according to Metson [31] classification. Again, the SOM of between 12% and 16.5% from ant nests was considered high compared to SOM of 2.5% obtained from termite nests according to Metson [31]. Similarly, by FAO [32] classification, all the tree-ant nests except those of *P. macrophylla* with base saturations of between 23 and 41% would be regarded as having medium fertility as opposed to ground-termite nests and *P. macrophylla* nests with base saturation of 20% each and classified as belonging to soils of low fertility. Similarly, both the tree-ant nests and ground-termite nests have high phosphorus content (23.6–54.2 mg/kg) judging by Enwezor et al. [33] classification. The exchangeable Ca^{2+} ranged from low to moderately high in tree-ant nest when compared to ground-termite nest with very low Ca^{2+} [30]. Also K^+ was high in tree-ant nests relative to the very low value obtained in the ground-termite nests using the classification of Black [30]. Conversely, Mg^{2+} content of tree-ant nests was moderately high compared to the termite nest which was very low after Black [30] classification. Except for *N. leavis* ant nests with neutral (pH = 7.28) soil reaction, all the ant- and termite-nest soils were slightly acidic with a pH range of between 6.2 and 6.8. The particle-size distribution of the various soil fractions showed that the ecosystem engineers' nests were all of sandy-loamy soil, while their corresponding adjacent soils were predominantly sandy soils.

The result of the soil location effect on chemical compositions showed that biogenic structures contain significantly higher percentages of organic carbon (12.6%), nitrogen (1.10%), organic matter (23.3%), base saturation (33.9%), CEC (51.4%), Ca^{2+} (4.92%), Mg^{2+} (5.2%), K^+ (2.21%), Na^{2+} (0.53%), and phosphorus (44.1%) than their respective adjacent soil nutrient contents of 0.74%, 0.10%, 1.30%, 25.4%, 1.67%, 1.70%, 0.13%, 0.46%, and 16.1% (Table 5). Similarly, both the pH and particle-size distribution of clay-sized (19.20%) and silt-sized (17.9%) particles in the structures were significantly higher for the nest structures compared with those of their adjacent surface soils of 9.3% and 9.7%, respectively. Both the particle sizes of coarse and fine sand fractions as well as the soil reactions in both H_2O and KCl of the nest structures did not differ significantly with those of their adjacent soil.

Differences in the combined effects of the nest substrates of soil engineers and soil locations differed significantly with respect to all the physiochemical properties assessed, except Na^+ content and coarse sand distribution (Table 6). There was a consistent trend of these constituent being higher amongst biogenic structure of ants and termites in the different substrates as opposed to their corresponding adjacent soils. Conversely, in all the chemical properties assessed, the unmodified adjacent soils did not show significant differences amongst the different nest substrates as the nest soils to their microhabitat. Furthermore, the interaction effects of nest sites and soil locations were only significant for C, N, SOM, base saturation. CEC, exchangeable bases (Ca^{2+}, K^+, and Mg^{2+}), soil-pH, clay, and silt contents. This is such that they were significantly higher in the various ant-tree nests (biogenic structures) than in ground-termite mound nest and their corresponding surrounding adjacent soils, except amongst the termitaria (Table 6).

4. Discussion

Soil engineers, notably ants and termites, have been reported to play important roles in the soil fertility in tropical ecosystems because of their impact on the soils they work on [2, 9, 13]. In the present study, however, efforts were made to ascertain whether these modifications significantly differed between biogenic structures of different soil engineers (ants and termites) and also if the modifications within biogenic structures were different for different nesting sites (trees) or locations.

Results of the laboratory assays however showed that the physicochemical properties of the ant biogenic structures were glaringly higher than those of the termites. Tree ants generally are exposed to more diverse range of plant litter diets and foraging materials than ground termites due to their proximity to dense litter falls from tree hosts. There is therefore always an increased resource access associated with ant nest construction relative to termite nest construction. This could therefore be harnessed in biofortifications of our impoverished tropical agricultural soils. Again, not only the soils of nests worked upon by the ecosystem engineers precisely contained higher values of the constituents assessed than their corresponding adjacent soils, but also their nesting sites played a major role in their constituents. Nesting sites differed as to their AWC, DR, and their dispersibilities in both calgon and water but their differences were not significant except for the AWC. Ant nests on *M. indica* consistently had higher AWC relative to other ant plant nests or epigeous termite ground nest. The higher AWC of ant nests from *M. indica* biogenic structures suggest higher tendency of ensuring more water in available form for crop development than those of other soils locations or nesting sites, which makes it still a good promise for biofortification. The process of soil dispersion in either water or calgon which is a function

Table 5: Main effect of soil locations on the mean values of some physicochemical properties of different soils types.

Soil location	C^1 (%)	N^1 (%)	SOM^1 (%)	$Base^1$ sat. (%)	CEC	Exchangeable bases				pH value		P (mg/kg)	Particle size $(\%)^1$				Textural class
						Ca^{2+}	Mg^{2+}	K^+	Na^{2+}	H_2O	KCl		Clay	Silt	Fine sand	Coarse sand	
Adj. soil	0.74_a	0.10_a	1.30_a	25.1_a	25.4_a	1.67_a	1.70_a	0.13_a	0.46_a	6.66_a	5.94_a	16.1_a	9.3_a	9.7_a	20.1_a	60.9_a	LS
B. structure	12.57_b	1.10_b	23.30_b	33.9_b	51.4_b	4.92_b	5.20_b	2.21_b	0.53_b	6.85_b	6.21_b	72.1_b	19.2_b	17.9_i	11.7_a	51.2_a	SL
t-value	321.86	143.75	271.07	6.07	51.52	175.53	96.79	686.77	13.45	7.07	7.40	197.69	16.53	19.31	1.74	3.12	—
d.f.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	—
P value	<0.001	<0.001	<0.001	0.022	<0.001	<0.001	<0.001	<0.001	0.001	0.014	0.012	<0.001	<0.001	<0.001	0.200	0.091	—

SOM: soil organic matter; LS: loamy soil; SL: sandy loam; B. structure: biogenic structure; Adj. soil: adjacent soil; P: phosphorus. C: carbon; N: nitrogen; CEC: cation exchange capacity.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significantly different.

TABLE 6: Interaction effects of soil engineers' nesting substrates (sites) and soil locations on the mean values of some physicochemical properties of soil engineers' biogenic structures and their adjacent soils.

Soil engineer	Nesting site	Soils locations	C[1] (%)	N[1] (%)	SOM[1] (%)	Base[1] sat. (%)	CEC	Exchangeable bases				pH value		P (mg/kg)	Particle size (%)[1]				Textural class
								Ca^{2+}	Mg^{2+}	K^+	Na^{2+}	H_2O	KCl		Clay	Silt	Fine sand	Coarse sand	
Ant	*C. nitida*	Adj. soil	0.6_a	0.09_a	1.1_a	36.2_b	12.2_a	1.9_{sb}	1.30_a	0.12_a	0.47_a	6.8_{sb}	6.2_{sb}	17.9_s	6.0_a	6.0_a	33.5_a	54.5_a	S
		B. structure	14.0_b	0.65_a	24.2_b	45.6_b	43.6_c	8.4_c	9.10_e	1.06_b	0.54_a	6.8_{sb}	6.5_b	90.0_b	19.0_b	16.0_{sb}	0.5_a	64.5_a	SL
Ant	*I. gabonensis*	Adj. soil	0.5_a	0.08_a	0.8_a	48.9_b	18.0_a	1.7_{ab}	4.00_c	0.14_a	0.48_a	6.7_{sb}	6.3_b	10.9_a	6.0_a	7.0_a	23.0_a	64.0_a	S
		B. structure	17.8_b	1.69_b	30.7_c	23.6_a	72.6_d	3.9_b	7.50_d	3.33_c	0.54_a	6.8_{sb}	6.4_b	97.5_b	26.0_b	29.0_b	0.0_a	45.0_a	SCL
Ant	*M. indica*	Adj. soil	0.7_a	0.11_a	1.2_a	8.9_a	36.6_{bc}	1.1_a	1.10_a	1.10_b	0.41_a	6.7_{sb}	5.7_{sb}	9.5_a	14.0_a	14.0_{sb}	7.0_a	65.0_a	SL
		B. structure	13.3_b	0.82_a	22.9_b	36.4_b	41.8_c	3.2_{ab}	2.80_b	3.27_c	0.51_a	6.4_{sb}	5.7_{sb}	76.6_b	21.0_b	16.0_{sb}	13.5_a	49.5_a	SCL
Ant	*N. leavis*	Adj. soil	0.7_a	0.08_a	1.4_a	26.2_a	25.0_a	2.5_{ab}	1.70_a	0.17_a	0.51_a	7.4_b	6.4_b	18.8_a	6.0_a	11.0_a	20.0_a	63.0_a	S
		B. structure	13.2_b	0.79_a	31.5_c	46.1_b	66.0_d	9.7_c	7.30_d	1.89_{bc}	0.58_a	7.2_b	6.4_b	75.2_b	15.5_b	21.0_b	14.5_a	49.0_a	SL
Ant	*P. macrophylla*	Adj. soil	1.0_a	0.14_a	1.7_a	16.8_a	28.6_b	1.7_{ab}	1.40_a	0.18_a	0.48_a	6.1_a	5.4_a	13.4_a	13.0_a	10.0_a	22.0_a	55.0_a	SL
		B. structure	15.6_b	2.41_b	27.2_b	23.2_a	43.6_c	2.6_{ab}	3.20_b	3.37_c	0.51_a	7.5_b	7.0_b	72.1_b	18.0_b	14.0_{sb}	16.5_a	51.5_a	SL
Termite	Ground	Adj. soil	1.0_a	0.11_a	1.7_a	13.5_a	31.8_b	1.1_a	0.70_a	0.08_a	0.40_a	6.1_a	5.9_{sb}	25.9_a	11.0_a	10.0_a	15.0_a	64.0_a	LS
		B. structure	1.5_a	0.27_a	3.4_a	28.4_b	40.6_a	1.8_{ab}	1.30_a	0.33_a	0.51_a	6.4_{sb}	5.4_a	21.4_a	16.0_b	9.0_a	26.0_a	49.0_a	SL
		F-value	12.96	14.55	10.31	4.20	4.97	22.20	9.86	44.89	0.34	11.91	9.67	10.45	4.77	9.66	2.62	0.68	—
		d.f.	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	—
		P value	0.001	0.001	0.001	0.008	0.003	0.001	0.001	0.001	0.883	0.001	0.001	0.001	0.004	0.001	0.053	0.641	—

AWC: available water capacity; DR: dispersion ratio; S: sand; SL: sandy loam; SCL: sandy clay loam; LS: loamy sand; B. structure: biogenic structure;
P: phosphorus. C: carbon; N: nitrogen; CEC: cation exchange capacity.
[1]Results of angular transformed data presented in the original scale.
Values within a column followed by the same letter are not significantly different.

of the soil organic matter content [34] and an index of nutrient availability to plants did not differ either between the nesting sites or between ant nests and termite nests.

Soil texture on the other hand was not significantly affected in the termite nest compared with the ant nests, but was considerably modified in the biogenic structures compared to their corresponding adjacent unmodified soil. Thus, the nests and their corresponding adjacent soils differed as to their textural classes. The soil engineers ensured greater mineralization of clay and silt which was found to be greatly higher in the biogenic structures than in the adjacent soils resulting in differences in their textural classes. All the soils affected by ants and termites had a greater proportion of clay and silt to the detriment of coarse and fine sand. This finding suggests that the ecosystem engineers prefer the selection of finer materials such as clay and silt for building of its structures, thus supporting the result of the ability of termites and ants to select building materials when presented with different physical size materials but not clay type [2, 35, 36]. Termites have been observed to favour finer particles in their mound constructions which match their ecological, physiological, and behavioural needs [35]. In this study, however, there was a clear distinction between the physical size distribution of soils worked by ants and those by termites. The greater proportion of clay and silt as opposed to sand on soils worked by ant and termites showed the greater impact of clay and silt than sand on soils worked upon by ants and termites in the course of their building activities.

Laboratory analyses of the various samples also showed that both the biota nesting sites and the soil locations richly influenced the SOM, base saturation, CEC, and soil-pH and significantly modified C- and N-contents and their exchangeable bases. It suggests therefore that there was more enrichment of C and N and exchangeable bases (Ca^{2+}, K^{+}, Mg^{2+}, and Na^{+}) in antnests most especially in antnests built on *I. gabonensis* and *P. macrophylla* compared with the termitarium, as nest structures generally were to unaffected adjacent soils. Tree antnests were richer in C, N, SOM, and exchangeable bases (Ca^{2+}, K^{+}, Mg^{2+}, and Na^{+}) compared with the termite nests. This result counteracts our first hypothesis as nesting sites have been shown to influence some of the nest soil properties. Therefore, better nest soil enrichment will be assured when nests are harnessed from *I. gabonensis, N. leavis,* and *P. macrophylla* trees. The ability of ants and termites to work and move through the soil and to build organomineral structures with specific physical, chemical, and microbiological properties has been well documented [15, 37]. The higher mineral contents of the ant-nests relative to the termite nests and the surrounding soils could be explained by (i) the relative intensities with which the two organisms impact on the soil, (ii) the differential efficiencies of the two organisms in the mineralization of the various nutrients, (iii) the quantum of food (organic matter or litter material) available, or their diversity (structural, biochemical, or biological attributes), and (iv) the soil conditions or fertility where the nest soils were formed. That the adjacent soils of the different nest hosts did not differ significantly in this study goes to excluding soil conditions as possible explanation for the differences in the ant and termite nest's chemical content and thus supports the hypothesis that nest soil properties are not a reflection of the initial soil properties when they were unaffected by soil engineers. Jouquet et al. [8, 13] suggests availability of more diversified litter materials at the disposal of the ants than at the disposal of termites as the probable cause of this difference. The quantity of litter materials to be found deposited around trees were likely to be higher than the sparse grassy vegetations reminiscence of a derived savannah ecosystem from where the termite mounds were excavated. Although it has been reported that tropical ant diversity positively correlates with plant structures [38], it was still not clear if litter diversity affects litter nesting assemblages and compositions [39]. From the stand point of this result, ants may be considered to be more efficient in the mineralization of organic nutrients than termites. Enhancement of soil nutrient concentrations according to Wagner [40] may be of general importance in understanding how plants benefit from interaction with ants, especially if ants are more likely to nest near plants bearing extrafloral nectaries.

Also the less abundance of organic matter in soils worked by termites may be attributed to the microenvironment where the mounds are located. Jones et al. [41] observed that termite mounds are usually exposed to intensive sunlight which may reduce the activity of microbes involved in the decompositions of organic matter they contain.

All the ant-nest soils irrespective of tree host contain very significantly higher phosphorus content than termite nests. Also the biogenic structures of either ant or termites irrespective of their nesting sites were found to contain significantly higher P-content than those of their corresponding adjacent surface soils. Ant tree nests were between 81 and 130% richer in P-content than termite ground nests. Similarly, the biogenic structures generally were about 348% richer in P-content than their corresponding adjacent soils. The richer P-content of ant-nested structures of trees relative to the ground termite mounds could still be explained by the higher SOM content of the former as opposed to the latter and the efficient mineralization potential of ants over termites. The rich P-content of the nest soil especially the tree nests could enable them be recommended in the biofortification of acidic tropical soils deficient in phosphorus induced by Fe- and/or Al-toxicity problems.

5. Conclusion

The physicochemical properties of arboreal ant nests, the ground-termite nests, and their corresponding adjacent soils were studied in addition to the influence of nesting sites on nest soil characteristics. Nesting site influenced nest soil characteristics. Ant nests pried from tree tops especially those from *M. indica* were rich in most of the chemical properties assessed compared to those of epigeous ground-termite nests or the adjacent surface soil samples. Holistically, soils altered by soil engineers, notably ants and termites, were also predominantly greater in these basic nutrients relative to their adjacent unmodified soil, whereas soils collected from trees and ground nests were either sandy-loam or sandy-clay-loam in texture; those of their corresponding adjacent surface soils were mainly sandy for soils near trees and loamy-sand for soils near termitaria.

The higher influence of ants than termites on the maintenance of ecosystem heterogeneity through its soil bio-perturbation effects was therefore revealed in this work. Ants in addition to termites have also been seen to influence soil properties by making resources available for other organisms. These findings and more could therefore be harnessed by culturing these organisms and protecting some of these prospective nesting sites like *M. indica, P. macrophylla,* and *I. gabonensis* capable of hosting nests of high mineral content. Such nests could be harnessed for a variety of bio-remediation and biofortification purposes for human use. Purposes where the soil engineers could be utilized include landfills to decompose waste, improvement of soils by composting materials, detoxification of hazardous substances, and the production of biomass of animal feed and biochemical. Besides being fed upon by animals, solid wastes constituting environmental hazards are decomposed and readily converted into useful forms for soil improvement. The soil engineers-mediated chemical changes of soil, commonly represented mainly by a shift in pH towards neutral from acidity and an increase in nutrient content, helps in soil detoxification.

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