TERMITE ACTIVITIES AND SURFACE CHARACTERISTICS OF COASTAL PLAIN SANDS

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ABSTRACT
This study evaluated the effect of mound building termites on the increase in the quantity of fine particles of the dimension of clay on the surface of coastal plain sands of south-eastern Nigeria. Six termite mounds were selected in different locations, destroyed completely and sampled in three replications. Surface and subsurface soils were sampled within the periphery of the termite mounds in similar replications as the mounds. Samples were processed and analyzed in the laboratory. Data were analysed using ANOVA, correlation and principal component. Termite mounds were not common but massive, with base diameter more extensive than height. The major determinants (responsible for 28%) of the effects of termite activities on the surface characteristics are total sand, clay and silt + clay. Termite mounds were similar to the surface soil in available phosphorus, exchangeable sodium and potassium, effective cation exchange capacity, fine sand and silt. These similarities result from homogenization through erosion and redistribution of the mound material within the surface soil vicinity. The fortified mound materials redistributed in surface soil vicinity is responsible for the high clay, elevated pH, enhanced effective cation exchange capacity, improved structural stability, minimized leaching and subsequently improved fertility of coastal plain sands.

Key words: termite mounds, pedogenesis, acid sands, biopedoturbation, surface fining

INTRODUCTION

The coastal plain sands are deeply weathered, characterised by larger quantities of coarse over fine textured fragments and possesses low physical and chemical fertility due to dominance of low activity kaolinitic clays, low pH and low organic matter content (Daniels *et al*., 1978; Lekwa and Whiteside,1986; Phillips, 2004). These characteristics are results of the dominance of quartz arenite within the mineral fraction and humid tropical environment that favours high rate of mineralization and leaching (Smith *et al*., 1976). The dominance of coarse fragments in the particle size fractions (psf), high amount of low activity clays, sesquioxides and very low organic matter content predisposes the soil to infiltration rate that is much higher than precipitation (Phillips, 2001; Obi *et al*., 2014; Obi, 2015). These processes give credence to the low cation exchange capacities which characterise coastal plain sands (CPS). The capacity of soils to withhold nutrients for

plant growth resides within the exchange sites (cation exchange capacity). The principal sources of these sites are clay and organic matter and these are known to be very low on the surfaces of CPS. Cation exchange capacity (CEC) is a measure of the negatively charged sites on the surfaces of the clay-humus molecules and determines the capacity of the soil to retain and exchange both natural and artificial sources of cationic plant nutrients (Tisdale *et al*., 1985). High rates of leaching and mineralization significantly reduce the quantities of clay-humus molecules and consequently the CEC. The exchangeable bases are adsorbed onto these surfaces created by CEC and most of them are crucial for plant growth and development. In acid sands, some of the exchange sites are occupied by Al^{3+} ion, which are conventionally excluded from the exchangeable bases (Chi and Richard, 1999) diminishing the meaningfulness of CEC. This explains the

significance of effective cation exchange capacity as a measure of active sites in acid sands. The coastal plain sands are well drained and dominantly Ultisols or Acrisols (Daniels *et al*., 1978; Szabo, 1985; Lekwa and Whiteside, 1986; Shaw *et al*., 2004). These are indications that they are characterized by base saturation of less than 35% indicative of severe weathering, less weathered than only the Oxisols. In addition to these is the dominance of coarse fragments in the particle size fractions to the detriment of clay and humus (the repositories of CEC). These consequently translate to low physical and chemical fertility status in addition to their classification as having narrow range of texture (Salchow *et al*., 1996; Bruand *et al*., 2003) with inherent very low water holding capacity (Al Majou *et al*., 2008; Obi *et al*., 2014). Therefore any process or activity that will increase finer fractions in the soil surface will enhance the productive capacity of coastal plain sands.

Termites are known for construction of point-centered and locally over-thickened biomantles on the soil surfaces of locations that possess requisite environmental conditions for their habitation(Johnson *et al*., 2003; Horwarth and Johnson, 2006).Their nests consist of chambers that house, protect the colony and store food (fungus gardens). Feeding habit of termites varies and food may include living and dead wood and herbaceous vegetable matter and humus. The nests may be subterranean, epigenous or arboreal structures and foraging galleries. These structures and galleries are constructed out of fabrics of repacked soil particles removed mainly from the B horizon, mixed with saliva and sometimes excreta (Venugapol, 1999). Termite mounds are continually eroded and sometimes broken while galleries are destroyed even faster. These activities lead to vertical and lateral transfer (turbation) of large volume of soil resulting in sorting, rearrangement, mixing and sometimes complete removal that could be either temporary or permanent (Jouquet *et al*., 2005; Phillips, 2007). Pedoturbation is primarily a physical process involving texture but indirectly affects other soil properties. Depending on the dominant species and mound size there is a maximum mound density per unit area (Lee and Wood, 1971). There foresoil formation and development continued unabated through faunal turbation in site habitable to termites (Kang,1978;Wood *et al*.,1983; Umeh *et al*.,1999; Jouquet *et al*., 2005).Termites are social insects that constitute the order Isoptera. They dominate the macro fauna of some tropical and subtropical soils and their activities as ecological engineers lead to the increase in clay content of the surface horizon with accompanying improvement in characteristics and fertility status (Obi and Ogunkunle, 2008). This

process is particularly significant in coastal plain sands known to have surface characteristics dominated by coarse fragments which play major roles in the pedogenesis (Obi, 2015). This study evaluated the effect of mound building termites in the improvement of surface characteristics of coastal plain sands of south-eastern, Nigeria.

MATERIALS AND METHODS
Description of the Study Area
The study was conducted on the gently undulating coastal plain sands geomorphic unit within AkwaIbom State in the south-eastern Nigeria (Fig. 1). The State is located between approximately latitudes 4° 30′ and 5° 30′ N and longitudes 7° 28′ and 8° 20′ E, and covers an area of approximately 7249 km². The climate is characterized by distinct rainy (March/April to October) and dry (November to March) seasons. The pattern of annual distribution of rainfall is bimodal (with peaks in July and September) and high intensity. Rainfall within the State varies between 2000 mm in the northernmost portion and 4000 mm along the coast (Udosen, 2014). Temperature is uniformly high (between 28°C and 30°C) and relative humidity is equally high (approximately 75%).

Previously the study area belonged to the humid tropical forest zone of southern Nigeria (Ituen, 2010) and the vegetation resulted from the interaction of climate, humidity, rainfall and soils (Aregheore, 2005). However, prolonged resource exploitation has converted the area to derived vegetation type. The area is currently characterized by secondary forest of predominantly wild oil palm trees of various densities and woody shrubs such as *Chromolaena odorata* and various grass undergrowth such as *Impereta cylinderica* which are indicators of land degradation (Obi, 2000).

The gently undulating coastal plain sands geomorphic unit in Akwa Ibom State is characterized by flat terrain and low-lying lands and soil profiles vary from sand on the surface to fine loamy in the subsurface. The characteristically low physical and chemical fertility of these soils are due to dominance of low-activity kaolinitic clays, and low organic matter content (Ofomata 1981; Ojanuga *et al*., 1981; Ogban and Ekerette 2001). They are well drained, deeply weathered, withudic moisture regime and isohyperthermic temperature regime. The soils have been classified as Typic Paleudult in siliceous, isohyperthermic family (Lekwa and Whiteside 1986) according to the US Department of Agriculture Soil Taxonomy, corresponding to Haplic Acrisol (Hyperdystric) of the World Reference Base (IUSS, Working Group WRB, 2007).

Field Studies

Reconnaissance study was carried out within the gently undulating coastal plain sands geomorphic unit in Akwa Ibom State, south-eastern Nigeria. It was observed that termite activities were not devastating, neither were mounds such a common soil surface feature as found in the savanna region of Nigeria (Obi *et al.*, 2008; Obi and Ogunkunle, 2008, 2009; Abe *et al.*, 2009). Yet they build structures that could possibly play significant role in the pedogenesis of coastal plain sands. Six termite mounds belonging to *Macrotermitinae bellicosus* were identified in IkotOkoro, AbakIkot, Use Offot, NungUdoeItak, IkotNkpo and NtongUna as shown in Fig. 1 and marked for the study. The characteristics of termite mound used for the study were as shown in Table 1. Each mound was destroyed, mixed thoroughly in a three sectoral distribution as shown in Fig. 2 and six subsamples were collected from each sector to give three replicate samples and overall total of 18 mound samples.

Three equidistant surface (0-15 cm) and subsurface (15-30 cm) soil samples was collected using soil auger at 0.50 m distance away from the base of each mound (Fig. 2). This was achieved by subdividing the circumference which has the radius that extends from the centre of the broken mound to the peripheral (0.50 m) soil-sampling-points into three equal sectors referred to as sector intervals as shown in Table 1 for each location. Six subsamples were collected per sector, bulked to make a sample for each depth. This was designed to capture maximally the effect of redistribution of mound material on the periphery of the mound without necessarily sampling the root of the mounds. Prior to the sampling, soil auger was used to determine the minimum distance at which soil sampling will not encounter root of the mounds. Mound and soil samples were preserved in sampling bags and sent to the laboratory for processing and analysis.

Laboratory Analysis

Particle size distribution was determined using the method of Dane and Topp (2002). Soil organic carbon (OC) content was determined as described in Sparks (1996) and organic matter content is OC multiplied by 1.724 (Odu *et al.*, 1986). Soil pH and electrical conductivity (EC) were determined in 1:2.5 (soil: water) solution using pH meter (McLean, 1982) and conductivity bridge (Rhoades, 1996), respectively. Exchangeable bases were extracted with neutral normal ammonium acetate (Odu *et al.*, 1986). Potassium (K) and sodium (Na) contents were determined with flame emission spectrophotometer, calcium (Ca), and magnesium (Mg) with atomic absorption spectrophotometer (AAS). Available phosphorus (AvP) was determined calorimetrically according to the Bray and Kurtz (1954) method. Exchangeable acidity was extracted with unbuffered 1 M potassium chloride solution and titrated with 0.01 M solution of sodium hydroxide to the first permanent pink endpoint as described by Anderson and Ingram (1993), while effective cation exchange capacity (ECEC) and base saturation (BS) were determined by computation (Soil Survey Staff, 2006).

Statistical Analysis

Data collected were subjected to analysis of variance in randomized complete block design with location as block for the evaluation of the effect of termite activities on the characteristics of the surface soil. In the evaluation of the effect of termite activities on the soil properties, representative mound and sector samples (surface and subsurface) were used as treatments (i.e. 3 treatments comprising mounds, surface and subsurface soils). Significantly different means of mound and soil properties were separated using least significant differences at 5% probability level. Effect of termite activities on surface and subsurface soil properties was evaluated using Pearson's correlation coefficient and principal component analysis. SAS/STAT® software version9.2 for Windows (SAS Institute 2011) and SPSS version 20 (IBM Corp., released, 2011) were used to perform the statistical analyses.

Principal component analysis was used to group the soil properties into statistical factors based on their correlation structure. Factor extraction was adopted because it does not require prior estimates of the amount of variation in each of the mound and soil properties explained by the factors and was performed on standardized variables using a correlation matrix to eliminate the effect of different measurement units on the determination of factor loadings. Factor loadings are the simple correlation between properties and each factor. Eigen values are the amount of variance explained by each factor. Standardization leads to the arrival on variance value of 1 for each variable. Factors with eigenvalues > 1 explained more total variation in the data than individual variable, and factors with eigenvalues <1 explained less total variation. Therefore factors with eigenvalues > 1 were retained for interpretation. Commonalities estimated the proportions of variance in each variable explained by the factors. A high commonality for any variable indicates that a high proportion of its variance is explained by the factors. In contrast, a low commonality for a soil property indicates that much of that variable's variance remains unexplained.

RESULTS

Properties of Termite Mounds, Surface and Subsurface Soil

The termite mounds used in the study were located in fallow land in five (5) out of the 6 locations studied. The exception was the one located in newly cleared fallow that was at the time of the study under sole cassava cultivation. This was found because the farmer did not destroy the mound. Yet, it was observed that the mounds occupied significant portions of the land. The termite mounds were massive, but not very tall, with height that ranged between 1.31 and 2.90 m. The massiveness of the termite mounds were more manifest in their base diameter that ranged between 2.51 and 2.80 m. These indicated that only the mound found in AbakIkot has height that is greater than diameter and the reverse was the case in others.

Normally termite mounds grow more in height than base diameter the observed contrary feature could be associated with the characteristic torrential rainfall which takes place between March and November (i.e. up to 10 months) of each year. This will discourage vertical growth and the option left for the caste is to enlarge the mound laterally to create enough space for the members of the caste. The mounds occurred on the flat portions of the gently undulating geomorphic units. This may be associated with the fact that the flat portions of the landscape are more stable and not disposed to constant modification as a result of erosion and the flat enjoys deposition which could provide more stable and clay enriched environment to the detriment of the upper positions within the landscape. Enrichment could be in terms of clay content of the soils. One of the preconditions for construction of termite mounds is the availability of requisite textual class that could support the structures. Other requirements such as food and temperature could be managed by scavenging and orientation of the mound. The characteristics of termite mounds constructed on the surfaces of coastal plain sands and their influence on the surface (0-15 cm depth) and subsurface (15-30 cm depth) soils were as presented in Table 2. Soil reaction is very important in the understanding and management of the relationship between the soil and crop responses. This is more important in soils that have reaction characteristics that do not depend on H^+ ion alone but also on Al^{3+} ions as in acid sands of southeastern Nigeria. The reaction of the mounds and soils of the study area was weakly acid with pH that ranged between 6.02 and 6.06. There were no significant differences between the pH of the termite mounds and soil at the uppermost 30 cm depth. Other soil properties that did not significantly vary included available phosphorus, exchangeable sodium,

potassium, effective cation exchange capacity, fine sand and silt. The soil properties that manifested significant variation when compared with the termite mound included electrical conductivity, organic matter, exchangeable calcium and magnesium, soil acidity, base saturation, total sand, coarse sand, clay and silt + clay. The termite mounds were significantly different (lower or higher) from the surface and subsurface soil in organic matter content, exchangeable magnesium, clay and silt+clay content. This is attributable to the requirement that clay content must meet a minimum amount for mound construction and this value may not necessarily correspond to the clay content of the surface soil.
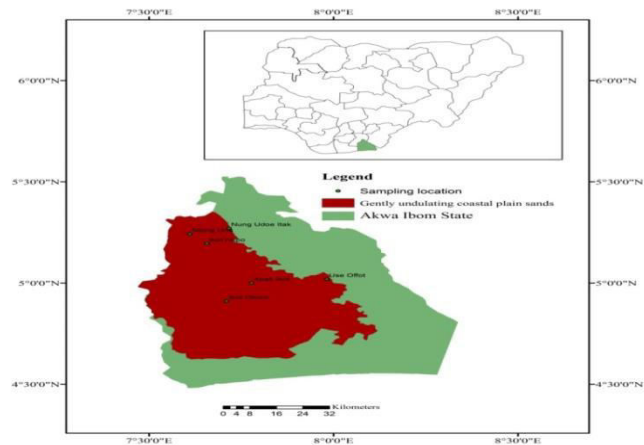

Figure 1: Map of AkwaIbomState in Nigeria showing sampling locations within the coastal plain sands
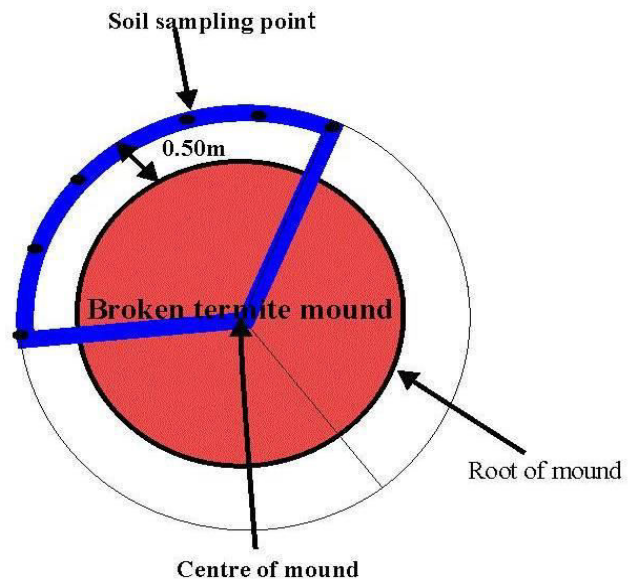

Figure 2: Termite mound and soil sampling scheme

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Table 1: Characteristics of termite mounds used for the study

Location	Land use	Elevation (m)		Mound height (m)	Base diameter (m)	Sector interval (m)
IkotOkoro	Fallow	68	Flat	1.81	2.80	11.76
AbakIkot	Fallow	74	Flat	2.90	2.80	11.76
Use Offot	Arable	73	Flat	1.30	2.50	10.83
NungUdoeItak	Fallow	115	Flat	2.30	2.51	10.86
IkotNkpo	Fallow	107	Flat	2.11	2.80	11.76
NtongUna	Fallow	114	Flat	1.51	2.70	11.45

Table 2: Comparison of mound material with coastal plain sands

Soil properties		Mound	Surface	Subsurface	LSD$_{0.05}$
pH		6.02	6.06	6.03	0.05
Electrical conductivity	dm s^{-1}	0.019	0.017	0.016	0.002
Organic matter	(mg kg^{-1})	3.20	3.70	3.70	0.38
Available phosphorus	(mg kg^{-1})	19.84	23.98	22.49	5.05
Exchangeable — Calcium		2.02	2.68	2.44	0.44
Magnesium		0.77	0.44	0.53	0.20
Sodium	cmol kg^{-1}	0.14	0.13	0.09	0.11
Potassium		0.19	0.22	0.20	0.12
acidity		1.06	1.40	1.77	0.38
Effective cation exchange capacity		4.74	4.61	4.85	0.82
Base saturation	(%)	76.61	69.90	60.40	7.37
Coarse sand		575.01	567.35	483.80	32.47
Fine sand		218.28	217.81	206.32	31.08
Total sand	mg kg^{-1}	702.08	785.17	781.33	13.16
Silt		28.44	23.89	22.88	9.45
Clay		269.47	194.78	190.94	10.49
Silt + Clay		297.92	214.83	218.67	13.16
Silt : clay ratio		0.10	0.13	0.12	0.05

The termite mound materials were similar to the surface soil but significantly different from the subsurface soil in electrical conductivity, exchangeable acidity, base saturation and coarse sand. These soil properties were homogenised by the erosive activities of the rain that continually washes material from the mounds and redistributes same on the surface of the soil. Exchangeable calcium was the only property that exhibited similarity between the termite mound materials and subsurface soil.

Termite Mounds and Characteristics of Coastal Plain Sands

The manifestations of the effect of termite mounds on the upper portions of the soil profile are presented in Tables 3 and 4 for surface and subsurface soils respectively. The principal component analysis (Table 5) was used to establish the strength of intercorrelation between the mound, surface and subsurface soil properties as a determinant of the major components of the soil that are most influenced by the activities of termites through mound construction (faunal pedoturbation). The pH of termite mound was found to associate and influence most of the soil properties including pH, available phosphorus, exchangeable potassium, total sand and silt + clay. One of the strongest association established between the pH of termite mounds and the soil properties was encountered in available phosphorus (r = -0.74, p < 0.01) indicating that the

capacity of termite to significantly decrease the availability of phosphorus while increasing the incidence of formation of recalcitrant form of phosphorus through fixation. This was evident in the amount of available phosphorus found in the termite mounds compared to the surface and subsurface soils. The importance of termite activities in the modification of soil pH is confirmed in the very strong relationship between the pH of termite mounds and that of the subsurface soil (r = 0.77, p < 0.01) shown in Table 5 as the only soil property significantly influenced in the 15–30 cm depth contrary to the observed on the surface. This further confirms the significance of termite activities on the surface characteristics of coastal plain sands commonly referred to as acid sands and characterised by dominance of recalcitrant form of phosphorus. The organic matter content of the termite mound significantly correlated with exchangeable potassium content of the surface soil. This could be associated with the characteristics of potassium within the acid sands which is normally influenced by organic matter. Further confirmation of the manifestation of the dynamics of potassium forms as influenced by termite activities is the highly significant correlation between potassium content of the surface soil and total sand (r = 0.66, p < 0.01), clay (r = -0.64, p < 0.01) and silt + clay (r = 0.66, p < 0.01) of the mound material. The strongest correlation coefficient established in the study was between exchangeable

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Table 3: Relationship between termite mound and surface soil

Soil properties	Mound properties																	
	pH	EC	Organic matter	Available phosphorus	Exchangeable					ECEC	Base Saturation	Sand content			Silt	Clay	Silt+Clay	SCR
					Ca	Mg	Sodium	Potassium	Acidity			Coarse	Fine	Total				
pH	0.57*	-0.39	-0.05	-0.22	-0.20	-0.27	-0.31	0.02	0.33	-0.29	-0.25	-0.21	0.08	-0.31	0.67**	-0.13	0.31	0.65**
Electrical conductivity	-0.14	0.44	0.21	-0.26	0.15	0.27	0.33	0.10	-0.39	0.23	0.23	0.38	-0.18	0.53*	-0.56*	-0.20	-0.53*	-0.52*
Organic matter	-0.12	-0.10	0.33	0.32	0.03	0.05	0.29	0.33	-0.08	0.05	0.09	0.55*	-0.34	0.65**	-0.40	-0.45	-0.65**	-0.30
Available phosphorus	-0.74**	-0.13	-0.33	0.44	-0.18	-0.14	0.30	-0.07	0.06	-0.02	-0.23	-0.11	0.13	-0.02	-0.13	0.12	0.023	-0.12
Exchangeable Calcium	-0.22	-0.08	-0.07	0.19	0.10	-0.04	-0.07	-0.19	-0.28	-0.08	0.32	-0.07	-0.04	-0.12	0.01	0.21	0.20	-0.03
Exchangeable Magnesium	-0.29	0.04	-0.02	0.22	0.15	0.03	-0.03	-0.17	-0.21	-0.02	0.27	-0.01	-0.03	-0.05	-0.09	0.12	0.05	-0.10
Exchangeable Sodium	-0.15	-0.08	0.33	0.28	0.35	0.41	0.98**	0.01	0.14	0.52*	0.16	0.34	-0.32	0.23	-0.22	-0.10	-0.23	-0.20
Exchangeable Potassium	0.48*	0.07	0.54*	-0.05	-0.07	-0.08	0.01	0.47	-0.22	-0.01	0.16	0.33	-0.02	0.66**	-0.15	-0.64**	-0.66**	-0.06
Exchangeable Acidity	0.03	-0.13	0.36	0.32	0.09	0.16	0.18	0.22	0.31	0.33	-0.17	0.59**	-0.56*	0.41	-0.43	-0.15	-0.41	-0.38
ECEC	-0.21	-0.04	0.30	0.41	0.26	0.23	0.32	0.08	-0.01	0.34	0.21	0.50*	-0.47	0.36	-0.40	-0.11	-0.36	-0.37
Base saturation	0.15	-0.03	0.09	-0.11	0.02	-0.12	-0.02	-0.08	-0.39	-0.25	0.37	-0.25	0.23	-0.18	0.27	0.01	0.18	0.24
Coarse sand	0.43	0.05	0.17	-0.20	0.17	0.02	-0.40	0.40	-0.43	-0.01	0.53*	0.00	0.09	0.14	0.24	-0.33	-0.14	0.26
Fine sand	-0.17	-0.19	-0.15	0.13	-0.39	-0.26	0.23	-0.23	0.30	-0.18	-0.54*	0.09	-0.16	-0.05	-0.17	0.18	0.05	-0.18
Total sand	0.49*	-0.24	0.04	-0.14	-0.38	-0.44	-0.33	0.31	-0.27	-0.34	0.00	0.16	-0.12	0.17	0.14	-0.29	-0.17	0.17
Silt	-0.40	0.24	-0.17	0.14	0.27	0.25	0.18	-0.12	0.19	0.12	0.09	-0.19	0.14	-0.19	0.15	0.11	0.19	0.15
Clay	-0.30	0.11	0.11	0.06	0.27	0.38	0.29	-0.33	0.20	0.37	-0.09	-0.04	0.03	-0.05	-0.34	0.30	0.05	-0.38
Silt + Clay	-0.49*	0.24	-0.04	0.14	0.38	0.44	0.33	-0.31	0.27	0.34	-0.00	-0.16	0.12	-0.17	-0.14	0.29	0.17	-0.17
Silt : Clay ratio	-0.35	0.21	-0.18	0.14	0.23	0.19	0.13	-0.05	0.19	0.06	0.08	-0.19	0.14	-0.18	0.22	0.05	0.18	0.23

Mg = magnesium; ECEC = Effective cation exchange capacity, $*p < 0.05$, $**p < 0.01$

Table 4: Relationship between termite mounds and subsurface soils

Soil properties	Mound properties																	
	pH	EC	Organic matter	Available Phosphorus	Exchangeable					ECEC	Base Saturation	Sand content			Silt	Clay	Silt+Clay	SCR
					Calcium	Mg	Sodium	Potassium	Acidity			Coarse	Fine	Total				
pH	0.77**	-0.36	0.11	-0.32	-0.28	-0.33	-0.34	-0.07	0.08	-0.40	-0.17	-0.32	0.22	-0.35	0.52*	0.02	0.35	0.46
Electrical conductivity	-0.16	0.54*	0.36	0.06	0.32	0.31	-0.13	0.28	-.57*	0.20	0.59*	0.55*	-0.37	0.61**	-0.45	-0.36	-0.61**	-0.40
Organic matter	0.11	0.11	0.25	-0.00	0.04	0.07	0.20	0.48*	-0.17	0.13	0.14	0.42	-0.17	0.63**	-0.08	-0.65**	-0.63**	0.01
Available phosphorus	0.08	-0.31	0.03	0.43	-0.11	-0.08	0.27	0.49*	0.43	0.16	-0.30	0.24	-0.22	0.18	0.11	-0.28	-0.18	0.19
Exchangeable Calcium	-0.28	0.15	-0.54*	-0.50*	0.25	0.23	-0.08	-0.16	-0.05	0.18	0.16	-0.53*	0.50*	-0.36	0.14	0.30	0.36	0.10
Exchangeable Magnesium	-0.16	0.51*	-0.48*	-0.52*	0.48*	0.49*	-0.01	-0.05	0.07	0.42	0.23	-0.27	0.34	-0.06	0.14	-0.04	0.06	0.16
Exchangeable Sodium	-0.22	-0.09	0.28	-0.01	0.05	0.02	-0.07	0.14	-0.02	0.06	0.08	0.30	-0.17	0.37	-0.22	-0.26	-0.37	-0.20
Exchangeable Potassium	0.23	-0.08	0.41	0.09	-0.02	-0.03	-0.04	0.26	-0.08	0.02	0.08	0.33	-0.13	0.51*	-0.26	-0.38	-0.51*	-0.21
Exchangeable Acidity	0.28	0.13	0.21	0.19	0.37	0.43	0.53*	-0.16	0.22	0.48*	0.06	0.19	-0.25	0.03	-0.38	0.24	-0.03	-0.38
ECEC	-0.38	0.09	-0.27	-0.27	0.32	0.32	0.12	-0.18	0.02	0.32	0.15	-0.29	0.25	-0.22	-0.10	0.32	0.22	-0.14
Base saturation	-0.23	0.14	-0.38	-0.59*	-0.07	-0.12	-0.41	0.13	-0.27	-0.20	0.15	-0.37	0.51*	-0.02	0.32	-0.21	0.02	0.33
Coarse sand	0.30	-0.05	-0.16	0.22	0.29	0.22	0.04	-0.14	0.50*	0.29	-0.05	-0.25	0.09	-0.39	0.29	0.23	0.39	0.27
Fine sand	-0.05	0.09	0.25	-0.16	-0.13	-0.05	0.05	0.25	-0.37	-0.11	0.09	0.45	-0.30	0.49*	-0.24	-0.38	-0.49*	-0.20
Total sand	0.10	0.13	0.31	0.04	0.29	0.35	0.22	0.36	0.12	0.37	0.13	0.67**	-0.63**	0.46	0.00	-0.52*	-0.46	0.05
Silt	0.14	0.09	-0.32	-0.13	-0.05	-0.08	-0.17	0.03	-0.24	-0.19	0.14	-0.47*	0.61**	-0.08	0.22	-0.08	0.08	0.21
Clay	-0.05	-0.20	-0.09	0.05	-0.28	-0.31	-0.11	-0.40	0.05	-0.25	-0.25	-0.35	0.20	-0.43	-0.17	0.61**	0.43	-0.21
Silt + Clay	-0.12	-0.13	-0.31	-0.04	-0.29	-0.35	-0.22	-0.36	-0.12	-0.37	-0.13	-0.67**	0.63**	-0.46	-0.00	0.52*	0.46	-0.05
Silt : Clay ratio	-0.14	0.12	-0.30	-0.13	0-.00	-0.03	-0.16	0.07	-0.24	-0.14	0.17	-0.41	0.57*	-0.01	0.22	-0.15	0.01	0.22

ECEC = Effective cation exchange capacity $*p < 0.05$, $**p < 0.01$

sodium content of the termite mounds and that of the surface soil (r = 0.98, p < 0.01) suggesting that most of the exchangeable sodium encountered on the surface soil originated from the termite mounds.

This very strong association may have been responsible for the significant correlation between effective cation exchange capacity of the termite mound and the exchangeable sodium of the surface soil. The significant correlation observed between organic matter content of the surface soil and sand and silt + clay content of the termite mounds were equally found to exist in the subsurface in addition to clay content. The soil properties that significantly correlated with each other as found in the mound and the soil were pH and exchangeable sodium in the surface, whereas in the subsurface included pH (r = 0.74, p < 0.01), electrical conductivity (r = 0.54, p < 0.05), exchangeable magnesium (r = 0.49, p < 0.05) and clay content (r = 0.61, p < 0.01). These are indications that the process of leaching which is a major source of loss and removal of nutrients from the soil was minimized by the activities of termites. The commonalities of the variables used in the principal component analysis as shown in Table 5 ranged between 0.63 and 0.98 and high enough to explain majority of the variation that occurred within the termite mound, surface and subsurface of the coastal plain sands. The principal component analysis was used to determine the soil properties that vary similarly in termite mounds, surface and subsurface soil and therefore measure the extent of their contribution in the structure and stability of the termite mound and enhancement of fertility status of the surrounding soils. It was observed that the soil properties that characterised the first factor are organic matter, coarse sand, total sand, clay and silt + clay. These properties that are components of the first factor contributed about 28% of the characteristics of the termite mound and highly influence the characteristics and fertility status of the upper most 30 cm depth of the termite infested gently undulating coastal plain sands of southeastern Nigeria.

The major determinants of the first factor are total sand, clay and silt + clay which are the fragments that met the requisite size for mound construction and their addition (especially higher amount of clay) could improve the texture of coastal plain sands characterised by dominance of coarse fragments. The clay and the organic matter serve as the binding agents, whereas sand particles provide enforcements and rigidity to the termite mound structure. The second factor classified as fertility factors comprise exchangeable calcium and magnesium, effective cation exchange capacity and to a less extent base saturation are major determinant of the influence of termite activities on the fertility status of the soils. The third factor comprising silt and

silt:clay ratio, the fourth was exchangeable acidity and base saturation, the fifth comprised electrical conductivity and coarse sand, the sixth comprised exchangeable sodium and potassium and component seven comprised pH and available phosphorus.

DISCUSSION
Effect of Termite Activities on the Surface and Subsurface Soil

The termite mounds encountered and used in this study were very massive considering the two major environmental conditions which play important role in mound construction. These environmental conditions are availability of materials that met requisite textural characteristics and moisture condition (Jouquet et al., 2011). These were premised on the fact that termite mounds represent the equilibrium of three forces including behaviour, material and climate (Harris, 1956). The termite mounds encountered within the flat terrain of gently undulating coastal plain sands were massive, but did not grow very tall, yet had dimension that fell within the range encountered in the savanna regions of Nigeria (Obi and Ogunkunle, 2009; Abe et al., 2011).

The observed concentration of termite mounds within the flat terrain of coastal plain sands is contrary to the concentration within similar terrain in the guinea savanna regions (Abe et al., 2009). The massiveness of the mounds were more manifest in their base diameter that than height. It was only the mound found in AbakIkot that had height that is greater than diameter but reverse was the case in others. Normally termite mound should grow more in height than breadth (base diameter), hence this 'abnormal' occurrence must be associated with characteristic torrential rainfall which take place between March and November (i.e., up to 10 months) of each year, accompanying low clay content and soil moisture conditions (Abe et al., 2009; Jouquet et al., 2015). The importance of moisture condition originated from the dominance of coarse texture fragment within the profiles of coastal plain sands which imposes free drainage (high infiltration rate) and low water holding capacity (Obi et al., 2011; Obi et al., 2014). These discourage vertical growth and the option left for the caste is to enlarge the mound laterally (diameter) to create enough space for the members of the caste.

Downward vertical growth (i.e., into the soil) may equally be discouraged as the frequent incidences of flooding and ponding that result from the precipitation rate that is always higher than the infiltration rate in addition to depositional flow of rain water towards the lowlands and flat portions of the landscape (Nwaukwa and Udosen, 2007; Okonkwo and Mbajiorgu, 2010; Afangideh et al., 2010; Essien, and Okon, 2011). The incidences of flooding and ponding

Table 5: Classification of major determinant of mound characteristics

Soil properties	1	2	3	4	5	6	7	Commonality
pH	0.10	-0.27	0.12	0.16	-0.35	0.15	-0.72	0.78
Electrical conductivity	-0.03	0.28	-0.25	0.15	0.75	-0.01	-0.02	0.72
Organic matter	0.60	-0.21	-0.08	0.14	0.02	0.40	0.21	0.63
Available phosphorus	0.15	0.13	-0.06	-0.11	-0.26	0.13	0.83	0.83
Exchangeable Calcium	-0.16	0.91	0.10	0.24	-0.05	-0.06	-0.03	0.92
Exchangeable Magnesium	-0.23	0.79	-0.17	0.31	0.07	0.00	0.08	0.81
Exchangeable Sodium	-0.08	0.23	-0.01	-0.06	0.02	0.80	0.26	0.77
Exchangeable Potassium	0.23	-0.06	0.01	0.03	0.12	0.75	-0.29	0.72
Exchangeable Acidity	0.24	0.05	-0.14	-0.91	-0.02	0.07	0.10	0.92
ECEC	0.04	0.90	0.02	-0.26	-0.05	0.22	0.04	0.94
Base saturation	-0.19	0.42	0.11	0.82	0.01	0.09	-0.18	0.94
Coarse sand	0.72	0.14	-0.20	-0.05	-0.59	-0.08	0.02	0.94
Fine sand	-0.05	-0.30	0.15	-0.12	0.81	0.15	-0.02	0.81
Total sand	0.95	-0.10	-0.14	-0.19	-0.03	0.04	-0.00	0.98
Silt	-0.24	0.00	0.95	0.11	-0.00	-0.01	-0.08	0.97
Clay	-0.95	0.11	-0.19	0.17	0.03	-0.04	0.03	0.98
Silt + Clay	-0.95	0.10	0.14	0.19	0.03	-0.04	0.00	0.98
Silt : clay ratio	0.05	-0.01	0.98	0.09	-0.02	0.01	-0.06	0.97
Eigenvalues	4.997	2.781	2.263	1.821	1.572	1.175	1.008	
Variance (%)	27.763	15.448	12.573	10.116	8.734	6.528	5.597	
Cumulative variance (%)	27.763	43.211	55.784	65.899	74.633	81.161	86.759	

ECEC = effective cation exchange capacity

ponding that is common in the area for at least 10 out of the 12 months of the year will render the locations below the surface of the soil unsuitable for termite habitation as already suggested by Harris (1956). The soil properties that did not significantly vary from the termite mounds included pH, available phosphorus, exchangeable sodium, potassium, effective cation exchange capacity, fine sand and silt. Alternatively, the soil properties that manifested significant variation when compared with the termite mound included electrical conductivity, organic matter, exchangeable calcium and magnesium, soil acidity, base saturation, total sand, coarse sand, clay and silt + clay. The similarities between the properties of the soil and mound materials are indications of the influence of termite mound on the soil properties.

Termites scavenge for material that could meet the requisite conditions for mound construction and could go as deep as B horizon, even beyond 55 m depth in search of moist soils (Harris, 1956; Holt and Lepage, 2000; Abe and Wakatsuki, 2010; Lamoureux and O'Kane, 2012). These materials are different from those on the uppermost portions of the soil as reported by (Abe *et al*., 2009; 2011). The mounds are continually eroded by water and redistributed on the surface of the soil in a build-up of soil physical, chemical and biological properties that boost fertility status (Ackerman *et al*., 2007; Obi and Ogunkunle, 2008, 2009; Mujinyaa *et al*., 2015). The effect of termite mounds on the improvement of the clay and silt + clay content of the uppermost 30 cm soils is very important in the improvement of the fertility status, minimization of infiltration rate and loss of nutrients through leaching in the coastal plain sands.

It was observed that clay and silt + clay were increased by approximately 39.7 and 37.5%, respectively. These compared very well with the observation in the savanna region of Nigeria where the clay content of topmost horizon of infested soils were higher than the horizon next to (i.e., below) it by approximately between 43.4 and 36.1 % (Obi and Ogunkunle, 2008). They reported that long period of faunal pedoturbation attributable to termite activities tends to reverse the distribution of clay content of profiles which result to downward decreases (i.e. reverse argilluviation) as a result of enrichment of the finer particles to the detriment of the coarse fragments on the soil surface (Phillips,2004 and Horwath and Johnson, 2006).

The profiles of coastal plain sands of southeastern Nigeria is characterised by larger quantities of coarse particles over fine textured fragments (Lekwa and Whiteside, 1986) and possess low structural stability (Ogban and Obi, 2010).The importance of the reversal of clay distribution and fining of the topmost layers over those below them is premised on the fact that clay and organic matter are the repositories of the exchange sites. But in the highly weathered tropical soils and in the incidences of very low organic matter content as a result of very high rate of mineralization, then any process that will improve clay content becomes critical to the improvement and maintenance of productive capacity of such soils. It has been reported that the structural stability of mounds constructed by fungus growing termites were more dependent on the higher clay than lower organic matter content of the mound materials (Contour-Ansel *et al*., 2000; Jouquet *et al*., 2004). Predicting the cation exchange capacity of the savanna soil of

Nigerian, Raji (2011) reported that clay content contributed as much as twice to the cation exchange capacity of the soils compared to organic carbon content. The clay-humus molecules determine the capacity of the soil to retain and exchange both natural and artificial cationic plant nutrients (Tisdale *et al.*, 1985). This could be achieved with the aid of termite activities within the coastal plain sands of southeastern Nigeria and has been reportedly achieved through appropriately planned and mediated management strategies that could encourage their habitation within an ecosystem (Boga *et al.*, 2015).

Determinant of Termite Mound Characteristics within Coastal Plain Sands
The role of termites as ecosystem engineers in the modification of soil characteristics through pedoturbation is obvious and has been severally reported. The key properties that could modify soil characteristics as a result of termite manipulation are primarily organic matter, coarse sand, total sand, clay and silt + clay. These properties are the determinants of pedogenesis within the coastal plain sands (Obi *et al.*, 2014; Obi, 2015). It was observed that pH of the termite mounds consistently influenced the soil pH at the uppermost 30 cm. This boost to soil pH was reported to be as a result of fortification of the termite mounds with exchangeable bases (Jouquet *et al.,* 2004). The characteristics of the coastal plain sands are dependent on the soil reaction and any process that could modify its pH will invariably mediate its capacity and management. This is because the cation exchange capacity of the coastal plain sands is pH dependent and moderation of the soil pH towards neutrality enhances its nutrient retention. These could possibly explain the strong influence of the termite mound pH on most soil properties including pH, available phosphorus, exchangeable potassium, total sand and silt + clay. This could reduce the incidence of fixation and increases availability of phosphorus. Ibia and Udoh (1993) reported that the major problem associated with phosphorus availability in the acid sands of southeastern Nigeria is fixation. The organic matter content of the termite mound significantly associated with exchangeable potassium content of the surface soil. This could be associated with the characteristics of potassium within the acid sands which is normally influenced by organic matter. Organic matter and reduced leaching, moderate soil temperature and pH to the extent that could influence potassium content of the soils (Raheb and Heidari 2011; Ayele, 2013; Uzoho and Ekeh, 2014; Saini and Grewal, 2014). These conditions are suitable but for inferiority of organic matter which has been reported for fungus growing termites, hence

termite activities did not change the potassium content of the soils in the study area.

Further confirmation of the manifestation of the dynamics of potassium forms as influenced by termite activities is the highly significant correlation between potassium content of the surface soil and total sand and silt + clay of the mound material. The minimization of leaching on the characteristics of mound modified soil as a result of increase in the clay content and their structural stability has influenced the exchangeable bases of the surface soil and consequently effective cation exchange capacity (ECEC). The importance of Al^{3+} has made cation exchange capacity of acid sands of little significance compared to ECEC. These emphasized the initial manifestation of pedogenesis, characterised the second factor and consists ECEC, exchangeable calcium and magnesium which are major contributors to the fertility of soils. Other manifestations of pedogenesis characterised by factor one as influenced by faunal turbation decreased subsequently to the seventh factor as the least soil properties directly dependent on factor one.

CONCLUSIONS
This study evaluated the effect of mound building termites (fungus growing) on the fining of coastal plain sands of southeastern Nigeria. The termite mounds were not common but individually massive with base diameter more extensive than height. The termite mounds were similar to the surrounding soils in the uppermost 30 cm depth in available phosphorus, exchangeable sodium, potassium, effective cation exchange capacity, fine sand and silt as a result of homogenization dueto erosion and subsequent redistribution of the mound materials. There is evidence of fortification of the termite mounds through the combined process of scavenging,manipulation and modification results to high clay,improved structural stability, elevated pHand enhanced effective cation exchange capacity of the soil.Benefits of theseare reduced leaching and improved fertility of coastal plain sands.Turbation through the activities of termites could mediate in pedogenesis, improve the characteristics of coastal plain sandsand enhance its fertility status for sustainable crop production.

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