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Rheological and physical properties of wormcast and termite mound soils in Nsukka subtropical area

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The study investigated variability of rheological and physical properties of wormcast (Wc) and termite mound (Tm) soils in relation to surrounding soils (Ss) in Nsukka tropical and subtropical areas. Rheological and physical properties, shear strength and compaction at different moisture contents were obtained. Relationships between rheological and other physical attributes were established. Consistency limits of Wc and Tm soils were significant. Mean shear strength (cohesion) of Wc and Tm were high. Mean shear strength of Wc was 85.09 kpa and 91.55 kpa for Tm soils), while Ss had 69.80 kpa. The maximum shear strength of compacted (15 blows) Wc and Tm was 188 and 190 kpa at 12 (db) moisture content, respectively. There was significant ($p<0.05$) positive relationship between gravimetric moisture content and clay. Sand had significant negative relationship with plasticity index. The study demonstrated the usefulness of characterizing Wc and Tm in relation to surrounding soil (Ss) and their relative efficacy in predicting soil behavior.

Key words: Rheology, physical property, termite mound, wormcast, tropical and subtropical area.

INTRODUCTION

Earthworms and termites are common biological agents that produce significant physico-chemical and rheological modifications to soil. Cast of earthworm is a digested material that is excreted back into the soil by different species of earthworm. Termite mound is a mixture of soil, organic debris or living plant tissues collected, often over extensive foraging areas, transported to their domain and subjected to intense degradation when it is digested by the termites (Ekundaye and Orhue, 2011). Reports have been made on detailed studies wormcast and Tm contribution to improve soil fertility and crop productivity (Debruyn and Conacher, 1997); improvement of soil porosity, soil nutrient availability and uptake by plants, minimizing production costs and maximizing yield and profit (Mba, 1978; Kang, 1978; Ariha, 1979; Lal, 1988; Frageria and Baligar, 2004; Semhi et al., 2008; Ekundayo and Orhue, 2011) and produce significant physical and chemical modifications especially clay mineral composition of these minerals (Jouquet et al., 2002).

In southeastern Nigeria, soils belong to different lithologies, hence variation in soil groups such as alluvial, coastal plain sands, false bedded sandstones, lower coal measures, shale and upper coal measures (Ndukwe et al., 2009). These soil groups vary in their particle size distribution and soil moisture retention characteristics.

There are rheological differences among Nigerian clays. Clay content, nature of clay, exchangeable cations and organic matter content of soils vary and these

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influence activity levels and plasticity of soils (Ndukwe et al., 2009). Clay has greater cohesion, plasticity and activity than other primary soil particles. Variation in hydraulic properties of soils including water flow characteristics of the pedosphere are determined by clay contents (Gerke et al., 2001). Thus, particle size of soils, soil moisture and plasticity determine stability of soils in response to loading forces from traffic, tillage and building foundations (Imhoff et al., 2004).

Differences in soil water content determine the strength of soils. Several reports have shown spatial heterogeneity in soil water behavior (Gerke et al., 2001), non-uniform water repellency in different soils under different vegetation (Dekker et al., 2001) and land use (Hallet et al., 2004). Published scientific study ascertaining the rheological properties and other physical characteristics of wormcast and termite mound as plant-soil systems is desired. Based on this, we investigated and characterized the dynamics and variability in rheological properties of soils formed under different species of earthworm and termites in relation to surrounding soil.

MATERIALS AND METHODS

Description of study area

The study was conducted in the laboratories of the Department of Soil Science and Land Resources Management, as well as Department of Mechanical Engineering, University of Nigeria, Nsukka. Earthworm cast and termite mound soils were collected from three locations: Nsukka, Ede Oballa and Orba. Nsukka and Ede Oballa are situated in Nsukka local government area (LGA), while Orba is in Udenu LGA. Nsukka LGA lies by latitude 6°51'24" and longitude 7°23'45"E with land area of 45.38 km^2. Udenu LGA lies between coordinates 6°55'N and 7°31'E with a total land area of 897 km^2 (http://www.nipost.gov.ng/postcode.aspx).

Rainfall is bi-modal; the rainy (April - October) and the dry season (November - March). There is usually a short break in August. Average annual rainfall is about 1600 mm. Average minimum and maximum temperature is 22 and 30°C, respectively. The relative humidity is rarely below 60% (Ezeaku and Egbemba, 2014). The geomorphology of the study areas is of the highlands stretching through the undulating hills to plain lands. The vegetation belongs to the semitropical rainforest type and complemented by typical grassy vegetation.

Field work

The study was conducted in 3 ha (300 m x 100 m) blocks in each location (Nsuuka, Ede Oballa and Orba). Each block of 1 ha consisted of four land use types: Cassava/yam cultivated field (LUT1), Fallow land (LUT2), Oil palm land (LUT3), and residential area (LUT4) with land area of 1250 m^2, 1250 m^2, 2500 m^2, and 5000 m^2, respectively. This delineation was done for the 3-ha blocks to avoid the overlap of land use systems.

In each 1 ha block a 3 m x 3 m grid was mapped out. Wormcasts and termite mound soils, taken as plant-soil systems, were collected through hand sampling in the grids replicated thrice to cover the 3 ha blocks. Earthworm species predominantly identified were *Eudrilus eugeriae* and *Agrotoreutus nyongii* (Mba, 1978; Fragoso and Lavelle, 1992), while the genera *Macrotermes* and *Odontotermes* species were identified in the termite mounds (Arihad, 1979). The number of earthworm casts and termite mounds in each land use type was recorded. The population count was done within the grid size (3 x 3 m) for the 3 ha block. The collected plant-soil systems were carefully put into plastic polyethylene bags, properly labelled and taken to the laboratory for air-drying. In each location, soils of the surrounding were collected at least 5 m away from each LUT at 0 to 30 cm depth, analysed and used for standardization. Core ring (inner volume of 96.6 cm^3) samples were taken at soil depth of 0 to 10 cm for soil physical determination.

In situ shear strength determination was done for all soil samples. It was measured with a shear vane tester (16 mm diameter vane) at depth 40, 80 and 120 mm on each sample and average strength was calculated. The corresponding moisture contents of the soil samples were obtained with a moisture meter.

Laboratory studies

The air-dried soil samples were taken to the laboratory and sieved through 2 mm size sieve to determine the followings: shear strength and compaction at different moisture contents using the shear vane tester. The soil samples were subjected to 5, 10 and 15 blows respectively with a standard proctor rammer (2.5 kg) at different moisture content level in a cylindrical metal mould. The mould was 100 mm in diameter and 120 mm height. A round wooden pad was placed on the soil before compaction to ensure uniform compaction. The shear vane was graduated in kilopascal (kpa). Measurements were taken at two depths: 40 and 80 mm respectively on each sample and the mean value of each set of two-depth reading was calculated and recorded.

Rheological (consistency) properties determined were plastic limit (PL), liquid limit (LL), shrinkage limit, plasticity index and coefficient of linear extensivity (COLE). Particle size distribution (fraction of sand, silt, and clay) was determined using hydrometer method (Gee and Or, 2002) with NaOH as dispersant. Bulk density (Bd) and linear extensibility were determined using Grossman and Keinch (2002) method. Gravimetric water content was determined.

Data analysis

Data on soil physical rheological properties were subjected to analysis of variance (ANOVA) using Genstat Discovery Edition 3, while significant variations in the means were determined using standard error difference ($SED_{0.05}$) and P-value. Relationships between physical and rheological properties were determined using Pearson correlation analysis.

RESULTS AND DISCUSSION

Distribution of earthworm casts and termite mounds

The population of wormcast and termite mounds (determined from population counts) in four land use types (LUT 1, 2, 3 and 4) across the three sites are presented in Figure 1. Total number of casts produced by *Agrotoreutus* spp was significantly higher ($p<0.05$) than that of *Eudrilus* spp by 34.7%. This suggests that the benefits derivable from the activities of *Agrotoreutus* spp could be more useful in improving soil productivity in tropical and subtropical area. This finding accords earlier

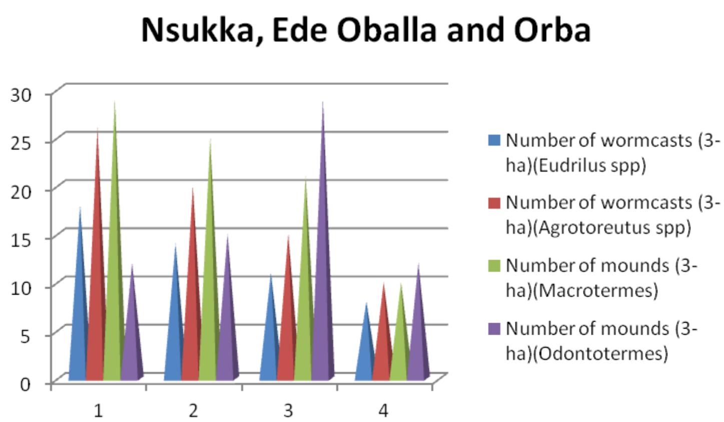

Figure 1. Number of wormcasts and termite mounds across the study location LUTs.

Table 1. Some physical properties of wormcast and termite mound soils in the 3-ha study sites.

Location	Sand gkg^{-1}	Siltgkg^{-1}	Clay gkg^{-1}	Silt + Clay gkg^{-1}	Texture	Bulk density gcm^{-3}	Φm gkg^{-1}
			Wormcast (*Eudrilus* spp and *Agrotoreutus* spp)				
Nsukka	360	270	370	640	CL	1.38	243
Ede-Oballa	340	190	470	660	CL	1.42	320
Orba	320	240	440	680	CL	1.44	238
All location fallow	700	80	220	300	SCL	1.51	170
$SED_{0.05}$	51.6	32.1	43.8	57.1		0.03	45.2
P-value	<0.0001	<0.0001	<0.0001	<0.0001		n.s	<0.0001
			Termite (*Macrotermes* and *Odontotermes spp*) mounds				
Nsukka	380	160	460	620	CL	1.38	244
Ede-Oballa	400	220	380	600	CL	1.42	321
Orba	340	220	420	640	CL	1.44	228
All location fallow	720	100	180	280	SCL	1.51	156
$SED_{0.05}$	54.2	28.8	46.1	47.2		0.03	55.1
P-value	<0.0001	<0.0001	<0.0001	<0.0001		n.s	<0.0001

Ks, soil saturated hydraulic conductivity; Bd, soil bulk density; TP, total porosity; NS, not significant; Nd, not determined; SL, sandy loam; SCL, sandy clay loam; LSD (P<0.05), least significant difference at 5% level of probability, $^{*}p<0.05$, $^{**}p<0.01$.

report (Karlen et al., 1997) that earthworm number is 'Level 1' indicator of a soil's ability to accommodate water entry for prolonged periods during high intensity rainfall and frequent irrigation events.Total number of *Macrotermes* spp mounds in LUT 1 & 2 across the study locations were significantly higher (p<0.05) than that of *Odontotermes* by 53.2%.

Soil physical properties of wormcasts and termite mounds

The percentage of finer particles in wormcasts and termite mounds could probably be the main effect on physico-chemical properties of soils. The statistical mean values of rheological and physical properties of wormcasts and termite mounds are presented in Table 1. The textural analysis showed that significantly higher clay contents were obtained in the wormcast (p<0.01) and termite mound soils (p<0.05) than the surrounding soils. The higher clay fractions that predominantly gave rise to clay loam texture could be associated to the preferential incorporation of clay by the species of earthworms and termites identified. This confirms earlier report by Kang (1978) and Debruyn and Conacher (1987) who reported significantly higher clay content in termite mounds than

Table 2. Rheological properties (Consistency limit) of wormcast and termite mound soils in the 3-ha study sites.

Location	Liquid limit	Plastic limit	Shrinkage limit	Plastic limit	COLE
		Wormcast (*Eudrilus spp* and *Agrotoreutus spp*)			
Nsukka	32.2	19.7	9.4	17.3	0.031
Ede-Oballa	33.7	20.3	10.3	17.0	0.035
Orba	38.3	18.1	8.4	12.8	0.033
All location fallow	18.6	12.1	4.2	5.4	0.009
$SED_{0.05}$	1.42	0.69	0.47	0.64	0.006
P-value	<0.0001	<0.085	<0.0001	<0.0001	<0.0003
		Termite (*Macrotermes* and *Odontotermes spp*) mounds			
Nsukka	42.5	28.7	28.1	18.0	0.035
Ede-Oballa	30.8	20.0	20.0	15.7	0.029
Orba	30.3	18.6	15.8	20.3	0.031
All location fallow	20.1	9.9	7.4	10.3	11.2
$SED_{0.05}$	1.37	1.36	0.33	0.69	0.004
P-value	<0.0001	<0.0001	<0.0001	0.0001	<0.0002

COLE = coefficient of linear extensivity, P= probability, SED= standard error deviation.

the surrounding soil.

Sandy clay loam obtained in surrounding soils could be attributed to nature of parent materials and high rainfall that could favor washing away and leaching of silt-sized and clay-sized fractions (Mbagwu, 1995; Lal, 1988, Franzluebbers, 2002).

Soil bulk density (Bd) value was significantly higher ($p<0.05$) in the surrounding soil (1.52 gcm^{-3}) when compared to the Wc and Tm soils. Soil Bd decreased by 13.2% in Wc and 5.3% in Tm relative to Ss and were statistically similar. Low Bd implies a positive productivity indicator as it helps in easing root penetration, and encourages downward movement of water, more soil water retention and availability for greater water use efficiency by crops (van Schaik et al., 2014). These results had been corroborated. Lavelle (1997), Francis and Fraser (1998) and Chan (2004) reported decreases in Bd and increases in moisture content.

The higher Bd in the surrounding soil may be associated to seasonal flooding of soils; resulting to continued wetting and drying of soils. There is also the possibility of soil surface crusting and crusting by compaction through raindrop impact and surface erosion. It is quite possible that the higher content of sand in the control soil (Table 1) was due to washing away of clay and silt sized-fractions by rainfall and runoff water and may have contributed to the higher bulk density obtained.

The *in situ* shear strength of Wc and Tm soils were found higher than that of Ss. Shear strength decreased with reduction in moisture content and increased as the gravimetric moisture content increased. Termite mound had highest mean shear strength of 90.36 kpa and could be associated to higher silt and clay content in it. Surrounding soil had the least shear strength of a total mean value of 56 kpa and may be due to presence of sandy soil mixed with clay soil.

Generally the shear strength of Wc and Tm soils increased with the number of Proctors' hammer blows and reached a maximum of about 15 blows in the moisture content range of about 12 to 14 (db). It was recorded that about 85% of the maximum shear strength was achieved at 10 blows. Greater shear strength in the Wc and Tm relative to Ss implies less susceptibility to compaction. The rheological properties of Wc and Tm relative to surrounding soils are shown in Table 2. Higher plasticity values were recorded in Wc and Tm across the locations than those of the Ss. Higher plasticity reflects higher clay contents and implies the possibility of higher activity in the forms which portend instability of soils especially under high engineering activity. Higher plasticity index (PI) values affected shrinkage behavior of soils as given by the coefficient of linear extensivity (Table 2). Atterberg limits (Liquid limit, plastic limit and plasticity index) had significant ($p<0.05$) positive relationship with gravimetric moisture content (Φm) and clay (Table 3). Coefficient of linear extensivity (COLE) had strong positive relationship with (Φm) and clay. These findings suggest possible use of these soil physical properties in predicting rheological properties in WC and Tm soils in the study locations. Sand content had significant ($p<0.05$) correlation with rheological properties, implying its efficacy in predicting soil behavior.

Strong relationship between soil moisture and PI ($r = 0.82$, $p<0.0001$) (Table 2) suggests that soil moisture is a major determinant of soil compressibility (McNabb and Boersma, 1996) among other factors such as bulk density (Imhoff et al., 2004) but the r-value (0.81) suggests that other undetermined factors could be

Table 3. Relationship between rheological properties (Consistency limit) and Some physical properties across wormcast and termite mound soils in the 3 ha study sites.

Factor correlated	Pearson correlation coefficient (r)	Significance p<0.09
COLE Vs Φm	0.83	<0.0001
COLE Vs clay	0.76	<0.001
COLE Vs **Bd**	0.48	<0.0001
COLE Vs sand	0.33	<0.001
LL Vs Bd	0.12	Ns
LL Vs sand	0.62	<0.0001
PL Vs Φm	0.70	<0.001
PL Vs clay	0.55	<0.001
PI Vs Φm	0.59	<0.001
PI Vs Bd	0.09	Ns
PI Vs sand	0.28	<0.001

COLE = coefficient of linear expansivity, Φm = gravimetric water content, Bd= bulk density, LL= liquid limit, PL= plastic limit, PI= plastic index, Ns= not significant.

influencing plasticity.

Conclusion

The results of this study show that clay contents in wormcast (Wc) and termite mound (Tm) soils, regarded as plant-soil system, were higher than the surrounding soils (Ss). Decreased soil bulk density and increased gravimetric water content were recorded in the plant-soil systems relative to Ss. Wormcast and termite mound soils had higher consistency limits and greater shear strength than the surrounding soils. Though the rheological and other physical properties varied with the Wc and Tm soils, they have shown their relative efficacy in predicting soil behavior. The study has demonstrated the usefulness of characterizing Wc and Tm in relation to surrounding soil.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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