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Stabilities of ant nests and their adjacent soils

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Abstract. Nests habour ants and termites and protect them from harsh environmental conditions. The structural stabilities of nests were studied to ascertain their relative vulnerability to environmental stresses. Arboreal-ant nests were pried from different trees, while epigeous-termite nests were excavated from soil surface within the sample area. Soils without any visible sign of ant or termite activity were also sampled 6 m away from the nests as control. Laboratory analysis result showed that irrespective of the tree hosts, the aggregate stabilities of the ant nests were lower than those of the ground termite, with nests formed on *Cola nitida* significantly showing lower aggregate stability (19.7%) than other ant-nest structures. Clay dispersion ratio, moisture content, water stable aggregate class <0.25 mm and sand mass were each negatively correlated with aggregate stability, while water stable aggregate class1.00-0.50 mm gave a positive correlation. Nest structures were dominated more by water stable aggregate class >2.00 mm but path analysis demonstrated that water stable aggregate class <0.25 mm contributed most to the higher aggregate stability of the termite nest than the other nest. Nest aggregates had greater structural stability compared to the control soil. The higher structural stability of termite nests over other nest and soil was considered a better adaptive mechanism against body desiccation.

Keyword: structural stability, arboreal-ant nests, derived savanna, termite nests

INTRODUCTION

Within the tropics, the most abundant animals are the ants which belong to the order Hymenoptera in the family *Formicidae*, and the termite in the order Isoptera in the family *Termitidae* (Jouquet *et al*., 2002). Related findings for instance from Ghana and Nigeria showed that as many as 80% of the total number of individual insects found on cocoa are ants (Hölldobler and Wilson, 1990). This in addition to the original lifestyle as predators makes them major components of both the terrestrial and arboreal ecosystems.

These soil macro-invertebrates (ants and termites) are regarded as ecosystem engineers (Jouquet *et al*., 2006). Termites are divided into either wood-dwelling or soil dwelling, but majority of the tropical termites are the soil dwellers that construct either above ground nests or dig underground galleries and are found mostly on dry areas. Wood dwelling termites do not create nests, but live in excavated galleries in the dry woods. Ants are responsible mainly for arboreal nests. They live mainly on live trees where they build nests with litter materials, soils and some decomposed organic materials on top of trees. The scholars stated that nests formed by the black ants, popularly known as carton nest, are formed by ants chewing up pieces of wood and mixing them with honeydew and a type of syrup very similar to those of wasps. Ants and termites are very vulnerable insects and require the protection of their bodies and colonies by improving the structural stability of their nests.

Ants and termites are important agents of soil, functioning through their bioturbation effects, which have been shown to be an important agent regulating soil aggregates and the creation of galleries and chambers as well as facilitate the water and gas transportation (Lavelle *et al*., 2001). They also indicated that the activities of some of the invertebrates on soil structure have serious impact also on soil aggregation and porosity, and hence on associated hydraulic properties and soil organic matter availability for microorganism. These invertebrates build organo-mineral structures of different stabilities, such as galleries, casts, sheetings, fungus-comb chambers and mounds (Jouquet *et al*., 2004).

Most results show that the aggregates of termite nests are only slightly more stable than surface soils in the vicinity of the nest (Garnier-Sillam *et al*., 1988). Soil structural properties particularly soil organic matter and clay content and quality play major roles in controlling this soil structural

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stability through their influence on water sorptivity and repellency as well as on the strength of bonds between particles. Rainfall is the main natural agent responsible for the breakdown of soil aggregates and its effect is three fold (Brady and Weil, 1999):

– raindrop impact destroys aggregations,
– splash detaches soil aggregates and particles,
– run off removes soil.

The susceptibility of a soil to these effects is often evaluated with measurements of aggregate stability. Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied.

Procedures for the characterization of aggregate stability of soils have been suggested by various workers (Six *et al.*, 2000; Zhang and Horn, 2001). Soil vulnerability to soil erosion was predicted using water-stable aggregate (WSA) and mean-weight diameter (MWD) by Amezketa *et al.* (1996). According to Six *et al.* (2000), the MWD remains an index that could characterize the structure of the whole soil by integrating the aggregate size class distribution into one number. However, Brady and Weil (1999) indicated that soil aggregate stability depends on organic matter (SOM), clay mineralogy, and oxide contents.

Ants and termites usually construct their nests based on their ecological requirements and therefore should vary in compositions. Jouquet *et al.* (2002) reported that termites favour finer particles such as clay and silt in their constructions which match their ecological, physiological and behavioural needs. Several researchers also reported that fungus-growing termites modify their immediate environment by increasing the clay and porosity in soil (Holt and Lepage, 2000; Jouquet *et al.*, 2002). It will be right therefore to conclude that the spatial and temporal heterogeneity of ant and termite nests are responses to their auto-ecological requirements. Therefore, one of the differences between the activities of ants and termites could be assessed in their amplitude of influence on soil biogeochemical heterogeneity ranging from soil aggregate stability and SOM dynamics.

This paper therefore reports on the aggregate stability difference between nest structures of epigeous ground termites and arboreal ants from different tree hosts *vis á vis* their surrounding surface soils. The specific objectives of the study were therefore to:

– compare the aggregate stabilities of nest structures made by arboreal- ants and ground termite,
– compare the aggregate stabilities of nest structures made by ants and termites and their adjacent unaffected soils,
– establish the primary factor contributing to the aggregate stability of the nest and soil.

MATERIALS AND METHODS

Soil samples were collected from Orba-Nsukka in Udenu Local Government Area of Enugu State, Nigeria (6°52'N, 7°24'E). It is in a derived savanna vegetational zone (rainfall ≈ 1800 mm year^{-1} at 447 m a.s.l.). The mean monthly temperature of the area is between 25 and 32°C (Igwe and Stahr, 2004). The soil is predominantly reddish-brown in colour and the area has annual bimodal rainfall with peaks around July and September of each year. The study site has not been cropped for the past 10 years, but suffers from occasional annual bush burning. The soil is well drained Typic Paleustult (Igwe *et al.*, 1995). There were conspicuous epigeous termite mounds on the ground and arboreal carton nests of ants on some trees. The entire landscape is grassy with scant distributions of tropical trees and occasional shrubby thickets.

Arboreal carton nests of ants were collected from five different trees, namely: mango (*Mangifera indica*), bush mango (*Irvingia gabonensis*), kola (*Cola nitida*), newbouldia plant (*Newbouldia laevis)* and oil bean plant (*Pentaclethra macrophylla*). The termite species sampled from the ground nest was *Odontotermes sudanensis* (Isoptera: *Termitidae*), while the ant species sampled from the carton nests was *Camponotus acvapimensis* Mayr (Hymenoptera: *Formicidae*). Epigeous ground nest samples were also collected from active forming termite nests excavated from 0 to 10 cm depth. Adjacent soils (without any visible termite or ant activity) were also sampled approximately 6 m away from sampled nest or tree but of same soil type. The arboreal nests were pried from the host trees, pulverised and placed in a plastic bag for laboratory analysis. The termite nests were also crushed, before bagging for laboratory analysis. Species of ants and termites sampled from the nests were identified.

The organic carbon (OC) content was determined by the method of Walkey and Black (1934) using potassium dichromate ($K_2Cr_2O_7$) as the oxidizing agent. The soil organic matter (SOM) content of each sample was obtained as: SOM (%) = OC (%) × 1.724.

The sodium hexametaphosphate calgon and water dispersed clay and silt were obtained by hydrometer method (Gee and Bauder, 1986). The percentage clay and silt obtained using the two dispersants separately were regarded as the total clay and silt. The CDR (clay dispersion ratio) was calculated as (WDC) / (T clay), where: WDC is water dispersible clay and T clay is total (calgon) dispersed clay.

The method described by Igwe and Stahr (2004) was used to separate water-stable aggregates (WSA). Air-dried soil sample (50 g) was sieved through 4.75-mm mesh. The sieved sample was later placed inside the topmost of four sieves of sizes 2, 1, 0.5, and 0.25 mm mesh arranged in that order. The sample was then pre-soaked with deionised water for 30 min. The sieves and its content were later oscillated 20 times at an amplitude of 4-cm and at the rate of 1 oscillation s^{-1}. After the wet sieving, the resistant soil materials on each sieve and the unstable (0.25 mm) aggregates were transferred into a clean beaker, dried gently in the oven at 40°C for 48 h. The dried samples were later weighed. The percentage ratio of aggregates in each sieve represent the

Table 1. Soil moisture, organic matter, clay dispersion ratios, calgon and water dispersible clay and silt of nest and adjacent unaffected soils

Nest/Soil sample	MC (%)	SOM (%)	Calgon dispersed		Water dispersed		CDR
			Clay	Silt	Clay	Silt	
C. nitida (ant)	7.78	12.6	12.5	10.6	15.2	2.5	1.216
I. gabonensis (ant)	5.03	15.8	16.0	17.6	20.7	4.0	1.294
M. indica (ant)	4.26	12.0	17.5	14.5	16.2	8.8	0.924
N. laevis (ant)	5.89	16.5	10.5	11.1	10.4	5.6	0.991
P. macrophylla (ant)	9.74	14.4	15.5	11.6	21.7	7.1	1.400
Termitaria (termite)	2.02	2.5	13.5	8.6	10.7	5.1	0.793
Adjacent soil	1.62	1.3	9.3	8.7	9.5	3.3	1.020
Mean	5.22	10.7	13.5	25.4	14.9	5.2	1.020
F-LSD$_{0.05}$	1.88	1.1	4.2	1.2	1.2	1.2	NA

MC – moisture content, CDR – clay dispersion ratio, *C. nitida – Cola nitida, I. gabonensis – Irvingia gabonensis, M. indica – Mangifera indica, N. laevis – Newbouldia laevis, P. macrophylla – Pentaclethra macrophylla*, NA – not analyzed.

WSA of sizes > 2.00, 2.00-1.00, 1.00-0.50, 0.50-0.25 and <0.25 mm. The mean weight diameter (MWD) of water-stable aggregate was calculated as:

$$\mathrm{MWD} = \sum X_i W_j ,$$

where: X_i is the diameter of the ith sieve size and W_j is the proportion of the total aggregates in the jth fraction. The aggregate stability was calculated as:

$$\frac{\textit{Mass of water stable aggregate - Mass of sand}}{\textit{Mass of original sample}} \frac{100}{1} .$$

The moisture retained at 60 cm tension (approx. 0.06 10^5 N m^{-2} tension) represented the field capacity moisture content. Beyond 0.06 10^5 N m^{-2}, the pressure plate and pressure membrane assemblies were used to determine water retention with 15 10^5 N m^{-2} representing the permanent wilting point (Igwe and Stahr, 2004). All the data were analysed in triplicates.

All data were subjected to analysis of variance (ANOVA) to determine any significant difference at 5% level using Steel *et al*. (1997). Significant differences were separated using F-LSD. The degree of relationships between aggregate stability and WSA, MWD, CDR, mass of sand, MC, SOM, calgon and water dispersible clay was later studied using correlation matrix. The correlation coefficient values were calculated by invoking a procedure for simple correlation analysis with Genstat (2007) to identify relative linear associations among the variables. Five variables (causal components) that correlated significantly with aggregate stability (effect) were:

- clay dispersion ratio (CDR),
- moisture content (MC),
- water stable aggregate class 1.00-0.50 mm (WSA 3),
- water stable aggregate class <0.25 mm (WSA 5),
- mass of sand, cause and effect relations of the variables,
- aggregate stability in space and time were examined using path coefficient analysis in order to establish the relative effects of the causal components on aggregate stability.

The indirect effects were determined by multiplying the correlations by their respective path coefficients. From the usual hypothesized equation for path analysis, represents path coefficients and represents simple correlation coefficients. Each normal equation partitions the simple correlations into direct and indirect effects. The subscript in the equation represents the variables (numerical values represent the independent factors) included in the path model, while *y* (the dependent factors). This is to establish the primary component contributing substantially to aggregate stability. The path coefficients were calculated and diagrammatically represented using statistical package as outlined by Arbunckle (1996).

RESULTS

Analysis of variance result on the chemical constituents of the nest and soil samples shows that there was significantly higher ($P<0.05$) moisture and soil organic matter contents on soils altered by ants and collected from various trees than on termite mounds (Table 1). Soils influenced by ants of different tree hosts (except those collected from *C. nitida* and *N. laevis)* also had higher clay dispersion ratio compared to soils of termite-built structures. Also, the CDR of ant nests collected from trees were numerically higher than their corresponding adjacent soils except on *M. indica* and *N. laevis* sampled nests where the adjacent soils were higher than the nests. Nest soils generally had significantly higher ($P < 0.05$) moisture content, soil organic matter, and calgon and water dispersed clay and silt relative to their surrounding surface soil.

The water-stable aggregates >2.00 mm dominated in all the tree nests and termitaria, but the differences amongst the nesting hosts did not attain any level of statistical significance (Table 2). The adjacent soils dominated in WSAs 0.50-0.25 and <0.25 mm. Amongst the nests, WSA >2.00 mm varied between 45.0% in *P. macrophylla* host and 51.3% in *M. indica* host with only 17.1% in the adjacent surface soils. WSA class 2.00-1.00 mm ranged between 9.24% in *I. gabonensis* host and 18.95% in termitaria mound, while the adjacent soils was 18.20%; but their differences were also not statistically significant (P > 0.05). WSA class 1.00-0.50 mm ranged from 6.43% (*N. laevis)* to 15.49% (termitaria); while WSA class 0.50-0.25 mm ranged from 8.22% (*N. laevis)* to 25.45% (*P. macrophylla*). Differences in the nesting hosts amongst the two WSA *ie* 1.00-0.50 and 0.50-0.25 mm were also not significant. WSA class <0.25 mm was the only WSA that significantly differed (P<0.05) amongst the nesting sites. This is such that termite-built nests had significantly lower (P < 0.05) WSA compared to arboreal ant nests of the tree hosts and the adjacent surface soils.

A highly significant difference (P < 0.05) was detected in the overall aggregate stabilities between termite - influenced soils and soils with ant activity or their adjacent surface soils (Table 2). The aggregate stability values ranged from 19.7% *(I. gabonensis* nest) to 69.3% (termiteria). Whereas the aggregate stabilities of ant nests on tree hosts ranged from 19.7% (*I. gabonensis*) to 46.4% (*M. indica*), those of termitaria was about 70%, those of the bulk soil was 29.9% The MWD seem to be more or less similar amongst the various nesting sites.

The result shows that WSA (WSA 3) class 1.00-0.50 mm correlated positively with WSA (2) class 2.00-1.00 mm (r = 0.908; P < 0.05) (Table 3). Correlation between WSA (3) class 1.00-0.50 mm and WSA (5) class <0.25 mm was not significant (r = -0.474). Conversely a significant positive correlation was established between WSA (3) class 1.00-0.50 mm and aggregate stability (r = 0.565). While WSA (5) class < 0.25 mm correlated negatively and significantly with aggregate stability (r = -0.867), the association between MWD and WSA (3) class 1.00-0.5 mm was not strong (r = -0.451). Clay dispersion ratio (CDR) was linearly correlated to moisture content, soil organic matter, water dispersible clay (WC), WSA (3), WSA (5), mass of sand and aggregate stability (P ≤ 0.05). Similarly, moisture content (MC) was linearly associated with CDR, SOM, WC, WSA 2, 3 and 5, mass of sand and aggregate stability (P ≤ 0.05).

Path analysis taking all nest/soil parameters as causal components of the aggregate stability (Table 4) revealed that the factors varied in their contributions to the aggregate stability. Further examination on CDR, WSA 3 and sand mass showed that they had negative and very low direct effects with aggregate stability. Their correlations with aggregate stability were high and significant (P<0.05). Their high negative correlations with aggregate stability appeared to be mediated via indirect effects through WSA 5. MC had little or no direct effect (+0.002) with stability but its correlation with stability was significant (r = -0.601) and indirect effect via WSA 3 was also positive (+0.333). WSA 5 was the only component with appreciably high direct effect (-0.702) with aggregate stability. Its association with stability was also very strong (-0.867). The coefficient of determination (R^2) which determines how best the causal factors accounted for the variability in the aggregate stability was 79.1% (Table 4). The residual factor R which indicates all the variables not accounted for in the models and the sampling error was computed as 0.46. The double arrowed lines in the path diagram (Fig. 1a) indicated mutual association measured by correlation coefficient, while the single line represented direct influences as measured by path coefficient. The hypothesized equation for the relationship between the variables

Table 2. Water stable aggregates, mass of sand, mean-weight diameter of aggregates and aggregate stability of nests and adjacent unaffected soils

Nest/Soil sample	Water – stable aggregate (dia in mm, %)					Mass of sand (g)	MWD (mm)	Aggregate stability (%)
	>2.00	2.00-1.00	1.00-0.50	0.50-0.25	<0.25			
C. nitida (ant)	47.8	11.06	7.62	10.52	17.20	13.31	1.91	19.7
I. gabonensis (ant)	48.2	9.24	6.52	8.30	19.45	12.12	1.89	31.5
M. indica (ant)	51.3	9.31	9.72	14.07	15.63	12.61	2.01	46.4
N. laevis (ant)	47.5	10.01	6.43	8.22	16.90	12.11	1.89	36.6
P. macrophylla (ant)	45.0	13.04	7.62	25.45	21.92	13.19	1.87	27.6
Termitaria (termite)	47.7	18.95	15.49	11.58	9.22	7.36	2.05	69.3
Adjacent soil	17.1	18.20	15.39	20.89	19.96	7.42	1.11	29.9
Mean	36.7	12.88	9.83	14.15	17.18	11.16	1.82	37.3
F-$LSD_{0.05}$	NS	NS	NS	NS	5.63	2.59	NS	16.7

MWD – mean-weight diameter, NS – not significant at 5% probability level.

Table 3. Simple correlation coefficients for calgon dispersible clay (CC) and silt (CS), water dispersible clay (WC) and silt (WS), clay dispersion ratio (CDR), moisture content (MC), mean-weight diameter (MWD), soil organic matter (SOM), water stable aggregates <2.00 mm, 2.00-1.00 mm, 1.00-0.50 mm, 0.50-0.25 mm and <0.25 mm (WSAs 1, 2, 3, and 5), mass of sand and aggregate stability

	Aggregate stability	CC	CDR	CS	MC	MWD	SOM	WSA 1	WC	WS	WSA 2	WSA 3	WSA 4	WSA 5
CC	0.182													
CDR	-0.790**	0.238												
CS	-0.205	0.709**	0.417											
MC	-0.601*	0.290	0.779**	0.233										
MWD	0.377	0.647*	-0.038	0.357	0.378									
SOM	-0.464	0.405	0.580*	0.671*	0.758**	0.513*								
WSA 1	0.243	0.663*	0.057	0.474	0.452	0.984**	0.644*							
WC	-0.378	0.773**	0.798**	0.712**	0.674*	0.374	0.622*	0.442						
WS	0.368	0.624*	-0.164	0.270	0.152	0.428	0.260	0.417	0.285					
WSA 2	0.434	-0.470	-0.411	-0.779**	-0.554*	-0.463	-0.919**	-0.611*	-0.538*	-0.277				
WSA 3	0.565*	-0.336	-0.645*	-0.639*	-0.789**	-0.451	-0.989**	-0.588*	-0.618*	-0.136	0.908**			
WSA 4	-0.217	0.006	0.318	-0.316	0.197	-0.471	-0.289	-0.511*	0.217	0.264	0.410	0.288		
WSA 5	-0.867**	-0.026	0.819**	0.314	0.523*	-0.472	0.420	-0.352	0.514*	-0.073	-0.341	-0.474	0.498	
Mass of sand	-0.564*	-0.488	0.630*	0.583*	0.855**	0.495	0.919**	0.619*	0.688*	0.289	-0.892**	-0.929**	-0.112	0.453

Significant at $^{*}P < 0.05$, $^{**}P < 0.01$.

Table 4. Direct and indirect effects of aggregate stability indices and aggregate stability based on path coefficient analysis

Character	CDR	MC	WSA 3	WSA 5	Mass of sand	Correlation with aggregate stability
Clay dispersion ratio (CDR)	**(-0.101)**	0.002	0.005	-0.575	-0.121	-0.790**
Moisture content (MC)	-0.079	(0.002)	0.006	-0.367	-0.163	-0.601*
Water stable aggregate (1-0.50 mm) (WSA 3)	0.065	-0.002	(-0.008)	0.333	0.178	0.566*
Water stable aggregate (<0.25 mm) (WSA 5)	-0.083	0.001	0.004	(-0.702)	-0.087	-0.867**
Mass of sand	-0.064	0.002	0.007	-0.318	(-0.191)	-0.564*
Residual						0.460
R^2						0.791

Significant at *P < 0.05, **P < 0.01, R^2 – coefficient of determination. Values in parentheses represent direct effect.

and aggregate stability was shown in Fig. 1b, with numerical values as independent characters and subscript "y" as the dependent.

DISCUSSION

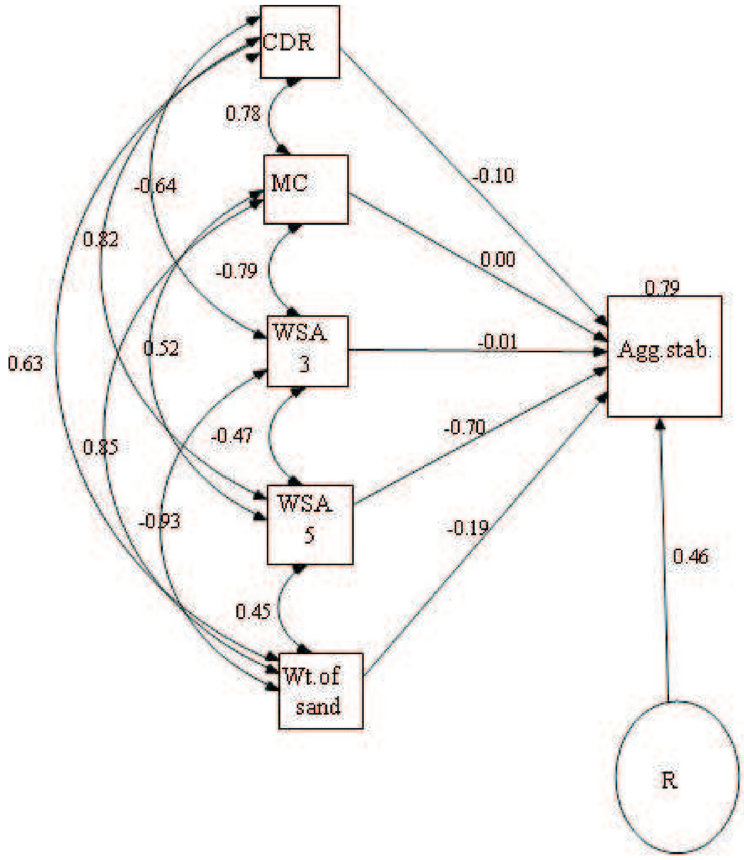
Comparative studies on ground-termite nests and arboreal-ant nests of various tree hosts revealed that soil organic matter was relatively higher in the arboreal-ant nest than in ground-termite nest. This suggests the availability of more litter materials at the disposal of the ants than at the disposal of 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. These differences were also evident in the clay and silt contents of their nests which were about heterogeneous in the two types of nest structures. The heterogeneity in clay and silt contents between ant and termite nests may stem from dissimilar efficiency in the attraction of these substances from soils by ants and termites for their nest construction. These organisms had earlier been noted to show a strong impact on clay-particle size and in their clay mineralization (Jouquet *et al*., 2004).

In the present study, nest-structures generally were found to be conspicuously greater in moisture content, soil organic matter, calgon and water dispersible clay than their adjacent soils. This was attributed to the enrichment of these nests with organic materials of litter and foliage and their greater content of clay for such nest construction. Ecosystem engineers, notably ants and termites generally transport organic debris to their nests from their surroundings for food. The mineralization within the nests for food of this organic debris was suggested to be responsible for the enriched SOM and other biologically important nutrients (N, P, Ca, Mg and K) in the nests compared to their surrounding soil (Lopez-Hernandez *et al*., 1989). According to Holt and Lepage (2000), the proportion of clays in the termite-built structures is always greater than in the bulk soil.

The increased soil organic matter content of the nest structure could also explain the higher moisture content of the nests compared with the adjacent soils within their vicinity. This result was supported by the findings of Christe *et al*. (2003) which explained that the high moisture content of nest facilitates development of an abundant and functionally specialized decomposer community with a large biomass concentrated at the lower trophic positions. The high moisture content with eventual high temperature also will favour the growth of heterotrophic microbes, which may be necessary for the development of "fungal garden" required as food and aid in the further breakdown of organic materials.

Although comparative studies of ant and termite nests showed that ant nests were significantly higher than the termite nests, with respect to their moisture content, SOM, calgon and water dispersible clay and silt contents, termite mounds were found to be higher in aggregate stability than the respective ant nests. The stability roles of the nest structure have been suggested to be controlled by SOM, clay content and quality (Brady and Weil, 1999). Incidentally, our results showed that ant nests were higher than the termitaria in all these parameters and therefore would not have been the contributing factors to aggregate stability. It does therefore suggest that other factors other than the above parameters were the primary factors of soil structural stability.

a



b

$$r_{1y} = P_{1y} + r_{12}P_{2y} + r_{13}P_{3y} + r_{14}P_{4y} + r_{15}P_{5y} \tag{1}$$

$$r_{2y} = r_{21}P_{1y} + P_{2y} + r_{23}P_{3y} + r_{24}P_{4y} + r_{25}P_{5y} \tag{2}$$

$$r_{3y} = r_{31}P_{1y} + r_{31}P_{2y} + P_{3y} + r_{34}P_{4y} + r_{35}P_{5y} \tag{3}$$

$$r_{4y} = r_{41}P_{1y} + r_{42}P_{2y} + r_{43}P_{3y} + P_{4y} + r_{45}P_{5y} \tag{4}$$

$$r_{5y} = r_{51}P_{1y} + r_{52}P_{2y} + r_{53}P_{3y} + r_{54}P_{4y} + P_{5y} \tag{5}$$

where: P_{ij} = path coefficients; r_{ij} = linear correlation coefficients.

Fig. 1. a – path diagram, b – hypothesized equations for the relationships between CDR, MC, water stable aggregates 1-0.50 mm and <0.25 mm (WSA 3 and 5), mass of sand (Wt. of sand) and aggregate stability (Agg. stab).

To support this assertion, Nwadialo and Mbagwu (1991), explained that SOM does not influence microaggregates stability greatly when values of soil organic matter are low or do not reach certain critical limits. Report of Mbagwu and Bazzoffi (1988) also confirmed that the role of soil organic matter as an aggregating agent tends to diminish when other aggregating agents such as silicate clay and polyvalent metals become predominant. Goldberg *et al*. (1990) further explained that soil organic matter could act as aggregating or disaggregating agent or have no influence at all on aggregation. Therefore, the significantly higher clay and SOM in ant nests relative to termites in this study suggested that another factor other than clay and SOM content might be responsible for the greater aggregate stability of the termite nest in contrast to the ant nests. The individual preferences or effectiveness in the harnessing of the particular clay quality necessary for stability was suggested to be responsible. Jouquet *et al*. (2004) while emphasizing the role of clay quality in the soil structural stability, illustrated that 2:1 clay types are rather responsible for the shrink-swell behaviour of soils and some termite species are more effective in the mineralization of this clay type. Similarly, other researchers focused on the role of SOM content and quality for determining the mechanisms responsible for the structural stability of Macrotermes nest (Contour-Ansel *et al*., 2000). Again, several other researchers also supported the thesis that soils handled by termites are very cohesive and can resist water disturbance (Contour-Ansel *et al*., 2000; Jouquet *et al.,* 2004). Jouquet *et al*. (2002) illustrated that termites *Odontermes n. pauperus* utilises soil selectively, favouring finer particles and making structures that match their ecological needs: to spend less energy (in terms of saliva enrichment). On the other hand, Jouquet *et al*. (2004) explained that many ants build mounds constructed from mineral and plant materials bound together by mandibular gland secretions. Thus, the use of finer particles instead of saliva secretion in nest construction by termites rather than ants might be another factor responsible for greater structural stability of the termite mounds over ant mounds, although beyond the scope of this study.

Use of path analysis in the current study therefore has helped to determine the contribution of the individual soil parameters assessed, suggesting that under the confines of this study, water stable aggregate (WSA 5) class <0.25 mm was the only factor with the highest direct (unmediated) effect and correlation with aggregate stability and therefore the primary contributor to the aggregate stability. From the result, irrespective of the high correlations of CDR, MC, WSA 3 and mass of sand with aggregate stability, they still appeared to be masked by the negative indirect influence of WSA 5 in most cases. This suggested that the finer the particles the higher the aggregate stability. This supports Jouquet *et al*. (2002) finding that termites utilize soil selectively, favouring finer particles in making their nests.

Results of the study to compare soils of nest structures and their corresponding adjacent surface soils showed a greater structural stability of the mound soil relative to the adjacent soil. Considering the significantly higher SOM, MC, Clay and Silt of nest structures over the bulk soil, the results were not unexpected. Several workers have attributed the greater structural stability of mounds over their neighbouring soils to the proportion of SOM and clay content and quality in these built structures (Holt and Lepage, 2000; Jouquet *et al*., 2002; 2004).

From this result also showed that ant nests from various tree hosts were predominantly favoured by WSA class < 0.25 mm which was significantly higher than values found in termite nests. Conversely, termitaria particle aggregates were found to be more stable than the arboreal ant nests aggregates of the various tree hosts. The higher aggregate stability of the termite nest over the ant nests would be tempted to be particularly attributed to the dominating higher WSA of class 1.00-0.50 mm. WSA of termite nest although was not statistically different from WSA of ant nests from trees, the value for termite nest soil was conspicuously higher than those of ant nest soils. A positive significant correlation of 0.565 was established between WSA class 1.00-0.50 mm and aggregate stability. The WSA of the finest particle < 0.25 mm however significantly contributed to the overall aggregate stability of the nest but negatively ($r = -0.867$). This class particle (< 0.25 mm) WSA for termitaria although was lower than those ants, it has a higher aggregate stability of 69.3% and a strong negative correlation of -0.867.

This result also showed that aggregate stabilities of the various nest-structures did not correlate with MWD ($r = 0.377$, $P > 0.05$). As a means of characterizing aggregate stability of soils, many researchers used water-stable aggregate (WSA) and mean-weight diameter (MWD) to predict soil erosion (Six *et al.,* 2000; Zhang and Horn, 2001). Levy and Miller (1997) showed that the breakdown of unstable aggregate results in the collapse of soil pores and production of finer particles and microaggregates. They explained that higher MWD values indicate higher proportions of macroaggregates in the sample and therefore higher stability and therefore less prone to erosion. But in this study MWD did not correlate significantly with aggregate stability.

However, the MWD and aggregate stability of nest structures were conspicuously higher compared with those of soils within the vicinity of the nests. This report and several others (Jouquet *et al*., 2004; 2006) have confirmed that the aggregate stability of nest structures is greater than that of soils without ant and/or termite activity. This may amply be attributed to the enrichment of the nest-structures with greater proportions of organo-minerals, which ensures greater SOM and clay availability and quality required for greater structural stability of the soil.

In our study, the CDR also showed a negative significant correlation with aggregate stability illustrating the increased role of clay in the aggregate stability.

CONCLUSIONS

1. Soils altered by ants irrespective of their tree hosts were less stable compared to soils worked by termites. This was suggested to be due to the low water stable aggregate of <0.25 mm class particles of ant mounds over termite mounds.

2. Generally the structural stability of nest structures was significantly higher than those without any nest (adjacent soils). This was attributed to organic matter, moisture, clay and silt contents of the former over the latter.

3. Nests collected from *Cola nitida* had the least aggregate stability relative to other tree nests sampled.

4. Water stable aggregate class <0.25 mm contributed most to the higher aggregate stability of the termite nest than the other nests, but negatively.

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