Makerere University Journal of Agricultural and Environmental Sciences
Vol. 10 (2). pp. 106 - 122, 2021
Printed in Uganda.
ISSN 1563-3721

Comparison of the physico-chemical status of termite mound and adjacent soil of four different *Eucalyptus species* plantations in Nigeria

Alamu, O.T.[1*], Ewete, F.K.[2] and Bobadoye, B.O.[1]

[1]Department of Forest Conservation and Protection, Forestry Research Institute of Nigeria, Ibadan, Nigeria
[2]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria

*Corresponding author: tomniyialamu@yahoo.com, alamu.ot@frin.gov.ng

Abstract

The *Eucalyptus* tree is an exotic species in sub-Saharan Africa, with reported negative environmental depletion of soil nutrients and water. Termites have special feeding preference for *Eucalyptus* tree species, and yet are important soil arthropods with the ability to recycle and improve soil nutrients. This study aimed to investigate the changes in the nutrients composition of termite mound soil and adjacent soil in four different *Eucalyptus* species plantations (*Eucalyptus camaldulensis*, *Eucalyptus citriodora*, *Eucalyptus cloeziana* and *Eucalyptus tereticornis*) in Nigeria. Soil samples were collected from four epigeal termite mounds and adjacent soil at different soil depths (0-10, 10-20, 20-30 and 30-40 cm) per plantation. The soil samples were analysed for soil texture, pH, organic carbon, and nitrogen content, Bray 1 P, and exchangeable bases. The results showed that significant variations in the percentage compositions of sand and silt in termite mound and adjacent soil was not a general occurrence in the four Eucalyptus species plantations. However, clay content in termite mound was significantly higher than that of the adjacent soils in the *Eucalyptus* species plantations, except *E. cloeziana*. Results showed Soil pH, organic C, N and exchangeable bases (Ca, Ma, K and Na) in termite mounds to be mostly similar to that of the adjacent soils at different depths. Bray 1 P content was, however, significantly different between termite and adjacent soil in *E. camaldulensis, E. citriodora* and *E. tereticornis* plantations. The plantation of *E. citriodora* had the least levels of organic carbon, nitrogen, and exchangeable bases.

Key words: Chemical properties, epigeal mound, Macrotermes spp., soil depth, texture

Introduction

Eucalyptus is an exotic tree species in sub-Saharan Africa and has contributed immensely to the change in the environment, especially in the replacement of indigenous species for fuel wood (Bayle, 2019). However, it has often been reported that *Eucalyptus* species have undesirable ecological qualities such as depletion of soil water and nutrients, aggressive competition for resources with native flora, and unsuitability for erosion control (Birhanu and Kumsa, 2018). Liang *et al*. (2016) reported that soil in *Eucalyptus* stands is more acidic and lower in organic matter and nutrient levels than nearby forest, and to adjacent agricultural land. Cultivation of *Eucalyptus* species lowered the soil pH and caused a significant decline in soil total nitrogen and organic C concentration (Mensah, 2016). The amount of N and P in *Eucalyptus* plantations were lowered compared to the native forest in Kiambu County, Kenya (Mensah, 2016).

The potential of *Eucalyptus* to recycle soil nutrient is weak (Jagger and Pender, 2000) and does not improve the soil organic matter (Chanie, 2009). Bajigo (2017) reported the preference of *Cupresus lusitanica* over *Eucalyptus saligna* in soil fertility restoration. Restoration with *E. tereticornis* and increase in its age caused a marked reduction in organic C, N, P and K (FAO, 2011). It has also been reported that *Eucalyptus* trees depleted soil nutrient in agroforestry system and also caused reduction in the yield of crops (Jagger and Pender, 2000; Chanie, 2009).

Termites are one of the dominant invertebrates in tropical soils, and through their activities exert a great influence on soil organic matter turnover, nutrient cycling, and soil structure formation (Lavelle *et al*., 1997; Brussaard, 2012). They are described to have a favourable influence on the structure and nutrient richness of soil (Jouquet *et al*., 2011; 2014), which in turn affect the distribution of plants and animals (Holt and Lepage, 2000). Their mound-building activities and the impact on plant growth, enhance the heterogeneity of their ecosystems. Increased soil fertility and moisture found near termite mounds have been reported to cause significant effects on vegetation communities and their productivity (Sileshi *et al*., 2010). They produce biogenic aggregates, which are different in physical and chemical properties, from the surrounding environment (Jouquet *et al*., 2016).

During an investigation on the alterations in soil chemical and physical properties promoted by pedobioturbation, during mound building, Sarcinelli *et al*. (2013) reported that the concentrations of nutrients, organic carbon, and clay-size particles were significantly higher in mounds than in surface soils. In the process of building mounds, termites have a high affinity for fine-size particles such as clays and oxides

(Fall *et al*., 2001; Abe *et al*., 2009) and/or modify the mineralogical properties of clays (Jouquet *et al*., 2002; 2007). Different studies have reported a higher proportion of finer sized particles in soil transported by termites and, therefore, typically demonstrates different clay mineral compositions than those predominating at the original surface (Dhembare, 2013; Pinheiro *et al*., 2013). Thus, termite mound soils are usually enriched in clay, compared to the surrounding soil environment.

Considering the above background that *Eucalyptus* species deplete soil nutrients, but termites contribute to the nutrient cycle and improve soil structure and fertility, it will be appropriate therefore, to examine the dynamism between the nutrient statuses of termite mounds and adjacent soils in *Eucalyptus* plantations. The objective of this study was to evaluate the physical and chemical properties of termite mounds and adjacent soils in different *Eucalyptus* species plantations in Nigeria.

Methodology

Description of the study area

The study was carried out in Afaka, Kaduna State in the Northern Guinea Savanna vegetation zone of Nigeria; located between latitude 10^0 33' N - 10^0 41' N and 07^0 26' E - 07^0 28' E. The climate of Afaka is characterised by a clear distinction between dry and rainy seasons. The rainy season lasts from mid-April to early October with the months of August and March being the peak of the wet and dry seasons, respectively. The mean annual rainfall is 1266.0 mm (NIMET, 2012). Temperatures are high throughout the year, with the highest in March (about 38.6°C) and the lowest in January (about 20.2°C). Relative humidity in the dry season is below 10% in the afternoon and 90% at dawn. During the rainy season, the relative humidity can be over 70% in the midday and 95% at dawn.

Collection and preparation of soil samples

A 100 m x 100 m sample plot was mapped out from which three 25 m x 25 m sub-plots were measured along one diagonal axis of the sampled plot in *E. camaldulensis*, *E. citriodora*, *E. cloeziana* and *E. tereticornis* plantations. Two of the sub-plots were located at the opposite end corners of the sampled plots and the third sub-plot was located at the middle. With the aid of soil auger, soil samples were collected from different depths, namely 0-10, 10-20, 20-30 and 30-40 cm along the diagonal axis of each sample plots, at 3m intervals. Soil samples were collected at three different points from each soil depth in each of the sampled plots. Samples of soil from the same depth at the sampling points in each plot, were bulked together and labeled properly. In all, nine soil samples each from different soil depths were collected from each of the *Eucalyptus* plantations.

Samples of soil were also collected from the base, middle and top portions of three active epigeal termite mounds within the 100 m x 100 m sample plot in each plantation, bulked together in sampling bag and properly labeled. Bulk soil samples collected from each soil depth and from termite mounds were air dried ground and sieved to remove materials greater than 2 mm in diameter. The less than 2 mm separates were used for laboratory analysis.

Soil analyses

Soil analysis was carried out using standard procedures in Nitrogen laboratory, Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria. Some of the physico-chemical properties of the samples analysed included particle size distribution, organic C and N, Bray 1P, exchangeable bases and soil pH. Particle size analysis was carried out using Boyoucos hydrometer method as described by Gee and Bouder (1986). Soil reaction (pH) was determined in water in a 1:2.5 soil solution ratio, using a Pye Unicam model 290 MK pH meter. The acid dichromate wet oxidation method of Walkley and Black as described by Nelson and Sommers (1986) was used in the determination of organic carbon. Total nitrogen was determined by the regular Macro Kjedahl method (Bremmer and Mulvaney, 1982). Available phosphorus was determined by the Bray – 1 method (Bray and Kurtz, 1945). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were extracted using neutral (pH 7.0) ammonium acetate (NH4OAc) solution and determined as described by Anderson and Ingram (1993).

Data analysis

Data collected was analysed statistically using ANOVA of SAS software *version* 9.3 and significant treatment means were separated using Tukey's HSD ($p<0.05$).

Results

Eucalyptus camaldulensis plantation

The percentage composition of sand in *E. camaldulensis* plantation was significantly lower than in the adjacent soil (Table 1). The sand content from the depth of 10–40 cm were not significant. The composition of silt in termite mound and adjacent soils at different soil depth in *E. camaldulensis* plantation was not significant. Clay content of soil from termite mound and soil at 10 cm was not significant, but was significantly higher than in soil at soil depths of 20–40 cm. The hydrogen ion concentration (pH), organic C and organic N of termite mounds and at different depths of soil were not significantly different from that of the termite mound. Available Bray 1 P present in termite mounds and at 20–40 cm soil depth in *E. camaldulensis* was not significant, but was significantly lower than that at 10 cm (Table 1). In *E. camaldulensis*

Table 1. Textural and chemical properties of termite mounds and adjacent soil in *Eucalyptus camaldulensis* plantation, Afaka, Nigeria

Soil properties	Soil sampling depth				
	Termite mound	10 cm	20 cm	30 cm	40 cm
Sand (gkg^{-1})	460.00±10.00b	536.67±33.33a	603.33±13.33a	570.00±11.55a	590.00±23.09a
Silt ($g\ kg^{-1}$)	250.00±10.00a	233.33±6.67a	260.00±11.55a	260.00±11.55a	226.67±17.64a
Clay ($g\ kg^{-1}$)	290.00±0.00a	230.00±30.55ab	136.67±6.67c	170.00±20.00bc	183.33±17.64bc
pH soil H_2O 1:2.5	6.00±0.00a	5.67±0.09a	5.73±0.12a	5.73±0.09a	5.80±0.12a
Organic C ($g\ kg^{-1}$)	5.29±1.10a	9.31±0.87a	7.52±0.86a	8.58±0.61a	5.79±0.92a
Organic N($g\ kg^{-1}$)	1.05±0.07a	1.05±0.08a	0.91±0.00a	0.98±0.07a	0.89±0.16a
Bray 1 P($mgkg^{-1}$)	3.07±0.09b	4.67±0.48a	4.26±0.21ab	4.15±0.31ab	4.03±0.10ab
Exch. Ca^{2+} ($cmolkg^{-1}$)	2.50±0.09a	2.47±0.24a	2.00±0.00ab	2.47±0.57a	1.87±0.18b
Exch. Mg^{2+}($cmolkg^{-1}$)	0.90±0.10a	1.10±0.12a	0.77±0.03a	0.93±0.24a	0.70±0.15a
Exch. K^{+} ($cmolkg^{-1}$)	0.26±0.01a	0.25±0.03a	0.23±0.02a	0.22±0.02a	0.23±0.03a
Exch. Na^{+} ($cmolkg^{-1}$)	0.15±0.11a	0.13±0.08a	0.19±0.09a	0.33±0.01a	0.25±0.04a

Means followed with the same letter in the row are not significantly different at Tukey's HSD ($P<0.05$)

plantation, exchangeable Ca^{2+} content of termite mound was significantly lower than what was recorded in the adjacent soil at different soil depth (Table 1).

Eucalyptus citriodora plantation

Sand and silt contents of termite mound and adjacent soil at different depths were not significantly different in *E. citriodora* plantation. Clay content recorded in termite mound was significantly higher than at soil depths of 10 and 20 cm but not significantly different in the adjacent soil at depths of 30 and 40 cm (Table 2). The result of hydrogen ion concentration (pH), organic C and organic N of the termite mound and the soil at different depths were not significantly different (Table 2). The differences in Bray 1P and exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) contents of termite mounds and adjacent soil up to a depth of 40cm in *E. citriodora* plantations were also not significant.

Eucalyptus cloeziana plantation

In the *E. cloeziana* plantation, sand contents obtained in the mound soil and adjacent soil at different depths were not significant (Table 3). Silt content at the soil depth of 20 cm was significantly higher than what was recorded in termite mound and at depths of 10, 30 and 40 cm. Differences in clay contents in the termite mound and adjacent soil at depth of 10 cm were not significant, but were higher than at the soil depth of 20–40 cm. Hydrogen ion concentration (pH), Bray 1 P, organic C and N, and exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) recorded in the termite mounds and the adjacent soil at different depths were not significantly different (Table 3).

Eucalyptus tereticornis plantation

Sand and silt contents of termite mound and adjacent soil in *E. tereticornis* plantation were not significantly different (Table 4). The quantity of clay in the termite mound was not significantly different from that of adjacent soil at 40 cm soil depth but was significantly higher than that at 10, 20 and 30 cm soil depth. It was further noted that pH, organic C and organic N of the termite mounds and adjacent soil at different depths were not significantly different. Bray 1P content of termite mound in *E. tereticornis* plantation was significantly low compared to adjacent soil. The exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) contents of termite mounds and adjacent were also not significantly different (Table 4).

Eucalyptus species effects

Table 5 shows the effect of different *Eucalyptus* species on the physico-chemical properties of soil pooled over different depths. The quantities of sand recorded in *E. camaldulensis*, *E. citriodora* and *E. tereticornis* were not significantly different, but were significantly higher than quantity of sand in *E. cloeziana* plantation. The quantities of silt and clay in the soil from the four *Eucalyptus* species plantations

Table 2. Textural and chemical properties of termite mounds and adjacent soil in *Eucalyptus citriodora* plantation, Afaka, Nigeria

Soil properties	Soil sampling depth				
	Termite mound	10 cm	20 cm	30 cm	40 cm
Sand (gkg^{-1})	435.00±30.96a	590.00±0.00a	556.67±67.66a	530.00±64.29a	456.67±70.55a
Silt (gkg^{-1})	270.00±12.91a	280.00±11.55a	246.67±40.55a	253.33±17.64a	253.33±17.64a
Clay (gkg^{-1})	295.00±26.30a	130.00±11.55c	196.67±48.07bc	216.67±46.67a	290.00±52.92ab
pH soil H_2O 1:2.5	5.45±0.16a	5.50±0.10a	5.67±0.03a	5.73±0.07a	5.70±0.06a
Organic C (gkg^{-1})	7.18±1.63a	5.92±0.33a	4.72±0.97a	4.19±0.61a	3.26±0.06a
Organic N (gkg^{-1})	0.86±0.06a	0.84±0.04a	0.79±0.02a	0.84±0.08a	0.63±0.07a
Bray 1 P ($mgkg^{-1}$)	3.85±0.16a	3.62±0.21a	3.80±0.12a	3.74±0.29a	3.68±0.04a
Exch. Ca^{2+} ($cmolkg^{-1}$)	2.20±0.29a	2.13±0.29a	1.33±0.13a	1.80±0.00a	1.33±0.20a
Exch. Mg^{2+}($cmolkg^{-1}$)	0.83±0.15a	0.90±0.12a	0.50±0.06a	0.57±0.03a	0.47±0.07a
Exch. K^{+} ($cmolkg^{-1}$)	0.34±0.13a	0.13±0.01a	0.13±0.02a	0.12±0.01a	0.13±0.02a
Exch. Na^{+} ($cmolkg^{-1}$)	0.08±0.04a	0.14±0.10a	0.15±0.07a	0.05±0.01a	0.03±0.01a

Means followed with the same letter in the row are not significantly different at Tukey's HSD ($P<0.05$)

Table 3. Textural and chemical properties of termite mounds and adjacent soil in *Eucalyptus cloeziana* plantation, Afaka, Nigeria

Soil properties	Soil sampling depth				
	Termite mound	10 cm	20 cm	30 cm	40 cm
Sand (gkg^{-1})	423.33±46.67a	390.00±100.66a	370.00±30.55a	400.00±68.07a	463.33±33.33a
Silt (gkg^{-1})	233.33±6.67b	266.67±29.06ab	393.33±40.55a	283.33±41.77ab	226.67±29.06b
Clay (gkg^{-1})	343.33±43.72a	343.33±81.92a	236.67±13.33b	283.33±13.33b	270.00±41.63b
pH soil H_2O 1:2.5	5.67±0.27a	5.40±0.06a	5.73±0.13a	5.57±0.09a	5.63±0.09a
Organic C ($g\ kg^{-1}$)	3.52±1.23a	10.38±1.80a	7.91±0.71a	9.71±1.79a	6.48±2.56a
Organic N (gkg^{-1})	1.10±0.12a	0.86±0.26a	1.24±0.12a	1.26±0.15a	1.15±0.38a
Bray 1 P ($mgkg^{-1}$)	3.27±0.26a	3.85±0.30a	3.44±0.16a	3.56±0.41a	3.21±0.06a
Exch. Ca^{2+} ($cmolkg^{-1}$)	2.13±0.18a	2.60±0.12a	2.00±0.20a	2.20±0.23a	2.07±0.24a
Exch. Mg^{2+}($cmolkg^{-1}$)	0.87±0.15a	1.20±0.17a	0.83±0.12a	0.97±0.12a	0.90±0.21a
Exch. K^{+} ($cmolkg^{-1}$)	0.22±0.02a	0.15±0.03a	0.13±0.02a	0.13±0.01a	0.13±0.02a
Exch. Na^{+} ($cmolkg^{-1}$)	0.13±0.05a	0.22±0.09a	0.23±0.05a	0.14±0.08a	0.10±0.06a

Means followed with the same letter in the row are not significantly different at Tukey's HSD (P<0.05)

Table 4. Textural and chemical properties of termite mounds and adjacent soil in *Eucalyptus tereticornis* plantation, Afaka, Nigeria

Soil properties	Soil sampling depth				
	Termite mound	10 cm	20 cm	30 cm	40 cm
Sand (gkg^{-1})	410.00±40.00a	563.33±35.28a	596.67±33.33a	580.00±15.28a	496.67±75.13a
Silt (gkg^{-1})	250.00±10.00a	266.67±24.04a	246.67±26.67a	233.33±26.67a	206.67±24.04a
Clay (gkg^{-1})	340.00±50.00a	153.33±31.80b	156.67±6.67b	183.33±17.64b	296.67±59.25ab
pH soil H_2O 1:2.5	5.85±0.35a	6.00±0.00a	6.13±0.03a	6.20±0.06a	6.20±0.06a
Organic C ($g\ kg^{-1}$)	6.99±1.20a	10.11±1.57a	9.44±1.18a	8.91±1.78a	7.51±2.44a
Organic N (gkg^{-1})	0.75±0.05a	1.14±0.09a	1.10±0.06a	1.07±0.24a	0.86±0.10a
Bray 1 P ($mgkg^{-1}$)	2.10±0.00b	3.44±0.36a	3.44±0.38a	3.74±0.29a	3.38±0.23a
Exch. Ca^{2+} ($cmolkg^{-1}$)	2.00±0.40a	2.60±0.23a	2.60±0.23a	2.67±0.59a	2.07±0.33a
Exch. Mg^{2+}($cmolkg^{-1}$)	0.60±0.10a	1.00±0.15a	1.03±0.15a	1.00±0.32a	0.77±0.13a
Exch. K^{+} ($cmolkg^{-1}$)	0.30±0.09a	0.16±0.01a	0.16±0.01a	0.16±0.03a	0.15±0.06a
Exch. Na^{+} ($cmolkg^{-1}$)	0.17±0.02a	0.23±0.04a	0.07±0.03a	0.22±0.09a	0.07±0.02a

Means followed with the same letter in the row are not significantly different at Tukey's HSD (P<0.05

Table 5. Effect of different *Eucalyptus* species on the physico-chemical properties of soil pooled over different depths

Soil properties	*Eucalyptus camaldulensis*	*Eucalyptus citriodora*	*Eucalyptus cloeziana*	*Eucalyptus tereticornis*
Sand (g kg^{-1})	575.00±14.50a	533.34±28.35a	405.83±20.15b	559.17±21.92a
Silt (g kg^{-1})	245.00±8.77a	258.33±7.39a	292.50±35.65a	238.34±12.58a
Clay (g kg^{-1})	180.00±19.34a	208.34±32.93a	283.33±22.28a	197.50±33.73a
pH (soil H_2O 1:2.5)	5.73±0.03b	5.65±0.05b	5.58±0.07b	6.13±0.05a
Organic C (g kg^{-1})	7.8±0.76a	4.52±0.56b	8.62±0.88a	8.99±0.55a
Organic N (g kg^{-1})	0.96±0.04ab	0.78±0.05b	1.13±0.09a	1.04±0.06a
Bray 1 P (mg kg^{-1})	4.28±0.14a	3.71±0.04b	3.52±0.13b	3.50±0.08b
Exch. Ca^{2+} (cmol kg^{-1})	2.20±0.16ab	1.65±0.2b	2.22±a0.13b	2.49±0.14a
Exch. Mg^{2+}(cmol kg^{-1})	0.88±0.09ab	0.61±0.1b	0.98±0.08a	0.95±0.06ab
Exch. K^{+} (cmol kg^{-1})	0.23±0.006a	0.13±0.002c	0.14±0.005c	0.16±0.003b
Exch. Na^{+} (cmol kg^{-1})	0.23±0.04a	0.09±0.03a	0.17±0.03a	0.15±0.04a

Numbers follow with the same alphabets in the row are not significantly different (Tukey's HSD, P<0.05) were not significantly different. Soil pH in *E. tereticornis* plantation was significantly higher than in the rest of the *Eucalyptus* plantations. Organic carbon content in *E. citriodora* plantation soil was significantly lower than in the other three *Eucalyptus* species plantations. Similarly, the soil organic N content of *E. citriodora* plantation was significantly lower than the soil organic N in *E. cloeziana* and *E. tereticornis* plantations but not significantly different from *E. camaldulensis* plantation. Bray 1 P content in the soil sample from *E. camaldulensis* plantation was significantly higher than in the rest of the *Eucalyptus* species plantation. The lowest content of soil exchangeable Ca^{2+} was recorded in *E. citriodora* plantation, which was not significantly different from that in *E. camaldulensis* and *E. cloeziana* plantations but significantly different from *E. tereticornis* plantation. In the same manner, *E. citriodora* soil had the lowest Mg^{2+} content and *E. cloeziana* plantation the highest. The exchangeable K^+ content in *E. citriodora* soil was the lowest whereas *E. camaldulensis* had the highest. The Na^+ content of the soil in the four *Eucalyptus* species plantation were not significantly different.

Discussion

Particle size distribution

The analysis of particle-size distribution showed that the soil in termite mounds was more enriched in clay compared to adjacent soils in the four *Eucalyptus* species plantations. This may be related to the fact that the mound building termites, especially *Macrotermes* species, selectively use soil particles to respond to ecological requirement, such as the water holding capacity (Jouquet *et al*., 2002). This was demonstrated by the finer texture of clay particle, which possesses an attribute of water retaining capacity. The accumulation of clay in termite mounds has also been reported to play an important role in the structural stability of termite mounds (Jouquet *et al*., 2004; Abe *et al*., 2009). Research findings have also shown that *Macrotermes* termites affect soil properties, especially by bringing up fine materials from deep soil horizons up to the soil surface for construction of mounds (Jouquet *et al*., 2011).

In *E. citriodora* and *E. tereticornis* plantations, sand and silt content in the termite mound and adjacent soil were similar at all depths. This may be an indication that epigeal mound builder in these plantations used adjacent soil for mound construction without adding any significant value. However, there were isolated cases where sand and silt content of adjacent soil differed from that of termite mound soil. Some factors like bedrock composition, mound age, evolution stage (active or inactive) and pedogenetic conditions in termite mound parts may influence the physico-chemical properties of termite mounds (Mujinya *et al*., 2013).

Organic carbon

The organic C contents of the mounds were not significantly different from the adjacent soils. This could be an indication that *Macrotermes* species, the most prominent epigeal mound builders in the study area did not add value to the organic C content of their mounds. It has been described that organic C distribution in termite mound is related to termite feeding habit and the type of materials used for mound construction (Fall *et al*., 2001; Sall *et al*., 2002). The results of this study are in line with the findings of Contour-Ansel *et al*. (2000) working with *Macrotermes bellicosus* who reported that it did not enrich the organic C content of the soil. On the other hand, Abe *et al*. (2009) reported low organic C content in *M. bellicosus* mound than adjacent soil in Mokwa, Southern Guinea Savanna of Nigeria.

Bray 1 P

Generally Bray 1 P was lower in termite mounds than adjacent soil. Also, the clay content of termite mound soil was generally higher than the adjacent soil in this study. Consequence accumulation of more free iron oxides in termite mounds than surrounding soils associated with clay enrichment by the action of termites would increase soil phosphorus fixation while lowering phosphorus availability. Similar finding have also reported that epigeal mound builder termite species, *Macrotermes bellicosus* can influence the form and composition of free sesquioxides, especially iron in the soil due to the direct effect of the enrichment of fine, clay-sized soil particles in the mound (Abe and Wakatsuki, 2010).

Exchangeable bases

Generally, the soil horizons at the study site showed acidic status and low contents of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}). The exchangeable bases contents of the mounds were mostly not significantly different from the exchangeable bases contents of the adjacent soils. These soil characteristics with poor fertility status are common in tropical savanna soils in West Africa (Windmeijer and Andriesse, 1993; Abe *et al*., 2010; Abe *et al*., 2011). In contrast, soil from termite mounds has been reported by different authors to be richer in nutrients than adjacent soil from where they were collected (Ekundayo and Aghatise, 1997; Frageria and Baligar, 2004; Dhembare, 2013). However, this assertion is inconclusive from this study for in most cases nutrient contents of the mounds were not significantly different from the adjacent soils. Similarly, Maduakor *et al*. (1995), in an extensive sampling in Nigerian ultisols also did not report an important nutrient enrichment in *Macrotermes* mounds in relation to adjacent soils.

Eucalyptus species effects

Generally, there were close similarities in particle size analysis of soil samples from the four *Eucalyptus* species plantations, except for *E. cloeziana* plantation where the soil sand content was significantly low. The close resemblance in the soil texture (sand, silt and clay) among the *Eucalyptus* species plantations reveals the presence of a similar weathered parent material on each site.

Observations on the content of soil organic carbon, Nitrogen, Ca^{2+}, Mg^{2+}, and K^{+} in *E. citriodora* plantation were low compared to that in plantations of other Eucalyptus species. This might be due to high rate of anthropogenic pressures on *E. citriodora* foliage because of its medicinal and aromatic uses to the local communities. This pressure on the foliage may have reduced the quantity of leaf litter at the forest floor in *E. citriodora* plantation. In addition, the Fulani herdsmen in the vicinity set the plantation on fire annually for a fresh re-growth of vegetation in the plantation as feed for their animals. Factors such as deforestation, removal of plant residues, bush burning among others have been identified as major causes of soil nutrient depletion (Aleminew and Alemayehu, 2020).

Conclusion

The physicochemical properties of termite mounds soils showed Bray 1 P in termite mound soil was lower than that of adjacent soil in two out of the four plantations studied. Termite mounds recorded a higher clay content in texture than adjacent soil. Other than that, there seemed not to be much difference between the physiochemical properties of termite mound and adjacent soils. *Eucalyptus citriodora* had the most reducing effect on organic carbon, nitrogen, and exchangeable bases.

Acknowledgment

The authors are grateful to Dr. Ezra Anamayi, Head, Trial Afforestation Station, Afaka, Nigeria who granted access to the different *Eucalyptus* plantation sites. The efforts of Professor J. O. Ogunwole and the laboratory technologists of the department of Soil Science, Ahmadu Bello University Zaria, Nigeria in analyzing the soil samples are highly appreciated.

References

Abe, S. S., Buri, M. M., Issaka, R. N., Kiepe, P. and Wakatsuki, T. 2010. Soil fertility potential for rice production in West African lowlands. *JARQ–Japan Agricultural Research Quarterly* 44: 343-355

Abe, S. S. and Wakatsuki, T. 2010. Possible influence of termites (*Macrotermes bellicosus*) on forms and composition of free sesquioxides in tropical soils. *Pedobiologia* 53:301-306.

Abe, S. S., Watanabe, Y., Onishi, T., Kotegawa, T. and Wakatsuki, T. 2011. Nutrient storage in termite (*Macrotermes bellicosus*) mounds and the implications for nutrient dynamics in a tropical savanna Ultisol. *Soil Science and Plant Nutrition* 57(6): 786-795.

Abe, S. S., Yamamoto, S. and Wakatsuki, T. 2009. Physicochemical and morphological properties of termite (*Macrotermes bellicosus*) mounds and surrounding pedons on a toposequence of an inland valley in the southern Guinea savanna zone of Nigeria. *Soil Science and Plant Nutrition* 55: 514-522.

Aleminew, A. and Alemayehu, M. 2020. Soil fertility depletion and its management options under crop production perspectives in Ethiopia: A review. *Agricultural Reviews* 41: 91-105.

Anderson, J. M. and Ingram, J. S. I. 1993. Tropical soil biology and fertility: A handbook of methods (2nd ed.). Wallingford: CAB International. 221pp.

Bajigo, A. 2017. The Effect of land use change on soil physicochemical properties over time in Ethiopia. *Journal of Developing Country Studies* 7(3):60-71.

Bayle, G. K. 2019. Ecological and social impacts of *Eucalyptus* tree plantation on the environment. *Journal of Biodiversity Conservation and Bioresources Management* (1): 93–104.DOI: https://doi.org/10.3329/jbcbm.v5i1.42189

Birhanu, S. and Kumsa, F. 2018. Review on expansion of *Eucalyptus*, its economic value and related environmental issues in Ethiopia. *International Journal of Research in Environmental Science* 4(3): 41-46.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total organic and available forms of phosphorus in soils. *SoilScience* 59: 39-45 https://doi.org/10.1097/00010694-194501000-00006

Bremner, J. M. and Mulvaney, C. S. 1982. Total nitrogen. In: A.L. Page, R.H. Miller, D.R. Keeny (Eds.), Methods of soil analysis, American Society of Agronomy and Soil Science Society of America, Madison, pp. 1119-1123.

Brussaard, L. 2012. Ecosystem services provided by the soil biota. In: D.H. Wall, R.D. Bardgett, V. Behan-Pelletier, J.E. Herrick, H. Jones, K. Ritz, J. Six, D.R. Strong, W.H. van der Putten (Eds.). *Soil Ecology and Ecosystem Services* (pp. 45-58). Oxford University. https://edepot.wur.nl/327592

Chanie, T. 2009. The effect of *Eucalyptus* on crop productivity, and soil properties in the Koga Watershed, Western Amhara Region, Ethiopia. M.Sc. Thesis, Graduate School, Cornell University. 60pp.

Contour-Ansel, D., Garnier-Sillam, E., Lachaux, M. and Croci, V. 2000. High performance liquid chromatography studies on the polysaccharides in the walls of the mounds of two species of termite in Senegal, *Cubitermes oculatus* and *Macrotermes subhyalinus*: their origin and contribution to structural stability. *Biology and Fertility of Soils* 31: 508-516.

Dhembare, A. J. 2013. Physico-chemical properties of termite mound soil. *Archives of Applied Science Research* 5(6):123-126.

Ekundayo, E. O. and Aghatise, V. O. 1997. Soil properties of termite mounds under different land use types in a Type paleudult of Midwestern Nigeria. *Environmental Monitoring and Assessment* 45: 1-7.

Fall, S., Brauman, A. and Chotte, J. L. 2001. Comparative distribution of organic matter in particle and aggregate size fractions in the mounds of termites with different feeding habits in Senegal: *Cubitermes niokoloensis* and *Macrotermes bellicosus*. *Applied Soil Ecology* 17: 131-140.

Food and Agriculture Organization (FAO). 2011.*Eucalyptus* in East Africa, socio-economic and environmentalissues, by Gessesse Dessie, Teklu Erkossa. Planted Forests and Trees Working Paper 46/E, Forest Management Team, Forest Management Division. FAO, Rome, Italy. 42pp.

Frageria, N. K. and Baligar, V. C. 2004. Properties of termite mound soils and responses of rice and bean to N.P. and K fertilization on such soil. *Communications in Soil Science and Plant Analysis* 35: 15-16.

Gee, G. W. and Bauder, J. W. 1986. Particle size analysis. Methods of Soil Analysis. Part 1 Agron. 2nd ed. 383 –412 ASA and SSSA, Madison, WI (c. ed. Klute R)

Holt, J. A. and Lepage, M. 2000. Termites and Soil Properties. In: Abe, T., Bignell, D.E. and Higashi, M. (eds.)Termites: Evolution, Sociality, Symbioses, Ecology. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-3223-9_18

Jagger, P. and Pender, J. 2000. The role of trees for sustainable management of less-favored lands: The case of*Eucalyptus* in Ethiopia. EPTD discussion paper no. 65. Washington, D.C. 20006 USA. 91pp

Jouquet, P., Blanchart, E. and Capowiez, Y. 2014. Utilization of earthworms and termites for the restoration ofecosystem functioning. *Applied Soil Ecology* 73:34–40. https://doi.org/10.1016/j.apsoil.2013.08.004

Jouquet, P., Bottinelli, N., Lata, J. C., Mora, P. and Caquineau, S. 2007. Role of the fungus- growing termite, *Pseudacanthotermes spiniger* (Isoptera: Macrotermitinae) in the dynamic of clay and soil organic matter content. An experimental analysis. *Geoderma* 139: 127-133.

Jouquet, P., Chintakunta, S., Bottinelli, N., Subramanian, S. and Caner, L. 2016. The influence of fungus-growing termites on soil macro and micro-aggregates stability varies with soil type. *Applied Soil Ecology* 101: 117-123.

Jouquet, P., Guilleux, N., Caner, L., Chintakunta, S., Ameline, M. and Shanbhag, R. R. 2016. Influence of soilpedological properties on termite mound stability. *Geoderma* 262:45– 51.

Jouquet, P., Lepage, M. and Velde, B. 2002. Termite soil preferences and particle selections: Strategies related toecological requirements. *Insectes Sociaux* 49: 1–7

Jouquet, P., Mathieu, J., Choosaï, C. and Barot, S. 2007. Soil engineers as ecosystem heterogeneity drivers. In: Ecology Research Progress. Munoz, S. (ed). Nova Science Publishing. New York NY, Chap, 7:187-199.

Jouquet, P., Tessier, D. and Lepage, M. 2004. The soil structural stability of termite nests: role of clays in *Macrotermes bellicosus* (Isoptera: Macrotermitinae) mound soils. *European Journal of Soil Biology* 40: 23-29.

Jouquet, P., Traore, S., Choosai, C., Hartmann, C. and Bignell, D. 2011. Influence of termites on ecosystemfunctioning. Ecosystem services provided by termites. *European Journal of Soil Biology* 47: 215-222.

Lavelle, P. 1997. Faunal activities and soil processes: adaptive strategies that determine ecosystem function. *Advance in Ecological Research* 27: 93-132.

Liang, J., Reynolds, T., Wassie, A., Collins, C., and Wubalem, A. 2016. Effects of exotic *Eucalyptus* spp. plantations on soil properties in and around sacred natural sites in the northern Ethiopian Highlands. AIMS *Agriculture and Food* 1(2): 175-193DOI: 10.3934/agrfood.2016.2.175

Maduakor, H. O., Okere, A. N. and Onyeanuforo, C. C. 1995. Termite mounds in relation to the surrounding soils in the forest and derived savanna zones of southeastern Nigeria. *Biology and Fertility of Soils* 20: 157 - 162

Mensah, A. K. 2016. Effects of *Eucalyptus* plantation on soil physico-chemical properties in Thiririka sub-catchment, Kiambu County, Kenya. M.Sc. Dissertation, Kenyatta University, Kenya. 93pp.

Mujinya, B. B., Mees, F., Erens, H., Dumon, M., Baert, G., Boeckx, P., Ngongo, M. and Van Ranst, E. 2013. Claycomposition and properties in termite mounds of the Lubumbashi area, D.R. Congo. *Geoderma* 192: 304-315.

Nelson, D. W. and Sommers, L. E. 1986. Total carbon, organic carbon, and organic matter. In: Klute. A .(Ed.). Methodsof soil analysis part II. SSSA, Madison, WI.

Nigerian Meteorological Agency (NIMET). 2002. Nigeria Climate Review Bulletin, 2012. Abuja: NIMET

Pinheiro, L. B. A., Pereira, M. G., Lima, E., Correia, M. E. F., Silva, C. F. and Ebeling, A. G. 2013. AtributosEdáficos e de Termiteiros de Cupim-de-Montículo (Isoptera: Termitidae) em Pinheira-lRJ. *Floresta e Ambiente* 20: 510-520.

Sall, S. N., Brauman, A., Fall, S., Rouland, C., Miambl, E. and Chotte, J. L. 2002. Variation in the distribution of monosaccharides insoil fractions in the mounds of termites with different feeding habits (Senegal). *Biology and Fertility of Soils* 36: 232-239.

Sarcinelli, T. S., Schaefer, C. E. G. R., Filho, E. I. F., Mafia, R. G. and Neri, A. V. 2013. Soil modification bytermites in sandy-soil vegetation in the Brazilian Atlantic rain forest. *Journal of Tropical Ecology* 29 (5): 439-448. doi:10.1017/S0266467413000497

Sileshi, G., Akinnifesi, F. K., Debusho, L. K., Beedy, T., Ajayi, O. C. and Mong'omba, S. 2010. Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-Saharan Africa. *Field Crops Research* 116 (1-2): 1-13. https://doi.org/10.1016/j.fcr.2009.11.014.

Sileshi, G. W., Arshad, M. A., Konaté, S. and Nkunika, P. O. Y. 2010. Termite-induced heteroge-neity in African savanna vegetation: Mechanisms and patterns. *Journal of Vegetation Science* 21: 923-937.

Windmeijer, P. N. and Andresse, W. 1993. Inland valleys in West Africa. An agro ecological characterization of rice growing environments. International Institute for land Reclamation and Improvement, Publication 52 Wageningen, The Netherlands.