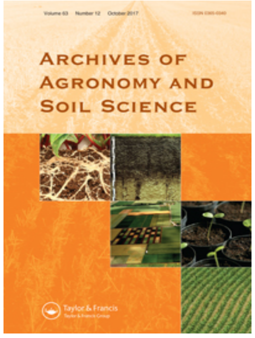

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Abdeta Jembere, Gezahegn Berecha & Alemayehu Regassa Tolossa

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ARTICLE

Impacts of termites on selected soil physicochemical characteristics in the highlands of Southwest Ethiopia

Abdeta Jembere[a], Gezahegn Berecha[b] and Alemayehu Regassa Tolossa[c]

[a]Department of Natural Resources Management, Wolkite University, Wolkite, Ethiopia; [b]Department of Horticulture and Plant Science, Jimma University, Jimma, Ethiopia; [c]Department of Natural Resources Management, Jimma University, Jimma, Ethiopia

ABSTRACT
Termites are reported to improve soil physicochemical properties thereby enhance soil fertility of their mound and foraging areas. Empirical study pertaining to these effects is missing in Southwest Ethiopia. For this study, soil samples affected by termite activities were collected at 1 m interval within 0–3 m distance from the base of six termite mounds on gently sloping and sloping land and analyzed for physicochemical parameters. The result of the analysis depicted that soil bulk density (1.38–1.15 g cm^{-3}) and moisture content (21.1–9.9%) decreased with increased distance from the mound base. While clay content decreased with increased distance from the mound base from72.0% to 45.5%, sand and silt contents increased from 8.0% to 21.3% and 19.3% to 28.5%, respectively. PH (6.23), organic carbon (3.85%), total nitrogen (0.4%), cation exchange capacity CEC (30.43 cmol kg^{-1}), exchangeable Ca (13.73 cmol kg^{-1}), Mg (3.15 cmol kg^{-1}), and PBS (56.8%) were higher on termite mounds. While, electrical conductivity (0.03 dS m^{-1}–0.06 dS m^{-1}), exchangeable K (0.52–0.93 cmol kg^{-1}) and Na (0.02–0.03 cmol kg^{-1}) showed increasing trend with the distance from the mound base. Our results indicated that termite mounds are important sinks of organic matter and mineral nutrients, and hence contribute to the enhancement of soil fertility. Thus, for subsistent farmers the uses of termite mounds as a fertilizer present an opportunity to improve agricultural production.

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Termite; mound; slope; soil physical properties; soil chemical properties

Introduction

Termites (Isoptera) are a large and diverse group of soil fauna (Arshad 1981; Kooyman & Onck 1987) consisting of over 2,600 species in 280 genera worldwide. In Africa, the United Nation Environmental Program (UNEP 2000) reported that there are about 1,000 termite species. Survey of termite prevalence in western, southern, and eastern parts of Ethiopia by Abdurahaman (1990) and Tadele et al. (2013) reported that 60 termite species belonging to 5 genera exist in the country.

Termites are grouped as damp-wood, dry-wood, subterranean, and arboreal nesters based on their infestation ability (UNEP 2000). Damp-wood termites derive their name from the fact that they live and feed in very moist wood, especially stumps and fallen trees on the forest floor. Unlike the subterranean termites, the dry-wood termites form colonies within the wood itself rather than in the soil below (Shelton et al. 2000). Subterranean termites require a moist environment for their survival and activities. To meet this need and to gain access to food sources and protect

CONTACT Gezahegn Berecha gezahegn.berecha@ju.edu.et Department of Horticulture and Plant Science, Jimma University, Jimma, Ethiopia

themselves from open air and dryness, most of them build distinctive mud tubes called nest or mound containing 3,000–200,000 individuals depending on the size of the mound (UNEP 2000).

According to Schaefer et al. (2009), the high pH consistently observed in the mounds may result from high Ca and Mg amounts accumulated with organic matter (OM). Termites decompose OM more effectively, with the aid of microorganisms in their guts or by fungi grown on fungus combs structures (Kooyman & Onck 1987). Enhanced digestion of OM because of termite action reported to increase OM content in soil with consequent enhanced porosity and stability of aggregates (Jouquet et al. 2011).

In southwestern highlands of Ethiopia, a preliminary survey indicated a widespread prevalence of mound-building termites. Large extent of them was found in Bedele district (PRA report Forthcoming 2012). The termites were identified as belonging to the *Macrotermes* genera and *Odontotermes* genera (Wood 1991) and such species were proven to have profound effects on soil properties in other parts of Ethiopia (Asawalam et al. 1999; Sarcinelli et al. 2009; Menichetti et al. 2014).

Termite mound and soil materials in the vicinity of mounds are widely used for fertilizing agricultural lands by resource-poor farmers in the highlands of Southwest Ethiopia. However, scientific information on the effect of termite activities on soil properties is rather scarce. Therefore, this study was aimed at investigating the effects of mound-building termites on soil physicochemical properties in Southwest Ethiopia. The result of this study contributes to the current pressing need for alternative soil fertility improvement in the country in view of the high price of chemical fertilizers, which are beyond the reach of subsistence farmers.

Materials and methods

Description of the study area and soil sampling

This study was carried out in Bedele district in the Illubabor Zone in Southwest Ethiopia (8° 14′ 44″ to 8° 38′ 4.90 N, 36°19′ 55″ to 36°62 25′ 31.90 E). The altitude of the area ranges from 1,300 to 2,500 m a.s.l. Annual mean temperatures in the study district range from a minimum of 9°C to a maximum of 31°C. The annual rainfall is bimodal and varies from 950 to 2,200 mm.

The dominant agricultural soils in the study area are Nitisols, developed from lower Tertiary volcanic rocks. The dominant land use is crop cultivation where maize *(Zea mays)*, teff *(Eragrostis teff)* and sorghum *(Sorghum bicolor)* are the major crops. Application of inorganic fertilizer particularly diammonium phosphate and urea and rarely organic compost is the common farmland management practice.

To investigate the effects of mound-building termites on soil physicochemical properties, soils subjected to the effects of termite activities and adjacent non-termite affected soils were comparatively evaluated. Six termite mounds (three mounds from each slope) were selected from two slope gradients: gently sloped (less than 3.25%) and sloped (between 3.25% and 6.12%) based on the Food and Agriculture organization of the United Nation (2006) system of slope classification. Soil samples unaffected by termite activities (Figure 1) were taken at a distance of 10 m from the mound base according to the techniques adopted by Ruckamp (2012) and Semhi et al. (2008).

The locations of soil sample were indicated as 0, 1, 2, 3, and 10 m distance away from the mounds as illustrated in Figure 1. The soil samples were taken from 30 cm depth.

Disturbed soil samples were taken with auger from and around the mounds at 1 m interval up to 3 m from the base of the mounds. Undisturbed soil samples were taken with core sampler to measure bulk density, moisture content, and porosity analysis. Composite soil samples were taken by thoroughly mixing soil samples from five points after which 1 kg was taken. In total, 30 disturbed and 30 undisturbed soil samples were collected from six mounds, five from each mound; four affected by termite activities and one unaffected, which was assumed as control.

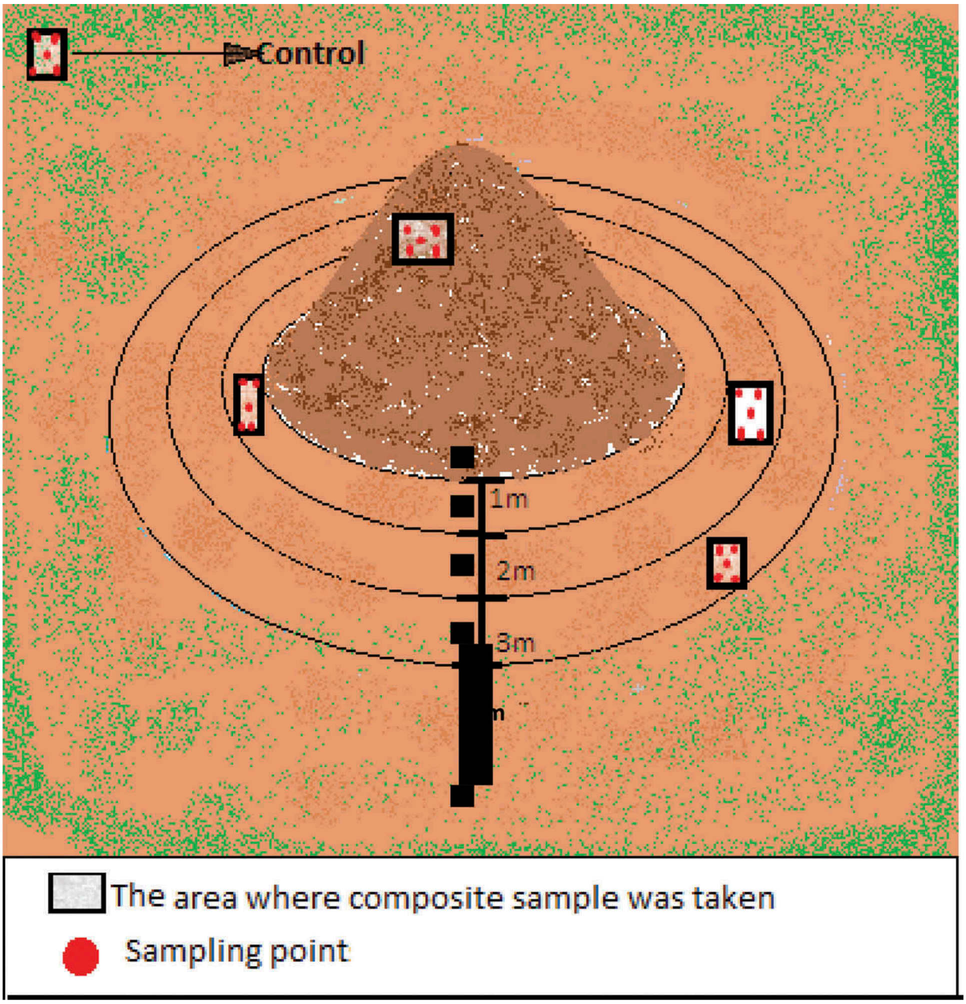

Figure 1. Schematic diagram of soil sampling points at and around termite mound.

Soil analysis

Soil samples were air-dried for 1 week and grinded with mortar and pestle and passed through 2-mm mesh sieve for storage. After 1 week storage, soil analysis was done at the Laboratory of soil science, Jimma University, Ethiopia. Soil pH was determined by glass electrode in 1:2.5 soils: water. Soil particle size distribution was determined by hydrometer method (Gee & Or 2002). Soil bulk density was determined by gravimetric method. Soil porosity was calculated as, $\text{Porosity} = 1 - \frac{\text{bulk density}}{\text{particle density}}$ by assuming particle density as 2.65 g cm^{-3} (Warrick 2002). Soil moisture content was determined by gravimetric method by measuring the initial weight of core sampled soil on the field. Soil electrical conductivity(EC) was determined by extracting the soil sample with water (1:5 soil:water ratio) and measuring with conductivity meter. Soil organic carbon (OC) was determined by combustion reaction (Nelson & Sommers 1996). Soil-available P was extracted by 100 ml of HCl 1 M mixed with 30 ml of NH4F 1 M, and diluted to 1 l with distilled water by Bray II method. Total Nitrogen (TN) was determined by Kjeldahl digestion procedure (Bremmer 1996). Exchangeable bases (Ca, Mg, Na, and K) were extracted by 1 N ammonium acetate (pH 7.0) and their concentrations quantified by atomic absorption spectrophotometer (Thomas 1982). The CEC was determined by the ammonium saturation method. Percentage base saturation (PBS) was computed from exchangeable bases and soil CEC.

Statistical analysis

Factorial in randomized block design was implemented for soil physicochemical analyses. Soil samples were taken from two slope ranges each with five sampling points including the area not affected by termite (control) with three replication, thus making a total of 30 disturbed and 30 undisturbed soil samples. Soil physicochemical data were checked for analysis of variance model assumptions. All assumptions were fulfilled for all data except soil moisture content and percentage of sand, for which square root transformation was implemented. Statistical Analysis Software (SAS 9.2 version) was used for the statistical analysis of soil data. Mean separation was done by Tukey's standardized test for significant response variables at 5% of significance.

Results and discussions

Soil physical properties

There was no significant interaction effect between slope and radius from mound for soil texture. Nevertheless, soil particle size around the mound was significantly different from control soil. Termite-driven enrichment was evident on the three soil particles viz, sand, silt, and clay percent to 2 m radius from the mound after which it was almost the same. Similarly, significant difference in sand (p = 0.028) and clay (p = 0.003) percentage was observed between gently sloping and sloping land. However, silt percentage did not reveal any significant difference between the two slope levels (p = 0.26). Higher percentage of clay was recorded from the mound areas, and decreased with increasing radius from termite mound. This might be attributed to the biological activities of termite regardless of the soil parent material. Dhembare (2013) reported proportion of clay particles increased in soils that termites used for building their nests. Gholami and Riazi (2012) also reported similar result and attributed their finding to preferred selection of clay particles by termites. According to Ruckamp (2012), through selective translocation of fine soil particles by termites, the silt enrichment was up to twofold higher in mound than in control soil.

Besides, the percentage of sand and clay showed significant difference between gently sloping and sloping lands, where the higher percentage of sand was observed from sloping and that of clay was from gently sloping (Table 1). This result was in line with Chen et al. (2004) who stated that the higher value of silt and clay fraction were attributed to the ease of movement of finer soil particles from relatively higher slope to the flatter slope. These finer soil particles in turn disseminate to surrounding soil by animals, erosion, and by termites itself when they forage about and maintain their gallery and also redistribute the finer particles to the surrounding area; thereby counteracting the textural variation along the distance from mound (Ackerman et al. 2007).

Slope gradient and distance from the base of termite mound revealed no significant interaction effect on soil bulk density (p = 0.30), soil porosity (p = 0.33), and soil moisture content (p = 0.58). Analysis of variance indicated significant difference in the soil bulk density ($p < 0.0001$), moisture content ($p < 0.0001$), and porosity ($p < 0.0001$) along metric distance from the base of termite mound. Soil bulk density and soil porosity varied significantly between gently sloping and sloping slopes (p = 0.0001) (Table 1). Soil bulk density and moisture content have shown decreasing trend from the mound spot to 3 m radius apart from the mound base in 1 m interval, while soil porosity increased with increasing distance from the mound base (Table 1). Though the magnitude of bulk density value decreased, their variation was not significant after 2 m radius. This depicts that termite effect on soil bulk density and moisture content is more pronounced until 2 m radius from the mound base. Arshad et al. (2010) reported that the termite mounds had higher bulk density

Table 1. Main effects of termites on soil texture, bulk density (BD), weight-based moisture content (MC), porosity, pH, and electrical conductivity (EC) (mean ± standard deviation).

Radius (m)	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	MC (%w/w)	Porosity (%)	pH	EC (dS m^{-1})
0	8.0 ± 5.1c	19.3 ± 2.3b	72.7 ± 6.5a	1.38 ± 0.09a	21.1 ± 4.9a	48.0 ± 3.5c	6.23 ± 0.06a	0.03 ± 0.01b
1	14.7 ± 1.4b	24.7 ± 3.5b	59.0 ± 5.9b	1.25 ± 0.04b	19.7 ± 1.5ab	52.7 ± 1.6b	6.08 ± 0.47a	0.03 ± 0.02b
2	19.3 ± 2.1b	25.5 ± 3.0ab	55.2 ± 2.5bc	1.17 ± 0.05c	17.7 ± 3.1ab	55.9 ± 1.9a	5.95 ± 0.05a	0.03 ± 0.01b
3	21.3 ± 2.6ab	28.5 ± 2.5a	50.2 ± 4.1cd	1.15 ± 0.05c	9.9 ± 1.8c	56.5 ± 1.8a	5.39 ± 0.27b	0.05 ± 0.01a
Control	25.0 ± 6.1a	29.5 ± 5.8a	45.5 ± 5.8d	1.14 ± 0.01c	13.0 ± 0.9bc	56.8 ± 0.3a	5.49 ± 0.21b	0.06 ± 0.01a
P-value	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Slope								
Sl	19.2 ± 6.4a	26.3 ± 4.2a	53.9 ± 9.7b	1.19 ± 0.08b	16.6 ± 5.0a	55.21 ± 3.1b	5.94 ± 0.36a	0.04 ± 0.02a
GS	16.1 ± 7.4b	24.7 ± 5.7a	59.1 ± 11.1a	1.26 ± 0.11a	16.7 ± 5.1a	52.6 ± 4.3a	5.72 ± 0.45b	0.04 ± 0.02a
P-value	0.03	0.26	<0.003	<0.01	0.95	<0.01	0.02	0.08

Values in the same column with different letters are significantly different by the Tukey's standardized test (α = 0.05).
Sl: sloping; GS: gently sloping.

than the surrounding soil, probably because termites repack soils with their saliva to form hard protective layers against open air and temperature fluctuation in the mounds.

Ali et al. (2013) reported mound soils generally have high clay content, enhancing water storage capacity and high bulk density, and suggested that termites regularly maintain their mound moisture for survival. Besides, termite galleries regularly receive moisture when termites transport moist soil from other area to renew their mound (Jenny 2005). Ackerman et al. (2007) reported that soil water content was 25% lower in the termite mound than in the adjacent soil. Soil water content did not show significant difference between gently sloping and sloping land (p = 0.950). On the contrary, Rahardjo et al. (2005) reported that soil water contents tend to be higher on gentle sloping than at the sloping land. This could be due to the higher clay percent in gently sloping land that had higher moisture-holding capacity than other soil particles. Soil bulk density also revealed significant difference (p = 0.0001) between gently sloping and sloping lands (Table 1). This also agrees with the study reported by Beatty (1993) that the bulk density of gently sloping land also decrease due to an increase in clay deposition and OM and the resulting increase in total pore space.

Soil porosity showed significant difference between mound soil 1 and 2 m radius from the mound base but not between the rest of the radius and the control soil. This could be directly related with termite effects on bulk density of the soil in 2 m radius from the mound. Ackerman et al. (2007) found similar result and reasoned out that termite mound soils are more compacted than surrounding soil supporting the finding of Agbonsalo et al. (2007) who found inverse relation between soil bulk density and soil porosity. Agbonsalo et al. (2007) also reported higher bulk density and lower porosity of the termite material than the surrounding soils. This result could be justified by the fact that soil finer particles, mainly clay, collected by termites on the mound undergo gradual translocation to the very near area by agents like erosion and animals. Thus, the translocation and accumulation of these finer soil particles decrease soil porosity (Jenny 2005). In line with the two slope classes, total soil porosity along 1 m radius from the mound base showed significant difference (p = 0.0001) between gently sloping and sloping land. Chen et al. (2004) from their investigation on effect of slope gradient on soil porosity reported similar result.

Soil chemical properties

Distance from the base of the mound and slope gradient had no significant interaction effect on both pH and EC (p > 0.05), but there was significant interaction effect on available phosphorus. There was highly significant effect of termite activity (p < 0.0001) on soil pH value, EC, and available phosphorus. Significant variation was observed after 2 m distance from the base of the mound in soil pH and EC. Soil pH value and EC did not show statistically significant difference between mound soil, 1 and 2 m distance from the mound base. Similarly, there was no significant variation in soil EC between 3 m distance and the control (Table 2).

Soil pH value was significantly different (p = 0.021) between gently slope and sloping land. A decreasing trend was observed between mound soil, 1, 2, and 3 m distance from mound base and control in soil pH value. Compared with soil taken from 3 m distance, the mound soil showed higher pH. This result agrees with those result reported by Seibert et al. (2007) that termite modify soil pH value due to the accumulation of OM, which in turn increase soil pH value in their nests. There was no significant difference in soil EC between mound soil, 1 and 2 m distance away from the mound base. Higher EC in soil at 3 and 10 m distance than mound soil and soil within 2 m was observed. This result contrasts with Abe and Wakatsuki (2011) who found significantly higher soil EC value in the nest body than in the neighboring soil.

Soil-available P decreased from mound soil to non-termite activity area on both slope gradients (Figure 2). This could be due to decreasing trend of soil pH with increase in distance from the mound (Brady & Weils 2002). Our result showed that the interaction of distance from the mound base and slope had no significant effect on soil OC and CEC (p > 0.05). However, soil OC was significantly different between sloping and gently sloping soil (p < 0.05), where the highest mean values were obtained from gently sloping. Soil OC was significantly varied among mound soil to 3 m distance from the mound base in 1-m interval (Table 2). This result agreed with those of Ackerman et al. (2007) and Menichetti et al. (2014) who reported an elevated OC and TN on termite mounds than adjacent soil.

Table 2. Main effects of termites on soil organic carbon (OC), total nitrogen (TN), cation exchange capacity (CEC), exchangeable bases, and percentage base saturation (PBS) (mean ± standard deviation).

Radius(m)	OC (%)	TN (%)	CEC (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Na (cmol kg^{-1})	PBS (%)
0	3.9 ± 0.7a	0.3 ± 0.1a	30.43 ± 4.29a	13.73 ± 3.35a	3.15 ± 0.44a	0.02 ± 0.00b	56.8 ± 4.3a
1	3.0 ± 0.4b	0.3 ± 0.0b	28.04 ± 3.84ab	11.87 ± 2.99ab	2.91 ± 0.40ab	0.04 ± 0.01a	55.0 ± 4.4ab
2	3.0 ± 0.5b	0.3 ± 0.1b	25.39 ± 3.52bc	9.80 ± 2.74bc	2.63 ± 0.36bc	0.05 ± 0.01a	52.0 ± 4.6abc
3	2.7 ± 0.3bc	0.3 ± 0.0b	24.77 ± 3.13bc	9.31 ± 2.44bc	2.57 ± 0.32bc	0.03 ± 0.01b	51.3 ± 4.9bc
Contro	l2.0 ± 0.6c	0.2 ± 0.1c	22.04 ± 2.57c	7.18 ± 2.00c	2.28 ± 0.27c	0.02 ± 0.01b	47.3 ± 4.8c
P-value	<0.01	<0.01	0.01	<0.01	<0.01	<0.06	<0.01
Slope							
Sl	2.7 ± 0.7b	0.27 ± 0.1b	24.42 ± 4.01b	9.04 ± 3.12b	2.53 ± 0.42b	0.03 ± 0.01a	50.1 ± 5.5b
GS	3.2 ± 0.8a	0.38 ± 0.1a	27.85 ± 4.18a	11.71 ± 3.26b	2.89 ± 0.43a	0.03 ± 0.01a	54.9 ± 4.3a
P-value	0.01	0.01	<0.01	<0.01	<0.01	0.54	<0.01

Values in the same column with different letters are significantly different at α = 0.05.
Sl: sloping; GS: gently sloping.

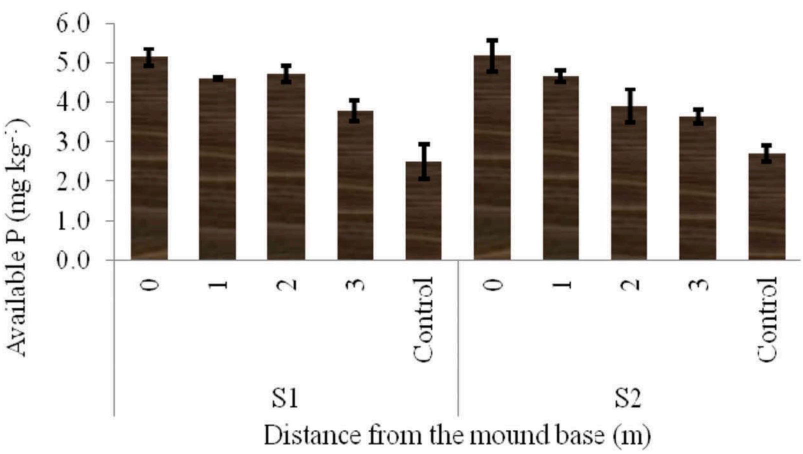

Figure 2. Soil-available P (mean values) as function of slope range and distance from the mound base.

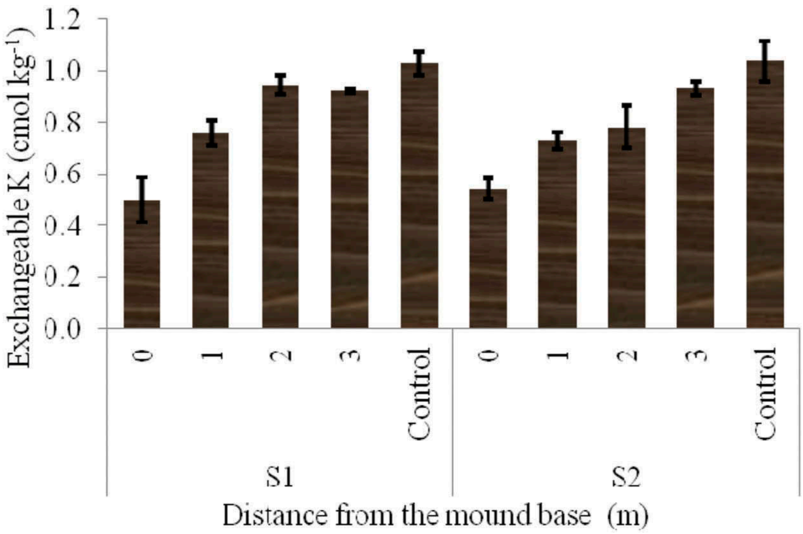

Figure 3. Soil exchangeable K (mean values) as function of slope range and distance from the mound base.

There was also a decreasing trend in soil OC from termite mound to non-colonized soils. The effects of termites on TN were found to be significant ($p < 0.05$). Higher concentration of TN was observed in termite mounds than in control soils. This was likely due to the release of termite excretions and the increased nutrient retention of the mound soil due to their higher CEC values than the control soil. In fact, the CEC showed a decreasing trend from mound soils, to 1, 2, and 3 m radius from the mound base and also control soil (Table 2). This result agreed with those by Seitlheko and Masiane (2013) who reported significantly higher CEC in termite mound than adjacent soil. In terms of slope, the highest values of soil TN and CEC were found in soils from gentle slopes. Chen et al. (2004), reported significantly higher CEC and TN in gently sloping land as compared with steeper soils. Exchangeable K was significantly influenced by the interaction effects of termite activity along the metric radius from the mound and slope gradient ($p < 0.05$), but the interaction between metric radius from termite mound base with slope gradient on soil exchangeable Ca, Mg, Na, and PBS was not significant. Significantly higher values of exchangeable Ca and Mg were observed from termite mounds at gentle slopes. The turnover of some primary minerals from deeper subsurface soil horizons by termites during nest construction might have contributed to the accumulation of these cations as reported by Schaefer (2001). Nonsignificant differences between slopes were observed for exchangeable Na. This result was in agreement with Seibert et al. (2007) who found significant differences among the slopes for exchangeable Ca, K, and Mg with increased value on gently sloped land.

The highest values of exchangeable Ca and Mg were observed under termite mound soil, while the lowest values were observed under the soil out of termite activities, which disagrees with Ackerman et al. (2007) who reported nonsignificant Mg concentrations, but elevated K, and depleted Ca on termite mound. Contrary to Ca and Mg, the highest value of exchangeable K was observed under the soil out of termite activities and the lowest value was observed under termite mound soil on both slopes. The highest value of Na was recorded from soil 2 m from termite mound base while lowest value was observed under mound soil and control. However, there was no distinct trend from the mound to the soil out of termite activity.

Unlike exchangeable Ca, Mg, and Na, exchangeable K was significantly influenced with the interaction effects of termite activities and slopes (Figure 3). Similar to soil exchangeable Ca, Mg, and PBS, there was significant termite effect on exchangeable K only until 1 m radius from the mound base. The elevated content of exchangeable K in the termite mound and its immediate vicinity might be due to the direct interaction between termites and the soil-derived materials that they handle, which has been suggested to promote weathering and neoformation of clay minerals (Jouquet et al. 2002).

Exchangeable Ca and Mg have shown decreasing trend from termite mound soil, 1, 2, and 3 m radius from the mound base to soil without termite activity (Table 2). On the contrary, exchangeable K was shown to be increased with increased metric radius from the mound base on both slopes. Similarly, the highest value of PBS was observed from mound showing decreasing trend from the mound base. However, there was no significant variation between their mean values after 1 m radius from the mound base. While Na was decreased on the mound soil, but significantly increased in 1 and 2 m radius and fall after 3 m radius from the mound base where, its lowest value was recorded from the soil with no termite activity. This result was in agreement with the finding of Jouquet et al. (2005) who reported that the level of exchangeable bases were greater in the termite mound soil than in the control soil. Slopewise, there was significant difference between sloping and gently sloping land in PBS. The highest value of PBS was observed from termite mound soil on gently sloping. This result was in agreement with Seibert et al. (2007), who found higher PBS value on gently slope.

Conclusion

Our study confirmed that termite activity improves physical and chemical soil properties, in particular, water-holding capacity, OC, and nutrient contents, in relation to higher clay content of the mound soils and termite-feeding activity. On the other hand, soil EC and exchangeable Na were observed to be decreased on termite mound and showed increasing trend to 3 m radius from the mound base. Termites might also have further effect on top soil beyond 3 m radius from the mound base. Hence, we recommend further study by concerning deeper soil profile and radius higher than the 3 m distance from the mound base.

Disclosure statement

No potential conflict of interest was reported by the authors.

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