International Journal of Agricultural Sciences ISSN: 2167-0447 Vol. 4 (12), pp. 326-333, December, 2014. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Studies on Ecology of mound-building termites in the Central rift valley of Ethiopia

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Accepted 13, June 2014

Despite the high density of epigeal termite mounds making a peculiar feature of the landscape of the Central Rift Valley of Ethiopia, no systematic ecological studies of termites had been conducted. Hence, this study was conducted from September 2011 to November 2012 in Dugda district of East Shawa Zone to assess termite mound density, status, and dimensions, and compare chemical properties of mound soil with adjacent soil, and the effect of mound soil on crop growth. The density of termite mounds was 9.72 mounds/ha. About 43% of the mounds were dead and they were 1.26 ± 0.09 m high with a basal diameter of 2.70 ± 0.19 m. Live mounds were 1.67 ± 0.09 m high with a basal diameter of 3.17 ± 0.67 m. A higher percentage of dead mounds were excavated by aardvarks (41%) and occupied by ants (64%) than live mounds, 21 and 24% for aardvark excavation and ant occupancy, respectively. Exchangeable cations (Ca, Mg, Na and K), electrical conductivity, pH, percent organic matter (OM) and total nitrogen (TN) and available K were significantly higher (P < 0.05) in mound soil than adjacent soil. Percent TN and OM, pH, and available K were significantly higher in mound perimeter than in adjacent soil. The higher accumulation of plant nutrients in mounds and their deposition in the mound perimeter by erosion have contributed to significantly higher differences in stem length, dry biomass, and yield of teff (*Eragrostis teff* L.) grown in the mound perimeter than on adjacent soil.

Key words: Adjacent soil, ecosystem engineer, Maki, mound perimeter, mound soil, nutrient accumulation, termite.

INTRODUCTION

A number of termite species, especially *Macrotermes*, *Odontotermes* and *Cubitermes* have been recorded affecting the soil chemically by concentrating nutrients. In most cases higher nutrient concentrations are noted in mound soil than in adjacent soil (Okwakol, 1992). The genus *Macrotermes* builds large epigeal mounds from which the termites forage outwards for distances of up to 50 m in galleries/runways either just below or on the soil surface (Abdurahman, 1990). The genus is found throughout the Ethiopian and Indo-Malayan zoogeographical regions and so far 12 species have been described in the Ethiopian region. In Africa they build large mounds which are a characteristic feature of many grasslands and savanna woodlands (Sileshi et al., 2009; Adekayode and Ogunkoya, 2009; Abdurahman et al., 2010).

Termites are recognized as "ecosystem engineers" - organisms that modulate the availability of resources for other species by maintaining, adjusting and creating habitats. Accordingly, termites contribute to micro-topographical and nutrient spatial heterogeneity in tropical forests over time. Termite activities during nest building in particular change the structure, drainage and chemical composition of soils. Termites, especially species of the genus *Macrotermes* that construct large epigeal nests and underground gallery systems, have major effects on soil chemical and physical properties throughout the tropics and subtropics (Kaschuk et al., 2006; Beaudrot et al., 2011). The chemical properties of termite-modified soil in comparison with the soil from which it is derived can be attributed to differential selection of soil particles, incorporation of saliva, incopo-ration of excreta in the form of linings to gallery walls, gallery in-fillings, and in the case of the large mounds of Macrotermitinae, to pedological changes (Wood and Sands, 1978). By mixing soil with decomposed leaf-litter,

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termites raise nutrient levels, particularly Ca, K and Mg of the soil used in mound building. Moreover, persistence of abandoned epigeal mounds has been estimated at 20–25 years and therefore mounds provide a nutrient enriched microhabitat for an extended period of time (Beaudrot et al., 2011). Dead mounds and their surroundings become favored locations for plant growth because of the higher water-holding capacity and nutrients availability than in the adjacent non-affected sites (Manuwa, 2009). The erosion of both inhabited and uninhabited mounds leads to mound materials being deposited on the surrounding soil. These materials modify the soil profile and may lead to changes in the soil physical and chemical properties (Maduakor et al., 1995).

Although a high density of epigeal termite mounds of *Macrotermes* termites making a peculiar feature of the rural landscape of the Central Rift Valley of Ethiopia, especially in Maki-Batu area of the East Shawa Zone of Oromia Regional State is documented, only little information was available in terms of their ecology. Thus, the objectives of the current study were to determine density, dimensions and status of epigeal termite mounds, compare textural and chemical properties of mound soil with adjacent soil, and evaluate the effect of mound soil and adjacent soil on crop growth. It was hypothesized that termite mound soils contained higher plant nutrients than adjacent soils and thus plants grow better in mound perimeter. Accordingly, the census of all *Macrotermes* mounds found within 500 m x 500 m was made to determine mound density. Dead and alive mounds and their dimensions were determined by sampling mounds within the study site. Textural and chemical properties of mound soil, soil of mound perimeter and adjacent soil were compared by general soil analyses method. The impact of mound soil on crop growth was evaluated by growing teff in mound perimeter and adjacent soil with and without fertilizer.

MATERIALS AND METHODS

Description of the study site

The study was carried out within 250,000 m^2 (500 m x 500 m) at about 3 km north of Maki town in Oda Bokota Farmers Association (8°10'N, 38°50'E, and 1666 m above sea level) in Dugda district at about 130 km south of Addis Ababa (Figure 1). The site was purposively selected because of its high termite mound densities and accessibility. Maki area is characterized by a semi-arid climate and the natural vegetation is composed of sparsely grown acacia trees and shrubs of various species as well as grasses. Generally, the soils of the area range from sandy to loam, loam to sandy clay loam with some clay loam and a few clay soils. In addition to salt crust (white and deep shiny black salt crust), the soils of the area are characterized by numerous gray-to-gray brown termite mounds (Kefyalew, 2008). The mean annual rainfall is 762.8 mm and the highest precipitation occurs between July and September. There is some additional rainfall between February and the end of April, but this usually varies. The annual means of daily maximum and minimum temperatures are 27.8ºC and 14.4ºC, respectively (Source: National Meteorological Agency of Ethiopia). Maize, haricot bean, teff, wheat, and barley are the major staple food crops grown by small scale farmers in the area.

The study site was located in farmlands which had been under cultivation for a long period of time and most of the mounds looked very old and eroded and new termite mounds were not found on cultivated lands. Whereas, on the narrow stripes of uncultivated land left for demarcation as borders between adjacent farms belonging to neighbors, small and young mounds were observed and these were always dug by aardvarks. Active and rapidly growing mounds were observed closer to the study site on uncultivated lands along roadsides of the highway from Addis Ababa to Shashamene city.

Methods

Termite Mound Density, Dimensions and Status

Mound density was determined by counting all the mounds within the study site of 500 m x 500 m and dividing the total number of mounds by the total area (Abdurahman, 1990; Meyer et al, 1999) using the formula $d = n/s$, where n = number of mounds sampled and s = area sampled. For determination of mound dimensions and status, a total of 51 mounds were sampled using a 50 m wide belt transect along the diagonal of the study site. The heights and basal diameter of all the mounds within the transect were measured and their status (whether they were alive or dead), occupancy by ants and excavation by aardvarks were recorded. Mounds were considered as being “alive” when (i) termite individuals were seen, (ii) fresh mound structures built by termites were present, (iii) the mound was dug to the center at different heights and termites were seen or (iv) a hole drilled into the mound was repaired by termites within one day. Otherwise, mounds were considered as “dead”. Average number of mounds/*qarxii* of individual farmer‟s field was recorded through interviews with 51 farmers. Local people measure farmland by *qarxii* which is equivalent to 50 m x 50 m (0.25 ha).

Analysis of Textural and Chemical Properties of Termite Mound Soil and Adjacent Soil

Soil Sampling and Laboratory Analysis

Three termite mounds were randomly selected (one each in a farmer‟s teff field) as replicates and soil samples were

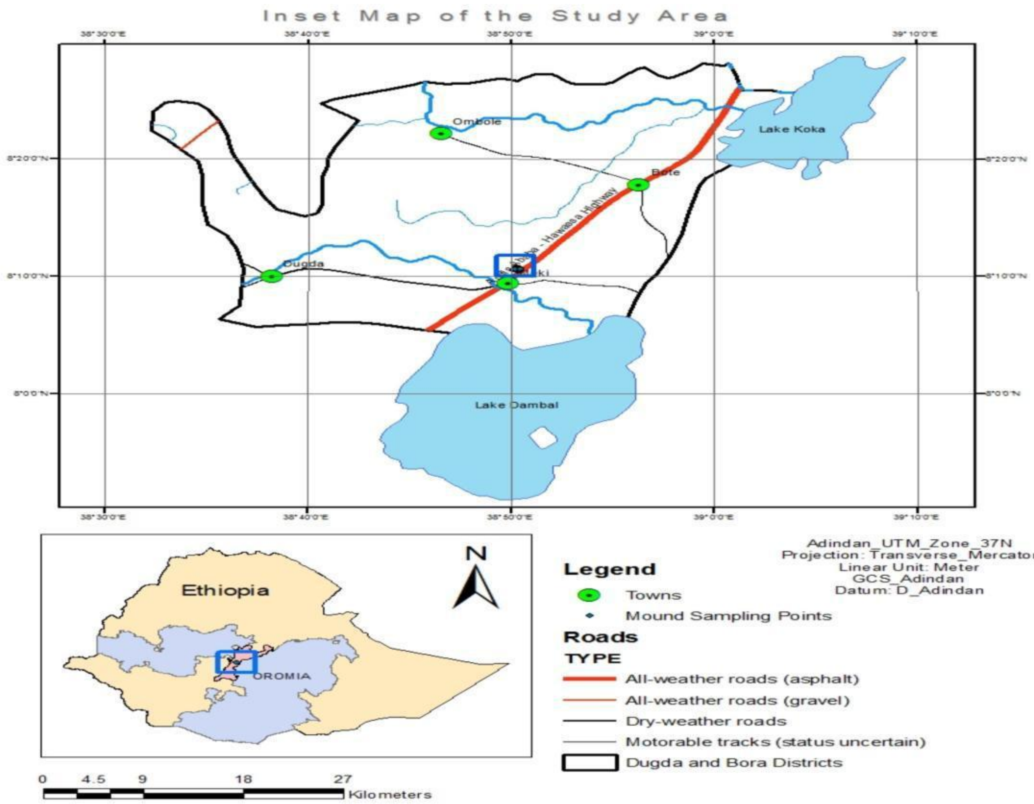

Figure 1 Map showing the study site.

taken at depth of 0-20 cm and 20-60 cm with an auger from top (T), base (B) of the mounds and 0.5 m distance from base of the mounds (mound perimeter). Samples were also taken at 8 m distance away from the base of each mound (from adjacent area free of mound effect) based mainly on the method used by Manuwa (2009) with some modifications. For each soil sample, sub-samples were drawn from four randomly selected locations and the sub-samples were composited for analysis based on National Soil Research Centre of Ethiopia (2000) according to the following methods: Soil particle size distribution was determined using hydrometer method. Available potassium (Av. K) was analyzed by extracting with Morgan‟s solution and measuring by flame photometer. Total nitrogen (TN) was determined by the Kjeldahl procedure and organic carbon (OC) content was determined after wet oxidation by the dichromate method. Soil organic matter contains 58% C. Conversion of % C to % OM was, therefore, done with the empirical factor of 1.724, which was obtained by dividing 100 by 58. Available phosphorus (Av. P) was determined by spectrophotometer following Olsen‟s method. pH was measured potention metrically on direct-reading pH meter in water suspension with soil to water ratio of 1:2.5. Electrical conductivity (EC) was measured by an electrical conductivity meter with soil to water ratio of 1:2.5. Cation exchange capacity (CEC) was measured by leaching the soil with ammonium acetate.

Exchangeable calcium and magnesium (exch. Ca and Mg) were determined by EDTA titration. Exchangeable sodium and potassium (exch. Na and K) was determined using flame photometer.

Evaluation of Termite Mound Soil on Crop Growth

Three termite live mounds were randomly selected as replicates and teff (*Eragrostis teff* L.) was *in situ* grown around them on a farmer‟s field. While the farmer was sowing his teff crop, three plots each of $1m^2$ size were selected: the first plot in the perimeter of mound, the second and the third plots at 8 m distance from the base of mounds (free from mound effect) and adjacent to each other. The plots and the rest of the farm were planted simultaneously with teff seeds by broadcasting so that there was no difference in seed rate between the plots and the whole field. During fertilizer application, the plot in the perimeter of the mound and one of the two plots found at 8 m distance from the mound were covered with plastic sheets to avoid fertilizer, while the other plot received fertilizer equally with the rest of the farm. At harvest, teff plants in each plot were uprooted from the soil by hand and were sun-dried separately. After drying: teff bundle from each plot was laid on a horizontal smooth

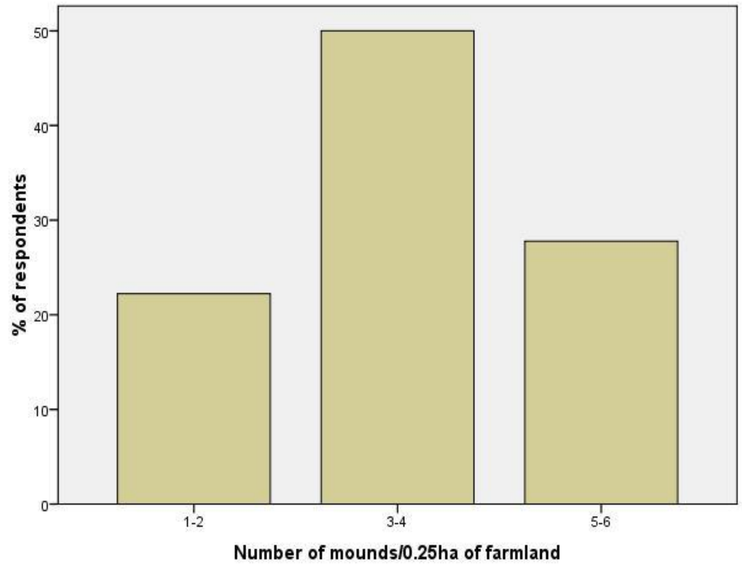

Figure 2 Percent of respondents and number of mounds/0.25 ha on their farmland.

surface and 20 tallest plants were randomly selected and their stem length was measured; teff from each plot was weighed to obtain the dry biomass per plot; and teff from each plot was threshed and grain was weighed to obtain the yield per plot.

Termite Sampling and Identification

Eighteen mounds were sampled across the diagonal of the study site. The mounds were dug and termites were hand-collected with forceps and were preserved in 80% ethanol and were later identified at genus level using soldier morphological characters with the help of Keys to the Genera of Ethiopian Termites (Abdurahman, 1991).

Data Analyses

Data on mound dimensions and mound status were analyzed using descriptive statistics with SPSS computer program version 17.0 for windows. Data on effect of termite mound soil on teff growth and chemical properties of soil were analyzed by analysis of variance (ANOVA) with SAS (SAS Institute, 2003). Mean separation was done using Least Significant Difference test (LSD) at 5% probability level.

RESULTS

Mound Density, Dimensions and Status

A total of 243 epigeal termite mounds within the study site (500 m x 500 m) were recorded and the average density of the mounds was about 9.72 mounds/ha. All the respondent farmers had epigeal termite mounds on their farmlands and about 50% of them reported that the number of mounds was 3-4/0.25 ha (Figure 2).

Mound status and dimensions are shown in Table 1. The mean height and basal diameter of the mounds were 1.49 ± 0.09 m and 2.96 ± 0.11 m (mean ± SE), respectively, irrespective of status. Of the total 51 mounds sampled, about 57% were alive and these had greater heights and diameters than dead mounds. The percentages of dead mounds excavated by aardvarks and occupied by different types of ant (species unidentified) were about twice and three-folds than live mounds, respectively. The mounds covered about 1800.63 m^2 (0.72%) of the total land in the study site and this is equivalent to 72.03 m^2/ha.

Textural and Chemical Properties of Termite Mound Soil and Adjacent Soil

Results of textural and chemical properties of termite mound soil and adjacent soil are shown in Table 2. Electrical conductivity (EC), pH, exch. Ca, Na, K and % OM values of termite mounds at 0-20 cm soil depth were significantly higher ($P < 0.05$) than that of the adjacent soil. Both the mound and adjacent soils had a pH value greater than 7. Soil in the perimeter of mound at 0.5 m distance was significantly higher in % TN, Av. K, exch. Ca and % OM than adjacent soil at both depths. Though there was no significance difference ($P > 0.05$), the values of Av. P were higher in mound soil than adjacent soil and the values were Top of mound > Base of mound

Table 1 Percentage of mound status, mean aardvark excavation, occupancy by ants and mound dimensions (mean ± Standard Error) of epigeal termite mounds.

Mound status	%	Height (m)	Basal diameter (m)	Basal area (m^2)	Presence of aardvark excavation	Occupancy by ants
Alive	56.9 (29)	1.67 ± 0.09	3.17 ± 0.12	8.14 ± 0.63	20.7 (6)	24.1 (7)
Dead	43.1 (22)	1.26 ± 0.09	2.70 ± 0.19	6.33 ± 0.94	40.9 (9)	63.6 (14)
Alive + Dead	100 (51)	1.49 ± 0.07*	2.96 ± 0.11*	7.41 ± 0.55*	29.4 (15) *	41.2 (21) *

* Figures are not the sum of the variables of alive and dead mounds in the table but they are results of the total 51 mounds irrespective of status.

Table 2 Textural and selected chemical properties of termite mound soil and adjacent soil At 0 -20 cm soil depth.

Soilsample	ECmmhos/cm	pH(H	%T.N	Av.Pinppm.	Av.K(mg/Kgsoil)	CEC(meq/100g)	Exch.Ca(meq/100g)	Exch.Mg(meq/100g)	Exch.Na(Cmolc/Kg	Exch.K(Cmolc/Kg	%OC	%OM	%moisture	Texture %Sand	%Silt	%Clay	Class
Top	1.53a	7.56a	0.07b	15.72a	270.20a	38.19a	36.38a	7.11b	0.36b	0.45a	2.90a	5.01a	11.35a	46.33a	37.33a	16.33a	Loam
Base	1.17a	8a	0.08b	12.9a	122.14b	44.54a	28.86b	13.79a	0.81a	0.42a	1.81ab	3.12a	8.19a	46.33a	37.33a	16.33a	Loam
0.5m	0.81ab	8ab	0.18a	7.08a	263.00a	44.20a	29.59b	5.99b	0.19bc	0.32b	1.58ab	2.73a	11.67a	54.33a	26.66b	19a	Sandy loam
8m	0.14b	7.03b	0.07b	3.38a	124.34b	41.87a	19.64c	7.85b	0.15c	0.32b	1.46b	2.53b	10.09a	51a	32ab	17a	Loam
LSD	0.90	0.56	0.02	18.07	72.12	9.88	6.15	3.86	0.21	0.06	1.35	2.33	6.87	8.42	6.79	4.07	
				At 20-60 cm soil depth													
Top	1.02ab	7.4a	0.06b	16.71a	325.98a	44.37a	36.13a	9.27ab	0.38b	0.46a	2.87a	4.96a	17.95a	47a	37.33a	15.66a	Loam
Base	1.34a	8.1a	0.04b	9.53a	127.53b	46.82a	25.06b	12.36a	0.94a	0.44ab	1.48b	2.55b	15.79a	46.33a	38a	15.66a	Loam
0.5m	0.20b	8.23a	0.15a	9.71a	256.23a	48.66a	29.11ab	10.03ab	0.77ab	0.37b	1.66b	2.87b	15.12a	53.66a	30a	16.33a	Sandy loam
8m	0.12b	7.46a	0.06b	2.04a	126.43b	47.27a	21.68b	7.61b	0.31b	0.36b	1.12b	1.93b	9.67b	49.66a	32a	18.33a	Loam
LSD	1.06	0.96	0.04	18.71	65.26	10.12	9.16	4.39	0.49	0.07	0.96	1.66	4.94	10.12	8.9	2.88	

Means within a column followed by the same letter do not differ significantly by Least Significant Difference Test (LSD) at 5% of probability.
Standard errors were not indicated due to shortage of space.

Av. K = Available Potassium; OM = Organic Matter; OC = Organic Carbon; TN =Total Nitrogen; Av.P = Available Phosphorus; EC = Electrical Conductivity; CEC = Cation Exchange Capacity; Ca = Calcium; Mg = Magnesium; Na = Sodium; K = Potassium; Exch. = Exchangeable.

Table 3 Effect of termite mound soil and adjacent soil on teff growth and yield.

Treatment/parameters	Stem length (cm) (mean ± SE)	Dry biomass (gm/plot) (mean ± SE)	Yield (gm/plot) (mean ± SE)
Base of mound without fertilizer	97.63 ± 3.71a	498.00 ± 86.23a	104.33 ± 22.64a
Adjacent mound soil with fertilizer	80.96 ± 3.05b	327.00 ± 17.27ab	72.00 ± 1.00ab
Adjacent mound soil without fertilizer	70.41 ± 0.17c	213.00 ± 8.90b	44.33 ± 1.20b

Means followed by the same letter within columns do not differ significantly by Least Significant Difference Test (LSD) at 5% of probability.

Plate 1. Teff grown around mound (A), way from mound with fertilizer (B) away from mound without fertilizer (C).

> Perimeter of mound > Adjacent soil at both depths. There was no significant difference (P > 0.05) in CEC, % moisture content and soil texture except % silt. All the soil samples at both depths contained higher sand followed by silt and low clay and the soil class was loamy except the soil sample at 0.5 m from base of the mounds which was sandy loam. Soil samples from top of termite mounds showed significant difference in Av. K, exch. Ca and K and % OM than adjacent soil (P < 0.05). Higher significant differences were recorded in EC, exch. Mg and Na, and moisture content values in the soil of the base of mounds than that of adjacent soil. No significant differences (P > 0.05) were recorded in % TN, CEC and exch. Mg and soil texture between mound soils and adjacent soils.

Effect of Termite Mound Soil on Crop Growth

The effect of termite mound soil and adjacent soil on teff growth is shown in Table 3. Teff grown in the perimeter of mounds (on termite modified soil) with no application of fertilizer showed significantly higher stem length, dry biomass, and grain yield than adjacent soil to which no fertilizer was added. Teff grown on termite modified soil also showed significantly taller stem length than teff to which fertilizer was applied (Plate 1).

Termite Diversity

Termite species representing only a single genus (*Macrotermes*) were identified from the collected termite samples.

DISCUSSION

Termite Mound Density, Dimensions and Status

The density of *Macrotermes* termite mounds in the current study was about 9.72 mounds/ha and this was relatively higher than in most reports from elsewhere in Africa. For instance, Yamashina (2010) recorded about 0.5 mounds/ha Namibia and Meyer et al. (1999) reported 0.73/ha in Kruger National Park (South Africa) and 3-5/ha of mounds for Macrotermitinae in Zambia. In western Wallaga (Ethiopia), where termite problem is severe to agricultural crops, forestry and rangeland, Abdurahman (1990) reported about 5.6 and 8.2 density of *Macrotermes* mounds/ha on cultivated land and grassland, respectively.

However, higher density of *Macrotermes* mounds also exists. Abdurahman (1990) has reported the existence of up to 37.5 mounds of *M. bellicosus* per hectare in Ivory Coast. Mound density can be governed by different general factors. The same termite species can have different mound densities in different parts of the world and there are a lot of factors which determine termite distribution and abundance. Termite numbers, species and nest variety increase as one moves towards the equator. Termite distribution can be related to temperature and rainfall (these change with latitude) and salt tolerance. Mound density can be affected by soil type, topography and soil‟s water drainage capacity (Pearce, 1997; Meyer et al., 1999; Yamashina, 2010).

Continuous cultivation of the land by farmers for many years and excavation of mounds by aardvarks seem to limit the density of mounds and existence of young mounds. Farmers cultivate their fields repeatedly and it occurs after alates‟ flight. Plowing fields destroys newly settling reproductives and thus prevents them from establishing new colonies. Sileshi et al. (2009) reported that tillage breaks foraging galleries and prevents termites from getting access to food and also exposing them to predators, harsh external environment, and hinders new colonies from being established. Aardvarks were common in the area and frequently dug flourishing young mounds and destroying them.

The Results of the current study showed lower mean mound height and higher basal diameter than reported by Abdurahman (1990). The decrease of the mound height over time could be attributed to the gradual washing of the mounds by rain water while the increase in the basal diameter was due to the deposition of the washed soil at the base of the mounds. The mounds looked very old and eroded. The higher mean mound height and basal diameter of live mounds than those of dead mounds was obviously due to the activities of termites continuously building the mounds which increase the dimensions.

In the current study, higher percentages of dead mounds were excavated by aardvarks and occupied by ants than live mounds. When live mounds were opened, ants quickly picked minute termite nymphs and termite eggs (pers. obs.).ants termites had played their role in termite colony death or they occupied already dead mounds by other factors was unknown. This needs further investigation for the possible use ants as biological control of termites in the area. Pearce (1997) and Sileshi et al. (2009) reported that aardvarks are natural predators of termites and check the population-build up.

Under the natural food chain, termite is the most favorite food for aardvark. Korb and Linsenmair (2001) noted that army ants seem to cause high mortality rates and short turn-over rates of termite colonies, because in all studies were they occurred, colony mortality rates were much higher than in an area without army ants. Thus, army ants seem to be, in general, a key factor in regulating population dynamics of fungus-cultivating termites in Africa. Culliney and Grace (2000) also reported that ants are the greatest predators of termites, and may have a considerable local impact on termite populations in some areas of the world.

Textural and Chemical Properties of Termite Mound Soil and Adjacent Soil

As described in the Results, exch. cations (Ca, Mg, Na and K), % OC, and % OM, were significantly higher in termite mounds than in adjacent soil; higher values of pH, Av. P and K were also recorded in mound soil. Similar findings have also been reported elsewhere (Manuwa, 2009; Susumu et al., 2011). The higher accumulation of exch. cations in mound soil than adjacent soil indicates that termites collect these minerals from the subsoil to build the mounds.

The higher exch. cations in the mound soil than adjacent soil in the current study, shows that mound soils were more alkaline and the cations had contributed for the higher EC and pH (slightly to moderately alkaline) values recorded in the mound soils than adjacent soils. In line with this, Susumu et al. (2011) have reported increased soil pH and EC values along with an increase in exch. cations content in the mound structures compared to those in adjacent soils.

Similarly, Wood and Sands (1978) have reported that in mounds of Macrotermitinae there is generally a small increase in pH compared with the subsoil from which the mounds are constructed but there is little difference with the topsoil and the difference is often correlated with an increase in calcium (Wood and Sands, 1978). The significantly higher % TN recorded in the soil of mound perimeter than the mound and adjacent soils at both depths could be attributed to the decomposition of debris to nitrates of plants vigorously grown in the mound perimeter. Similarly, the higher % OM in the soil of mound perimeter than adjacent soil at 0-20 cm depth resulted from the decomposition of the debris of the plants. The higher OM in the mound soil than adjacent soil is in agreement with Susumu et al. (2011) who reported that the fungus-growing termites such as *Macrotermes* spp. use their saliva to bind soil particles, resulting in a subtle increase in OM in the mound structures.

Effect of Termite Mound Soil on Crop Growth

The significantly higher stem length, grain yield and dry plant biomass of teff grown in the mound perimeter than adjacent soil could be an indication of higher nutrient content in the former. This was evidenced by the significantly higher values of % TN, exch. Ca, % OM, average K and available P than adjacent soil at 0-20 cm soil depth. These are some of the essential plant nutrients and their higher values in the termite modified soil had contributed to the vigorous plant growth on the mound soil affected area than adjacent soil. The residues of the higher plant biomass produced in the mound perimeter would further release more nitrogen and OM upon decomposition and mineralization. This is in agreement with Sileshi et al. (2009) who noted significantly higher plant biomass and grass growth around termitaria compared with the ones grown far away from mounds. Maize grown on mound perimeter produces larger cob and thus gives higher yield than the one grown far from mound (pers. comm. with local farmers). From field observations, it was also noted that crops grown on soils in mound perimeter were dark green while the ones grown on adjacent soil were yellowish in color.

Most researches show that termitaria contain significantly higher concentrations of TN and exch. cations (Ca, Mg, Na, and K) than adjacent soils (Sileshi et al., 2009). In tropical wet–dry climates, down slope erosion could enhance the soil fertility around termitaria compared with leached soils away from it (Sileshi et al., 2009). The nutrients in mounds are slowly released and spread on the mound perimeter as the mound is eroded, thus creating spatial mosaics of relatively more productive areas or „„fertility islands"" (Kaschuk et al., 2006; Sileshi et al., 2010).

However, erosion is not the only factor which distributes nutrients found in the mound soil on the mound perimeter. During the field work in the current study, it was noted that mound soil was broken and distributed by the activities of livestock such as goats, sheep and cattle when licking the mounds and scratching their bodies with the mounds. Similarly, animals which use mounds as shelters or nests and aardvarks while digging mounds to feed termites, also increase the mineral content of the mound perimeter by breaking and spreading the mound soil.

Termite Diversity

Mound-building termite genera include *Macrotermes, Cubitermes*, *Amitermes*, *Odontotermes*, *Procubitermes* and *Trinervitermes* (Pearce, 1997; Meyer et al., 1999). However, in the current study, all the collected termites from the sampled mounds were identified as *Macrotermes.* This may strongly indicate that the peculiar high termite mound density in the area was built by the genus *Macrotermes.* This is in agreement with Wood (1986) who collected only *Macrotermes* termites from 15 km from Mojo towards Maki, 3 km north of Maki, Batu town, and 10 km south of Batu town.

CONCLUSION AND RECOMMENDATIONS

About 43% of the mounds in the area were dead. A higher proportion of these mounds were excavated by aardvarks and occupied by ants than live mounds. Termite modified soil differed from adjacent soil in most of the analyzed chemical properties. Exchangeable cations, EC, pH, % OM, % TN, available P and K were higher in mound soil than adjacent soil. However, termite activities did not significantly influence the soil textural properties unlike the chemical properties. Teff grown in mound perimeter showed higher teff stem length, dry biomass and grain yield than non-modified soil because of accumulation of more nutrients in the mound soil than adjacent soil.

The yield reduction which farmers complain caused by the physical occupation of the field may be compensated by the vigorous crop growth around the mounds and bigger cob formation in maize. Resource poor farmers in the area can use termite mound soil as fertilizer, without affecting termite population and activity for the sustainable use of the mound soil and ecosystem services. The effect of ants on termites in the area as biological control and the impact of continuous soil cultivation on establishment of new colonies and colony size need further research.

ACKNOWLEDGEMENTS

The authors are grateful to Adama Science and Technology University for funding the research. Special thanks go to Obbo Battee Kello for his unreserved assistance from the start to the end of the study. Mr. Kefyalew Assefa, manager of Ziway Soil Laboratory, and the staff are highly thanked for allowing us using the laboratory, providing us all the necessary reagents without charging and assisting us in soil analysis. All other field assistants are also thanked.

REFERENCES

Abdurahman Abdulahi (1990). Foraging Activity and Control of Termites in Western Ethiopia, Ph.D. Thesis, University of London, pp. 277.

Abdurahman Abdulahi (1991). Keys to the Genera of Ethiopian termites. Crop Protection bulletin No.1 Ministry of Agriculture. Addis Ababa. p.15.

Abdurahman Abdulahi, Abraham Tadesse, Mohammed Dawd (2010). Importance and Management of Termites in Ethiopia. Pest Mgt. J. Eth. 14: 1-18.

Adekayode FO, Ogunkoya MO (2009) Comparative study of clay and organic matter content of termite mounds and the surrounding soils. Conference Proceedings, African Crop Science, Uganda. Vol.9. pp. 379 – 384,

Beaudrot L, Du Y, Rahman Kassim A, Rejmánek M, Harrison RD(2011). Do Epigeal Termite Mounds Increase the Diversity of Plant Habitats in a Tropical Rain Forest in Peninsular Malaysia? PLoS ONE. 6(5): e19777. doi:10.1371/journal.pone.0019777

Culliney TW, Grace JK (2000). Prospects for the Biological Control of Subterranean Termites (Isoptera: Rhinotermitidae), with Special Reference to Coptotermes formosanus – a review. Bul.Ent. Res. 90: 9-21.

Kaschuk G, Julio CP, Jaime AA, Deise CS, João FB (2006). Termite Activity in Relation to Natural Grassland Soil Attributes. Sci. Agric. 63(6): 583-588.

Kefayalew Asefa (2008). Characterization and classification of irrigated soils and irrigation waters of major water supply sources in Meki-Ogolcha area in East Showa Zone Of Oromia, Ethiopia. MSc Thesis, Haramaya University, Ethiopia.

Korb J, Linsenmair KE (2001).The Causes of Spatial Patterning of Mounds of a Fungus- cultivating Termite: Results from Nearest-neighbour Analysis and Ecological Studies. Springer-Verlag. 127: 324-333.

Maduakor HO, Okere AN, Onyeanuforo CC (1995). Termites mounds in relation to surrounding soils in the forest and derived savanna zones of southeastern Nigeria. Biol Fertil Soils. Spriner-Verlag. 20: 157-162.

Manuwa SI (2009). Physico-Chemical and Dynamic Properties of Termite Mound Soil Relevant in Sustainable Food Production. African Crop Science Society. 9: 365-369.

Meyer VW, Braack LE, Biggs HC, Ebersohn C (1999). Distribution and density of termite mounds in the northern Kruger National Park, with specific reference to those constructed by Macrotermes Holmgren (Isoptera: Termitidae). Afr. Entomol. 7(1): 123–130.

National Soil Research Center (2000). Procedures for soil and plant analysis. Technical paper No. 74. Ethiopian Agricultural Research Organization. Addis Ababa, Ethiopia. p. 110.

Okwakol MJ (1992). The Importance of Termites in Rangelands. pp. 70-73, In: Henderlong PR., Sabiti EN, Bareeba FB, Mwebaze SN (Eds.) Proceedings of the Pasture Management for Livestock Production in Uganda, held at Makerere University, Kampala, 14-17, December, 1987.

Pearce MJ (1997). Termites: Biology and Pest Management. CAB International, New York, p. 172.

SAS Institute (2003). SAS Qualification Tools User‟s Guide, Version 9.0 edition. SAS Institute Inc., Cary, NC.

Sileshi GW, Arshad MA, Souleymane K, Philip OY (2010). Termite-induced Heterogeneity in African Savanna Vegetation: Mechanisms and Patterns. International Association for Vegetation Science. J. Veg. Sci. 21:923-937.

Sileshi G, Nyeko P, Nkunika P, Sekematte B, Akinnifesi F, Ajayi O (2009). Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. Ecology and Society. 14(1): 48. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art48/

SPSS Inc. (2008). SPSS Statistics 17.0, SPSS Inc., Chicago IL.

Susumu SA, Yoshinori W, Taisuke O, Takashi K, Toshiyuki W (2011).Nutrient Storage in Termite (Macrotermes bellicosus) Mounds and the Implications for Nutrient Dynamics in a Tropical Savanna Ultisol. Soil Sci Plant Nutr. Japanese Society of Soil Science and Plant Nutrition. 57: (6) 786-795.

Wood TG (1986). Assessment of Termite Damage in Ethiopia and Recommendations for Short-term Control and Development of Long-term Pest Management Practices. Report prepared for the World Bank. p. 58.

Wood TG, Sands WA (1978).The role of termites in ecosystems. In: Brian M.V. (ed.) Production ecology of ants and termites. Cambridge University Press, Cambridge, Great Britain. pp. 245-292

Yamashina C (2010). Interactions between Termite Mounds, Trees, and the Zemba People in the Mopane Savanna in Northwestern Namibia. African Study Monographs, Suppl.40: 115-128.