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Impact of Termite Activities on Soil Physicochemical Characteristics in Different Land Use Types in Lalo Asabi District, Western Ethiopia

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Abstract

A longitudinal study was undertaken from October 2018 to February 2019 within 250,000 m^2 (500 m x 500 m) of farm, range and protected lands to identify mound building termite species, determine mound density and evaluate physico-chemical properties of termite mound soil (TMS) and surrounding control soil (SCS) in Lalo Asabi district (LAD), western Ethiopia. Ten live mounds per land use type were sampled across the diagonal of the study site. The mounds were dug and termites were hand-collected with forceps and preserved in 80% ethanol labeled vials. Later identification of the termite specimen to species was done using soldier morphological characters with the help of keys to the genera of Ethiopian termites and mound characteristics. In addition, termite mound density per hectare of land type was estimated. For physico-chemical analysis, soil samples were taken from three randomly selected termite live mounds as a replicate per study site. The samples were taken at depth of 20-60 cm by digging each dome shaped sample mound. Control soil samples were also taken at 8 m distance away from the base of each mound from adjacent area of each experimental mound free of mound effect. From each mound and control soil, 1kg soil samples were taken according to standard methods and transported to Nekemte Regional Soil Laboratory for further analysis. Soil laboratory analysis was done and data were analyzed using SAS software version 2002. Mean comparison and least significant difference (LSD) were used to compare soil physico-chemical properties between TMS and the SCS in the three land use types. All the termite specimens collected from the active mounds were found to be *Macroterms herus*. Significant difference in average density of the mounds among the three land use types were recorded with higher average density in the range land followed by farm land and protected land in that order. Physico-chemical properties of TMS varied as compared to the SCS by land use types implicating that anthropogenic factors such as agriculture and livestock grazing have significant impact on termite activities and hence the top soil environment. Using soil conservation as integrated termite management will improve the impact of land use changes on termite activities and agriculture in the study setting.

Keywords

Land Use Types, Termites, Termite Mound Soil, Surrounding Control Soil

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1. Introduction

A wide range of different soil macrofauna provides several key ecosystem services. In the tropics, termites are the most influential soil-dwelling ecosystem engineers [1], whose biogenic structures such as nests, soil sheeting, foraging holes, etc. modify the availability of resources for other organisms. Termites incorporate plant litter and crop residues into the soil, thereby modifying biological, chemical, and physical soil processes that affect the flow of energy and

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material [2]. Termites have an important role in the maintenance of soil structural stability and fertility in many natural and man-modified habitats. They have a very strong impact on the soil environment and are therefore called "ecosystem engineers." The effects of termites on soil character and quality may rival that of vertebrate herbivores, being one of the most important biological agents for reworking the soils [2].

Nowadays, top soil depletion driven by anthropogenic and other biotic factors is one of the global challenges threatening sustainable agriculture particularly water and food security. Termites are one of the biotic factors that directly impact on both top soil depletion and restoration in most dry land and tropical ecosystems. In Ethiopia, termite activity driven topsoil depletion and landslide warrant research priority particularly in western part of the country including Lalo Asabi District (LAD). Termite activities have significant impact on top soil composition and dynamics of organic matter, inorganic matter and nutrients.

On the other hand, termites have been regarded as serious pests that attack a wide range of agricultural crops, forest trees and buildings in Western Ethiopia [3]. Agricultural production is more difficult in the area where high infestation of termites exist and these results in poor crop production which in turn has negative impact on the farmer's profits, increases household food insecurity and famine in the rural small scale farmers and abandon them from the world market competition. Despite high termite problems in western Ethiopia including LAD, published scientific reports on the impact of termite activities on soil physicochemical properties with respect to land use types are scanty.

Moreover, the negative impacts of termites as agricultural pests were emphasized and their positive impacts as ecosystem engineers were overlooked in western wollega by previous studies [3, 4]. The later studies need concern because the detrimental impacts of termites on agriculture may be due to the conflict between termite activities and anthropogenic activities. Anthropogenic activities bring land use changes that affect termite activities. The present study was undertaken to assess the impact of termite activities on soil physico-chemical properties in different land use types in LAD. The study aims to identify mound building termite species, determine mound density and evaluate the impact of the termite species on physico-chemical properties of termite mound soil (TMS) as compared to the surrounding control soil (SCS) in different land use types in LAD, western Ethiopia.

2. Methods

2.1. Description of the Study Area

Lalo Asabi district (LAD) is located in west Wollega Zone, Oromia Regional State, Ethiopia (Figure 1). The district has 27 peasant associations and four urban administrations in 2017. It is located at a distance of 464 Km from Addis Ababa, and 23 Km from Ghimbi, the capital city of west Wollega zone. Total population of LAD is 94,623 out of which 46,247 are male and 48,376 are females [5].

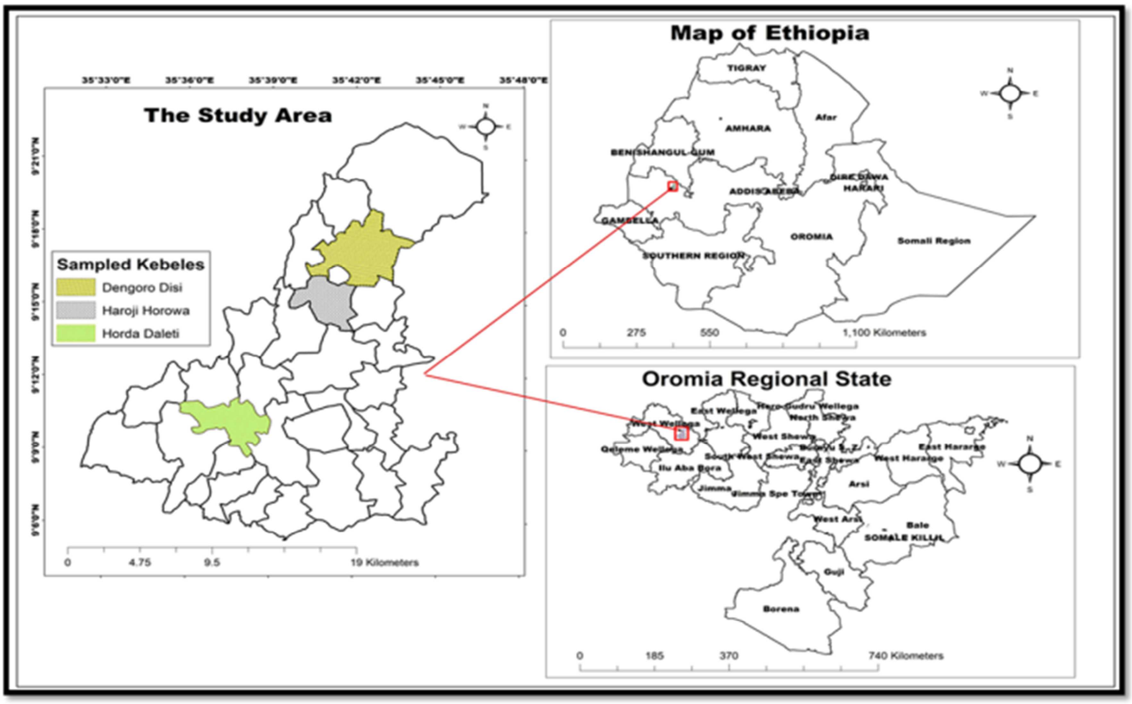

Figure 1. Map of the study sites in Lalo Asabi District in Oromia Regional State, Western Ethiopia.

The absolute location of LAD is 9°-20°N and 35°-45°E, and covers a total area of 43,355 hectare or 433.55km^2. The annual rain fall of the study setting ranged from 1750-2200mm/year whereas its maximum and minimum temperatures were 30°C and 25°C, respectively. Its altitude ranges from 1500 to 1900 meters above sea level. The major soil types are Loamy soil (58%), clay soil (32%) and sandy loamy soil (10%) [5].

Major types of natural vegetation of the area include forest, woodland, Shrub, bush land and savanna. Termites are serious pests in West Wollega particularly in LAD. They cause considerable damage to agricultural crops, rangelands, forestry seedlings and wood structures such as rural houses, stores, fences, bridges and losses of crop productivities due to termite activities in the study area were immense.

2.2. Study Design and Sampling Technique

Both field and laboratory-based quantitative descriptive and analytical research methods were used in this study. The study was carried out within 250,000 m^2 (500 m x 500 m) of farm, range and protected lands that will make a total of 750,000 m^2 of land in LAD. The sites were purposively selected based on high termite mound abundance, availability of farm, range and protected lands and accessibility for investigation.

2.3. Termite Sampling and Identification

For sampling termites first alive and dead mounds were inspected in each study site. A mound was considered as being “live” when termite individuals are seen, (fresh mound structures built by termites are present), the mound was dug to the center at different heights and termites are seen or a hole drilled into the mound was repaired by termites within one day. Otherwise, a mound was considered as “dead”.

After conducting mound census, ten live mounds per land type was sampled across the diagonal of the study site. The mounds were dug and termites were hand-collected with forceps and preserved in 80% ethanol labeled vials and later termite identification was done at genus and species level using soldier morphological characters with the help of Keys to the genera of Ethiopian termites and mound characteristics [4].

2.4. Determination of Densities of Termite Mounds and Foraging Holes

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 (Daniel *et al*., 2014) using the formula d = n/s, where n= number of mounds sampled and *s* = area sampled. In addition, mound density per hectare of land type was estimated from number of mound samples per hectare of the land type. Density of each termite species foraging holes was determined by recording foraging holes within square meter quadrant. Each of the 500m X 500m farm, range and protected land selected for the survey was divided into five quadrants (four in the corner and one in the center) and from each quadrant termites and their foraging holes were inspected and recorded within the square meter. The forager termites were sampled and preserved as indicated earlier.

2.5. Soil Sampling and Analysis

2.5.1. Collection of Soil Samples

The mound soil samples were collected from three land use types namely farm land, range land and protected land during October 2018, to February 2019 after the long rainy season when termite activity peaks. Soil samples were taken from three randomly selected termite live mounds as a replicate per land use type. Soil samples were taken at depth of 20-60 cm by digging by auger each dome shaped sample mound from top center. Samples were also taken at 8 m distance away from the base of each mound from adjacent area of each experimental mound free of mound effect (Daniel *et al*., 2014). From each mound and control soil 1kg soil sample was taken and packed in plastic bag, labelled, numbered with date of collection according to standard methods and taken to Nekemte Regional Soil Laboratory for analysis.

2.5.2. Soil Analysis

The samples were air dried, passed through a 2mm sieve and the content of gravel (>2 mm) by weight was determined. Particle size distribution was determined by sieving sand fraction, the silt and clay fraction. For each soil sample, analysis was done based on the National Soil Research Centre Guideline of Ethiopia [6]. Soil particle size distribution was determined using hydrometer method. Available potassium (Av.K) was analyzed by extracting with Morgan”s solution and measured by flame photometer. Organic matter (OM) and total nitrogen (TN) 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. Bulk density was determined by using undisturbed core sampler method using volumetric cylinder & calculated by dividing the oven drying at 105°C. Available phosphorus (Av.P) was determined by spectrophotometer following Olsen’s method. pH was measured metrically on direct-reading pH meter in distilled 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 [7].

2.6. Data Analysis

The soil physical and chemical data was analyzed using SAS software (2002). One way analysis of variance (ANOVA), mean comparison and least significant difference (LSD) were used to compare soil physical and chemical properties between termite mound soil and the surrounding control soil in the three land use types. Differences were considered significant only when p values were lower than 0.05.

3. Results

3.1. Termite Species Composition

Overall, 54 soldier termite specimens were collected from the active mounds of the three land-use types, and all were found to be *Macroterms herus* belonging to one genera representing one family *Termitidae.* The number of *M. herus* was higher in range land 44.4% (24/54) followed by farm land 31.5% (17/54) and protected land 24.1% (13/54) in that order.

3.2. Termite Mound Density

A total of 217 dome-shaped epigeal termite mounds within the study site (500 m x 500 m) were recorded and the average density of the mounds was calculated as 2.9 mounds/ha. *Macrotermes herus* mounds were observed in all land use types with peak mean density per hectare in range land, followed by farm land and protected land from higher to lower respectively (Figure 2).

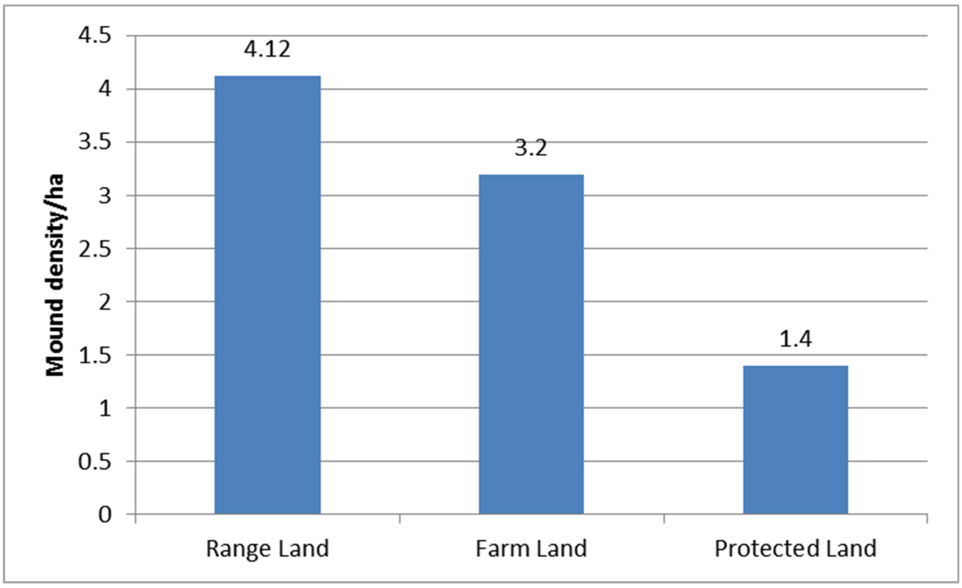

Figure 2. *Macrotermes herus* mound density by land use types in Lalo Asabi district in 2019.

3.3. Mound Density Versus Termite Foraging Hole Density

The density of *Macrotermes herus* mounds and foraging holes are shown in Table 1. Termite mounds and foraging holes were observed in all of the land use types with significantly higher mound density and foraging hole density in the range land as compared to the other two land use types.

Table 1. *Macrotermes herus* mound density and foraging hole density in different land use types in Lalo Asabi district in 2019.

Land type	Average mound density	Foraging hole density/m2)
Farm land	3.18 ± 0.22	9 (2.0±0.57)
Range land	4.11 ± 0.30	11 (2.9±0.79)
Protected land	1.33 ± 0.06	6 (8.6±1.4)

3.4. Physicochemical Properties of Termite Mound Soils Versus the Control Soils

3.4.1. Textural Properties of Termite Mound Soil by Land Use types

Results of textural properties of TMS versus SCS by land use type are shown in Table 2. In farm land, % Clay, % silt and electrical conductivity (EC) values at 20-60cm soil depth the TMS were significantly higher ($P < 0.05$) than that of SCS. However, in the same land type, there were no significant difference between the TMS and SCS in their % sand and bulk density (BD). In the range land similar BD were observed between TMS and the SCS. Nevertheless, % sand, % Clay, % silt and EC values were significantly higher in the SCS than that of the TMS. In protected land, except BD, there were significant differences between TMS and the SCS in all the parameters considered with higher values of % sand, % Clay, % silt and EC in the SCS than the TMS.

Table 2. Textural properties of termite mound soil versus the control soil by land use types in Lalo Asabi district in 2019.

Land use type	Soil Sample	Parameters				
		%Sand	%Clay	%Silt	%EC	BDg/cm^2
Farm land	TMS	32.33 ± 2.66a	46.33± 3.33a	22 ±2.30a	63.95± 36.56a	1.36±0.12a
	SCS	32.33± 3.33a	45.66± 1.76b	21.33 ±0.66b	48.09± 17.64b	1.14±0.06a
	LSD	5.15	6.92	10.30	0.3	112.73
Range land	TMS	21± 5.29a	63.66± 2.40a	15.33± 3.52a	37.48 7.64a	1.27±0.04a
	SCS	37.66± 1.33b	44.33± 0.66b	18 ±1.15b	35.66 0.37b	1.28±0.09a
	LSD	11.85	10.47	6.67	0.29	36.9
Protected land	TMS	34.33±2.90a	47±2.30a	18.66± 0.66a	30.29± 3.83a	1.21±0.07a
	SCS	40.33± 0.66b	37± 1.15b	22.66± 1.76b	63.55 ±13.23b	1.23±0.05a
	LSD	8.27	7.16	5.23	0.15	38.25

Note: TMS (Termite mound soil), SCS (Surrounding control soil), LSD (Least significance difference), M&SE (Mean and standard error)

3.4.2. Chemical Properties of TMS Versus SCS

Table 3 shows results of chemical properties of TMS as compared to the SCS by the land use types. As it can be seen in the table, in the farm land, except % TN, the average values of P^H, % OC, %OM, available phosphorus and potassium were significantly higher (P < 0.05) in the TMS versus the SCS.

Likewise, in the range land, except % TN, there were significant difference between the TMS and the SCS but, the average values of % OC, %OM, available phosphorus and potassium were significantly higher (P < 0.05) in the SCS versus the TMS except for pH in which it was higher in the TMS. With regard to the protected land, significant differences were observed between the TMS and the SCS in %OC, %OM and available potassium with higher than SCS but significantly higher. However, in the same land type there were no significant difference in P^H, %TN and available phosphorus average values between the TMS and the SCS.

Table 3. Chemical properties of termite mound soil versus the control soil by land use type in Lalo Asabi district in 2019.

Land use type	Soil Sample	Parameters					
		pH	%OC	%OM	%TN	AV. P (ppm)	AV. K (ppm)
Farm land	TMS	5.25± 0.3a	1.93 ± 0.2a	3.3 ± 2.3a	0.16±0.03a	6.8 ±55.6a	184.2±94.23a
	SCS	4.6 ± 0.2b	1.7 ± 0.19b	2.93 ± 0.3b	0.15±0.01a	4.7 ± 1.5b	96.7 ± 83.2b
	LSD	1.32	1.13	1.74	0.08	8.45	21.31
Range land	TMS	4.75±0.02a	1.91± 0.09a	3.29 ±0.02a	0.17±0.01a	5.02±6.30a	176 ± 62.42a
	SCS	4.5± 0.05b	2.25±0.014b	3.9 ± 0.25b	0.19±0.01a	3.93±0.38b	9.01 ± 1.6b
	LSD	0.2	0.55	0.96	0.04	4.6	101.3
Protected land	TMS	4.59± 0.4a	1.89 ±44.28a	3.26±0.51a	0.16±0.02a	7.08±4.15a	95.5 ± 65.6a
	SCS	4.5 ± 0.18a	2.77 ± 0.13b	4.77 ± 0.22b	0.24±0.01a	7.11 ± 0.60a	80.33±46.61b
	LSD	0.72	0.9	1.55	0.07	2.31	222.7

Note: TMS: Termite mound soil, SCS: surrounding control soil. Means within two rows for each parameter followed by the same letter do not differ significantly by Least Significant Difference Test (LSD) at 5% of probability.

4. Discussions

Results revealed that the entire mound building termite specimens collected from active mounds from farm land, range land and protected land were *Macroterms herus* belonging to the genus *Macroterms* and representing the family *Termitidae*. This finding coincides with earlier reports by Abdurahman Abdulahi, Abraham Tadese and Mohammed Dawd [3] and Abdurahman Abdulahi [4] who found that *Macroterme herus* is the termite species responsible for building low, flat, dome-shaped closed mounds in western Ethiopia. Likewise, Daniel Getahun Dabalo and Emana Getu Degaga [8] also found that *Macrotermes* are the only mound-building termites in the central Rift valley of Ethiopia. The possible explanation for lack of termite species diversity in this study area might be attributed to limited collection of termite samples and limited use of sampling methods. The present study prioritized identification of mound building termites and randomly sampled termites from live mounds by hand collection with forceps and as a result the local termite fauna diversity that occur in the different land use types that may require different termite sampling methods were not considered and warrant further research.

Results also showed higher average *M. herus* mound density in the range land (4.12 mounds/ha) followed by farm land (3.20 mounds/ha) with the lowest average mound density in the protected land (1.4 mounds/ha). These *M. herus* mound density are relatively lower than previous reports from western Ethiopia. For example, Abdurahman [4] reported about 5.6 and 8.2 density of *Macrotermes* mounds/ha on cultivated land and grassland respectively. On the other hand the present mound densities are higher than in most reports from elsewhere in Africa. For instance Yamashina [9] recorded about 0.5 mounds/ha from Namibia and Meyer *et al*. [10] reported 0.73/ha in Kruger National Park in South Africa. In this connection, variable *Macroterms'* mound densities will be expected across Africa because of locally variable environmental factors that directly impact on termite nesting, foraging and feeding activities.

The results also underline that *M. herus* average foraging hole density (FHD) was significantly higher in the range land followed by farm land with the least FHD in protected land in that order. This could be expected because in protected land termites have more optional food sources and less competition with grazing animals for food and as a result FHD decreases in protected lands and farm lands were animal protection against grazing is expected unlike open range lands. The present findings are in agreement with Abdurahman Abdulahi [11] who reported that number of termite foraging holes per m^2 (FHD) became significantly greater in unprotected rangelands than in the protected ones in Manasibu district, western Ethiopia. The same paper revealed that foraging activity of termites increased in overgrazed rangelands and this implicates the presence of competition between livestock and termites in the study settings.

Results also revealed that physico-chemical properties of TMS varied as compared to the SCS by land use types implicating that anthropogenic factor such as land use for agriculture has significant impact on termite activities and hence top soil environment. In particular, results showed that in farm land, except % TN, the average values of P^H, % OC, %OM, available phosphorus and potassium were significantly higher in the TMS compared to the SCS. In agreement with the present results, higher values of P^H, % OC, %OM, available phosphorus and potassium in TMS relative to SCS were also reported in previous studies [12]. However, in all of the land use types, %TN composition of the TMS were similar to the SCS which was unexpected finding in the study. In support of this result: Daniel Getahun Dabalo and Emana Getu Degaga [13] recorded significantly higher % TN in the soil of mound perimeter than both the mound soil and adjacent control soils. The authors suggested that the higher %TN in the mound perimeter could be attributed to the decomposition of debris to nitrates of plants vigorously grown in the mound perimeter. In the present study the influence of plant debris in the perimeter of the TMS was not considered and need further research.

Unlike in the farm land, the average values of % OC, %OM, available phosphorus and potassium in the range land were significantly higher in the SCS versus the TMS. These findings were also unexpected and might be influenced by plant debris in the perimeter of the TMS and potentially more decomposed waste matter of grazing animals as range lands are more exposed to livestock than farm and protected lands.

With regard to the protected land, significant differences were observed between the TMS in %OC, %OM and available potassium with higher than the SCS. This would be expected because in protected land mound building activities of termites can result in accumulation of more %OC in TMS than SCS due to availability of protected vegetation and their debris. And these findings are generally coinciding with many previous reports [12]. However, in the same protected land significantly higher% OM and available phosphorus were found in the SCS than the TMS. These could be explained by local differences in vegetation cover and enrichment of nutrients and minerals in the SCS relative to TMS. In the same protected land, the soil surrounding termite mounds may differ in their mineral and nutrient enrichments driven by differential vegetation cover and due to significant impacts of topography and erosion. Termite mound building activities accumulate soil nutrients and minerals and the accumulated material is later redistributed by erosion causing changes in soil microstructure and fertility [14]. The impacts of topography, vegetation cover and erosion on termite activities and mound soil composition have not been addressed in this study and need future research.

In the end, this study focused on mound building termites and as a result species identification of only mound nesting termites was done. As limitation of the current study local termite fauna species diversity in different land use types were not addressed and need further research. In addition, species identification of the mound nesting termites were done by using Ethiopian taxonomic keys for termites and physical characteristics of the termite mounds all of which were based on morphological methods. Therefore molecular techniques for identification of termite species were not employed and need to be considered in future research. Furthermore, the impact of plant debris in mound perimeter, topography, vegetation cover and erosion on mound soil composition were not addressed in this study and warrant special consideration.

5. Conclusions

Results underscore that *Macrotermes herus* is the sole termite species responsible for building low, closed, flattened and dome-shaped mounds in all the three land use types in LAD. Termite mound density and foraging holes density significantly varied in different land use types in LAD. Likewise, physico-chemical properties of termite mound soil varied as compared to the surrounding control soil by land use types implicating that anthropogenic factors such as agriculture and livestock grazing have paramount impact on termite activities that impact on either top soil depletion or restoration. Therefore, using soil conservation as integrated termite management will improve the impact of land use changes on termite activities in the study setting and elsewhere.

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References

[1] Bignell, D. E. (2006). Termites as soil engineers and soil processors. In H. König & A. Varma (Eds.), *Intestinal microorganisms of soil invertebrates* (pp. 183–220). Berlin: Springer.

[2] Khan MA, Ahmad W., and Paul B. (2018). Ecological impacts of termites. In M. A. Khan, W. Ahmad (eds.), *Termites and Sustainable Management*, Sustainability in Plant and Crop Protection, Springer International Publishing AG 2018.

[3] Abdurahman Abdulahi, Abraham Tadese and Mohammed Dawd (2010). Importance and Management of termite in Ethiopia. *Pest Management Journal in Ethiopia,* 14, Pp. 1-18.

[4] Abdurahman Abdulahi (1990). Foraging Activities and control of termite in Western Ethiopia. University of London, Pp. 277.

[5] CSA, 2017). Central Statistical Agency of Ethioipia, Addis Ababa, Ethiopia.

[6] Susumu, S., 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, Japanese. *Journal of Soil Science Plant,* 57, (6), 786-795.

[7] Abdeta Jambere, Gezaheng Berecha and Alamayehu Regassa Tolesa (2017). Impacts of Termites on selected soil physiochemical characteristics of the highlands of South Western Ethiopia. *Archives of Agronomy and soil science, 1476-3567 (*Online*) Journal homepage: http://www.tandfonline.com/loi/gags20*

[8] Daniel Getahun Dabalo and Emana Getu Degaga (2014). Termite Species Composition in the Centeral Rift vally of Ethiopia. *Agricultual of Biology Journal Northern America*, 5 (3), Pp. 123-134.

[9] 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.

[10] 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.

[11] Abdurahman Abdulahi (1991). *Key to the genera of Ethiopian termite*, bulletin No 1 crop protection and regulatory Department ministry of Agriculture. Addis Ababa, Pp. 15.

[12] Manuwa, S. I. (2009). Physic-Chemical and Dynamic Properties of Termite Mound Soil Relevant in Sustainable Food Production. *African Crop Science Society*, 9, 365-369.

[13] Daniel Getahun Dabalo and Emana Getu Degaga (2014). Studies on ecology of mound building Termite in the Central Rift valley of Ethiopia. *International Journal of Agricultural sience*, Addis Ababa, Ethiopia, 4, (12), 326-333.

[14] Chisanga K, Mbega ER, Ndakidemi PA. Prospects of using termite mound soil organic amendment for enhancing soil nutrition in Southern Africa. Plants. 2020; 9 (5): 649.