ADDIS ABABA UNIVERSITY

GRADUATE PROGRAMME

Studies on Species Composition and Status of Termites in different Land use systems and their Management on Maize in East Wollega Zone, Western Ethiopia

By

Temesgen Beyene Hunde

Department of Zoological Sciences (In sect Sciences)

Addis Ababa University

A thesis submitted to the Graduate Programme of the Addis Ababa University in Partial Fulfillments of the Requirements for the Degree of Doctor of Philosophy in Zoological Sciences (Insect Sciences)

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Declarations

I, hereby declare that this PhD Dissertation is my original work and has not been presented for any degree in any other University and all sources of material used for this dissertation has been duly acknowledged.

Name: Temesgen Beyene Hunde

Signature__________

Date______________

This PhD Dissertation is submitted for examination with my approval as an advisor.

Name: Emana Getu Degaga (PhD), Professor of Entomology

Signature______________

Date _________________

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This is to certify that the thesis prepared by Temesgen Beyene, entitled: Studies on Species Composition and Status of Termites in different Land use systems, and their Management on Maize in East Wollega Zone, Western Ethiopia and submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Zoological Sciences (Insect Sciences) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Dedications

This dissertation is dedicated to,

My mother Tadelu Wirtu Duguma

My late father Beyene Hunde Delesa and my late brother Emiru Beyene

My wife Meselu Fufa

My sons, Olyad and Robera

My daughters, Muluwork, Beliyou, Chaltu, Ayantu and Martha

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Abbreviations/Acronyms

AAS	Atomic absorption spectrophotometer
ANOVA	Analysis of variance
AS	Adjacent soil
BD	Bulk density
CSA	Central Statistical Agency
EIAR	Ethiopian Institute of agricultural research
FAO	Food and Agriculture Organization
ITM	Integrated Termite Management
LSD	Least Significant Difference
m.a.s.l.	Meter above sea level
MOA	Ministry of Agriculture
MS	Mound soil
NPK	Nitrogen, Phosphorous, Potassium
OC	Organic Carbon
OM	Organic matter
ONRS	Oromia National Regional State
PD	Particle density
PPSE	Plant Protection Society of Ethiopia
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SPSS	Statistical Package for the Social Sciences
WU	Wollega university

Studies on Species Composition and Status of Termites in Different land uses and their Management on Maize in East Wollega Zone, Western Ethiopia

Abstract

In Ethiopia, agro ecological based termite infestation emerged with the spread of invasive termite species. In response, various species and assemblage were come to exist in Ethiopia, western and Eastern Wollega areas since 1904. Therefore, continuous studies on various aspects are crucial in termite prone sites. Hence, the current study was aimed at species composition and status of termites in different land uses and their management on maize in east Wollega zone; Nunuqumba, Diga, Limu and Nekemte districts from August 2017 to December 2021.Qualitative survey using questionnaire was employed for data collection from 90 smallholders in each districts. Termite encounters are surveyed and identified. Data was analyzed using SPSS. For soil physicochemical analysis of four land uses and three patches in each land use having a plot size of (100 m x 100m) three mound in each patch and soil sample from 0-20cm, 20-40cm and 40-60cm mound position and adjacent soil in each patches was collected and composited from purposively selected sites in Fitbako *kebele.* The experiment was designed in a randomized complete block design (RCBD) in three replications and adjacent soil was used as a control. There are 16 treatments replicated three times. The sub-samples composited soil was analyzed with reference to National soil research center of Ethiopia. Cultivated land termite soil, adjacent and non-mound soil nnutrients composition and their effect on maize plant growth in the presence or absence of NPK in green house condition were experimented with soil collected at the depth of 0-30cm in which adjacent and non-mound soil were collected 5m and 20m away from the mound respectively. Maize variety BH-661 and NPK fertilizer were the materials .In the experiment three kg sample soil was added to each pots, the experiment was laid out in (CRD) with 12 treatments replicated three times and termite genera, termite mound, adjacent and non-mound soil physicochemical value , plant growth traits at 2,4 and 8 weeks and yield parameter data were collected and analyzed.For the determination of botanical efficacy on termite management the locally available botanicals , *Croton macrostachys*(Hochst), L. *Jatropha curcas* and *Phytolacca dodecandra* L leaves were collected dried under shade, grounded in to a fine powder, sieved and stored. The experiment was conducted on irrigation and rain fed field (3 mx7.5m) arranged in (RCBD) with four replication. Botanical powder 300 g was weighed and soaked in 1000 ml distilled water and filtered and collected to

200ml beaker, from the beaker 20 ml was powered to syringe and injected to each hole 10 days before planting and at different growth stages of maize and data of termites, galleries and mounds were recorded two days before planting and every two days after treatment application at all growth stages of maize plant and at harvest, maize cobs were collected and yields were analyzed. A total of 295 termite specimens collected were Termitidae in its four Sub families and nine genera. These termites are traditionally known and are high in low altitude of grazing land and low in high altitude of disturbed forest, Standard quadrat Survey also revealed high termite density (n), galleries and mound in grazing land followed by cultivated land and disturbed forest. They are recorded from Nunuqumba and Diga districts. Mound constructing termites improve mound soils texture and enable retaining of pH, OC, OM TN, P, K, Ca and Mg than Adjacent and Non-mound soil. Soil nutrients retain was contributed by Macrotermes, Pseudacanthotermes and Odontotermes. Nutrient rich mound soil favour plant growth and resulted in high mean plant growth trait at 2, 4 and 8 weeks, subsequently, grain yield weight of maize at harvest show significant ($p<0.05$) result than in non-mound soil. However, termites are regarded as pests of agricultural products and structures. Termite management relay on chemical insecticide and mound destruction. Botanical termite management involved , *Croton macrostachys*(Hochst), L. *Jatropha curcas* and *Phytolacca dodecandra* L leaf extract at the rate of 20ml/plant separately or combined used were deterring termites. The three mixed botanicals extract were more effective than two mixed botanicals. The present study concluded that agroecology and land use systems impose similar termite genera compositions to occupy similar location, study of termite agroecology and land uses therefore contribute to understand and plan termite management. Overgrazing due to high traffic of grazing animals favour abundant termite genera compositions in grazing land. The location and the red soil type of Nunuqumba and Diga districts favored termite prevalence. Mound Soil nutrient mixed with NPK induces extraordinary growth .Therefore, applications of NPK fertilizer on plots having termite mound is not recommended. Termite control with mixtures of plants such as *C. macrostachys, J. curcas* and *P. dodecandra extracts* can be used as part of an integrated termite's management (ITM).

Key words; Agroecology, *Croton macrostachys* (*Hochst*), ITM, *Jatropha curcas* L. land use system, Mound soil, *Phytolacca dodecandra* L.

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CHAPTER 1 INTRODUCTION

1.1 General Introduction

In Ethiopia, agro ecological based termite infestation emerged with the spread of invasive termite species from their origin to the new area. However*,* Termite distribution is highly regulated by temperature and moisture (Hemachandra, 2014). Across the world, there are more than 3016 termite species in 300 genera, Among the world fauna, 1000 species belong to African termite's fauna (Krishna *et al.,* 2013).There are 61 species 25 genera and four families of termite in Ethiopia (Ahmed *et al.,* 2011).Termite fauna of Western Ethiopia include the genera: *Macrotermes, Odontotermes, Microtermes, Amitermes, Microcerotermes, Angulitermes,* and *Trinervitermes* .Out of these. *Macroterms subhyalinus* (Rambur) and *Microtermes adschaggae* (Sjosted) were the most abundant ones (Abdurahman Abdulahi, 1990).They are mostly subterranean, which were difficult to locate and destroy (Ahmed Ibrahim and Abraham Taddesse 2014). Termites genera of Wollega zones are *Macrotermes Microtermes, Odontotermes,* and *Microcerotermes (*Cowie & Wood, 1989).

Maize damaging termites in western Ethiopia are; *Macrotermes, Odontotermes* and *Pseudacanthotermes* (Abdurahaman Abdulahi, 1990; Emana Getu *et al*., 2008).In Ethiopia, maize (Zea *mays* L.) is a major staple food that grows in nearly all agro-ecological zones (FAO, 2011). It is the source of food and cash for those who are engaged in agriculture. It contributes to the Gross Domestic Product (GDP) and earnings of employment (CSA, 2013).Maize alone accounts for over 30% of poor farmers' income, 60% of dietary calories and 50% of protein intake in Africa (IITA, 2009).

Though, maize is the livelihood of the overwhelming majority of Ethiopians, termite's (Isoptera) are implicated and severely threaten maize production in East Wollega zone. These termites rapidly spread easterly direction from the more affected districts of the West Wollega areas (Ofgaa Dijirta *et al,* 2007). The fast increase in population intensified termite infestation and impose termite to access Eastern Wollega along trader's walk ways.

In the course of infestation, termites create bio structures; mounds, galleries, sheeting's, etc. and influencing the distribution of natural resources; water and nutrients in the land use system where they inhabit. In so doing they amend soil fertility that facilitate diversity of soil microbes; plants and animals which has direct role in rehabilitating degraded soils (Adugna *et al*.,2018),Termites amend soil fertility with its soil dwelling symbionts, free living N_2 fixing bacteria *Azotobacter and Bacillus* which able to digest and decompose the foraged materials *(*Sathiya *et al*.,2018).

This decomposed organic material incorporated to the soil and changed soil texture to make it more porous and stable aggregates (Jouquet *et al.,* 2015). As a result, mound soil enriched with cumulated OC, OM, and pH, Ca, K, N and Mg more than adjacent soil (Jouquet *et al.,* 2011). In supporting Mahsa *et al*. (2017) reported that, mound soil organic matter content was five-times greater than those in adjacent soils. Rich fertility of termite soil richness encourage majority of African's, including the highlanders of resource poor farmers of southwest Ethiopia use termite soil as a fertilizer (Abdeta Jembere *et al.,* 2017).Mound soil fertilizer was further practiced in developing countries as an alternative to inorganic fertilizer in nutrient depleted soils (Avitabile *et al*., 2015). In developing countries, this adds mixture of soil act as alternative to high price inorganic fertilizer inputs (Adugna *et al*.,2018) .

Moreover, mound soil with inorganic fertilizer consists of NPK get higher demand in improved-maize varieties (Frageria and Baliga, 2004). In the current study however, combination of mound soil with NPK is not advised as both combination promote extra ordinary growth to the maize plants (Temesgen Beyene and Emana Getu, 2020). While some termites are making nutrient rich mound that function as fertilizer, the others are destructing pests. Kumari and Patil (2013) reported that, there are over 300 pest species of termites all over the wide. Those of Ethiopian's termites were known as serious pests as they attack a wide range of agricultural crops, forest trees and buildings. Moreover, severe pests were found in the desert areas (Daniel Getahun and Emana Getu, 2014).

In pest termite management, chemical insecticides are applied by many farmers. However, it is condemned due to its environment backlash human health concern (Grdisa and Grsic, 2013).Alternatively, cultural and traditional method like mound demolition for queen and colony disturbance were widely used (Emana Getu *et al*., 2008). In addition, termite botanical management was recommended by scientists (Nyeko *et al*., 2010).In this regard, Temesgen Beyene and Emana Getu (2020) reported that, botanicals mixtures of plants such as *Croton macrostachys* (*Hochst*), *Jatropha curcas* L. and *Phytolacca dodecandra* Lucan be used as part of an integrated termites' management.

Over all, Ethiopia is rich in termite fauna. Termite infestation was earlier reported in western Ethiopia and western Wollega. Some reports elucidate these termite get access to the Eastern Wollega areas. (Ofgaa Dijirta *et al,* 2007).). However, inventory of termites in west Wollega was a long time history; there is no termite activities inventory document in East Wollega zone Western Ethiopia. Therefore, the objectives of this study include;

1.2 Objectives

1.2.1 General Objective

To investigate species composition and status of termites in different land use system and their management on maize in East Wollega zone.

1.2.2. Specific Objectives

- To assess species composition, distribution and pest status of termites in different agro-ecology and land use system.
- To characterize termite mound soil physicochemical properties from different land uses at different mound soil depths.
- To investigate nutrient composition of termite soil and their effect with and without inorganic fertilizer on yield and yield components of maize grown under green house condition.
- To determine the efficacy of botanical extracts against termites on maize plant growth under field condition.

CHAPTER 2 LITERATURE REVIEW

2.1 Overview of Some Facts about Termites Biology

Termites are representatives of the invertebrate macro fauna of the world (Bottinelli *et al.,* 2016). In the world, they represent 10% of animals and 95% of soil insect biomass (Ghaly and Edwards, 2011).With this abundance, they are evolutionary and ecologically most successful insects that share a common ancestry with cockroaches (Bottinelli *et al.,* 2016),

Termite success was attributed to several factors; they are Hemimetabolous insects that shortly transform their generation and occupy a wide array of microhabitats, able to establish their nest that prevent them from predation ,experiencing varied feeding habit, compensate for the scares food, maintain nutrient cycle, controlling agro ecology by occupying different altitudinal class, and soil properties (Jouquet *et al*., 2011). Moreover, it is believed that pheromone regulation of the colony, cast size and its activity, its small size to occupy any patch and its cryptic behavior in addition to polyphagous and voracious foraging practice contribute to their further success in the varied agroecology (Saha *et al.,* 2016).

Agro ecology; in this context include altitudinal class high, mid and low land that developed by the Ethiopia Ministry of Agriculture (MOA) and Ethiopian Institute of agricultural research (EIAR) (Dereje Gorfu *et al.,*2011).As various cultivation is possible in agro-ecologies, termites are attracted by human activity to these varies land use system. Land use system in this particular scenario refers to the ways that people of the area use land and the natural resources it provides. In the studied agro ecologies, the dominant land use systems were; farm/ cultivated, grazing, disturbed forest and built-up, their features were demonstrated according to (Olugbemi, 2013). Built-up land use was characterized as small village.

As the document of the present literature revealed, termites are said to be abundant and diversified and comprise of 3106 described species (Krishna *et al.,* 2013).When termite diversity frequently increases, termite soon represents real microhabitats biological entities of the world (Engel , 2011).Termites were locally decentralized in their habitats. They have self-organized social life systems. No single insect acts do as any single termite acting alone. Termites were able shoulder such heavy kind of responsibilities at the expense of their colony (Engel 2011).

A typical colony of termites contain termite queens that lay about 25 eggs per minute, 36,000 eggs per day and 13,140,000 eggs annually (Sutuma Edosa ,2015),All these eggs live in mounds founded by a single primary king and Queen. The mound supports colony that comprises of 3,000 – 200,000 individuals it can also accommodate more than these family members as the size of the mound allows (UNEP, 2000). The colony members comprises of castes; sterile castes (worker, soldier,) and fertile castes (alates, secondary reproductive's, queen and kings).Each castes perform activities independently and had contribute for the perpetuation of the colony by being communicating through secreting pheromones. Termites regulate the proportion of different castes in the colony to maximize the survival of the colony, Based on their habitat these termites are categorized to damp wood dwellers, dry wood dwellers under and aboveground dwellers (Bignell *et al*., 2011).

2.2. Distribution and Species composition of termites

Termites are found in all terrestrial environments under and above the ground, but never inhabit aquatic areas as they may have delicate body cover. Termites in terrestrial environment occupy a wide array of microhabitats, distributed vertically from deep in the soil to the crowns of emergent trees (Rahman *et al.,* 2013). Such wide distribution of termite in the tropics and some temperate region extend up to 45^{o}N and 50^{0} S implies termite cannot perpetuate beyond this altitude (pears, 2006) In spite of this, termite distribution may cover over two-thirds of the landmass of the world (Abdurahman Abdulahi, 1991).These unlimited distribution allow termite fauna of Ethiopia to includes; Pan-African, East African and West African or sub-Sahelian species. As a result Ethiopian termite fauna comprises; a single Palaearctic species, ten endemic species to Ethiopia and the others are from the neighboring regions. Termite distribution depends on agrecology and land use system. As the Land-use intensification has a direct effect on termite encounters, individuals and species richness in an ecosystem. Termite densities are also independent of land-use systems **(**Olugbemi, 2013).

Termite's worldwide distribution was at the expense of their polymorphic nature of the colony (Indrawan *et al*., 2007). But, the geotropic termite surveys for analysis of the global biogeography report indicated there were latitudinal variation in termite's richness and abundance even on small geographic coverage. Because, with varied latitude there is integration of temperature and precipitation gradients that are the major predictors of global patterns of vegetation structure, productivity, and plant and animal species richness (Hawkins *et al.,* 2007).

Termite distribution is more abundant both in tropical and subtropical ecosystems, particularly its richnes decreases with increase in land-use intensity. They are highly distributed in low lands where there is dry temperature and red soil is found and more abundant in grazing lands where there is high traffic of grazing animals (Jones and Eggleton, 2011). As a result in tropical terrestrial forests, ecosystems termites' density and biomass may reach 10, 400 individuals.m^{-2} and 120 g.m-^{2} respectively (Eggleton *et al,*. 1996). Study conducted in Amazonian rain forest reveals that the abundance of termite per hectare reaches up to 90 species (Martius, 1994).

Termite composition and abundance has paramount importance to know the role of termites in ecosystem processes and functioning as it provided important insights into termite abundance and biomass (Dahlsjo *et al*., 2014).Species composition refers to overall total termite species collected from sampling area without estimating population density. Species composition enables predictions of how ecological systems are likely to respond to environmental changes since termites are important decomposer organisms functioning ecosystem processes (Gessner *et al.,* 2010).

The current review demonstrates, species composition differs among plots within the same land use, or across a single site in relation to topographical or other environmental factors (Eggleton *et al*., 1995; Eggleton *et al*., 2002). Hence, standardized direct search sampling protocol (Transect or quadrant) are used for searching different microhabitats (Dawes-Gromadzki, 2008). The study of termite species composition and assemblages may be used as a model to evaluate the disturbance effects on an ecosystem that alter climatic change in a given area. Land-use intensification has a direct effect on termite encounters, individuals and species richness in an ecosystem. However, termite densities are also independent of land-use systems (Olugbemi, 2013).

Although, termite had a long history in the world, its study begins from the first world war in 1969.As report in the literature reveals, globally over 3,000 species of termites are known (Munthali *et al.* 1999).These termites are grouped under seven families and 281 genera (Grohmann *et al*., 2010; Logan *et al.,* 1990; Pearce, 1999). When termite study begins there were 17 invasive termite species that established in new habitats. In the year 2011however, these invasive termite species increased to 28 invasive termite species (Evans, 2010) and distributed all over the world.

Phylogenetically there are two categories of the lower and higher termite. The higher termites are the most advanced termites that form monophyletic group (Aanne *et al*., 2002; Krishna *et al.,* 2013) .Both higher and lower termite's categories in all agroecology and land use systems of the world,

Based on their habitat termites are categorized as subterranean termites (live beneath the soil), dry wood termites (spend their life in dry wood) and damp wood termites (prefer to live in moist wood) (Govorushko, 2019). However, termites based on their feeding habits divided into four groups; wood feeders, soil feeders: fungus growing and grass feeders (Brauman *et al.*, 2015).Their distribution was estimated to occupy over one third of land mass of the world.

In Africa there are three lower termites' families; Kalotermitidae, Rhinotermitidae and Hodotermitidae and one higher family called Termitoidae (Maayiem *et al.*, 2012). This termite species richness in Africa was contributed by the presence of favorable climatic conditions (Eagleton, 2000; Maayiem *et al.*, 2012),As a result, African is known in termite fauna, for the reason that 1000 species of termite fauna in the world are belong to the African continent (Engel *et al.,* 2011). Therefore, by world standard Africa ranked the top continent in terms of termite species richness with over 70% of all the identified species (UNEP, 2000; Ahmed Ibrahim *et al.,* 2011; Ahmed Ibrahim *et al.,* 2014).

The rise in human population pressure of West Africa gears the intensification of land-uses system, that consequently contributes to an increase of termite diversity (Ahmed et *al.,* 2011). Moreover, termite assemblages in African ecosystems were dominated by subterranean species (Sileshi Gebre *et al.*, 2010). The 1986 and 1987 assessment of termite damage cause to crops, forestry and rangeland in southern, western and eastern Ethiopia render to access the assemblage of termite fauna of Ethiopian .At present, Ethiopian termite fauna were 61 species that belongs to 25 genera in four families. These termites are representing about 6.3% of the African termite fauna (Cowie & Wood, 1989).

Despite the high population prevalence of termites, termite inventory was conducted in only few parts of the country. This limited national termite inventory was due to scares tools and presence of few specialists in Africa (Daniel Getahun and Emana Getu, 2017). In this long period termite survey, four families; Kalotermitidae, Hodotermitidae, Rhinotermitidae and Termitinae were found as termite assemblage of Ethiopian. From these assemblage, western Ethiopia share the subfamily Macrotermitinae that comprises of the genera; Macrotermes, Microtermes, Odontotermes and Pseudacanthotermes (Daniel Getahun and Emana Getu, 2015)

2.3. Termite species composition in different agroecology land use systems

Termite species composition assemblage in agroecology land use system varies depending upon the nature and availability of resource. To this end, the land uses are described as indicated in Table 2 1

Table 2 2.Description of Disturbed Forest, Grazing and farm land uses system (Olugbemi, 2013)

Land use system	description
Disturbed Forest	Primary Forest with some degree of human disturbance, such as logging, grazing, and with lighter canopy compared to primary forest
Grazing land	Savanna like , runner grass and bushes
Farmland	Cultivated land of diverse characteristics, comprising few trees, plots of cultivated land for subsistence agriculture, and high percentage of bare ground

2.3.1 Termite species composition in grazing land

Grazing/ pasture land is the area currently under grasses and open wooded shrubs that are used for grazing and it has been under intensive grazing for a long period of time. Grazing areas are suiting several termite species. Consequently, in *Macrotermitinae several* species consume grass litter as a significant part of their diet in most part of tropical Africa. The most common of these species belong to the genera *Macrotermes, Odontotermes* and *Pseudacanthotermes* (Wood and sands, 1991).

Grass feeders are typically foraging through subterranean galleries. They lead galleries to surface of foraging holes from which termites emerge to remove dead grass and grass litter under cover of constructed soil sheeting. Termite foraging is particularly obvious during the dry season when bare rangeland did make up to 55 foraging holes per m^2 (Cowie and Wood, 1989; Mugerwa *et al*., 2008). In this regard Mugerwa *et al.* (2008) reported that termites were the major barrier to pasture restoration on degraded bare patches and consumed over 60% of standing grass biomass. They are typical pasture feeders in the semi-arid ecosystems of Uganda (Demissie *et al.*, 2019). Additionally, the same genera were also reported in rangelands of Ethiopia (Wood and Sands 1991).

Similarly, in the Durfur region of Sudan, the genera *Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes* and *Microtermes* remove dead grass and grass litters with emerging through subterranean galleries. Grass eating termites are often many in tropical and subtropical grass lands where livestock also graze and compete with grazing animals for forage. Most of grass foraging termites forage grass in dry season more than any time (Demissie *et al.*, 2019). There are grass harvesters in Diga district in East Wollega zone, Western Ethiopia. Mound making *Macrotermes* species are also abundantly found in grazing land semi-arid district of Nakasongola (Hirpha Legesse *et al.,* 2013).

Termites feed on pasture grasses, also feed crops, and woody materials found in the range land. The most prevalent termite species in rangeland vegetation were subterranean termites (Mugerwa, 2007).Termite assemblages in the rangelands of Central Uganda consist of species from only one family (Termitidae), three subfamilies (*Macrotermitinae, Termitinae and Nasutitermitinae) and eight genera (Macrotermes, Odontotermes, Microtermes, Ancistrotermes, Pseudocanthotermes, Trinervitermes, Cubitermes,* and *Procubitermes*). All of these genera infest and cause damage to grass. However, subfamily Macrotermitinae and the genus *Macrotermes* infest more than others, because they constitute over 69% species (Mugerwa *et al.,* 2011).

Termite species from the rangelands of Uganda for example can consume over 60% of the available herbaceous (grasses and forbs) vegetation and resulted in bare land that facilitate extra-ordinarily high rates of erosion which eventually reduced soil productivity and gives the opportunity for the succession of shrubs (Mugerwa *et al.,* 2013).Overall, various species of *Macrotermitinae Odontotermes* and *Pseudacanthotermes militaris* (Hagen) are inhabit grazing lands of Africa, Ethiopia and western Ethiopia. However, *Macrotermes* termites density in the southern zone are higher than in western and central Ethiopia Western Wollega had the dominant grass feeder M*acrotermes subhyalinus* termite almost everywhere in the area. O*dontotermes* spp. and *Pseudacanthotermes militaris* are locally distributed in higher altitudes of ManaSibu, Nedjo-

Jarso, Ghimbi and Ayra-Guliso districts (Daniel Getahun, 2018).In this part of the country termites damage and causes denuded grasslands in Wollega were regarded as the primary cause of vegetation denudation. Likewise in Borana zone of southern Ethiopia ONRS, high densities of *Macrotermes* termite mounds pressure contribute to the extreme removal of grasses (Demissie *et al*., 2019).

2.3.2. Termite species composition in cultivated land

The cultivated field (crop land) has been under cultivation with oxen drawn plow for more than 30 years and planted for different annual crops. During the study the field was cultivated with teff crop. Mono-cropping is the dominant cropping practice. In Africa soil-feeding termites were computing for soil fertility in cultivated land, *Macrotermes, Odontotermes* and *Cubitermes* are the common termites that build mound on or underground surface of this area (Oliveira *et al.,* 2012). In Ethiopia, mound builder and soil feeding termites are the genus *Macrotermes* specifically *Macrotermes subhyalinus* (Rambur) and *Macrotermes. Herus* (Sjostedt) (Abdurahman Abdulahi *et al.*, 2010).

The genera *Macrotermes, Pseudacanthotermes* and *Odontotermes* which reported in western Ethiopia were the termite faun of west Wollega regions thought to occur in four districts of West Wollega areas. Daniel Getahun and Emana Getu, (2014) in their study conducted in three districts of East Shawa Zone of Oromia Regional State three land-use types: farmland, rangeland, and protected lands maximum infestation of termite genera; Macrotermitinae (subfamily *Macrotermes Microtermes Odontotermes)* were reported in sandy light soil (48.7 %) followed by alluvial soil (27.3 %) and (8.0%) light black soil.. However, termites are found in all types of soils except in semi permanently water logged areas and in certain deeply cracking vertisols. Whatever the soil type was, termites infest soil by removing the vegetation cover that ultimately enhances soil degradation by reducing erosion (Demissie *et al*., 2019). Such termite activities alter soil environment and make soil inconvenient for productivity of crops (Gebreslasie and Meressa, 2018).Crop land pests of termite species composition in southern Zambia were the genera; *Macrotermes, Odontotermes, Pseudocanthotermes, Allodontotermes, Ancistrotermes, Amitermes* and *Microtermes* (Ahmed *et al.,* 2010).

In addition, others are also specialized soil feeders in the family Termitidae and subfamilies *Termitinae, Nasutitermitinae* and *Apicotermitinae. Nonetheless*, these soil feeder's workers mouthparts must suit adapted for soil types as they are dependent on soil. Termites are an important factor in the characterization of the dominant farming system (Ogunkunle *et al.,* 2008).

2.3.3. Termite species composition in Forest land use

The field identified as the forest land has no cropping history. Currently, the field is under disturbed or mixed natural forest comprising bushes, shrubs and wood plants. The dominant woody plants in the site are Acacia species, *Croton macrostachyus*, *Ficus sycomorus*, *Ficus capensis* and *Prunus africanus*. Termites are important pests in tropical forestry, especially in areas where exotic forestry trees are planted. More importantly, they are one of the major agro forestry pests in the tropics (Nyeko and Olubayo, 2005).

Termites in dry and semi-desert areas collect live green plant material and cause damage to living grasses, crops and seedlings. In addition they attack weak plants that are wilting or damaged. The act of termites on green plants leads them to be considered as important agricultural and domestic pests. In accordance with this, Sileshi Gebre *et al*. (2009) and Abdurahman Abdulahi *et al*. (2010) viewed that the presence of termitarium adjacent to the crop field, forest and near trees aggravates termite damage. Termitarium host termites that cause damage to crops that found adjacent to this mound. In East Africa, the loss caused by adjacent hosted termites on various crops and tree species ranging from 50-100% (Nyeko *et al*. 2010). 100% transplanted eucalyptus seedling loss is common from seedling up to the matured tree (Abdurahman Abdulahi, 1995),

In western Ethiopia, termites cause severe devastations on the forest, and thus soil remains bare and exposed to elements of soil erosion (Gebreslasie and Meressa, 2018). *Macrotermes* termites are known to infest forestry seedlings, including the matured tree bark as these trees restore water from deep ground, Therefore termites infest from the base of stem below the soil surface up to a height of two to three meter above ground to get rid of water (Abdurahman Abdulahi *et al*., 2010). For instance, Eucalyptus and junipers tree bark were damaged and terminate translocation of water and nutrients and cause complete drying of barked trees and eventually the tree wilt and die, In similar case, Macrotermes attacks, the edible parts of head cabbage under soil cover and infestation on sugar cane root system (Gebreslasie and Meressa.2018).

2.4. Global Economic impacts of termites

From economic perspectives, there is a controversial idea about termites, Termites are representatives of the invertebrate macro fauna that play an important ecological role in many ecosystem particularly in nutrient-poor environment (Avitabile *et al*., 2015).

Termites which act as soil engineers, decompose and recycling organic matter and improve soil fertility for butter crop yield (Jouquet *et al,.* 2014), This termite performance able them to be the most dominant arthropod decomposers and have an extraordinary ecological impact on both agricultural and nonagricultural ecosystems through playing a significant role in the global carbon cycle, decomposition process and mineralization of nutrient-rich cellulose (Traore *et al.,* 2015). Termites are social consumers of cellulose and lignocelluloses found in dead wood, grass, micro epiphytes, leaf litter, and sometimes cultivated fungi that account to their fertility.

Out of the 4000 estimated termite species, the 3000 termites species described were distributed to a tropical and temperate area to maintain varies fundamental life activities. Termite's in their habitats process between 50% to 100% of dead plant biomass (Hartke and Baer, 2011), Beside, they maintain soil pH, increasing water retention, mediating decomposition and nutrient cycling, and creating surface areas for easy access of microbial colonization. (Traore *et al.,* 2015)

In so doing termites create favorable conditions for primary producers, thereby serve as food source for a variety of animals; birds, amphibians, reptiles, and mammals, including humans (Ghaly and Edwards, 2011; Bandeira et *al.,* 2010).In this aspect, termites together with ants and earthworms, constitute the three soil ecosystem engineers (Lavelle *et al*., 2006).They are directly or indirectly involved in modifying and making the available nutrients for other organisms through the decomposition of plant materials. Termites are not only limited to the decomposition of wood and leaves but, also decomposes and recycle bark straw and animal products like mammalian hooves and dung matter (Jouquet *et al*., 2011).

Termites decomposed materials make organic matter OM and also add exchangeable K and available P up to 76 times in mound soil that in turn increases N, P and K contents of maize leaf (Frageria and Baligar 2004, Ricardo *et al,* 2004). Ca, K and Mg nutrient level of mound soil also increased when decomposed leaf-litter was mixed with soil (Daniel Getahun and Emana Getu, 2017).Termite mound soil therefore has nutrients more than the surrounding soil **(**Dhembare, 2015).This add mixture of mound soil nutrient increase mound soil organic matter content five-times greater than those in adjacent and non mound soils,(Mahsa *et al*..2017).

In developing countries, nutrient rich mound soil accordingly can amends soil fertility as an option to high price inorganic fertilizer inputs (Abiyot Lelisa *et al*., 2016).The change in physical and chemical properties of mound soil was attributed by termite *Macrotermes, Pseudacanthotermes* and *Odontotermes* (Afolabi, *et al.,* 2014). These termites allow mound soil to be better in soil texture (bulk density, moisture content ,porosity and high mineral nutrients pH, OC, OM,TN exch. Ca, Mg, K and P to be significantly higher ($p<0.05$) in termite mound soil than in adjacent soil. In supporting this, Daniel Getahun and Emana Getu, (2017).reported that the higher accumulation of exchange cations in mound soil than adjacent soil indicate that termites collect these minerals from the subsoil to build the mounds.

As a result, termite mound soil materials in the vicinity of mounds are widely used for fertilizing agricultural lands by resource poor farmers in the highlands of southwest Ethiopia (Abdeta Jambere *et al.,* 2017).In so doing, termites shoulder important task to deliver ecosystem services through the functioning of self-organized inter-nested systems (Lavelle *et al.,* 2016).

Plant grown in mound soil treated were tall and dark green with large-sized stems and ears (Alemu Lelago and Tadele Buraka, 2019).while plants from the untreated plots were relatively weak and lanky (Rajagopal, 2015).Better performance of maize growth trait is attained in termite mound soil combined with NPK, in agreement with this Ezekiel *et al.* (2018) and Olowoboko *et al*. (2017) reported that, the application of inorganic fertilizer NPK to mound soil facilitates growth of the maize crop. Frageria and Baliga, (2004) stated that, number of panicles ,shoot in rice and pods in bean, dry weights of shoot and grain of upland rice and common bean grown on termite mound soil were significantly increased by the NPK treatment.

In addition to this, it was indicated that termites are eaten by man in many parts of the world including Africa. Alates are so rich in protein and fat content that they are consumed by some family members in Africa (Pearce, 1997). They are also used as food source of by some domestic animals. Mushrooms that grow out of fungus gardens in mounds of some termites were eaten by Chinese people and sold in markets in Asia and tropical Africa (Ofgaa Dijirata *et al,* 2007).

Termites were also used as medicine in Australia and South America. In Ethiopia, termite as a food source is not reported, but used for fattening ox in few areas (Key informants)

2.5. Pest status of termites in agroecology of different land use systems

In spite of providing several benefits, some species of termites are described as destructives insects. They damage agricultural products, forest and structural materials including home furniture's and also retard the productivity and composition of plant communities. The loss due to termite damage demand expensive repairs and prevention these altogether require worldwide costs of $40 billion. In which, 80% of this costs was contributed by termites from the family Rhinotermitidae (Rust and Su, 2012).

In supplementing this, Ye *et al.* (2004) reported that more than $40 billion worldwide loss comes from termite damage. Termite economic loss across the world therefore, impel the present day worldwide termite study (Bong *et al.,* 2012).This indicate that, successful termite management need adequate knowledge of pest status and the range of material which termite attack and geographical preference of the termite (Daniel Getahun and Emana Getu, 2014)Termites do not pose damage at fast rate but, resulted slowly as it has several food source options, the damage imposed gradually and escalate with prompted change in termite survival strategies, specifically, ecological change, resulting from interference caused by an expanding human and its intensified activities together with the raise in livestock population.

In Ethiopia, termite problem in western part of the country was reported in 1904.Termite population were so increases and infestation claimed in over a wide area and spread in different directions of Eastern Wollega region following trader's foot walk ways and become a major constraints of crops to this Wollega area (Ofgaa Djirata *et al*., 2007). Though, termites constitute 10% of all animal biomass (Van Huis, 2017).More than 300 termite species are known pest (Kumari *et al.,* 2013).There are pest termite pest species members in all higher and lower termite families. However, majority of pest termites are categorized in Termitidae (UNEP, 2000).

Termite's pestiferous act is related to its agrecology and land use system. Where there is high termite abundance (n) agrecology and land use system the damage is high following the high infestation (Van Huis, 2017). Most tropical Africa pestiferous termite species to crops, trees, and rangeland belong to the family Termitidae subfamilies; *Macrotermitinae, Nasutitermitinae,*

Termitinae, and *Apictotermitinae.* About 20% of Termitidae families were serious pests that cause over 90% damage to agricultural crops, forestry trees, buildings and wooden structures. These are Macrotermitinae termites that comprises of majority of Macrotermitinae termites cause damage in Africa and Indo-Malaya regions. In this subfamily, the genus *Macrotermes* are known to result strong damage as they own large colonies which constitute several million individuals.

It was believed that less than 5% of the African termite's fauna are pests (Sileshi Gebre *et al*., 2008) .Likewise, Maayiem *et al.* (2012) reported that termites pose evident threats to both food and industrial crops. For instance, Uganda farmers have reported termite attacks on maize and cassava crops, coffee and vegetables, which had been also reported from Kenya, Malawi, Zambia, Ghana and Ethiopia (Mugerwa *et al.,* 2014). It was reported that, pest termite species in Ethiopia are the genera; Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes, Amitermes and Microtermes. Ten of these species are endemic to Ethiopia (Abdurahman Abdulahi, 1990).These pests were known damaging teff, vegetables and Eucalyptus in several parts of Wollega and Asossa zones. Maize pre and postharvest losses reported due to these termites are up to 50% (Daniel Getahun and Emana Getu, 2014).

Similar sever termites damage was reported in low land grazed area of Wollega (Abdulahi *et al*., 2010).The damage is sever and pose huge infestation up to 100% crop loss .These Pest termite fauna of western Ethiopia are in the family's *Kalotermitidae, Hodotermitidae, Rhinotermitidae* and *Termitidae.* About 25% of these species are pests of agricultural crops, forestry seedlings and grazing lands. Termite fauna of west Wollega (*Microtermes aethiopicus* (Sjostedt) and *Firmitermes abyssinicus* (Sjostedt) *are* endemic to Ethiopia (Sands 1976; Abdulahi *et al*., 2010).

2.5.1 Termite damage to rangelands

Termites are known by their beneficial and destructive aspects to range lands. They directly or indirectly modulate habitat and resource availability. In some instance, they are thought to be important in nutrient recycling as soil engineers also regarded as the main factors in range land damage that result in soil erosion. Macrotermitinae consume grass litter as a significant part of their diet throughout tropical Africa, the most common of these species belong to the genera *Macrotermes, Odontotermes* and *Pseudacanthotermes (*Mugerwa, 2011).These *Macrotermes, Odontotermes* and *Pseudacanthotermes* are the major pest species that devastated pasture in the semi-arid ecosystems of Uganda. Some of these genera constitute majority of pest species in the rangelands of Ethiopia (Pearce *et al.,* 1995).

Pest species of termites; *Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes* and *Microtermes* were responsible for the destruction of pasture and crops in the Durfur region of Sudan (Mugerwa, 2011). Range land termites damage grasses through leading subterranean galleries to surface foraging holes from which termites emerge to remove dead grass and grass litter under cover of constructed soil sheeting, these forager termites are active during the dry season. In the dry season they can easily make high up to 55 foraging holes per m^2 (Cowie and Wood, 1989).

Termites do not bring about sudden damage to range land, but, occasionally associated with severe damage to rangeland vegetation (Pearce, 1997).The intensity of range land damage that resulted by *Macrotermes* species was high due to high competition for grazing between termites and livestock's. This situation enhance soil degradation by hastening erosion (Demissie *et al.,* 2019).Subsequently, resulted in reduced feed which cause livestock deterioration and death in Nakasongola and Uganda (Mugerwa *et al.,*2011). Extreme range land damage is common in pastoral communities (Demissie *et al.,* 2019).Termite impacts to plants community induce population dynamics that ultimately alter distribution of birds, bats, mammals, and arthropods including tree seedlings with decomposing standing, dead trees and stumps (Evans, 2011),

In Ethiopia, particularly in western Ethiopia, western Wollega *Macrotermes subhyalinus, Odontotermes* spp.*Pseudacanthotermes militaris*is were the cause for rangeland denuded that happen to facilitate serious erosion (Daniel Getahun and Emana Getu,2017).In particular, *Macrotermes* are often the dominant grass feeder that leads to degradation of the pastureland in higher altitudes in the absence of fodder and soil erosion (EECMY-WS, 1997). Various report indicate that, large termite colony of *Macrotermes,* in a savanna habitat can remove more than one tone of vegetation annually (Pearce, 1997). In a study conducted in Dire District of Borana zone, 98% of the respondents recognize that the poor rangeland productivity cause starvation that ultimately make susceptible for various disease of animals poor feed lower milk, beef yield and poor traction. These all are affecting the socio-economy of the community.

2.5.2. Termite damage on Maize crops

Termites can cause widespread damage to all crops from seedling to harvest stage (Wood and sands, 1991).In Ethiopia termite problem is more severe in western part of the country and is a predominant problem in the termite infested areas of Oromia National regional state, specially Wollega (East Wollega Horo Guduru Wollega, Kelem Wollega and West Wollega), (Jima-, Buno Bedelle-, Ilubabor Bor- and East Shawa- Zone).In this part of the country, termite problem is escalating gradually and has become worse than ever (Daniel Getahun, 2020). The most severely attacked crops among others were maize, teff, finger millet, pepper and sugarcane. According to FAO (2011) report, 50% of maize and hot pepper damage in Wollega was due to *Macrotermes* Species. More importantly, *Macrotermes subhyalinus* causes damage to maize, teff, eucalyptus, grasses, wheat, barley, pepper, tomato and other vegetable crops. Termites of west Wollega ManaSibu and LaloKile districts attack these crops from the seedling to maturity stage causing up to 100% yield loss. Girma Demisse *et al.* (2009).report shows that termites 50% pre- and post-harvest damage on maize and pepper and serious damage on young eucalyptus trees was caused by *Macrotermes herus* (Abdurahman Abdulahi *et al*., 2010).

In Africa Maize among other cereal crops gets more susceptible to termite damage as it was exotic and it has not been exposed to the range of termite life-history (Ayuke, 2010). Hence, termite damage management on maize need to have compensatory growth by surviving plants following early season attack, harvest of cobs on the ground from plants lodged late in the season (Daniel Getahun, 2020).

2.5.3. Termite damage to cultivated land use

Termite infestation is an important factor in the livelihood of the dominant farming system. It demands appropriate attention in the characterization of the effect of termite infestation on some crop types and the constraints it imposes on their farming system. A soil infested with termite mostly resulted in distortion of soil structures and compactions. Hence soil becomes difficult to plough, this in turn results in a reduction of productivity of crops (Gebreslasie and Meressa, 2018).Termite pest species in agriculture of African genera are; *Macrotermes, Odontotermes, Pseudocanthotermes, Allodontotermes, Ancistrotermes, Amitermes* and *Microtermes* (Ahmed Ibrahim *et al,* 2010).

The majority of the species from the subfamily *Macrotermitinae* are not only harvester species also resort to consume standing crops (maize, sorghum, wheat, teff, pasture etc.) *Macrotermes* species are polyphagous pests consume multifaceted food sources. As a result devastate agricultural crops plants (seedling, green foliage wood fibers) and postharvest stored products (Upadhyay, 2013).Termites in dry and semi-desert areas collect live green plant material and cause damage to living grasses, crops and seedlings. Wilting plants are so weak and frequently attacked. This situation leads termites to be important agricultural and domestic pests (Logan *et al.,* 1990).

In accordance with this Sileshi Gebre *et al*.(2009); and Abdurahman Abdulahi *et al*. (2010) stated that the presence of termitarium adjacent to the crop field, forest and near trees aggravates termite damage that consequently cause economic hardship to individual producers (Sileshi Gebre *et al*., 2008). In which rural small scale farmers are the victims among others

2.5.4. Termite damage to Forest land use system

Forest trees support the survival of living organisms through soil and water conservation, carbon sequestration, nutrient recycling, and ameliorating/improve/environmental pollution and also support wildlife which form the part of the ecological functions of environment (USDA, 2016).However, termite damage is a major problem in tropical forest especially where exotic tree species are used. Particularly, stressed trees are the most susceptible to termite attack. These forest trees are highly infested with dry-wood termites (Kalotermitidae) that live and feed on dead wood and living parts of mature trees.

The most common termite genera associated with forest destruction were; *Coptotermes, Rhinotermes, Macrotermes, Odontotermes, Reticulitermes* and *Microtermes* (Su *et al.,* 2000).Out of these genera, *Coptotermes* (Rhinotermitidae) causes more widespread and serious damage to mature trees in Malaysia and Australia. Geographic regions determine the extents to which termites are problems to trees and the nature of loss they brought about is very much related phenomena to each other. In low rainfall tropical and sub-tropical regions of the world, a dry savannah-type of forest has developed. This makes easy termite attacks and appears most acute and cause serious problems in the development of nurseries and young tree plantations. Daniel Getahun and Emana Getu (2017) state, tree species of the tropical planting are susceptible to termite of a popular group.

In Africa, the most serious losses of trees reach up to (100%). It was predominantly due to various *Macrotermitinae (*Termitidae) that include *Macrotermes, Odontotermes* and *Microtermes.* In dry regions these termites occur in young, exotic Eucalyptus trees and where exotic forestry trees are planted. Therefore they are most likely one of the major agro forestry pests in the tropics (Nyeko and Olubayo, 2005). Termite loss on various crops and tree species in East Africa reach (50-100%) (Nyeko *et al*., 2010). Of the aforementioned *Macrotermitinae*, the most troublesome types are the fungus-growing termites that able to cause over 90% damage in agriculture, forestry and urban settings. These termites induce damage through building large mounds adjacent to agriculture, forestry and urban settings for easy infestation in one way and make the African landscape to be visually impressive in the other way (Sileshi Gebere *et al*., 2009; Abdurahman Abdulahi *et al*., 2010).

In Ethiopia, serious termite damage was mentioned as a loss of 100% Eucalyptus tree one to two years after transplanting, 45- 50% of maize, 50-100% of teff and 25% of sorghum in highly termite infested districts of Western Wollega zone (Abdurahman Abdulahi, 1990, 2000; OADB, 2001).The devastated forest tree of western Ethiopia pose serious soil erosion (Gebreslasie and Meressa, 2018).In addition, they cause damage to the transplanted seedlings by cutting the stem at or near the ground level. Macrotermes colonize the bark to suck water stored in the bark. They get rid of water problem through ringing the bark of the stem and attack the root system specifically the tap root and cause wilt that eventually cause death of plants (Cowie *et al*., 1989).

The absence of damage or the incident of little damage recorded both on indigenous and exotic tree seedlings in the Maki-Batu area of the Central Rift Valley of Ethiopia may be due to the absence of pest species, low termite population density and presence of enough food (Daniel Getahun and Emana Getu, 2017**)**. Abdurahman Abdulahi *et al*. (2010) reported that in western Wollega, *Macrotermes subhayalinus, Microtermes, Ancistrotermes, Pseudacanthotermes militaris, Odontotermes* are the most damaging termite species.

2.6. Management of Termites

Termites cannot deliberately cause damage unless in the process of performing their ecological roles or in the absence of food source for their forage. When this termite’s engaged in such intensified activities they cause severe problem in all over the world (Paul *et al.,* 2018).Termite multiplies rapidly to increase their population. It is when termite population was high that they excrete massive destruction to materials .In order to halt these termite problem, termite control should involve killing every single one of them in or around property. With controlling pest termite species and other arthropods importance ecosystem services can be achieved (Paul *et al.,* 2018).

Termite management seeks to limit the survival and reproduction of potential pests by removing sources of water, food, and shelter. Moreover, termite management practice was either to reduce the population or to reduce the magnitude of the severity of damage (Ogedegbe and Ogwu, 2015).However, no single control method is sufficiently effective against these pest termites. Termite management therefore needs various management options used in integration of cultural, traditional and botanical methods, this approach is sometimes referred to as 'Integrated Termite Management' (ITM). Integrated Termite management is environmentally safe to humankind (Paul *et al.,* 2018).

2.6.1 Overview of termite management practices in Africa

In Africa, various termites' management strategies have been developed over the last few decades under laboratory, in different field and on horticultural crops. Over long years ago farmers have developed several strategies and indigenous techniques to cope with increasing vulnerability to the termite problem. They employ traditional practice to shift away from the stress and devise a means to tolerate termites However, termite management strategies in Africa is in accordance with the experience adapted per continent (Akutse *et al.,* 2012). In most cases the management rely on traditional (indigenous understanding) preventive and curative approach. Curative management applies to rectification of termite attacks established in existing environment with considering termite's biology, ecology and behavior (Mahapatro *et al.,* 2011). In the African setup, traditional methods are found simple to follow and conduct. Moreover, are cost effective (Sileshi Gebre *et al.* 2008),

Ethiopia is among the most countries in tropical Africa which are known for their termite fauna (Cowie *et al.,* 1990).Ethiopian termite fauna consist of 61 species belonging to 25 genera in four families. This data was recorded in 1986 and 1987 assessment of termite damage on crops, forestry and rangeland in southern, western and eastern; Sidamo, Gamogofa, Wollega, Illubabor, Hararge, Shewa and Keffa areas was conducted .This inventory render to access the assemblage of termite fauna of Ethiopian. The present report elucidate these termites are representing about 6.3%

of the African termite fauna (Cowie & Wood, 1989).Termite species composition assemblage in agrecology land use system varies depending upon the nature and availability of resource.

Accordingly, the Ethiopian termite fauna consist of species which are widely distributed in sub-Saharan Africa. They include species of *Macrotermes, Microtermes, Synacanthotermes, Microcerofermes,* and *Trinervifermes* These African termite fauna diversity belong to termite fauna of Western Ethiopian (Ahmed Ibrahim *et al.,* 2011).Termite's genera of the western Ethiopian include *Macrotermes, Odontotermes, Microtermes, Amitermes, Microcerotermes, Angulitermes,* and *Trinervitermes.* These Western Ethiopian genera are common in west Wollega regions such as *Macrotermes, Microtermes, Odontotermes*, and *Microcerotermes* (Cowie & Wood, 1989),

Among *Macrotermes, Macroterms subhyalinus* (Rambur) and *Macrotermes adschaggae* (Sjosted) were mostly the abundant termite's species of Ethiopia and Wollega regions. Most of them are confined as subterranean that exhibited difficult behavior to locate and destroy (Abdurahman Abdulahi, 1990). Moreover, termite assemblages in African ecosystems were dominated by subterranean species (Sileshi Gebre *et al.*, 2010). In Ethiopia, mound builder and soil feeding termites are the genus Macrotermes specifically *Macrotermes subhyalinus* (Rambur) and *Macrotermes. Herus* (Sjostedt) (Abdurahman *et al.*, 2010).

Despite the large range number of termites species composition, termite inventory was conducted in few parts of the country. This limited national termite inventory was due to scares tools and very few specialists in Africa, Ethiopia ((Daniel Getahun and Emana Getu, 2017).As termite's population tremendously increases they move to East Wollega zone ((Ofgaa *et al,* 2007).Termites pest's in Ethiopia are reported serious pests as they in discrimately attack a wide range of agricultural crops, forest trees and buildings. Moreover, severe pests are found in the desert regions (Daniel Getahun and Emana Getu, 2014).

The four termite families composed of pest species in Ethiopia are Ka1otermitidae, Hodotermitidae, Rhinotermitidae and Termitidae (Abdurahman Abdulahi, 1991). These Ethiopian termite species feeding on dead plant materials, soil organic matter, or herbivore dung (Cowie and Wood 1989). 20% of Termitidae are known serious pests. These termite cause over 90% of damage to agricultural crops, forestry trees, buildings and wooden structures .Maize, teff and sorghum crops are mostly damaged by *Macrotermitinae* termites as they own large colonies which constitute several million colony members. These termites damage crop and results up to 50% pre and postharvest losses in maize. The damage was also severe in teff, vegetables and Eucalyptus in several parts of Wollega and Asossa zones (Daniel Getahun and Emana Getu, 2014).Termite's damage on badly denuded grasslands in Wollega are regarded as the primary cause of vegetation denudation (Demissie *et al*., 2019).

In most part of the country the grass lands turned bare as termite infestation continue sever .However, *Nasutitermitinae* eat only dead grass and appear harmless (B&M Development Consultants 1997). Termite infests soil by removing the vegetation cover that ultimately enhances soil degradation and erosion. Such termite activities alter soil environment and make soil inconvenient for productivity of crops (Gebreslasie and Meressa, 2018). Aggressively infested soil loss their fertility and turned to acid.

In Ethiopia, mound builder and soil feeding termites are the genus Macrotermes specifically *Macrotermes subhyalinus* (Rambur) and *Macrotermes. Herus* (Sjostedt) (Abdurahman *et al.*, 2010).Annual crops grown Tree seedlings in western Ethiopia are attacked by one or more species of termites throughout growth stages (Abdurahman Abdulahi, 1990). Termites are important pests in tropical forestry, especially in areas where exotic forestry trees are planted. Forest tree are highly infested with dry-wood termites (Kalotermitidae) which live and feed in dead wood (Daniel Getahun and Emana Getu, 2014). Forest tree plants provide water in dry areas. Gebreslasie and Meressa (2018) reported that, in western Ethiopia, termites cause severe devastations on the forest, and thus soil remains bare and exposed to elements of soil erosion.

The frequent damage of building houses, fences, crop heaping base, bridges and traditional crop store structure by subterranean termites would unfortunately lead to deforestation and erosion and subsequent ecological disasters .The 1938 report of B &M Development Consultants, (1997) shows termite damage occurs over 40-50 years around Kiltu Kara a small town in Manasibu district, western Ethiopia. The worst part of a termite infestation is that it is very often not apparent. Termites largely stay underground or in the wood they're infesting, meaning that the infestation goes unnoticed by the homeowner until the damage is already done the far west Wollega Zone of Oromiya Region has been known to suffer from increasing termite problems for the last 20 years. This force 6% of the dweller's migrating to low lands (Abdurahman Abdulahi, 1990).This migration expose to malarial infestations and other problems like wild animal attack on livestock.

Termite control in Ethiopia relay on chemicals, traditional methods are employed to shift away from the stress or to devise a means to tolerate termites. Flooding mounds, queen removal with mound destruction , and suffocating mound with straws in excavated top of mounds ,powering dissolved salt+pepper+areke and tela residue ,manually removing galleries from the wall of house, adding ash to mounds established in house ,using termite resistant plant for construction, keeping harvested teff on craton leaf, making heap of crops on base made of termite resistant wood, traditional storage structures are among cultural methods, Daniel Getahun Debelo and Emana Getu (2017).Stated that, farmer's that pain with termites' problems used different methods of indigenous termite control. Traditional termite management varies with the farmer practices often termite venerable areas are more adopting the managent. Laboratory trials and farmers based field trials are rarely practice.

2.6.1.1. Mound destruction

Mound destruction for termite management involved physical and mechanical means to keep the population of termites at a certain level. Mound destruction is the common practices of termite management in Africa's. The physical mound distraction involves dequeening or removing of the queen from the colony, which may eventually cause destroy of colonies. Though, mound destruction was difficult, it was done through tillage and excavate using hand hoe. Mound destruction was not the fundamental means of termite control. It only provides a temporary relief from termite damage (Tasida & Gobena, 2013). Demolition of mound ground expose the internal mound to the direct sunshine rays that subsequently led to desiccation of termite as they lack hard protecting body cuticles.

2.6.1.2 Cultural termite management practice

Cultural termite management involves clean cultivation, high-density sowing, soil management, balanced use of fertilizers, proper irrigation, weeding, mulching, timely harvesting, crop rotation intercropping, (Ogedegbe and Ogwu, 2015). Cultural termite management practice was simple to follow and cost effective especially in the African practice (Sileshi Gebre *et al,* 2008; Ogedegbe and Ogwu, 2015). Cleaning and cultivation of field borders destroys the termite reservoirs and reduces foraging activities of termites and improves plant health, this allow plant to resist termite attack Termite galleries and mound constructions which hasten termite damage can be managed through proper tillage (Mahapatro &Chatterjee, 2018).

The proper use of fertilizer, well-decomposed farmyard manure, frequent irrigation and use of recommended agricultural practices increases plant vigor, which ultimately retard termite attacks (Negassa & Sileshi, 2018);Paul *et al*.,2018) ;Diouf & Rouland-Lefevre, 2018).Negassa and Sileshi (2018) described that the integrated use of manure and fertilizer improves soil fertility, crop yield, prevents soil degradation and reduces the invasion of termites. Mulching with dead plant litter or green plant biomass in the field is a good strategy to keep crops less exposed to pest (Nyagumbo *et al.,* 2015). Timely harvesting of the crops may also be very effective and efficient practice to minimize termite damage. Crop rotation and intercropping approaches are used to improve soil fertility, plant growth, natural enemy fauna and breakdown of the life cycle of termites by growing non-preferred crops (Nyagumbo *et al.,* 2015). Eerily harvested crops are secured from termite damage.

2.6.1.3 Farmers 'indigenous knowledge for termite control

Several strategies are used by farmers to minimize the effect of termite on crop, grasses and plant seedlings are introduced to the new area. For instance, introducing local potatoes to maize and sorghum field, introducing; como grass, vetivar grass and other to susceptible grasses and introducing; Oda '(locally named tiqur enchet); and other indignant seedling where there are exotic plants and bare lands favour and increase in the production of tolerant crops in all studied areas Nunuqumba, Diga and Limu districts,

In Nunuqumba, nursery site was established in termite project site for this purpose. Mound destruction campaign, slush burn in high termite infested area, crop residue removal by either burning or collecting to one place, smoking mound with using pepper pods a eucalyptus tree leaves to suffocate mounds, Dusting ashes around houses to protect termite damage, flooding of the mounds to reduce termite population, applying the residue of local Areke and local Tella to the base of construction poles and small mounds established around the wall of house.

In some few study area, cow and goat urine is applied to the mounds. Suffocation of the mound by burning of the crop residues inside and on the open side of the mound to generate heat that force the colony to withdraw from mound is also the best termite managent practice that Indians also uses (Verma *et al.*, 2018).Though burning of the crop residues provide smoke and heat, but, un able to kill reproductive alates as the mound structure provide enough resistant (Cao and Su, 2015). According to Nyeko and Olubayo (2005) report, farmers' ferment a mixture of tobacco leaves, red pepper and wood ash in water for about 5–14 days and pour the fermented solution to slightly excavated top surface of the mound and seal it as the fermented solution deter and disturb the colony. Farmers also destroy epigeal nests by direct heating and applying old engine to destroy colonies (Nyeko and Olubayo, 2005).

Direct running water in to mounds through vents of the trenches, pouring hot water, human and goat urine in to the mounds through holes are some of the practice used to disturb and kill colonies. In limu districts Fitbako *kebele*, farmer's practice applying salt mixed with local alcohol and bear residue in to the mound established around their home to kill or deter the colonies. Farmer's use weevil drug to kill the Queen. They place three capsules at any side of the mound for termite protection. However, termite establish another mound on about 20 to50 m with abandoning the former mound (Key informants 2019)Cattle dung host termites in one hand and expel termites when the dung combined with cattle urine or alone. For instance Kenya, farmers smear cow dung on posts to protect them from termite attack. Zambia farmers also apply fresh cow dung to protect termite from maize damage in the field. Southwestern Nigeria farmers believe that goat and cow dung reduces termite damage.

The ability of cattle excretes in the reduction of range land vegetation damage was seen in the experiment conducted in the 'Cattle Corridor' of Uganda (Banjo *et al.,* 2003).Similar report of Mugerwa *et al*. (2008) state that, accumulation of cattle excretes in re seeded plots deterred termites from attacking and cutting pasture seedlings. On the other hand, cattle excreta were reported as tentative feed sources of termites, improve soil fertility to promote plant growth and enhanced survival and proliferation of entomopathogenic organisms that could have checked termite activity.

In Ethiopia, wood ash was known to amend the soil fertility and deter termites and ants from long spread in the surrounding. However, wood ash has been widely used for termite control in Uganda, eastern and southern Zambia and Nigerian countries (Sileshi Gebre *et al.,* 2008).Wood ash termite control potential was not yet emphasize, it was broadcasted in pasture swards or top dressed on rows of re-seeded pasture seedlings. When Mozambique and Uganda farmers use leftover pork or beef to control termites,

Nigerian farmers reduce termite attack on crops with bury dead animals or fish viscera (Sileshi Gebre *et al.* 2008). In South Africa, Macrotermes mounds were 'poisoned' with dead animals, meat, and sugarcane husks. In accepting this, Riekert and van den Berg (2003) experimentally demonstrated how fish meal show significant reduction in termite damage on maize. Termite damage protections through protein-or sugar-based products are reported through increasing termite predatory ants (Logan *et al.,* 1990).

2.6.1.4 Botanicals extracts

African farmers use various plant and plant materials to control termites, For instance planting *Euphorbia tirucalli* in crop fields, in pasture or applying its branches in planting holes found deters termites in Malawi, Zambia and Uganda (Sileshi Gebre *et al.,* 2008).*Euphorbia tirucalli* plant is also used in fence making to mitigate termite damage on wooden fencing poles. The leaves and roots of *E. tirucalli* are soaked in water and the solution is sprayed to protect seedlings from termites in Tanzania (Logan *et al.,* 1990),

Farmers in Zambia and Madagascar apply crushed pods of Bobgunnia (Swartzia) in planting holes for mitigating termite damage (Nkunika 1998; Sileshi *et al*., 2008).In Malawi and Zambia. Leaves extracts of *Tephrosia vogelii* are also used to protect tree seedlings (Nkunika 1998; Sileshi Gebre *et al.,* 2008). In the current study, Temesgen Beyene and Emana Getu (2020) reported that single or mixed botanical extracts involved ***C.*** *macrostachys, J. curcas and P. dodecandra* control termite damage on maize *where* mixed botanical extracts found more potent than separate use. Botanicals are available, economical and environmentally friendly. However, insecticidal plant compounds that naturally occur were easily degrade when exposed to the sunlight and therefore have short half-life of persistence to the environment (Choudhury *et al.,* 2017).

In Ethiopia, Some farmer's practiced using *Croton macrostachyus* leaves for supporting the heap of harvested teff and millet as they thought the leaf used to protect termite damage (Temesgen Beyene un published).Similarly, Chomo grass does well on degraded and termite infested fields in ManaSibu district. Some villages of Diga district in East Wollega zone were increasingly engaged in producing fodder crops such as Rhodes grass (*Chloris gayana*), Napier grass (*Pennisetum* *purpureum*). In addition to serving as animal feed Chomo grass (*Brachiaria humidicola*) used on their fields for protecting termite damage and thereby maintain land degradation (Dereje *et al*., 2014).

Aloe species plant extract was also used in pepper plot to deter termite in Diga few farmer's pepper field .Following conventional pesticides adverse effect, botanical pesticides for termite management gain more attention in several laboratory and field experiments. Therefore, botanical pesticides are found the alternatives to conventional pesticides as they are non- persistent and biodegradable in the environment, selectivity towards beneficial insects and low toxicity to humans (Grdisa and Grsic, 2013). Botanical pesticides are naturally occurring secondary metabolites extracted from the plant sources to control and killing pests (Ahmed Ibrahim and Abraham Taddesse, 2014),

According to Cynthia *et al*. (2016) report, mixing of *Zingiber officinale* and *Allium sativum* significantly reduced termite damage on hot peppers. Maximum termites and their symptoms reduction realized on the plots that received mixtures of *C. macrostachys, P. dodecandra* and *J. Curcus.* Tadele Shiberu *et al*. (2014) reported that, the combination of *P. dodecandra* and *J. Curcas* gave 100% termites mortality in 2 hrs exposure time in the laboratory. Simon Kebede and Nnah (2018) and Qwarse Michael *et al*. (2017) demonstrated the effects of some botanicals applied in the soil hinder termites from forming extensive galleries. Ahmed Ibrahim and Girma Demisse (2013) compared the seed and leaf extracts of C. *macrostachys* and found out that seed extract significantly shortened termites galleries. Ibe *et al*. (2018) demonstrated the efficacy of *J. Curcas* applied to the soil significantly prevent subterranean termites from making of tunnels. Tilahun Mola (2018) reported that Chomo grass (*Brachiaria humidicola* (Rendle) Schweick)) hinder termite further infestation by reducing the formation of tunnels.

Moreover, the extent of termites' galleries formation depends on the potential of each botanical extract (Shahid *et al*., 2012) .In the experiment conducted using Potential of *Jatropha curcas* L. *Croton macrostachyus* Hochst and ,*Phytolacca dodecandra* in controlling termites in the field condition, Mixture application of *C. macrostachys, P. dodecandra* and *J. curcas* leaf extracts were found to be highly effective in the management of termites on maize when the termites species composition are *Macrotermes*, *Odontotermes* and *Pseudacanthotermes* (Temesgen Beyene and Emana Getu 2020)

2.6.1.5 Chemical control measures

Chemical control of termites are tiresome as termites are eusocial, living everywhere with collaborating each others, Beside, they exhibit cryptic behavior that able them to escape from enemies, for instance, in Fitbako study area they escape from their mound and build another mound some were 50m distance away from their nest upon farmers applying three weevil granule s (key informants 2018).

Termites mound wall provide them protection as it guards eggs, worker, soldier and alates (Abiyot Lelisa, 2016). Chemical control success may attain when all about termite ecology, distribution and species composition were clearly investigated (Daniel Getahun and Emana Getu, 2017). Termiticides are more effective when systematically applied and more effective when topically employed at early stage and further effective in contact application to workers, soldiers and alates. Subterranian termites can be removed when applying Termiticides to foraging galleries. Worldwide used termiticides for termite managent are; imidacloprid, chlorpyrifos, fipronil, spinosad, chlorfenapyre, bifenthrin, cypermethrin, permethrin, disodium octaboratetetrahydrate, calcium arsenate, lindane, endosulfan and chlorantraniliprole. These insecticides show effective act of termite control within a short period of time. But, there are difficulties associated to the application as termites are eusocial insects and live in mounds or many inches below the soil surface to keep them protected from outside threats. In addition to this, their adverse effect to environment and human health, further more it is uneconomical which many resource poor-African farmers cannot afford (Ahmed Ibrahim *et al*.,2006).

Though, chemical control has negative impact, their formulation varies for easy application, liquid formulation is more preferred than granule formulation. Among the aforementioned insecticides Aldrin was revealed as effective as DDT in field crop and structural damage control. Whilst the chemical treatment measures are one of the various techniques used to control the infestation of termites, termite damage continue to prevail in all environment. Therefore, these devastated termite problem urge to tackle and suppress in all areas where termite cause unlimited damage regardless of any agricultural activities (Rust and Saran, 2006).

2.6.1.6 Integrated termite management (ITM)

Integrated termite management (ITM) is described as the combination of the available effective control measures that are economically, socially and environmentally safe to humankind (Forschler *et al.*, 2007; Forschler, 2011).In this perspective, cultural or traditional, physical, botanical and chemical insecticides were thought the preferred options since found effective management of termites .ITM was not only to get rid of the termite population but to keep it away or to reduce its activity from economically important areas. Thus, ITM is a sustainable program (Ahmad *et al*., 2019).

Moreover, the decision for termite management should be made after getting enough knowledge of termite biology and ecology, infestation level, soil characteristics, cropping systems, cost of control, chemical and non-chemical termite management approaches and availability of proper termiticides, barriers, baits and professional experts (Forschler, 2011) Sustainable termite control is comprised of various strategies, as monitoring, chemical and non-chemical practices. The effective measure depends on threshold their biological and ecological ground which done through sampling and monitoring.

Non-chemical strategies are the best remedy in ITM since, the techniques include physical and mechanical control (dequeening, heating ,freezing, electrical, microwaves, toxic and non-toxic barriers), cultural control (cultivation techniques, mulching, crop rotation and intercropping), intrinsic heritable plant resistance, biological control (predators, parasitoids, entomopathogens and botanicals), some modern techniques (such as attractive baits and termatrac) and emerging biotechnology tools (RNA) interference. (Tasida *et al.,* 2013).These all provides mechanism of insight in to the sustainable termite management practices. However, the implementation and success of an ITM program are still much needed. (Ahmad Ibrahim *et al*., 2019).

CHAPTER 3

Assessment of Species Composition, Distribution and Pest Status of Termites in Different Agro-ecology and Land Uses of selected districts of East Wollega Zone, Western Ethiopia

3.1. Introduction

Numbers of tropical termite species are high and many of them are not yet described due to their taxonomic difficulty, lack of sufficient termite taxonomists and less availability of tools in Africa

(Daniel Getahun and Emana Getu, 2014).This inconvenience hinders efforts to develop systematic termite inventory that would provided important insights into termite abundance and biomass as new batches frequently come to raise species composition. Species composition refers to overall total termite species collected from sampling area without estimating population density (Dahlsjo *et al.,* 2014). In spite of the local species compositions investigation, the current global termite studies however, concentrated on economic loss caused by termite damage (Bong *et al.,* 2012).These termites are eusocial, ubiquitous, evolutionary and ecologically very successful insects sharing a common ancestry with cockroaches (Bottinelli *et al.,* 2016),

Nearly, 70% of the area of the world is infested with termites. About 2000-4000 individual termites are found per square meter. This figure may occasionally extend to 10,000 individuals per square meter as there is no single insect acts do as any single termite acting alone, showing that termites were able shoulder further responsibilities at the expense of their colony (Engel 2011).

There are about 3016 termites species in300 genera that belonging to the order Isoptera (Krishna *et al.,* 2013).About 1000 species of these world termite fauna are found in African (Daniel Getahun o and Emana Getu, 2014).70% of these African termite fauna are identified and described. Africa is therefore said to be rich in termite fauna (Ahmed *et al.,* 2011).The abundance of termite in Africa induced by the prevailing dry climate (Maayiem *et al.*, 2012).

In Ethiopia there are 61 species of termites that are belonging to 25 genera and four families. These termite fauna of Ethiopia constitute about 6.3% of the African termite diversity and termite fauna of Western Ethiopian (Ahmed Ibrahim *et al.,* 2011).Termites' genera of western Ethiopia include *Macrotermes, Odontotermes, Microtermes, Amitermes, Microcerotermes, Angulitermes,* and *Trinervitermes.* Western Ethiopian genera are common in west Wollega region. They include; *Macrotermes, Microtermes, Odontotermes*, and *Microcerotermes* (Cowie & Wood, 1989), Among *Macrotermes,* Macroterms *subhyalinus* (Rambur) and *Macrotermes adschaggae* (Sjosted) were the abundant (n) termite's species of Ethiopia and Wollega regions. They are confined as subterranean that exhibited difficult behavior to locate and destroy (Abdurahman Abdulahi, 1990).

Termites are ubiquitous insects whose distribution is high both in tropical, subtropical and warmer temperate regions of the world between latitudes 45^{o}N and 50^{0} S with species diversity and total biomass being greatest in the tropics and generally declining with increasing latitudes and are scarce or absent at higher latitudes (Eggleton, 2011).

Termite's activities are constrained by varied weather condition. It was stated in several reports that, global distribution of termites is terminated primarily by temperature and moisture (Hemachandra, 2014).Land use intensification also determined termite abundance and diversity along influencing termite altitude, drainage conditions and intensity of tillage. Consequently, fewer species are available at higher altitudes than at lower altitudes and in poorly drained areas than in well-drained areas. Though, termite distribution varies with agroecology, termite densities however are independent of land-use systems, (Olugbemi, 2013).Moreover, termite diversity, composition and their associated functions vary within and between ecosystems and these may shift under changing land-use systems ((Daniel Getahun and Emana Getu , 2017).

Termites are "xylophages" social insects which are capable of attacking crops, forestry, rangelands, houses, structures, regardless of altitude, season and time in agro ecology and land use system. Thus, they are known as pests (Subekt, 2016).).So far, 300 termite pest species are identified in all over the world (Kumar *et al.,* 2013).Pest termite in Ethiopia are reported as serious pests as they in discriminately attack a wide range of agricultural crops, forest trees and buildings. Moreover, severe pests are found in the desert regions (Daniel Getahun and Emana Getu, 2014).

While the increased noticeable termite fauna composition and their frequent distribution regardless of agroecology and wide spread infestation, there is no systematic inventory in Africa and else were in Ethiopia. In West Wollega termite inventory was a long time report and these termites are reported extending to the Eastern Wollega areas (Ofgaa *et al,* 2007). However, there is no termite inventory document in East Wollega where high infestation of termite was repeatedly reported ((Daniel Getahun and Emana Getu, 2014).Though the problem due to termite's is apparent in East Wollega zone, information regarding the different local termite species composition, distribution and pest status in different district land uses specifically (grazing, cultivated and disturbed forest) land uses are not adequately documented. Therefore, the present study was initiated with the following objectives;

- To assess farmers agrological based perception of termite activities.
- To determine termite generic composition and their distribution under different agro-ecology and land use system.

3.2. Materials and methods

3.2.1. Description of the Study area

Study on termite species composition, distribution and pest status was conducted in three districts' site of East Wollega, (Nunukumba, Diga and Limu) which were found in South West and North West of Nekemte, the regional capital of East Wellega Zone (Figure 3.1) East Wollega Zone is located at 328 km away from Addis Ababa to the West. This zone lies between $8^0$27'N to $10^0$13'N latitudes and $36^0$08'E to $37^0$38'E longitudes (Temesgen F. 2014). These districts were known to receive bimodal pattern of rainfall. The main rainy season is from the months of June to September. All the three districts, Nunukumba, Diga and Limu are located in East Wollega zone of Western Ethiopia and the coordinates, elevations, mean annual rainfall and temperatures of the study districts are presented inTable 3. 1

Table 3 1The Coordinates, elevations, mean annual rainfall and temperatures of the study sites

Districts	Coordinates		Altitude m.a.s.l.	Temperature 0c	
				Maximum	Minimum
Nunukumba	$8^0$39'53''N,	$36^0$45'25''E	1560-2300	$28.1^0{}_C$	17.8^0c
Diga	$9^0$04'18''N,	$36^0$18'23''E	1380 - 2300.	30.1^0c	19.8^0c
Limu	$9^0$10'19''N,	$36^0$20'24''E	1100 - 2400	27.1^0c	18.8^0c
Nekemte	9° 06' N	36°31'E	1200 - 2400	29.1^0c	16.8^0c

Source: National Meteorological Agency of Ethiopia (Average of 15 years) (2019)

Out of the 17 Eastern Wollega districts, the seven districts were identified to low mid and high agro ecology based on agro-climatic conditions in which low land consists of 56.4% (1200-1799 m.a.s.l.), mid land 28.2 % (1800 -2450 m.a.s.l.),) and high land 15.4% (2460- 3178 m.a.s.l.),) (Temesgen Fita,2014). As a part of Ethiopia, there are traditional agro ecological zones that include Bereha, Kolla, Woina Dega, Dega, Wurch and Kur which gives an opportunity for the cultivation of various crops to provides food for the expanding population .However, agricultural productivity are constrained by several factors, among which termite's implicates threaten maize in East Wollega Zone

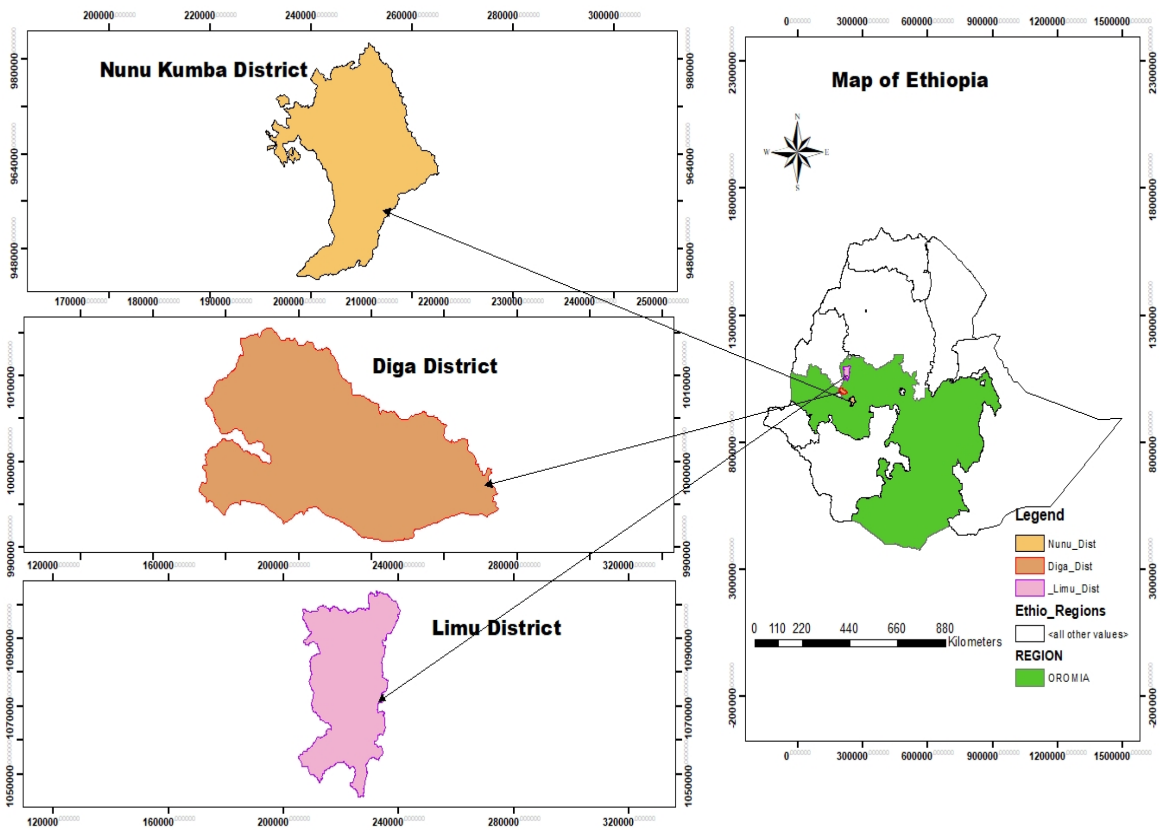

Figure 3. 1 Map of the Survey area

3.2.2 Research design and Sampling procedure

This study used mixed research approach, in that both qualitative and quantitative data were gathered. The qualitative approach employed a descriptive survey, while in quantitative approach field observation was employed (Kothari, 2004).

Sampling procedures

There are 17 districts in East Wollega Zone. Out of these seven districts have agro ecological /altitude class identified *kebele's* (high, medium and low altitude). Accordingly, from Nunukumba district; Harosabu, KorbuSaka and Wama dire *kebele's,* form Diga district, Gamachis, Bikla and Kersadako *kebele's,* and from Limu district Warsu, Melkalami and Fitbako *kebele's,* totally nine *kebele's,* were purposively selected based on peak crop production and high termite infestation. Qualitative data through questionnaire were gathered from 30 purposively selected household from each agro ecologically identified *kebele*, 90 from each district and 270 from all districts. Well informed household about termite's behavior are selected with referring to Extension Officer List (EOL).

For quantitative study, in each three districts, three land uses; (cultivated, grazing and disturbed forest) in each purposively selected *kebele's* were identified through survey. In each land use three each termite hot spots area or patches were identified. Each patch was delineated to (50mx50m) plot size with tape meters Then the nine basic sampling area of each land use (3x3=9) were purposefully selected. From each patch five quadrates each with (2mx2m) size of a land for ecological study were established in five different points. Five quadrates, two at each corner (four) and one at the center were laid. Therefore 5 quadrat on each spots a total of n=5x3=15 quadtrats in each land uses and total of 45 quadrates in all land use of each district were established in equidistance area.

3.2.3 Termite data collection and identification

Questionnaires and checklists were used to collect qualitative and quantitative data sources respectively.

Qualitative data;

- agro ecological perception of production constraints,
- termites infestation level,
- land use that support abundance (n) of termites,
- Termite incidence by land use, agricultural practice favors the pests and status of pest.
- Farmers practice for termite management and the widely used cultural practice were also collected.

Quantitative data include;

- The presence and absence of termite encounters (hit) from all districts land uses were indicated with plus (+) and minus (-) sign using Kalleshwaraswamy *et al*. (2018) procedure. S
- sampled termite soldier's across land uses,
- Persentage termite's genera composition and distribution in the study area and
- relative abundance of termites and

Termite identification,

Termites were hand collected by digging the cultivated land up to 25cm depth using fork, from grazing lands by uprooting damaged grasses and from disturbed forest by observing through litter and the fallen wood bark of tree (Almeida, 2015). All standing tree and other non- convenient for survey were left for other redesign following Eggleton *et al.* (1990) procedure.

Data were collected by the researcher and knowledgeable individuals employed for three months on temporality basis. Termite observation occurs once in a day in the morning from 9: 00 to 11: 00 Am following Jamil (2017) procedure.

- **Termite species recorded** in the quadrats center a (1mx1m) from the three replicates of each land-use type were combined and regarded as the termite species occurred **in that particular land-use.**
- Those sampled from all land use were considered as the **termite species composition** (fauna) of the study districts.
- The number of **present and absent encounters with termites** of a given genus was taken as a relative abundance of the genus within that **land-use-type.**
- **Termite‘s soldier's** which had been collected are added to the labeled vial containing 80% alcohol for identification. Taxonomic identification was done at the genus level using Keys to the Genera of Ethiopian termites based on soldier characters.
- **Voucher specimens** from this study were deposited in the laboratory of Entomology, Addis Abeba University.

3.2.4 Data analysis

The qualitative data collected through structured questionnaire were analyzed using descriptive statistics such as frequency and percentage using SPSS version 23.Tthe quantitative data generated from the field observation from the three districts in different land use systems were analyzed using SAS software (SAS Institute Inc., 1991). One-way analysis of variance (ANOVA) was performed and the Least Significant Difference (LSD) test at 5% was used to separate significant means ($p<0.05$).

3.3. Results

3.3.1 Farmer's Perception on termite activities

Production constraints, farmer's knowledge and traditional classification of termites in the study area

With regard to agro ecological based perception of production constraints at the study area, more than (66.3%) surveyed small holder farmers mentioned that termites are the main constraints of crop production than weevil, disease and locust are, implying termites are the most important problem limiting production and productivity of crops in the study area that the problem of production was largely attributed by termites (Table 3.2; Appendix 3.1).Table 3.2.also describes farmer's knowledge about termite in the study area. Accordingly (100%) of the respondents aware what termites are and traditionally able to identify the prevailing common termite species termites . Majority (37.03%) of respondents agreed underground moving termites (subterranean), others (29.63%) of the respondents justified dung dwellers. About (25.92%) respondents say immigrant's termite (that sometimes appears and frequently disappear from the area). Few (7.14%) say mound making termites (Table 3.2; Appendix 3.1).

Table 3 2 Percent of respondents and constraints of productions, termite knowledge and termite traditional classification in agroecology and land use systems (N=270

		Respondents	
Variables	categories	Frequency	Percentage %)
Production Constraints	Disease	16	5.9
	Weevil	58	21.5
	locust	17	6.3
	Termites	179	66.3
	Total	**270**	**100.0**
Farmer's knowledge of termite	Yes	270	100
	Total	**270**	**100.0**
Types of termites	Subterranean	100	37.03
	Mound making	20	7.41
	Immigrants	70	25.92
	Total	**270**	**100.0**

Incidence of termites in agroecology

Termite's incidence in agroecology was indicated in Figure 3.2. Most respondents (57.0%) indicated that, abundant termites live in low land altitude. The others (31.1%) respond termite's inhabited mid land and about (21.1%) respondents say termites live in high lands According to the study, majority of termites live in low land, some considerable high amount live in mid land and few termite's live in high land use system of the study area. The abundance of termite in low land indicate that termites are favored by low altitude environmental conditions (Figure 3.2; Appendix 3.1)

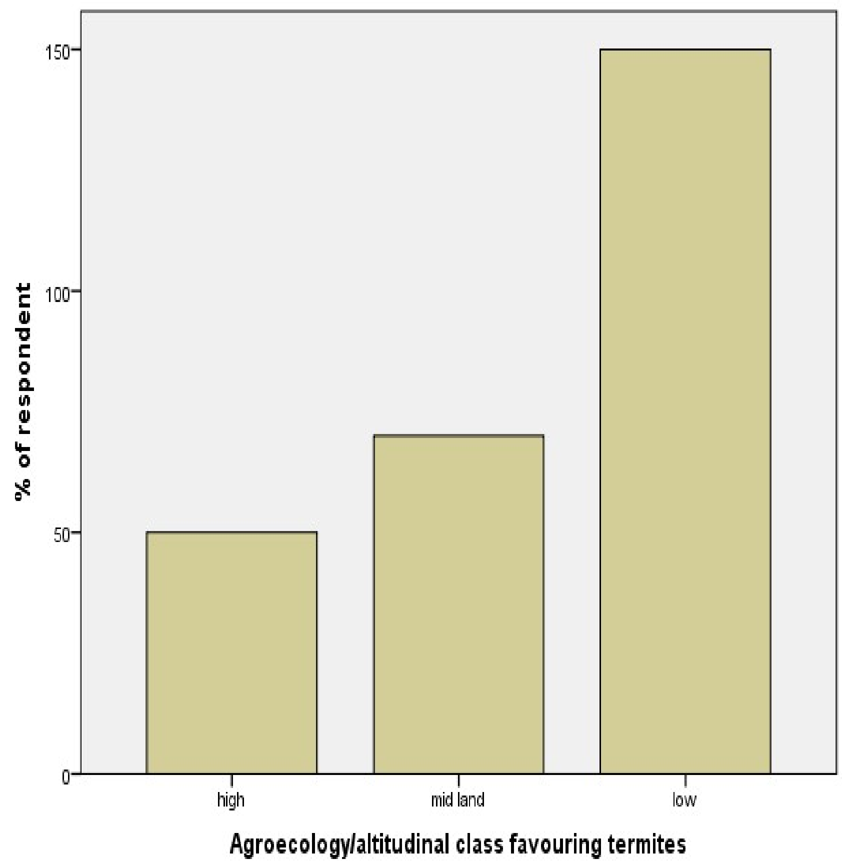

Figure 3.2 Percent of respondents and termite's incidence with agroecology

Termite abundance (n) with land use and reason for their abundance

Termite's abundance (n)(in number) in the land use system and factors contributing for their abundance were shown in Table 3.3. Most of (52.2%) respondents accepted that termites are abundant in grazing land. In the study also farmer's revealed that termites live in cultivated land (27.0%) and in disturbed forest (18.5%) respectively. The abundance of termite in grazing land were contributed by food source (38.9%), climate (32. %2) and farming practice (23.3%) respectively. (Table 3.3; Appendix 3.1).

Table 3. 3; Termites encounter's and factors enhancing termite prevalence in land use system (N=270)

Variables	Category	Respondents Frequency	Respondents Percentage (%)
Termites abundance(n)	Cultivated	73	27.0
	grazing	141	52.2
	disturbed forest	50	18.5
	uncertain	6	2.2
	Total	**270**	**100.0**
Factor that favor termite abundance	Food source	105	38.9
	Climate	87	32.2
	farming practice	63	23.3
	lack of enemies	15	5.60
	Total	**270**	**100.0**

* (n) = in number

Infested status of land use system and agricultural practices that favors termite pest

Table 3.4 Shows, infestation status of land use and agricultural practice that favors termite pest. Most of (39.3%) of respondents agree that grazing land is mostly infested than other land uses. While (33.3%) and (27.0%) respondents said cultivated and disturbed forest respectively. Accordingly, the level of pest increases in grazing land may be due to overgrazing. Agricultural practices like monoculture, non-fallow farming, and deforestations equally contributed to increase termite damage (Table 3.4). According to the study, about (43.7 %) of the respondents said that termites in the study area are minor pests, while about (25.2%) of the respondent said termites are sporadic pests. Still about 20% of the respondent said termite is a major pest. About (11.10%) failed to demark the status of termites (Table 3.4.; Appendix 3.1).

Table 3 4 Status of land use infestation and agricultural practice favors pest termite in land use system (N=270)

Variables	Category	Respondents	
		Frequency	Percentage (%)
Termite incidence by land use	cultivated	91	33.3
	Grazing	106	39.3
	disturbed forest	73	27.0
	Total	**270**	**100.0**
Agricultural practice favors termite 's living condition	monoculture	59	21.9
	non-fallow	59	21.9
	overgrazing	93	34.4
	Deforestations	59	21.9
	Total	**270**	**100.0**
Termite's pest status	Sporadic	68	25.2
	Minor	118	43.7
	Major	54	20.0
	Uncertain	30	11.1
	Total	**270**	**100.0**

Farmers management practice s for the control of termites

Farmers' practice various traditional methods to control termite's damage in all study districts. The majority (51.7%) of responded agree with managements cultural means. Other (29.62%) respondents say chemicals for termite management. Few (9.25%) respondents agreed that termite management is using with biological/botanical means. However, still very few (9.25 %) failed to locate termite management practice (Table 3.5; Appendix 3.1

In the study area, the widely used cultural practices for termite control were shown in Table 3.5. More than 44.40% of the respondents indicate mound demolition was mostly used cultural termite management. Other respondent said that, growing termite resistant plants (19.3%), Flooding mound with directing flood, powering salt and pepper dissolved in water (18.5%), removing galleries (11.1%), and botanical leaves and seed extracts (6.7) respectively. Mound destruction with human labor was further adapted as it contribute to the disturbance of colony survival more than the other cultural termite control methods (Table 3.5; Appendix 3.1).

Table 3 5 Percent of respondents on termite management practice and the widely used cultural practice (N=270)

Variables	Category	Respondents	
		Frequency	Persentage
Termite management practiced	Cultural	140	51.85
	Chemical	80	29.62
	Biological/botanical	25	9.25
	uncertain	25	9.25
	Total	**270**	**100**
Widely used cultural practice	mound demolition	120	44.4
	Flooding mound	50	18.5
	Removing galleries	30	11.1
	botanical leaves, extracts	18	16.7
	termite resistant plants	52	19.3
	Total	**270**	**100.0**

3.3.2. Termites genera composition

The presence and absence of termite encounters (hit) from all districts land use system were indicated with plus (+) sign and minus (-) sign respectively was shown in Table 3.6.Accordingly, *Macrotermes* and *Microtermes* are recorded from all districts land uses. *Odontotermes* and *Pseudacanthotermes* were absent from disturbed forest land use of all districts. Amitermes was also not recorded from grazing land of Nunukumba and grazing and disturbed forest of Diga and disturbed forest of Limu districts. *Microcerotermes* was absent from cultivate land of Nunukumba and Diga districts by the time of observation. *Angulitermes* was not observed from disturbed forest of Nunuqumba and cultivated land use of limu districts. *Trinervitermes* was not recorded from disturbed forest land use of Nunukumba and cultivated land of Limu districts. *Apicotermitinae* was not recorded from disturbed forest and cultivated of Diga and cultivated and disturbed forest of limu Districts (Table 3.6)

Table 3 6Termite genera distribution recorded as present (+) and absent (-) from the three districts in three ecological habitats land uses (2017-2018)

Termite genera	Termite genera distribution in districts the District land uses								
	Nunukumba			Diga			Limu		
	Land use			Land use			Land use		
	Gl	Cl	Df	Gl	Cl	Df	Gl	Cl	Df
Macrotermes	+	+	+	+	+	+	+	+	+
Microtermes	+	+	+	+	+	+	+	+	+
Odontotermes	+	+	-	+	+	-	+	+	-
Pseudacanthotermes	+	+	-	+	+	-	+	+	-
Amitermes	-	+	+	+	-	-	+	+	-
Microcerotermes	+	-	+	+	-	+	+	+	+
Angulitermes	+	+	-	+	+	+	+	-	+
Trinervitermes	+	+	-	+	+	-	+	+	-
Apicotermitinaee	+	+	-	+	-	-	+	-	-

+ =present- =absent, Gl= Grazing land, Cl= Cultivated land, DF= Disturbed forest

In total, 295 soldier termite samples were collected and all of them collected with standardized quadrat from the three each land-use types of the three districts. All sampled termite species were from one families, *Termitidae*, and comprising four sub-families; *Macrotermitinae, Termitinae, Nasutitermitinae,* and *Apicotermitinae*.(Table 3.7) all the recorded genera composition were ; *Macrotermes, Microtermes, Odontotermes, Pseudacanthotermes Amitermes, Microcerotermes, Angulitermes, Trinervitermes* and *Apicotermitinae.* All the genera recorded from the area were also recorded from grazing land uses system. However *Apicotermitinae* was absent from cultivated and disturbed forest land uses, *Pseudacanthotermes* and *Amitermes* were also not recorded from disturbed forest land uses

Table 3 7 Termites subfamilies and genera in family termitidae recorded from the three land-uses using standardized quadrat (2017-2018)

Subfamilies	Termite genera surveyed in land-use type		
	Grazing land	Cultivated land	Disturbed forest
Macrotermitinae	*Macrotermes*	*Macrotermes*	*Macrotermes*
	Microtermes	*Microtermes*	*Microtermes*
	Odontotermes	*Odontotermes*	*Odontotermes*
	Pseudacanthotermes	*Pseudacanthotermes*	--
Termitinae	*Amitermes*	*- Amitermes*	---
	Microcerotermes	*Microcerotermes*	*Microcerotermes*
	Angulitermes	*Angulitermes*	*Angulitermes*
Nasutitermitinae	*Trinervitermes*	*Trinervitermes*	*Trinervitermes* -
Apicotermitinaee	*Apicotermitinaee*	--	--

3.3.2.1. Termites Genera composition and distribution in the study area

Termites Genera composition in Nunukumba, Diga and Limu districts agro ecologically identified *kebele's* land uses systems were shown in (Table 3.8; Appendix 3.2-3.4) Totally, 295 solider samples were collected from all sites .Of these, 119 (40.34) from Nunukumba 99 (33.6) from Limu and 77 (26.10) from Diga district. Termite soldier sample collection irrespective of land use system in all districts shows 115 from grazing land, 93 from cultivated land and 85 from the disturbed forest. .Altitudinal distribution from all districts indicates, 74 from high, 90 from mid and 103 from low land altitude.

Table 3 8 Percent (n) Distribution of termite's encounters surveyed in Nunukumba, Diga and Limu district's agrecology and land use system (2017-2018)

Districts	Agrecology	Kebele	Land use				Total%
			GL	Cl	Df	Total	
Nunukumba	High	Harko sabu	10	10	9	29	119(40.34)*
	Midland	Korbusaqa	17	11	7	35	
	Low land	Wamma dire	26	12	17	55	
Diga	High	Gamachis	9	7	5	21	77(26.10)
	Midland	Biqila	9	7	8	24	
	Low land	Kersa dako	12	10	10	32	
Limu	High	Warsu	8	10	6	24	99(33.6)
	Midland	MelkaLami	11	11	9	31	
	Low land	Fitbako	13	15	16	44	
	Total		**115**	**93**	**87**	**295**	

Gl= grazing lands, Cl=cultivated lands, DF= disturbed forest

*Number in parenthesis is the percentage of the total encounters

3.3.2.2. Relative abundance of termites

The relative abundance based on the number of encounters of each genus in land-use types was given in Table 3. 9. Out of the 295 total occurrences 105(35.59) were *Macrotermes*. They are recorded in all land uses. *Apicotermitinaes* which accounts the lowest 4(1.36), record was from grazing land uses, *Apicotermitinae* was not recorded from cultivated and disturbed forest land uses. *Pseudacanthotermes* and Amitermes were also not recorded from cultivated and disturbed forest land uses, (Table 3.9; Appendix 3.2-3.4).

Table 3 9 Percent (n) encounters/occurrences of termite genera sampled in all land-uses patches (100mx100m) area with standardized quadrat, (2017-2019)

Termite genera	No. and percentage of termite genera			
	Grazing land(100m^2)	Cultivated land(100m^2)	Disturbed forest (100m2)	Total
Macrotermes	50(16.95)	34(11.53)	21(7.11)	105(35.59)
Microtermes	28(9.490	19(6.44)	20(6.78)	67(22.71)
Odontotermes	14(4.750)	8(2,71)	12(4.07)	34(11.53)
Pseudacanthotermes	13(4.41)	9(3.05)	0(0.0)	22(7.46)
Amitermes	6(2.03)	8(2.71)	0(0.0)	14(4.75)
Microcerotermes	7(2.37)	5(1.69)	6(2.03)	18(6.10)
Angulitermes	13(4.41)	9(3.05)	2(0.68)	24(8.14)
Trinervitermes	4(1.35)	2(0.68)	1(0.34)	7(2.37)
Apicotermitinaes	4(1,35)	0(0.0)	0(0.0)	4(1.36)

*Number in parenthesis is the percentage of the encounters/occurrences

3.4. Discussion

The agro ecological based Perception elucidates that termites are recorded as the primary production constraint than other pests (weevil, locust and disease) in the study area. In line with this Daniel Getahun and Emana Getu (2017) reported that termites ranked as number one of all the existing pests, this evidence comes from data collected at Mana Sibu and Ayira districts Agricultural and Rural Development Offices in western Ethiopia. In supporting this, Hirpa Legesse *et al. (*2013) stated termites are present and result in problem throughout the surveyed 13 of the 21 *kebeles* in the Diga districts including the research sites. In agreement to this, Sileshi Gebre *et al*. (2008) reported similar results consistent with evidence from literature.

According to the traditional termite identification done by the local people ,the prevailing local termite compositions are subterranean, immigrants; mound maker's and dung dwellers,. In line with this, Sekamatte and Okwakol (2007).stated that local communities are able to identify total of 14 species with distinct vernacular names in Tororo Uganda, which is in agreement to Hirpa Legesse *et, al. (*2013) who in his study reported that, Werrartu (invaders' non-mound forming) and

Marimartu (migratory type)) in Afan Oromo were identified by farmers based on body size, head color, feeding habit and mound formation. Sileshi Gebre *et al.* (2009) also indicated that, farmers possess overwhelming ability to identify major genera and species using simple community based taxonomic skills.

The result of the study revealed that there is high density (in number) of termites in low agroecology grazing land use system than cultivated and disturbed forest land uses. In agreement to this, Jones and Egglton, (2011).stated that, termites are highly distributed in low lands where there is dry temperature and red soil is found and more abundant in grazing lands where there are high traffic of grazing animals. Daniel Getahun and Emana Getu (2015) reported that termites are greater in lowland rather than highland areas where there infestation is thought higher. In supporting this, Eggleton(2011) reported that, termite distribution is more abundant both in tropical and subtropical ecosystems, particularly, species diversity and total biomass being greatest in the tropics and generally declining with increasing latitudes and are scarce at higher latitudes. This is in contrast to Egglton *et al.* (1996) who stated tropical terrestrial forests, ecosystems termites' density and biomass may reach 10,400 $m\text{-}^2$ and 120 $g.m\text{-}^2$ respectively. Ackerman.*et al.* *(*2009) reported that, termite species richness, abundance, and function often decline when forests are replaced by agriculture, According to the study result; the abundance of termite in grazing land use was due to available termite food. Favorable climate, farming practice and absence of natural enemies also has significant contribution for termite abundance. Implies grazing land support more termite species due to palatability of grasses, Agreed to this, Mugerwa *et al.* (2013) stated that rangelands of Uganda accommodate over 70% of the total termite species which can consume over 60% of the available herbaceous (grasses and forbs) vegetation .

As indicated in the result, termite incidence was high in grazing land uses merely implies the high infestation of grazing lands by termites was attributed by overgrazing. Inconsistent to this, Girma Demissie *et al.* (2019) reported that, grass eating termites are often many in tropical and subtropical grass lands where livestock also graze and compete with grazing animals for forage. This was supported by Abdulahi *et al*. (2010) who state that termites damage is sever in low lands grazed area where there is high infestation in Wollega area. The result of the study revealed agricultural practices like monoculture, non- fallow farming and slush burn forest had similar contribution for termite abundance. In line with this, Daniel Getahun and Emana Getu (2014)

demonstrated that, agroecology, land use and farmer's intensified activities determine termite abundance in particular area. Where there is high termite abundance (n), the damage is high following the high infestation (Van Huis, 2017).

In contrast to their high abundance, termites are designated as minor, sporadic and major pest few smallholder farmer's even do not sense the harm. In agreement to this, Daniel Getahun (2020) describe that, termite problem is escalating gradually and has become worse than ever. Mugerwa (2011) stated that, termite was the major pest species that devastated pasture in the semi arid ecosystems of Uganda. In agreement with Abdurahman *et al.* (2010) reported that the genus *Macrotermes* pest species in Ethiopia the; *M. subhayalinus* and *M. herus* need managent before reaching sever pests status.

As demonstrated in the result, farmers continue applying chemicals for termite control, Cultural termite management specifically; Mound demolition, flooding mound, removing galleries, plant leave or leaf extracts and resistant plants. Among these, Mound destruction for termite control was mostly practiced. In agreement with this, Daniel Getahun and Emana Getu (2017) stated that, farmer's who feel pain with termite's problems used different methods of indigenous termite control like combination of two or more methods including; good silviculture, cow dung, wood ash and queen removal. In agreement with, Sileshi Gebre *et al.* (2008) mention that, traditional methods are simple to follow and conduct and cost effective especially in the African setup However, Akutse *et al.,(*2012) state termite management strategies in Africa is in accordance with the experience adapted per continent. In accordance to this Hirpa Legesse *et al.* (2013) states these; cultural practices were effective when done in combination. In agreement with this, Sileshi Gebre *et al.* (2009) reported that farmers have a rich knowledge of termite biology and the ecosystem services provided by termites In the current study mound disturbance was reported as the dominant cultural termite management practice, In accordance with Nyeko and Olubayo (2005) reported destruction of termitaries and the colony included digging the nest and removing the queen; burning wood, grass, or cow dung; pouring hot water, insecticides, Rodenticides, or paraffin; and flooding the nest with rainwater to kill the colony.

Termite genera composition presence and absence in the land uses was indicated by plus '+'or minus '-'sign respectively. This was in accordance with Kalleshwaraswamy (2018) who used to collected termite species with indicating '+' plus and '-'minus signs for present; and absent species while conducting a comparative study of species abundance and richness in three ecological habitats.

Termite soldier's collected from three district agroecology land uses, were from family, Termitidae, four sub-families; *Macrotermitinae, Termitinae, Nasutitermitinae and, Apicotermitinaes.* The nine genera composition were ; *Macrotermes, Microtermes, Odontotermes, Pseudacanthotermes Amitermes, Microcerotermes, Angulitermes, Apicotermitinaes* and *Trinervitermes,* All the nine genera were recorded from grazing, land use, few are absent from cultivated and disturbed forest land uses. *Apicotermitinaes* is only genera present in grazing land use .Out of the sampled termites genera, majority of them are from Nunuqumba district land uses and relatively low termite genera are sampled from limu and Diga district disturbed forest. In line with this Daniel Getahun and Emana Getu (2014) reported that all the termite species belonging to the seven genera recorded in the area were from the family Termitidae, and also collected from protected land uses. This report was in agreement with Abdurahaman Abdulahi (1990) who stated termite assemblage in western Ethiopia were those belongs to Termitidae the subfamily Macrotermitinae and the genera *Macrotermes*, *Microtermes*, *Odontotermes* and *Pseudacanthotermes*.

3.5. Conclusion

The findings of this study showed that all the termites' genera were found major constraints of production than other pests. The abundant (n) genera composition was recorded from low altitude of grazing land uses of Nunuqumba districts. Pest status was high in this area where there is more termite infestation. Termite genera composition and distribution were similar in all agrecology land use system Farmers control pest termite species with cultural practice largely by mound destruction for killing the queen and disturb the colony. From the current study, it can be concluded that multiple genera of termite species can occur in one or all land uses with abundant (n) population in low agrecology of grazing land uses and pest termites can be managed culturally with mound destruction supplemented with other traditional practices

CHAPTER 4

Physicochemical properties of Termite mound Soil at different depths under different land use systems at Limu District, Western Ethiopia

4.1. Introduction

High quality of nutrient accumulated in termite mound soils has placed termite mound soil as a gold mine for soil invertebrates. Termitarium soil as a result found viable source of bio fertilizer. This significant change of mound soil physiochemical property was induced by termite's peculiar activities for essential utilization of soil resources (Lima *et al*., 2018). Termites are ascribed amongst the main macro invertebrate decomposers in arid and semi-arid environments (Saha *et al.,* 2016).Termites built termitaries from a mixture of soil, organic debris or living plant tissues collected decomposed, degraded and digested with the help of microbial communities and transported from distant extensive foraging areas to their sites (Adugna *et a.,,* 2018). Termite also mix decomposed leaf-litter and other feeding materials to raise nutrients; Ca, K and Mg level in mound soil, (Daniel Getahun and Emana Getu, 2014).

Termites, in varied land use system creates bio structures; mounds, galleries, sheeting's, etc. with influencing the distribution of natural resources like water and nutrients in the landscape to facilitate the diversity of soil microbes, plants and animals. In so doing termite amends soil fertility that enable rehabilitate degraded soils (Adugna *et al*., 2018). These termite activities vary from and among land uses system. Land use system is the arrangements, activities and inputs people undertake in a certain land cover type (Ufot *et al*., 2016). Termite mound soil in different land use system exhibited different physical and chemical properties and retain better physical environment and retain more nutrients than the surrounding adjacent soil (Dhembare, 2015). Termites mound soil organic matter content is also five-times greater than that of in adjacent soils (Mahsa *et al*., 2017).

This admixture of mound soil amends soil fertility and promotes production (Abdurahman Abdulahi *et al*., 2010). Developing countries use nutrient rich mound soil as alternative to high price inorganic fertilizer inputs (Daniel Getahun and Emana Getu, 2014). However, Mound soil in East Wollega Zone has not been supported by rational farming, yet create traction problem and mound structure (height) that also influences the land escape heterogeneity by either creating patches rich nutrient or nutrient deficient landscapes. Termite mound construction projects are common in all over the world from rainforests to back yards where termite colony has been established. African soil-feeding termites; *Macrotermes, Odontotermes* and *Cubitermes* are able to build mound underground or on surface up to 30 feet height (Oliveira *et al.,* 2011).

In Ethiopia, mound builder termites are the genus *Macrotermes,* the species; *Macrotermes subhyalinus* (Rambur) and *Macrotermes herus* (Sjostedt) (Abdurahman Abdulahi *et al*., 2010). African *Macrotermes* termites in the genera *Macrotermes, Pseudacanthotermes* and *Odontotermes* are also reported in Western Ethiopia West Wollega regions (Abdurahman Abdulahi *et al.,* 2010; Daniel Getahun, 2018). These termites are ought to establish the high density of epigeal termite mounds making a peculiar feature of the landscape of the Central Rift Valley and West Wollega Manasibu district (Daniel Getahun and Emana Getu,2014). In Western part of Ethiopia, in East Wollega zone there are mounds, majority are found in limu district Fitbako *kebele* different land use system, Termites of these area cause profound effects on soil properties as in other parts of Ethiopia in which Eastern Wollega several districts are included. In spite of the fact that, termite in this part of the country influences organic matter dynamics and affect soil nutrient for varied productivity of the ecosystem, there is no information documented on the physicochemical properties of termite mound soil and adjacent soil found in different land uses (cultivated, grazing, disturbed forest and built-upland use). Therefore, the present study was initiated with the following objectives;

- To characterize termite mound soil physical properties under different land use system at different depths
- To characterize termite mound soil chemical properties under different land use system at different depths
- To compare the physicochemical properties of termite soil under different land use systems with adjacent soil

4.2. Materials and Methods

4.2.1. Description of the study area

The study was conducted in Fitbako *kebele*, Limu District, East Wollega Zone, Oromia Regional State, in Western Ethiopia (Fig 4.1). The study was conducted at $9^{O}36'78''$N latitude, $6^{O}3'2168''$

E longitude and at an elevation of 1383meter above sea level (m.a.s.l.).Maximum and minimum temperatures of the area were13.0°C and 28.0 °C, respectively. The relative humidity was 55.45% and the average annual rainfall was 1301 mm, maximum rain is obtained during summer (*kremt*) season from June to September and the minimum rain fall during spring (*belg*) season from March to June. Sandy, clay and loam soils were dominant soils. The topography is plain, flat slopes, undulating slopes and valleys parts. Common land use systems were; cultivated, grazing, disturbed forest and built up lands. The specific features the land uses were characterized according to Oliveira *et al.* (2011). Cultivated lands are known with long time cultivation of maize and sorghum since Derg regime (1974), Grazing land use has savanna type grass mixed with runner grass and bushes. In the disturbed forest, there are rebuild bamboo trees, prominent long trees and bushes. There are abundant thatched roof and few tin roofed houses in the built-up (small village) land uses (personal observation 2017).The study area Fitbako *kebele* is about 418 km from Addis Ababa to the West and 90km away from Nekemte town to North West of East Wollega Zone. It was characterized as lowland that found below 1500 m.a.s.l

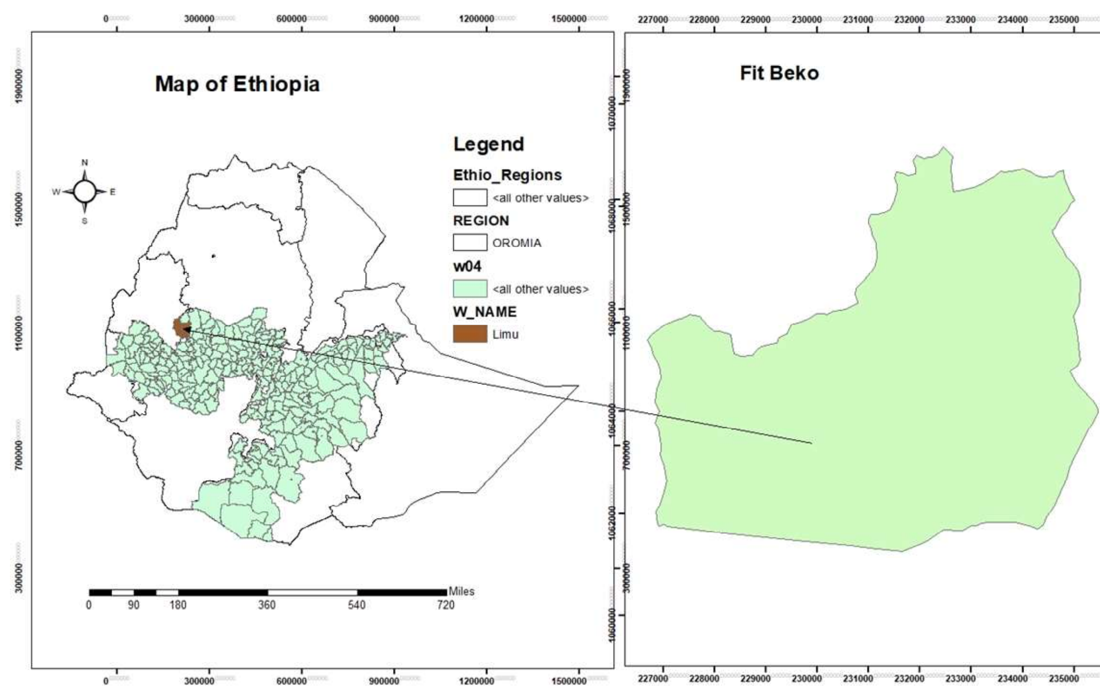

Figure 4. 1 Map of the study area

4.2.2. Site Selection

For this study, Fitbako *kebele* (*kebele*= lower Ethiopian administrative units) was purposively selected from limu districts. The site selection was based on the presence of abundant termite mounds and high termite infestation. Prehistoric and current information of the study area was obtained from expertise of East Wollega Zone Agriculture office, (2018). With reconnaissance survey, four land uses (cultivated, grazing, disturbed forest and built-up lands) which were found adjacent to each other are identified. In each selected land use three patches were purposively selected and a (100m x100m) line was drawn in each patch and three mounds found in similar slope from each patch were selected purposively. Working soil sample from purposively selected termite mound bottom, middle and top position were collected following (Daniel Getahun and Emana Getu, 2014) procedure.

4.2.3. Experimental Design and Treatments

The experiment has different combination and the combination contains two factors; land use systems and soil depth with four levels and three levels respectively. The experiment was arranged in factorial combination and laid in Randomized Complete Block Design (RCBD) and adjacent soil was used as control. Totally there are 16 treatment combinations replicated three times shown in Table 4.1.

Table 4 1.Treatments arrangements (Dhembare, 2015).

Treatment No	Treatments
T1	Cultivated Land +0-20cm (mound soil depth)
T2	Cultivated Land+20-40cm (mound soil depth)
T3	Cultivated Land +40-60cm (mound soil depth)
T4	*(As) from mound of cultivated land +0-30cm
T5	Grazing Land+0-20cm (mound soil depth)
T6	Grazing Land+20-40cm(mound soil depth)
T7	Grazing Land+40-60cm (mound soil depth)
T8	*(As) from mound of Grazing land +0-30cm
T9	Disturbed Forest Land+0-20cm (mound soil depth)
T10	Disturbed Forest Land+20-40cm (mound soil depth)
T11	Disturbed Forest Land+40-60cm (mound soil depth)
T12	(As) from mound of Disturbed Forest Land+0-30cm
T13	Built-up land+0-20cm(mound soil depth)
T14	Built- up land+20-40cm (mound soil depth)
T15	Built- up land+40-60cm (mound soil depth)
T16	(As) from mound of Built-up Land+0-30cm

*(As) =Adjacent soil,

4.2.4. Soil Sample Collection

Following the standard procedure, soil samples were collected after pits were opened from mound of each land use systems selected patches in October 2019 right after the rain has stopped following (Daniel Getahun and Emana Getu, 2014) procedure. Soil sample was collected from one mound found in the patch and replicated three times in each land uses system at three depths (0-20, 20-40 and 40-60cm) of mound soil using augur and core sampler. Soil from adjacent area free of mound effect collected at 1.5m away from the base of mound soil used as control followed Daniel Getahun and Emana Getu (2014) procedure with a little modification. Both undisturbed and disturbed soil samples were taken from three mounds of each land use at 0-2cm, 20-40cm and 40-60cm sampling depths based on the heterogeneity of land unit. Each soil were mixed and form composite soil sample for each land uses. Undisturbed soil samples were taken by core sampler to measure the soil bulk density, whereas the disturbed soil samples were taken by using auger to measure the rest selected soil physical and chemical properties. During the collection of soil samples, gravel materials, dead plants, old manures, areas near trees and compost pits were excluded. For undisturbed soil sample, 12 core samples from three mound of one land use and 36 core samples from all land use systems were collected. In addition one core sample was collected from adjacent soil of each land uses. The soil samples were air dried grounded, mixed well and passed through a 2 mm sieve for analysis.

Plate 4.1 Mound soil sample collected from Fitbaqo *kebele* cultivated land uses system (2018).

Plate 4. 1 Preparation of sub -soil sample

4.2.5. Analysis of soil physical and chemical properties

For each soil sample, subsamples were drawn from four purposively selected patches from all land uses and the sub-samples were composited for analysis. Analysis was done in reference to National Soil Research Centre of Ethiopia (Mulugeta Tufa *et al., 2019*)). Soil moisture content was tested using gravimetric method. The bulk density (BD) of the soil was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105 °C (Black, 1965). The total porosity of soil samples was estimated from the values of bulk density (BD) and particle density (PD) (assuming an average particle density of mineral soil is 2.65 g cm-3). Then the total porosity (TP) was calculated as, TP (%) = (1-Bulk density/Particle density) * (100).The pH of the soils was measured in water (H_2O) suspension in a 1:2.5 (soil: liquid) by pH meter,

To determine organic carbon, the (Walkley and Black, 1965) method was used in which the carbon was oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid solution. Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724 following the assumptions that OM is composed of 58% carbon. The total nitrogen content in soils was determined using the Kjeldahl digestion distillation and titration method by oxidizing the OM in concentrated sulfuric acid solution (0.1N H_2SO_4) as described by Black (1965). The available P was calculated by the Olsen method using sodium bicarbonate (0.5M$NaHCO_3$) as an extraction solution (Olsen *et al*., 1954).Exchangeable bases (K, Mg and Ca) were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc) at pH 7.0. Exchangeable K was analyzed by flame photometer while Ca and Mg in the extracts was analyzed using atomic absorption spectrophotometer (AAS) as described by Rowell (1994). The soil analysis was done in Bako Soil Research Laboratory.

4.2.6. Termite identification

Termite species identification was based on key to the genera of Ethiopian termites which was done qualitatively using the internet search, termite webs and relevant books (Daniel Getahun and Emana Getu, 2014).

4.2.7. Statistical Analysis

The two way analysis of variance (ANOVA) was used to test differences in soil physical and chemical properties of mound soil across land use types and depths. Significant means ($P<0.05$) were separated using Tukey’s Studentized Range test (HSD) (SAS, 1999)

4.3 Results

4.3.1. Termite species composition

Termite genera identified were; *Macrotermes, Pseudacanthotermes* and *Odontotermes* (Table 4.2). Some were common from all land uses (cultivated, Grazing, Disturbed forests and built-up land. All species belong to Termitidae family. The encounters from the land uses were labeled by indicating present (+) for the encounters and (-) minus for non- occurred. *Macrotermes* are present in all land use. However, *Pseudacanthotermes* and *Odontotermes* are absent in grazing land use. The *Macrotermes* species are *Macrotermes subhyalinus* and *Macrotermes herus* which were common in Ethiopia and in west Wollega Zone

Table 4 2.Termite genera recorded from mounds found in different land use's patches in Limu district Fitbako *kebele* study sites, (2019)

Termite Genera	Land uses			
	Cultivated (m^2)	Grazing (m^2)	Disturbed forest (m^2)	Built-up land (m^2)
Macrotermes	+	+	+	+
Odontotermes	+	-	+	+
Pseudacanthotermes	+	-	+	+

+ =present, - = absent.

4.3.2. Physical characteristics of termite mound and adjacent soil of different land use system

Selected soil physical characteristics for representative profiles were described in Table 4.3 and Appendix4.1. Analysis of variance for mound soil of different land use system at various soil depths showed significant difference ($p<0.05$) on selected soil physical properties. Bulk density of mound soil at different depth showed variations among the different land uses (Table4.3; Appendix 4.2).The highest bulk density of (1.53gm/cm3) was recorded on grazing land mound soil at 40-60cm depth, while the lowest bulk density of (0.82gm/cm3) was recorded from adjacent soil to mound in disturbed forest land use

As indicated in Table 4.3 and Appendix 4.3. The highest porosity of (86.1%) was obtained from disturbed forest land use at 40-60cm mound soil depth, which implies that termite activity increases the soil porosity; which has significant influence on mound water infiltration. The lowest porosity value (45.92%) was recorded from adjacent soil of mound in the cultivated land use.

Beside this, the highest soil moisture content of (17.85%) was recorded on grazing land use mound soil at 40-60cm soil depth and the lowest moisture content of (7.95%) was noted from adjacent soil of mound in disturbed forest land use.(Table 4.3; Appendix 4.4). This may be due to low the OM content and subsequent increase in bulk density.

Table 4.3 Selected physical properties of termite mound and adjacent soil of different land uses at three depths

Treatment numbers	Land uses	Mound soil depth(cm)	Bulk D. (gm/cm^3)	Porosity (%)	Moisture Content(%)
1	Cultivated	0-20cm	1.13^{abcd}	57.83^{b}	12.37^{cd}
2		20-40cm	1.33^{abcd}	52.71^{cd}	13.85^{bc}
3		40-60cm	1.47^{ab}	46.69^{hi}	13.47^{c}
4		Adjacent soil	0.98^{bcd}	45.92^{i}	$10.9d^{e}$
5	Grazing	0-20cm	1.26^{abcd}	48.94^{fg}	12.75^{cd}
6		20-40cm	1.23^{abcd}	52.53^{d}	15.7^{b}
7		40-60cm	1.53^{a}	49.53^{ef}	17.85^{a}
8		Adjacent soil	0.99^{bcd}	48.14^{g}	13.2^{c}
9	Disturbed forest	0-20cm	1.38^{abc}	47.1^{h}	12.8^{cd}
10		20-40cm	1.51^{ab}	47.1^{h}	8.68^{f}
11		40-60cm	0.86^{cd}	86.1^{a}	11.89^{cd}
12		Adjacent soil	0.82^{d}	46.53^{hi}	7.95^{f}
13	Built-up	0-20cm	1.47^{ab}	49.69^{ef}	10.85^{ed}
14		20-40cm	1.33^{abcd}	49.89^{e}	11.8^{d}
15		40-60cm	1.36^{abc}	53.4^{c}	12.48^{cd}
16		Adjacent soil	1.13^{abcd}	48.95^{f}	9.52^{ef}

Means followed by the same letter (s) within a column are not statistically different from each other at 5% level, LSD.

4.3.3. Chemical characteristics (pH, OC and Av.P) of termite mound and adjacent soil of different land uses

Selected soil chemical characteristics are presented in Table 4.4 and Appendixes 4.5. Analysis of variance showed that selected chemicals nutrients; including OC, Av. P and the pH, were significantly affected ($p<0.05$). ANOVA of OC showed significant difference ($p<0.05$) in all treatments. As indicated in Table 4.4 and Appendix 4.6. Maximum pH value (7.06 pH; H_2O) was recorded from mound soil collected at the depth of 40-60cm from cultivated land uses and the minimum pH value (4.82pH:H_2O) was recorded from adjacent soil from mound of grazing land.

As illustrates in Table 4.4 and Appendix 4.7.The highest OC of (2.63%) was recorded under soil collected from mound soil of built- up land use at the depth of 40-60cm.This may be due to the accumulation of house debris and the lowest OC value of (0.42%) was registered from adjacent soil of mound found in grazing land use. The lowest OC contents of the surface layer of the cultivated field could be due to continuous cultivation that aggravated OC oxidation

On the other hand the maximum available P value of (21.33ppm) was recorded from soil collected at depth of 40-60cm mound found in cultivated land and the minimum available P value of (5.87ppm) was recorded from adjacent soil from mound of grazing land.(Table 4.4 and Appendix 4..8). Statistically significant difference ($p<0.05$) were observed among the treatments

Table.4.4 Comparison of Selected chemical properties of nutrients on different land uses at different depths.

Treatment numbers	Land uses	Mound soil depth(cm)	OC (%)	Av. P (ppm)	pH pH; H_2O)
1	Cultivated	0-20cm	2.04^{bcd}	8.67^{cde}	6.41^{b}
2		20-40cm	2.05^{bcd}	9.67^{bc}	6.63^{b}
3		40-60cm	2.05^{bcd}	21.33^{a}	7.06^{a}
4		Adjacent oil	1.73^{de}	7.35^{ef}	5.37^{cd}
5	Grazing	0-20cm	0.92^{gh}	$8.00d^{ef}$	5.05^{de}
6		20-40cm	0.72^{hi}	$8.00d^{ef}$	5.37^{cd}
7		40-60cm	0.63^{hi}	$8.33cd^{ef}$	5.04^{de}
8		Adjacent soil	0.42^{i}	5.87^{g}	4.82^{e}
9	Disturbed forest	0-20cm	1.50^{ef}	9.00^{cd}	5.47^{cd}
10		20-40cm	1.39^{ef}	9.00^{cd}	5.39^{cd}
11		40-60cm	0.86^{gh}	8.67^{cde}	5.52^{c}
12		Adjacent oil	$1.25f^{g}$	6.83^{fg}	$5.05d^{e}$
13	Built-up land	0-20cm	2.43^{ab}	11.00^{b}	5.05^{de}
14		20-40cm	2.17^{bc}	8.67^{cde}	5.68^{c}
15		40-60cm	2.63^{a}	7.5^{edf}	5.72^{c}
16		Adjacent oil	1.97^{cd}	7.00^{fg}	4.89^{e}

Means followed by the same letter (s) within a column are not statistically different from each other at 5% level, LSD.

4.3.4. Chemical characteristics (OM, TN, Av. K, Ex.Ca and Ex Mg) of termite mound and adjacent soil of different land uses

Selected soil chemical characteristics of representative profiles are presented in Table 4.5.Appendix 4.5. Analysis of variance showed that selected chemical nutrients; OM, TN, av. K, Ex.Ca and Ex Mg were significantly affected ($p<0.05$) by soil collected from mound soil of different land use systems at different soil depths. The maximum OM value of (3.68%) was recorded under soil collected from mound of built-up land use at 0-20cm soil depth. The highest OM contents of mound of built-up land use could be due to continuous cultivation of house wastes and the minimum OM value of (0.74%) was registered in adjacent soil of grazing land. (Table 4.5 and Appendix 4.9).

The highest TN value of (0.19%) was obtained from soil collected from mound soil of cultivated land at 0-20cm depth. The lowest TN value of (0.03%) was recorded under adjacent soil from mound of grazing land (Table 4.5).The lowest TN contents of the grazing surface layer could be due to continuous cultivation that aggravated OC oxidation which resulted in reduction of TN of termite mound.(Table 4.5 and Appendix 4.9).

As illustrated in Table 4.5.and Appendix 4.10.the highest available K value of (1.73cmol/kg soil) was recorded from mound soil collected from built-up land use at the depth of40-60cm and the lowest available K value of (0.61cmol/kg soil) was registered under adjacent soil from mound of grazing land.

As demonstrated in Table 4.5 and Appendix 4.11, the highest Exchangeable Ca value of (29.17 meq/100g soil) was observed from mound soil collected from cultivated land at the depth of 40-60cm. The lowest exchangeable Ca value of (5.15meq/100g soil) was recorded from adjacent soil of disturbed forest. The highest exchangeable Mg value of (9.39meq/100g soil) was recorded from mound soil collected from cultivated land at the depth of 0-20cm. The lowest exchangeable Mg value of (1.12meq/100g soil) was noted from adjacent soil collected built-up land at the depth of40-60cm (.Table 4.5 and Appendix 12).

Table.4.5. Comparison of Selected chemical properties of nutrients OM, TN, Av. K, Ex.Ca and Ex. Mg on different land uses at different depths.

Treatment numbers	Land uses	Mound soil Depth (cm)	OM (%)	T. N (%)	Av.K cmol/kg soil	Ex.Ca (meq/100 g soil)	Ex.Mg meq/100 g soil)
1	Cultivated	0-20cm	3.56^{a}	0.19^{a}	1.58^{ab}	14.60^{c}	9.39^{a}
2		20-40cm	3.47^{a}	0.18^{ab}	1.64ab	21.65b	3.01^{b}
3		40-60cm	3.50^{a}	0.17^{ab}	1.51ab	29.17a	3.51^{ab}
4		Adjacent soil	2.99^{b}	0.15^{ab}	1.47abc	14.49c	2.44^{b}
5	Grazing	0-20cm	1.72^{d}	0.07^{c}	0.81^{ef}	10.00^{d}	4.00^{ab}
6		20-40cm	1.59^{de}	0.067^{cd}	0.79^{ef}	8.00^{e}	1.97^{b}
7		40-60cm	0.83^{g}	0.06^{cd}	1.40^{bc}	7.00^{ef}	1.57^{b}
8		Adjacent soil	0.74^{g}	0.03^{d}	0.61^{f}	5.87^{fgh}	1.18^{b}
9	Disturbed forest	0-20cm	2.41^{c}	0.16^{ab}	1.43^{abc}	6.37^{fgh}	4.00^{ab}
10		20-40cm	2.39^{c}	0.14^{b}	1.32^{bc}	5.64^{gh}	3.00^{b}
11		40-60cm	1.49^{de}	0.07^{c}	1.52^{ab}	6.51^{fg}	2.53^{b}
12		Adjacent soil	1.30^{ef}	0.05^{cd}	0.98^{de}	5.15^{h}	1.42b
13	Built-up land	0-20cm	3.68^{a}	0.18^{ab}	0.84^{ef}	10.33^{d}	3.00^{b}
14		20-40cm	3.75^{a}	0.19^{a}	1.17^{cd}	6.63^{fg}	2.60^{b}
15		40-60cm	1.05^{fg}	0.07^{cd}	1.73^{a}	6.68^{fg}	1.12^{b}
16		Adjacent soil	1.02^{fg}	0.03^{cd}	0.82^{ef}	6.01^{fgh}	1.02^{b}

Means followed by the same letter (s) within a column are not statistically different from each other at 5% level, LSD.

4.3.5. Agricultural potential of termite mound soil and adjacent soil

Selected physical and chemical characteristics of mound and adjacent soil mean value, standard range and its rate value/ critical value compared to soil for crop production was shown in Table 4.6 and Table 4.7. As described in the result**, t**he maximum Bulk density (BD) of mound soil (1.35g/cm3) recorded from grazing land was higher than adjacent soil of (0.83.g/cm^3) of disturbed forest. The mound soil (BD) was higher than the normal value of bulk densities (1.16g/cm^3) and rated as moderate agricultural soils.

The mean value of termite mound soil porosity (86.1%) recorded from cultivated land is higher than the adjacent soil (45%) of cultivated land and it is higher than the average range value /critical level (50%) and rated very high as compared to standard soil for crop production (Table 7)Moisture content (17, 85%) recorded from grazing land was higher than the adjacent soil (7.95 %.) of disturbed forest .The mound soil moisture content was higher than the standard range value (10-50%) and rated moderate for crop growth.

Table 4.6 Selected physical properties of mound and adjacent soil average value, standard range and their ratings as agricultural soil

Selected physical properties	Average Value			Rating as agricultural soil
	Mound soil (%)	Adjacent soil (%)	Standard range (%)	
Moisture content	17.85%	7.95 %	10-50%	Moderate
Bulk density	1.35g/cm3	0.83g/cm3	1.16g/cm3	Moderate
Porosity	86.1%	45%	50%	Very high

ANOVA of the Selected chemical characteristics of mound and adjacent soil; pH, OC, OM, TN, Av. P, Av. K, Ex..Ca and Ex .Mg were significantly higher ($p<0.05$) than the standard value range/Critical level. Where pH, Av. P, Av, K, Ex.Ca and Ex Mg rated very high and OC, OM, TN rated medium when compared to the standard value range/critical level of soil for crop production (Table 7).

Table 4 7 Selected chemical properties of mound soil and adjacent soil, average value, standard range and their ratings as agricultural soil

Selected physical properties	Average Value		Standard range	Rating as agricultural soil
	Mound soil	Adjacent soil		
pH pH;$H_2$0	7.66	4.82	7.3	very high
OC%	2.63	0.42	1.5-3	Medium
OM%	3.68	0.74	2.6.-5	Medium
TN%	0.09	0.03	0.1-0.15	Medium
Av.P ppm	21.33	5.87	>3	very high
Av. K cmol/kg soil	1.73	0.61	>12	very high
Ex.Ca meq/100gsoil	29.	5.15	>20	very high
Ex. Mg meq/100gsoil	9.39	1 1.12	>8	very high

4.4. Discussion

The Current study provides evidence for termite diversity and physico-chemical analysis of different termite soil samples. The termite genera; *Macrotermes, Pseudacanthotermes* and *Odontotermes* are from the family Termitidae. *Macrotermes* recorded from all experimental land uses, however, *Pseudacanthotermes* and *Odontotermes* are absent from grazing land use system. The present investigated termites are according to Kalleshwaraswamy *et al*. (2018) who employed plus (+) and minus (–) for present and absent of termites respectively. Varied value of selected physical and chemical characteristics of mound and adjacent soil are attributed by these termites, consequently, high value is observed in mound soil than adjacent soil. This study was in agreement with, Afolabi, *et al*. (2014) who reported termite mound soil offer diverse range of physical and chemical environment of the mound soil that differ significantly from adjacent soil.

In the study, it is confirmed that, Maximum value of Bulk density, porosity and moisture content were recorded under grazing land then in disturbed forest land uses mound soil. Soil in grazing land and disturbed forest were evaluated as moderate agricultural soil as compared to the standard range value and minimum Bulk density, porosity and moisture content was recorded from adjacent soil in all land uses. The high value of soil physical characteristic in grazing land was attributed due to the pressure exerted by livestock's trafficking as it was described by Abera Donis and Kefyalew Assefa

(2017). Soil of this area consequently compacted with accommodating organic matter. Organic matter makes the soil porous to allow the movement of liquid thereby increases soil moisture content. Mahsa *et al.* (2017) stated that, overgrazing also hasten vegetation removal. This clearing of vegetation makes the land bare for facilitation of infiltration that eventually increases moisture content of termite soil. In supporting this, Afolabi, *et al*. (2014) stated termite galleries regularly receive moisture when termites transport moist soil from other area to renew their mound for survival, Termite soil bulk density was rated moderate for crop production. This was inconsistent with Ackerman *et al*. (2007) who noted that termite mound soils are more compacted and had more bulked soil than surrounding soil. In contrasting this, Omofunmi *et al*. (2017) reported that bulk density of the termite mound soil was 44 per cent lower than the surrounding soil

The high value of porosity obtained due to high bulk density in termite soil was resulted due to accumulation of fine clay particles in termite soil .In agreement with this, Ackerman *et al*. (2007) reported that clay collected by termite translocation and accumulated to the very near area by agents like erosion and animals result in increase soil porosity of the termite material than the surrounding soils. As described in the result, the separated tabulation of the selected chemical character ,(pH, OC and Av .P) and **(**OM, TN, Av. K, Ex.Ca and Ex Mg) is in line with Pandiaraj *et al. (*2018) who reported (pH, OC and Av .P) in one table and the other macronutrient in the other table and investigate the maximum result of ; pH, OC, OM, TN) Ex. Ca), Mg av.K, and Av.P in termite mound soil than in adjacent soil is in consistent with Daniel Getahun and Emana Getu, (2014).who reported that 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

As demonstrated in the result, the highest pH value was recorded at depth of 40-60cm from cultivated land and the lowest pH value was recorded from adjacent soil of grazing land. This termite soil pH value was higher than the standard range (pH 6.5) of soil for agricultural crops indicates termite activities lead to an increase in soil pH. In agreement with these Omofunmi *et al.*, (2017) describe termite activities lead to increase termite mound soil pH to affect soil ion solubility. In supporting this, Seibert *et al*. (2007) stated that, termite modify soil pH value due to the accumulation of organic matter which in turn increase soil pH value in their nests to affects microbial activity and plant growth. This was accepted by Mulugeta Tufa *et al. (*2019) who stated termite mound is moderately acidic and high in soil nutrients suitable for the growth of maize plant.

As illustrated in the result, highest OC was recorded from mound soil of built -up land at depth of 40-60cm. In contrast to this, Dahlsjo *et al.,* (2014), reported that OC in termite mounds decrease in relation to the control soil. This could happen due to minimal potential of soil microorganisms in the release of OC.

The present result demonstrated that highest OM content of mound soil of built -up land at depth 0-20cm and the lowest OM value from adjacent soil of grazing land. Termite soil which installs high OM is known to be moderate to the standard range value of crop production. In accepting this Afolabi, *et al*.,(2014) stated termite activity increases the content of organic matter in the soils through modifying the clay mineral composition thereby increases the Cation Exchange Capacity CEC and water holding capacity of soil. However this result was argued by Tilahun *et al*. (2012) who stated that the contents of organic matter were not higher in termite mound as compared to adjacent soil. This is inconsistent to Kamaraj *et al*. (2018) who states that there is significantly lower organic matter content in the termite mound than adjacent soil. The highest TN result was recorded from mound soil of cultivated land at depth 0-20cm. and the lowest TN result was recorded from adjacent soil of grazing land. This is happen due to TN retention from prolonged time accumulation of Nitrogen in application of commercial fertilizer The result obtained in termite soil is therefore evaluated moderate to crop production This result was accepted by Fairhurst,(2012) who stated that the termite soil is rated moderate as compared to the standard range value 0f N (0.20%) In supporting this Menichetti *et al*.(2014) reported that an elevated OC and TN on termite mounds more than in adjacent soil was likely due to the release of termite excretions and the increased nutrient retention of the mound soil

In the result, highest av. P was recorded from mound soil of cultivated land at 40-60cm and the lowest av P recorded from adjacent soil of grazing land was in agreement to Tilahun *et al*.(2012) who stated av. P concentrations were significantly($P < 0.05$) increased by 90, 59, and 70% in termite mound materials compared to the adjacent soils. In accepting this Seymour *et al*. (2014) reported that N and P concentrations in termite soil variation is seasonal dependent (dry and rain fall), the concentration may significantly exceed those in the matrix during the dry season.As shown in the result, the highest av. K was recorded from mound soil of built- up land and the lowest av. K recorded in adjacent soil of grazing land, the highest av. K result was rated moderate as compared to the standard range value for crop production. In accepting this, Fageria *et al*.

(2004) reported that av.K contents of termite mound soils were increased much more than that of the adjacent soils. An increase in av. K is due to the fact that termites feed on dead cereal and legume straw which resulted in substantial increase in levels of av.K concentrations, In supporting Fairhurst (2012) stated that av.K is one of the essential elements required by plants for their growth and av. K input increase through activating enzymes, photosynthesis, starch synthesis, nitrate reduction and sugar degradation.

The highest and lowest Ex. Ca and Mg records in termite soil and adjacent soil of different land use at different soil depth result were in agreement with the finding of Tilahun Mola *et al*. (2012) who stated significantly higher ($P < 0.05$) amounts of exchangeable Ca, Mg and av.K were recorded in termite mound material compared to the adjacent top soils at both site. Fageria *et al*. (2004) further stated termite activities lead to an increase in extractable Ca and Mg in mound soil than in adjacent soil. Omofunmi *et al*. (2017) also reported significantly higher values of exchangeable Ca, Mg and av.K were observed from termite mounds than adjacent soil, this substantial increase in levels of extractable Ca and Mg related to termites feeding material. In contrary to this, Ackerman *et al*. (2007) reported that the highest value of exchangeable Ca and Mg were observed under the soil out of termite activities and the lowest value was observed under termite mound soil

4.5. Conclusion

In the present study, termite mound soil was found higher than adjacent soil in most of the analyzed selected physical and chemical properties. Termite soil selected physical properties (Bulk density, Porosity and Moisture content,) and selected chemical nutrients (OC, OM, TN, Av. P, Av. K, Ex.Ca, Ex .Mg) and the pH average value are significantly higher in the mound soil than the adjacent soils and rated moderate and in some case very high for crop production as there was accumulation of more nutrients for plant growth in the mound soil than adjacent soil. Varied value of selected physical and chemical characteristics of mound and adjacent soil are attributed by termites, genera; Macrotermes, Pseudacanthotermes and Odontotermes hosted in the study area. Termite mound soil with high value of selected physical and chemical properties allows better plant growth than adjacent soil. Farmers in the available termite mound area can use termite mound soil as fertilizer to compensate the high expense of commercial fertilizer for crop production without altering termite ecology

CHAPTER 5

Some physicochemical properties of Termite mound soil and its effect on Yield and yield components of Maize (Zea mays L.) under Greenhouse condition, at Wollega University (WU) in East Wollega zone, Western Ethiopia

5.1. Introduction

Termites are considered to be one of the most destructive pests in the world. But, termite mound soil amends soil fertility and utilized as an alternative to NPK fertilizers by cash constrained smallholder farmers in some parts of Africa. (Abdeta Jembere *et al*., 2017). However, there is little knowledge on mound mineral nutritional value and the impact they have on plant growth and yield in western Ethiopia particularly Nekemte areas where high maize production, high termite mound distribution and termite infestations is there. Termites mostly feed on dead plant matter like woodchip, decayed wood (logs), leaf litter and soil. They are considered major pests of cereals like maize, sorghum and teff among others (Daniel Getahun and Emana Getu, 2014).Termites are also important component of agro-ecosystems as their mounds amend nutrient depleted soils (Avitabile *et al*., 2015).

Termites are large and diverse group of soil fauna consisting over 3000 species in 280 genera and seven families in the world (Abdurahaman Abdulahi, 1990). In Africa, there are about 1000 termite species. Termite prevalence survey conducted in western, southern, and eastern parts of Ethiopia provided basic information on termite fauna of Ethiopia .In Ethiopia, there are 61 species of termites belonging to 25 genera and four families (Abdeta Jembere *et al*., 2017). Termites live in their own mound there are also some inquilines. The density of termite in a mound depends on the size of the mound. Huge mounds have more colony members. Subterranean termites mound harbor 3,000–200,000 individual termites.

Termite mound is constructed from a mixture of soil, termite saliva and dung/plant materials. The top of the mound consists of a central chimney surrounded by an intricate network of tunnels and passages (Daniel Getahun and Emana Getu, 2014).The genus *Macrotermes b*uilds large mounds that have a characteristic feature of many grasslands and savanna woodlands in Africa. Termite genera that build mound include *Macrotermes, Cubitermes, Amitermes, Odontotermes, Procubitermes* and *Trinervitermes* (Abdurahaman Abdulahi,1990;Mokossesse *et al*.,2012).Mound building termites are abundant in degraded low soil fertility and high soil acidity areas particularly in areas that were converted to pasture lands (Rückamp, 2012). Termites feed on a whole range of living and dead plant materials and decompose it to concentrate nutrients in the mound (Avitabile *et al*., 2015).It is with the aid of soil dwelling free living N_2 fixing bacteria, Azotobacter *and Bacillus* that termites digest the foraged materials and decompose it to organic matter *(*Sathiya *et al*.,2018).

These admixture in one hand alter the natural texture of soil and on the other hand accumulate more soil organic carbon (OC), organic matter (OM),PH, Ca, K, N and Mg in mound soil (Jouquet *et al.,* 2011).Such kind of termite's mound debris/organic matter and nutrients content amends soil fertility for the better functioning of the ecosystem (Bonachela *et al.,* 2015).Termites act of bioturbation changed soil texture and make it more porous (Jouquet *et al.,* 2015). Abdeta Jember *et al*. (2017) reported mound making termites such as Macrotermes and Odontotermes significantly influence soil properties and amend soil fertility. Savanna regions Nigerian farmer's and others including the highlanders of resource poor farmers of southwest Ethiopia use termite mound soil as fertilizer (Abdeta Jembere *et al.,* 2017).

Small holder famers use termite mound soil as a fertilizer mainly due to inflated cost of commercial fertilizer. Fageria and Baliga (2004) after testing it on improved maize variety recommended the use of mound soil in combination with NPK fertilizer as it improved plant growth and gave high yield. Though there is high density of mounds in East Wollega Zone, little or no study was conducted to analyze the mineral contents of mound soil and its effect on yield and yield components of maize.Therefore, the present study was initiated with the following objectives,

- To investigate the nutrient composition of termite soil for maize plant growth
- To compare termite mound soil with/out inorganic fertilizer and adjacent soil with/out inorganic fertilizer on maize plan growth

5.2. Materials and Methods

5.2.1. Description of the study area

The Green house experiment was conducted at Wollega University (WU) in East Wollega zone, Western Ethiopia (Figure 5. 1) from January 2019 to June 2019. The study was located at 9'5.887'N latitude, 36'34.647'E longitude and at an elevation of 2080 meter above sea level (m.a.s.l.). The maximum and minimum temperatures of the area were 21.66°C and 13.62°C, respectively. The relative humidity was 55.45% and the average rain fall was 1862.33mm.The study area, Nekemte town was 335km away from Addis Ababa to the west.

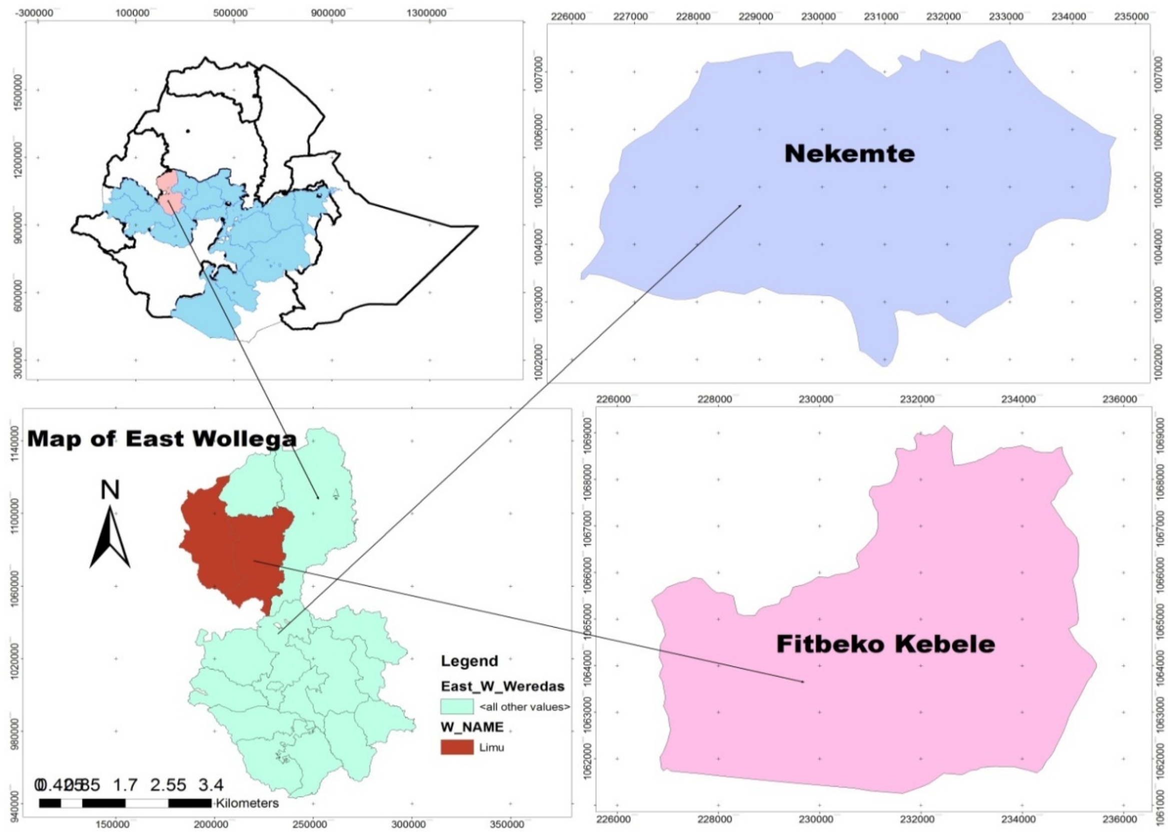

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Figure 5. 1 Map of the study area

5.2.2. Termite Sampling and identification

Mounds in the cultivated land were purposively selected, dug and opened with hoe. Termite soldier samples which came out of the mound for defense were hand-collected with forceps and were preserved in 80% ethanol following Abdurahaman Abdulahi(1990), and Daniel Getahun and Bekele Jembere(2006) procedures. Collected specimens were taken to Addis Ababa University, Insect Science Laboratory for identification. Morphological identification was done using Keys for the Genera of Ethiopian Termites. Moreover, books, pictures and reference collections were used for the identification (Emana Getu *et al.,* 2008). The shape and the size of the mandible were the major features considered for the identification.

5.2.3. Experimental materials

Samples of termite mound soil, adjacent soil and non-mound soil were collected from cultivated land of Limu district, Fitbako *kebele* in Eastern Wollega zone. Widely grown maize variety, BH-661 and NPK fertilizer were obtained from Zone Office of Ministry of Agriculture based at Nekemte town.

5.2.4. Pot preparation and filling of soil in the pot

Twelve pots (plastic buckets) which have 50 litters capacity were purchased from local market. The buckets were perforated at the distance of 5cm from the bottom with nail to prevent inundation. From the stock of Mound soil (MS), Adjacent soil (AS) and Non-mound soil (NMS) three kilogram each were weighed and added to each bucket following Ezeaku *et al*.(2015) and Ezekiel *et al*. (2018) procedures. After filling the pot with appropriate soil sample based on the treatment, all buckets were kept at one-meter distance and watered two days before planting. All buckets were watered twice per day throughout the experimental period. Fertilizer was applied at the rate of 150kg/ha following Ezekiel *et al*. (2018) procedure. Two maize seeds were planted in circular hole having 15cm depth and 30 cm diameter made with finger in each bucket following (Mokossesse*et al*. 2008).procedure. Two weeks after planting when the seedlings attained two leaves stage, one seedling was removed to minimize competition. Weeding was done by hand and deposited in their respective buckets.

5.2.5. Experimental design and Treatments

The experiment was laid out in a completely randomized design (CRD) with three replications. The treatments were Mound soil (MS), Adjacent soil (AS), NPK (15: 15: 15), Non-mound soil (NMS) following from (Olowoboko1 *et al*., 2017).The interactions MS+AS, MS+NPK, MS+NMS, AS+NPK, AS+NMS, NMS+NPK, MS+AS+NMS and MS+AS+NMS+NPK

5.2.6. Data collection

Termite genera composition, termite mound and adjacent soil selected physical and chemical properties, plant growth traits at 2, 4 and 8 weeks and yield parameter. Yield per plant (g) and yield (kg/pot) weighed were some data collected

5.2.7. Soil Sampling and analysis

During preliminary survey a plot having100mx100m size was delineated from cultivated land for sampling mounds. Three mounds in this patch were marked with permanent marker randomly. Soil samples were taken from bottom, middle and top of the termite mounds and mixed up thoroughly to get composite sample of 10 kg from the three mounds. Composite soil sample collection of 10 kg was done at the depth of 0-30cm using auger for adjacent soil 5m away from the mounds. Composite non-mound soil of 10kg at similar depth with that of adjacent were collected 20 m away from the mounds following Daniel Getahun and Emana Getu (2014) procedures. From each soil types, 3 kg were drawn and used for physiochemical analyses based on National Soil Research Centre of Ethiopia (2000) established procedure. Then some selected physical and chemical properties were analyzed. 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 (Gupta, 2000). 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 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 "method using glass electrode (Olsen, 1954). The pH of the soil was measured potention metrically on direct reading pH meter in water suspension with soil to water ratio of 1:2.5. Exchangeable basic cations (Ca, Mg, K and Na) were extracted with 1M ammonium acetate at pH 7. Exchangeable Ca and Mg were determined from this extract with atomic absorption spectrophotometer, while exchangeable K and Na were determined from the same extract with flame photometry (Abera Donis and Kefyalew Assefa, 2017). The soils were analyzed at Bako Agricultural Research Centre soil laboratory.

5.2.8. Statistical analysis

Analysis for the effect of Mound soil, NPK, Adjacent soil and Non-mound soil on growth trait and maize yield component were done using ANOVA was employed using SAS software version 9.1. Significant means were separated using Tukey's Studentized Range Test (HSD) at 5% significance level (SAS, 1999).

5.3. Results

5.3.1. Termite diversity

Termite genera collected from Fitbako *kebele* mounds of cultivated land use were shown in Table 5.1. Out of the 60 solider samples collected from the three mounds, the genera Macrotermes and Odontotermes were recorded. About 75% of these termites were from the Genus Macrotermes. *Macrotermes subhyalinus* (Rambur) species were collected from mound1 and mound 2. *Macrotermes herus* (Sjostedt) were collected from mound3.

Table 5.1. Termites ‘Genera composition of Fitbako *kebele* cultivated land use

Termite mounds	Termites genera	
	Macrotermes	*Odontotermes*
Mound 1	25	0
Mound 2	20	0
Mound 3	0	15
Composition (%)	75	25

5.3.2. Selected physical properties of Mound soil, Adjacent and Non-mound soil

Selected physical property of mound soil and adjacent soil analyzed from composite soil samples were shown in Table 5.2; Appendix 5.1. The bulk density of mound soil was higher than adjacent soil and non mound soil. However, bulk densities of both termite mound, adjacent and non-mound soil were at the normal value range (1.02-1.35gcm) as compared to agricultural soils. The moisture content of mound soil was higher than adjacent and non mound soil. This showed the presence of available water content in the mound soil for normal crop plant growth. The porosity of mound soil was higher than the adjacent and non-mound soil. However, the value of both termite mound soil, adjacent and non-mound soil are more than the normal soil porosity value (50%), for crop production,

Table 5. 2 Laboratory analyses of Bulk density, Moisture content and Porosity of Mound, Adjacent and Non mound soil of Fitbako *kebele.* From Cultivated land use site

Soil type	Bulk density (g/cm^3)	Moisture content (%)	Porosity (%)
Mound soil	1.24	13.20	60.16
Adjacent soil	1.04	10.1	52.55
Non-mound soil	1.0	8.5	52.36

5.3.3. Selected chemical properties of Mound soil, adjacent soil and Non-mound soil

Selected chemical properties of termite mound soil, adjacent soil, and Non-mound analyzed from composite soil samples soil are shown in Table 5. 3; Appendix 5.2. Non-mound soil had the lowest pH 4.5 PH (1:1.25), while that of mound soil was the highest 5.44 PH (1:1.25). Organic carbon (OC) in mound soil was the highest. However, the mound, adjacent and non-mound values are less than the standard range value of OC (>3%) for agricultural soil. The mound soil had higher organic matter (OM) with the value of 4.88% than the adjacent soil (1.30%) and non-mound soil (1.21%) present medium range of OM (3-5%) compared to crop land soil. The highest total nitrogen (TN) (0.14%) was observed in mound soil and the lowest TN (0.04%) was recorded on Non mound soil. All the TN values recorded were lower than the range value of (TN) (0.25%). The highest concentration of P, (9.00) ppm was recorded from mound soil, while the lowest (7.23) ppm of P was recorded from non-mound soil. The highest exchangeable Ca and Mg values were 7.70meq/100g and 1.90meq/100g in mound soil. Mound soil had more k (1.97 cmol/kg soils) than adjacent soil (0.96 cmol/kg soil) and non-mound soil (0.56 cmol/kg soil). However, the value of K in mound soil, adjacent soil and non-mound soil were greater than the critical level of K (0.38 cmol/kg soil) for crop production. Slightly higher Mg (1.90meq/100g soil) content was found in mound soil than adjacent soil Mg =1.87meq/100g soil) and non- mound soil (Mg = 1.86meq/100g soil). However, the value of Mg in mound soil, adjacent soil and non-mound soil were greater than the critical level of Mg (0.50meq/100g soil) for the soil used for crop production.

Table 5 3 Selected chemical properties of Mound soil adjacent soil and Non-mound soil collected from Fitbako *kebele.* Cultivated land use

Categories	PH (1:1.25) H_2O	% OC	%OM	%TN	Ava. P(ppm)	Ex. K(cmol /kg oil)	Ex.Ca (meq/100gsoil)	Ex.Mg (Meq/100 g soil)
Mound soil	5.44	2.83	4.88	0.14	9.00	1.97	7.70	1.90
Adjacent	5.10	0.76	1.30	0.06	7.30	0.96	7.33	1.87
Non-mound soil	4.5	0.35	1.21	0.04	7.23	0.56	7.21	1.86

5.3.4. Effect of termite Mound soil, adjacent soil and Non-mound soil on maize plant growth traits two weeks after planting

Effects of termite mound soil, NPK, adjacent soil and non-mound soil on maize growth traits two weeks' after planting were shown in Table 5.4;Appendix 5.3. Treatments effects were significantly different ($p<0.05$) two weeks after planting. The highest plant height (32cm) was recorded from the four treatments combination i.e., MS+AS+NPK+NMS while the lowest plant height (16.04cm) was recorded from plants grown on non-mound soil. As depicted in Table 5.4;Appendix 5.4, Termite mound soil alone and termite soil combined with other treatments significantly ($P<0.05$) affected plant growth. The highest stem width was observed in four combined treatments (MS+AS+NPK+NMS), while the lowest plants stem width was recorded from non-mound soil. Plants grown in applied inorganic fertilizer NPK and treatments' combination (MS+ AS+NPK+NMS) significantly ($P<0.05$) higher in number of leaves and leaf area (cm) than adjacent and non-mound soil (Table 5.4; Appendixes 5.5).

Table 5. 4 Effect of termite Mound soil, Adjacent soil, NPK and Non-mound soil on means (±se) of maize growth traits two weeks after planting

Treatments	Plant height (cm)	Stem width(cm)	No of leaf	Leaf width (cm)
MS	24.1±2.7^{c}	2.8±0.26^{b}	8.0±2.1^{bc}	2.8±0.27^{bc}
AS	18.0±1.8^{e}	2.3±0.24^{de}	7.0±1.8^{d}	2.5±0.20^{d}
NPK	23.6±2.7^{cd}	2.7±0.25^{bc}	7.2±2.0^{c}	2.4±0.25^{de}
NMS	16.4±1.7^{f}	2.0±0.21^{e}	6.0±2.0^{de}	2.1±0.23^{ef}
MS+AS	25.0±2.7^{b}	2.60±0.24^{cd}	8.0±2.1^{bc}	2.4±0.25^{de}
MS+NPK	30.0±2.9^{ab}	2.8±0.29^{ab}	9.0±2.5^{b}	2.7±0.24^{c}
MS +NMS	24.0±2.7^{cd}	2.7±0.28^{c}	8.0±2.1^{bc}	2.6±0.22^{cd}
AS+NPK	20.0±1.8^{d}	2.5±0.23^{d}	7.0±2.0^{c}	2.5±0.20^{d}
AS+NMS	18.0±1.8^{e}	2.3±0.22^{de}	7.0±2.0^{c}	2.5±0.20^{d}
NMS+NPK	17.4±1.7^{ef}	2.1±0.21^{e}	6.0±2.0^{de}	2.1±0.23^{ef}
MS+AS+NMS	24.1±2.7^{c}	2.8±0.26^{b}	8.0±2.1^{bc}	2.8±0.27^{bc}
MS+AS+ NMS+NPK	32.0±2.9^{a}	3.1±0.34^{a}	10±2.6^{a}	3.5±1.29^{a}

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium. Means followed by the same letter (s) within a column are not significantly different from each other at 5% level, Tukey's Studentized Range Test (HSD).

5.3.5 Effect of termite Mound soil, adjacent soil, Non-mound soil on maize plant growth traits four weeks after planting

Maize plant growth traits were significantly ($P<0.05$) high on plants grown on treatments combination except number of leaves which were not statistically different ($P>0.05$) in all treatments four weeks after planting (Table 5.5, Appendix 5.6). Maize plant growth traits were significantly ($P<0.05$) low in non-mound soil.

able 5 5 The effect of termite Mound soil, , Adjacent, NPK and Non- mound soil on mean (±se) maize growth trait four weeks after planting

Treatments	Plant height (cm)	Stem width (cm)	No. of leaf	Leaf width (cm)
MS	67.10±9.35^{c}	7.12±1.36^{ab}	10.0±2.1^{ab}	7.5±2.19^{b}
As	53.20±7.32^{f}	5.67±0.98^{d}	9.6±2.0^{b}	5.6±1.89^{d}
NPK	66.89±9.35^{d}	7.02±1.36^{b}	10.0±2.1^{ab}	6.9±2.19^{c}
NMS	50.20±7.29^{g}	4.30±0.80.^{e}	9.0±1.2^{c}	4.9±2.19^{e}
MS+AS	64.30±9.35^{e}	6.13±1.21^{bc}	9.3±1.4^{bc}	7.0±2.09^{bc}
MS+NPK	76.30±10.72^{b}	7.25±1.36^{ab}	10.0±2.1^{ab}	8.0 ±0.19^{ab}
MS+NMS	67.10±9.35^{c}	7.12±1.36^{ab}	10.0±2.1^{ab}	7.5±2.09^{b}
AS+NPK	66.34±9.35^{d}	6.27±1.21^{bd}	9.9±2.0^{b}	6.9±2.09^{bc}
AS+NMS	56.20±7.29^{g}	4.35±0.80.^{e}	9.3±1.4^{bc}	4.9±2.19^{e}
NMS+NPK	53.20±7.32^{f}	5.67±0.98^{d}	9.6±2.0^{b}	5.6±1.89^{d}
MS+AS+NPK	77.30±10.72^{b}	7.25±1.35^{ab}	10.0±2.1^{ab}	8.0±2.19^{b}
MS+ AS+NPk+NMS	80.00±11.41^{a}	7.30±1.36^{a}	10.4±2.2^{a}	10±2.59^{a}

*MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium. Means followed by the same letter (s) within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.6 Effect of termite Mound soil, adjacent soil and Non-mound soil on maize plant growth traits eight weeks after planting

Effect of plant growth input on mean number of maize growth trait eight weeks after planting was significantly affected ($P<0.05$) by treatments. However, statistically non-significant ($p>0.05$) difference is observed in plant height and leaves number for all treatments (Table 5.6.).Beside this, stem and leaf width were significantly affected ($p<0.05$) by treatments. The highest stem width (9.2cm) and the highest leaf width (9.4cm) were recorded from four combined treatments respectively and the lowest stem width (5.13cm) and the leaf width (5.7cm) were recorded from NMS respectively. Stem and leaf width growth traits also resume significant growth from MS and MS+NPK treatments (Table 5. 6; Appendixes 5.7-5.9).

Table 5.6 The effect of termite Mound soil, Adjacent soil, NPK and Non-mound soil on mean (±se) maize growth trait eight weeks after planting.

Treatments	Plant height (cm)	Stem width(cm)	No of leaf	Leaf Width (cm)
MS	1.32±0.17[a]	8.5±1.19[bc]	11.0±0.86[ab]	7.6±1.16[b]
As	1.44±0.17[a]	5.13±1.18[de]	11.0±0.86[ab]	6.5±1.26 [cd]
NPK	1.30±0.17[a]	7.53±1.18[c]	11.8±0.86[ab]	6.7±1.26[c]
NMS	1.30±0.17[a]	5.0±1.11[de]	11.2±0.86[ab]	5.7±1.06[d]
MS+AS	1.32±0.17[a]	6.5±1.10[d]	11.9±0.86[ab]	7.1±1.16[b]
MS+NPK	1.50±0.17[a]	8.9±1.08[b]	11.2±0.86[ab]	7.7±1.16[b]
MS+NMS	1.41±0.17[a]	9.2±1.18[a]	11.3±0.86[a]	9.4±1.06[a]
AS+NPK	1.32±0.17[a]	7.5±1.18[c]	11.8±0.86[ab]	7.1±1.16[b]
AS+NMS	1.40±0.17[a]	8.9±0.18[b]	11.2±0.86[ab]	7.7±1.16[b]
NMS+NPK	1.50±0.17[a]	5.0±1.11[de]	11.2±0.86[ab]	5.7±1.06[d]
MS+AS+NPK	1.51±0.17[a]	9.2±1.18[a]	12.3±0.86[a]	9.4±1.06[a]
MS+AS+NPK+NMS	1.61±0.17[a]	9.2±1.18[a]	12.3±0.86[a]	9.4±1.06[a]

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.7 Effect of plant growth inputs (termite Mound Soil, Adjacent and Non-mound soil) on yield components at harvest

The effect of termite mound soil, NPK, adjacent soil and non-mound soil on mean number of maize yield components at harvest was shown in Table5.7.Appendixes 5.10-5.13.There was no significant difference($p>0.05$) between the plant height. However, other maize plant growth performance and yield were significantly affected ($p<0.05$) by application of treatments. In cob, there was significant difference among the applied treatments. However, all the recorded treatments are all most revealing similar mean number of cobs. ANOVA of grain yield per pot shows significantly difference ($P<0.05$) among the treatments. (Table 5.7)

As revealed in the result, the highest grain yield per pot was recorded from combined MS+AS+NPK+NMS treatments and the lowest grain yield were recorded from non-mound soil. Termites are considered to be one of the most destructive pests in the world. But, termite mound soil amends soil fertility and utilized as an alternative to NPK fertilizers by cash constrained smallholder farmers in some parts of Africa. However, there is little knowledge on mound mineral nutritional value and the impact they have on plant growth and yield in western Ethiopia particularly Nekemte areas where high maize production, high termite mound distribution and termite infestations is there.

As illustrated in the result, statistically significant difference ($P< 0.05$) was observed in yield per pot form all treatments at harvest (Table 5.7). The highest yields were recorded from four MS+AS+NPK+NMS combined treatments and the lowest yield per pot was observed from Non-mound soil. Significant yield production was also observed in MS and further more yield was recorded from four mixed treatment MS+NPK+AS+NMS than Non –mound soil

Table 5.7 Effect of termite Mound soil, NPK, Adjacent and Non-mound soil on mean (±se) of maize yield components**.**

Treatments	Plant height (m)	No of cobs per plant	Yield per plant	Yield per pot
MS	$3.53±0.01^{a}$	$2.7±1.46^{ab}$	$1.5±0.29^{b}$	$8.3±1.48^{bc}$
As	$3.57±0.01^{a}$	$2.2±0.46^{c}$	$1.5±0.29^{b}$	$7.0±1.40^{d}$
NPK	$3.52±0.01^{a}$	$2.5±1.46^{b}$	$1.4±0.29^{bc}$	$8.0±1.48^{c}$
NMS	$3.52±0.01^{a}$	$2.0±0.06^{d}$	$1.0±0.10^{d}$	$3.7±0.40^{de}$
MS+AS	$3.55±0.01^{a}$	$2.3±0.46^{bc}$	$1.3±0.19^{c}$	$8.0±1.48^{c}$
MS+NPK	$3.54±0.01^{a}$	$2.3±0.46^{bc}$	$1.6±0.29^{ab}$	$9.0±1.46^{b}$
MS+NMS	$3.53±0.01^{a}$	$2.7±1.46^{ab}$	$1.5±0.29^{b}$	$8.3±1.48^{bc}$
AS+NPK	$3.53±0.01^{a}$	$2.3±0.46^{bc}$	$1.3±0.19^{c}$	$7.0±0.40^{d}$
AS+NMS	$3.53±0.01^{a}$	$2.3±0.46^{bc}$	$1.3±0.19^{c}$	$7.0±0.40^{d}$
NMS+NPK	$3.53±0.01^{a}$	$2.3±0.46^{bc}$	$1.3±0.19^{c}$	$7.0±0.40^{d}$
MS+AS+NPK	$3.55±0.01^{a}$	$2.3±0.46^{bc}$	$1.3±0.19^{c}$	$7.0 ±0.40^{d}$
MS+AS+NPK+NMS	$3.55±0.01^{a}$	$3.0±1.55^{a}$	$1.9±1.19^{a}$	$13 ±2.40^{a}$

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.8. Effect of treatments contribution to maize plant growth trait and yield components

Plant growth trait; plant height, stem girth, leaf width, No, of cobs and yield per plant pot result has shown in Table 8..Plant growth trait and yield components were significantly ($p<0.05$) affected by all treatments. As result significant growth was attained from all treatments at 2, 4 and 8 weeks after planting (WAP) than non-mound soil. The highest total grain weight of maize was recorded from pot treated with termite mound soil than non-mound soil. Significant yield per pot was also observed in MS and further more yield was recorded from four mixed treatment MS+NPK+ AS+NMS than non mound soil (Table 5 8).This article was published (Appendix 7.1)

Table 5. 8 Effect of termite Mound soil, Adjacent soil, NPK and Non-mound soil on means (±se) of maize growth traits two weeks after planting

Treatments	Plant height (cm)	Stem width(cm)	No of leaf	Leaf width (cm)
MS	24.1±2.7^{c}	2.80±1.26^{ab}	8.0±1.8^{cd}	2.8±0.27^{bc}
AS	18.0±1.8^{e}	2.30±0.24^{de}	7.0±1.8^{de}	2.5±0.25^{d}
NPK	23.6±2.7^{cd}	2.75±0.28^{bc}	7.2±1.8^{a}	2.4±0.25^{de}
NMS	16.4±1.7^{f}	2.04±0.21^{e}	6.0±0.8^{e}	2.1±0.23^{e}
MS+AS	25.0±2.7^{b}	2.60±0.27^{cd}	8.0±1.8^{cd}	2.4±0.25^{de}
MS+NPK	30.0±2.9^{ab}	2.87±1.26^{b}	9.0±1.8^{bc}	2.7±0.27^{c}
MS +NMS	24.0±2.7^{cd}	2.70±0.24^{cd}	8.0±1.8^{cd}	2.6±0.26^{cd}
AS+NPK	20..0±1.8^{d}	2.50±0.04^{d}	7.0±1.8^{de}	2.5±0.25^{d}
AS+NMS	18.0±1.8^{e}	2.30±0.14^{de}	7.0±1.8^{de}	2.5±0.25^{d}
NMS+NPK	17.4±1.7^{ef}	2.14±0.21^{e}	6.0±0.8^{e}	2.1±0.23e
MS+AS+NMS	24.1±2.7^{c}	2.80±0.26^{ab}	8.0±1.8^{cd}	2.8±0.27^{bc}
MS+AS+ NMS+NPK	32.0±2.9^{a}	3.16±2.22^{a}	10.0±2.8^{a}	3.5±0.29^{a}

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium. Means followed by the same letter (s) within a column are not significantly different from each other at 5% level, Tukey's Studentized Range Test (HSD).

5.3.9 Effect of termite Mound soil, adjacent soil, Non-mound soil on maize plant growth traits four weeks after planting

Maize plant growth traits were significantly ($P<0.05$) high on plants grown on treatments combination except number of leaves which were not statistically different ($P>0.05$) in all treatments four weeks after planting (Table 5.5, Appendix 5.6). Maize plant growth traits were significantly ($P<0.05$) low in non-mound soil.

Table 5 9 The effect of termite Mound soil, , Adjacent, NPK and Non- mound soil on mean (±se) maize growth trait four weeks after planting

Treatments	Plant height (cm)	Stem width (cm)	No. of leaf	Leaf width (cm)
MS	67.10 ± 9.35^{c}	7.12 ± 1.36^{ab}	10.0 ± 2.2^{a}	7.5 ± 1.59^{b}
As	53.20 ± 7.32^{f}	5.67 ± 0.98^{d}	9.6 ± 2.2^{a}	5.6 ± 1.19^{c}
NPK	66.89 ± 9.35^{d}	7.02 ± 1.36^{b}	10.0 ± 2.2^{a}	6.9 ± 1.89^{bc}
NMS	50.2 ± 7.29^{g}	$4.30\pm0.80.^{e}$	9.0 ± 2.2^{a}	4.9 ± 2.19^{d}
MS+AS	64.30 ± 9.35^{e}	6.13 ± 1.21^{bc}	9.3 ± 2.2^{a}	7.0 ± 1.18^{bc}
MS+NPK	76.30 ± 10.72^{b}	7.25 ± 1.36^{ab}	10.0 ± 2.2^{a}	8.0 ± 2.39^{ab}
MS+NMS	67.10 ± 9.35^{c}	7.12 ± 1.36^{ab}	10.0 ± 2.2^{a}	7.5 ± 2.19^{b}
AS+NPK	66.34 ± 9.35^{d}	6.27 ± 1.21^{bd}	9.9 ± 2.2^{a}	6.9 ± 1.89^{bc}
AS+NMS	56.2 ± 7.29^{g}	4.35 ± 0.80^{e}	9.3 ± 2.2^{a}	4.9 ± 2.19^{d}
NMS+NPK	53.20 ± 7.32^{f}	5.67 ± 0.98^{d}	9.6 ± 2.2^{a}	5.6 ± 1.19^{c}
MS+AS+NPK	77.30 ± 10.7^{b}	7.25 ± 1.36^{ab}	10.0 ± 2.2^{a}	8.0 ± 2.39^{ab}
MS+ AS+NPk+NMS	80 ± 11.41^{a}	7.30 ± 1.36^{a}	10.4 ± 2.2^{a}	10 ± 2.69^{a}

*MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium. Means followed by the same letter (s) within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.10 Effect of termite Mound soil, adjacent soil and Non-mound soil on maize plant growth traits eight weeks after planting

Effect of plant growth input on mean number of maize growth trait eight weeks after planting was significantly affected ($P<0.05$) by treatments. However, statistically non-significant ($p>0.05$) difference is observed in plant height and leaves number for all treatments (Table 5.6.).Beside this, stem and leaf width were significantly affected ($p<0.05$) by treatments. The highest stem width (9.2cm) and the highest leaf width (9.4cm) were recorded from four combined treatments respectively and the lowest stem width (5.13cm) and the leaf width (5.7cm) were recorded from NMS respectively. Stem and leaf width growth traits also resume significant growth from MS and MS+NPK treatments (Table 5. 6; Appendixes 5.7-5.9).

Table 5.10 The effect of termite Mound soil, Adjacent soil, NPK and Non-mound soil on mean (±se) maize growth trait eight weeks after planting.

Treatments	Plant height (cm)	Stem width(cm)	No of leaf	Leaf Width (cm)
MS	1.32±0.17[a]	8.5±1.78[bc]	11.0±0.86[ab]	7.6±1.22[bc]
As	1.44±0.17[a]	5.1±0.56[d]	11.01±0.86[ab]	6.5±0.06 [d]
NPK	1.3±0.17[a]	7.5±1.18[c]	11.8±0.86[ab]	6.7±0.08[cd]
NMS	1.3±0.17[a]	5.0±0.48[d]	11.2±0.86[ab]	5.7±0.06[e]
MS+AS	1.32±0.17[a]	6.5±0.88[cd]	10.9±0.86[ab]	7.0±0.75[c]
MS+NPK	1.5±0.17[a]	8.9±2.38[b]	11.2±0.86[ab]	7.7±1.32[b]
MS+NMS	1.41±0.17[a]	9.2±2.46[a]	12.3±0.86[ab]	9.4±1.54[a]
AS+NPK	1.32±0.17[a]	7.5±1.18[c]	10.8±0.86[ab]	7.1±1.06[c]
AS+NMS	1.4±0.17[a]	8.9±2.38[b]	11.2±0.86[ab]	7.7±1.32[b]
NMS+NPK	1.5±0.17[a]	5.0±0.48[d]	11.2±0.86[ab]	5.7±1.06[e]
MS+AS+NPK	1.51±0.17[a]	9.2±2.46[a]	12.3±0.86[ab]	9.4±1.54[a]
MS+AS+NPK+NMS	1.61±0.17[a]	9.2±2.46[a]	12.3±0.86[ab]	9.4±1.54[a]

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.11 Effect of plant growth inputs (termite Mound Soil, Adjacent and Non-mound soil) on yield components at harvest

The effect of termite mound soil, NPK, adjacent soil and non-mound soil on mean number of maize yield components at harvest was shown in Table5.7.Appendixes 5.10-5.13.There was no significant difference($p>0.05$) between the plant height. However, other maize plant growth performance and yield were significantly affected ($p<0.05$) by application of treatments. In cob, there was significant difference among the applied treatments. However, all the recorded treatments are all most revealing similar mean number of cobs. ANOVA of grain yield per pot shows significantly difference ($P<0.05$) among the treatments. (Table 5.7)

As revealed in the result, the highest grain yield per pot was recorded from combined MS+AS+NPK+NMS treatments and the lowest grain yield were recorded from non-mound soil. Termites are considered to be one of the most destructive pests in the world. But, termite mound soil amends soil fertility and utilized as an alternative to NPK fertilizers by cash constrained smallholder farmers in some parts of Africa. However, there is little knowledge on mound mineral nutritional value and the impact they have on plant growth and yield in western Ethiopia particularly Nekemte areas where high maize production, high termite mound distribution and termite infestations is there. As illustrated in the result, statistically significant difference ($P < 0.05$) was observed in yield per pot form all treatments at harvest (Table 5.7). The highest yields were recorded from four MS+AS+NPK+NMS combined treatments and the lowest yield per pot was observed from Non-mound soil. Significant yield production was also observed in MS and further more yield was recorded from four mixed treatment MS+NPK+AS+NMS than Non –mound soil

Table 5.11 Effect of termite Mound soil, NPK, Adjacent and Non-mound soil on mean (±se) of maize yield components**.**

Treatments	Plant height (m)	No of cobs per plant	Yield per plant	Yield per pot
MS	3.53 ± 0.01^{a}	2.7 ± 0.89^{ab}	1.5 ± 1.10^{b}	8.3 ± 1.40^{bc}
As	3.57 ± 0.01^{a}	2.2 ± 0.40^{c}	1.5 ± 0.10^{b}	7.0 ± 1.40^{d}
NPK	3.52 ± 0.01^{a}	2.5 ± 0.87^{b}	1.4 ± 0.19^{bc}	8.0 ± 1.42^{c}
NMS	3.52 ± 0.01^{a}	2.0 ± 0.24^{d}	1.0 ± 0.19^{d}	3.7 ± 1.40^{d}
MS+AS	3.55 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.3 ± 0.19^{c}	8.0 ± 1.42^{c}
MS+NPK	3.54 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.6 ± 1.19^{ab}	9.0 ± 1.55^{b}
MS+NMS	3.53 ± 0.01^{a}	2.7 ± 0.89^{ab}	1.5 ± 0.10^{b}	8.3 ± 1.45^{bc}
AS+NPK	3.53 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.3 ± 0.19^{c}	7.0 ± 1.40^{d}
AS+NMS	3.53 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.3 ± 0.19^{c}	7.0 ± 1.40^{d}
NMS+NPK	3.53 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.3 ± 0.19^{c}	7.0 ± 1.40^{d}
MS+AS+NPK	3.55 ± 0.01^{a}	2.3 ± 0.46^{bc}	1.3 ± 0.19^{c}	7.0 ± 1.40^{d}
MS+AS+NPK+NMS	3.55 ± 0.01^{a}	3.0 ± 1.46^{a}	1.9 ± 2.19^{a}	13 ± 2.40^{a}

* MS= mound soil, AS=adjacent soil, NPK: N= Nitrogen, P= Phosphorus and K= Potassium Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

5.3.12. Effect of treatments contribution to maize plant growth trait and yield components

Plant growth trait; plant height, stem girth, leaf width, No, of cobs and yield per plant pot result has shown in Table 8..Plant growth trait and yield components were significantly ($p<0.05$) affected by all treatments. As result significant growth was attained from all treatments at 2, 4 and 8 weeks after planting (WAP) than non-mound soil. The highest total grain weight of maize was recorded from pot treated with termite mound soil than non-mound soil**.** Significant yield per pot was also observed in MS and further more yield was recorded from four mixed treatment MS+NPK+ AS+NMS than non mound soil (Table 5 8).This article was published (Appendix 7.1)

Table 5 12.Treatment contribution to maize plant growth trait and yield component Mean (±se)

Treatment	Plant height(cm)			Stem girth (cm)			Leaf width(cm)			Cob No	Yield/pot
	2WAP	4WAP	8WAP	2WAP	4WAP	8WAP	2WAP	4WAP	8WAP		
MS	24.1±2.7^{c}	67.10±9.35^{c}	1.32±0.17^{a}	2.8±0.26^{b}	7.12±1.36^{ab}	8.5±1.19^{bc}	2.8±0.27^{bc}	7.5±2.19^{b}	7.6±1.16^{b}	2.7±1.46^{ab}	8.3±1.48^{bc}
As	18.0±1.8^{e}	53.20±7.32^{f}	1.44±0.17^{a}	2.3±0.24^{de}	5.67±0.98^{d}	5.13±1.18^{de}	2.5±0.20^{d}	5.6±1.89^{d}	6.5±1.26^{cd}	2.2±0.46^{c}	7.0±1.40^{d}
NPK	23.6±2.7^{cd}	66.89±9.35^{d}	1.30±0.17^{a}	2.7±0.25^{bc}	7.02±1.36^{b}	7.53±1.18^{c}	2.4±0.25^{de}	6.9±2.19^{c}	6.7±1.26^{c}	2.5±1.46^{b}	8.0±1.48^{c}
NMS	16.4±1.7^{f}	50.20±7.29^{g}	1.30±0.17^{a}	2.0±0.21^{e}	4.30±0.80.^{e}	5.0±1.11^{de}	2.1±0.23^{ef}	4.9±2.19^{e}	5.7±1.06^{d}	2.0±0.06^{d}	3.7±0.40^{de}
MS+AS	25.0±2.7^{b}	64.30±9.35^{e}	1.32±0.17^{a}	2.60±0.24^{cd}	6.13±1.21^{bc}	6.5±1.10^{d}	2.4±0.25^{de}	7.0±2.09^{bc}	7.1±1.16^{b}	2.3±0.46^{bc}	8.0±1.48^{c}
MS+NPK	30.0±2.9^{ab}	76.30±10.72^{b}	1.50±0.17^{a}	2.8±0.29^{ab}	7.25±1.36^{ab}	8.9±1.08^{b}	2.7±0.24^{c}	8.0 ±0.19^{ab}	7.7±1.16^{b}	2.3±0.46^{bc}	9.0±1.46^{b}
MS+NMS	24.0±2.7^{cd}	67.10±9.35^{c}	1.41±0.17^{a}	2.7±0.28^{c}	7.12±1.36^{ab}	9.2±1.18^{a}	2.6±0.22^{cd}	7.5±2.09^{b}	9.4±1.06^{a}	2.7±1.46^{ab}	8.3±1.48^{bc}
AS+NPK	20.0±1.8^{d}	66.34±9.35^{d}	1.32±0.17^{a}	2.5±0.23^{d}	6.27±1.21^{bd}	7.5±1.18^{c}	2.5±0.20^{d}	6.9±2.09^{bc}	7.1±1.16^{b}	2.3±0.46^{bc}	7.0±0.40^{d}
AS+NMS	18.0±1.8^{e}	56.20±7.29^{g}	1.40±0.17^{a}	2.3±0.22^{de}	4.35±0.80.^{e}	8.9±0.18^{b}	2.5±0.20^{d}	4.9±2.19^{e}	7.7±1.16^{b}	2.3±0.46^{bc}	7.0±0.40^{d}
NMS+NP	17.4±1.7^{ef}	53.20±7.32^{f}	1.50±0.17^{a}	2.1±0.21^{e}	5.67±0.98^{d}	5.0±1.11^{de}	2.1±0.23^{ef}	5.6±1.89^{d}	5.7±1.06^{d}	2.3±0.46^{bc}	7.0±0.40^{d}
MS+AS+ NPK	24.1±2.7^{c}	77.30±10.72^{b}	1.51±0.17^{a}	2.8±0.26^{b}	7.25±1.35^{ab}	9.2±1.18^{a}	2.8±0.27^{bc}	8.0±2.19^{b}	9.4±1.06^{a}	2.3±0.46^{bc}	7.0 ±0.40^{d}
MS+AS+ NPK+NMS	32.0±2.9^{a}	80.00±11.41^{a}	1.61±0.17^{a}	3.1±0.34^{a}	7.30±1.36^{a}	9.2±1.18^{a}	3.5±1.29^{a}	10±2.59^{a}	9.4±1.06^{a}	3.0±1.55^{a}	13 ±2.40^{a}

* MS= mound soil, AS=adjacent soil, NMS= Non-mound soil, NPK: N= Nitrogen, P= Phosphorus and K=potassium. W-Week, A=After, P=Plantation.

Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

Maize (Zea mays l.) grown on different treatments after 4 weeks

Plate 5. 1 Maize plant grows on adjacent soil.

Plate 5 2 .Maize plant growth on Adjacent+ NPK

Plate 5 3.Maize plant growth on Mound soil

Plate 5 4.Maize plant growth on Mound soil+ NPK

5.4. Discussion

In the analyzed experimental result, the selected physicochemical properties of mound soil; bulk density, moisture content, porosity and soil; % OM, % OC, TN, P, pH, Ex, Ca, Mg and K were found higher and are effective in crop production than non-mound soil. The current findings were in line with the finding of Alemu Lelago and Tadele Buraka (2019) that reported termite induce the change in physical and chemical properties of mound soil better than non-mound soil, This physicochemical variation in termite soil was attributed by foraging termites *Macrotermes* collected from majority of labeled mounds than *Odontotermes.* In accordance to this, Sutuma Edossa Wako (2015), demonstrate that each mound consisted of dissimilar colonies of termites.

The result of bulk density recoded in the current study, showed higher in mound soil than non-mound soil. In accepting this, Arshad *et al*. (2010) stated that, the termite mounds had higher bulk density than the surrounding soil reveal termites repack soils with their saliva to form hard protective layers against open air and temperature fluctuation in the mounds. In current study moisture content of mound soil was greater than the non-mound soil. This is accepted by Kaschuk *et al*. (2006) who reported that, termite increase soil depth and regulate water flow into the soil for efficient use of water by crops. In selected analyzed soil chemical properties soil; % OM, % OC, TN, P, pH, Ex, Ca, Mg and K showed higher in mound soil than non-mound soil. In agreement with this, AlemuLelago and Tadele Buraka (2019), stated, chemicals recorded in termite mound soil were found higher than those in non-mound soil, In supporting this, Daniel Getahun Debelo and Emana Getu Degaga, (2014) reported that exch. cations (Ca, Mg, Na and K), were significantly higher in termite mounds than in non-mound soil and higher values of organic matter %OM and slightly acidic pH, were also recorded in mound soil than in anon-mound soil, this result was accepted by Jouqu *et al*. (2014) who stated that the mound soil organic matter is increased significantly due to the high amount of mound soil organic matter return from organic debris or plant living tissue foraged and degraded during mound construction. In contrast to this, Susumu *et al*. (2011) reported that cations had contributed more alkaline to the mound soil and make it (moderately alkaline) values than non-mound soils. In supporting, Daniel Getahun Debelo and Emana Getu (2014) stated there is a small increase in pH of Macrotermitinae when compared with the subsoil from which the mounds are constructed but there is little difference with the topsoil

Plant growth trait; Plant height, stem and leaf width and leaves number of maize growth were significantly higher from mound soil and more growth was attained from (MS+AS+NPK+ NMS) than non-mound soil. Subsequently this growth induce cob to retain more yield per plant. In accepting this, Daniel Getahun and Emana Getu (2014) states maize grown on mound perimeter produces larger cobs and this led to subsequent increase in yield than the one grown far from mound. Because in mound soil there were significantly higher values of % TN, ex. Ca, % OM, average K and available P. In accepting this, Sileshi Gudeta *et al*. (2009), reported, significantly higher plant biomass and grass growth around termitaries compared with the ones grown far away from mounds. As revealed from the result. plant grown in non- mound soil appear yellowish and poor stand stem, while, deep green in mound soil and deeper and well performed stem in MS+AS+NPK+NMS.This is in accordance with Daniel Getahun and Emana Getu (2014) who reported that, crops grown on soils in mound perimeter were dark green while the ones grown on non-mound soil were yellowish in color. In accepting this, Rajagopal (1983) also states plants from treated plots were tall and dark green with large-sized stems and ears, whereas the plants from the untreated plots were relatively weak and lanky (tall and thin),

MS+AS+NPK+NMS application were found to be highly effective on maize growth performance and resulted in better yield production than from non- mound soil, in agreement with this, Ezekiel *et.al.* (2018) and Olowoboko *et al.* (2017) reported that, the application of inorganic fertilizer NPK to mound soil facilitates growth of the maize crop. Fageria and Baligar (2005) also stated that, number of panicles, shoot in rice and pods in bean dry weights of shoot and grain of upland rice and common bean grown on termite mound soil were significantly increased by the application of NPK treatment.

5.5. Conclusion

In the current study it was conceived that mound soil exceed in most of the analyzed selected physical soil; Bulk density, Moisture content, Porosity and chemical properties soil; pH, % OM, % TN, Ca, Mg, av. P and K than non-mound soil. Physiochemical backup of mound soil was attributed by termites *Macrotermes,* and *Odontotermes* forages. From the current study it can be concluded that mound soil amends soil fertility than non-mound soil and allow effective maize growth performance, better maize growth and subsequent increase in yield/pot was attainedfrom mound soil mixed with As, NPK and NMS. The use of NPK fertilizer on plots having termite mound is not recommended. However, further research is needed on how to use mound soil on large plot of land.

CHAPTER 6

Efficacy of botanical extracts against Termites on Maize (*Zea mays* L.) under field condition in Western Ethiopia

6.1. Introduction

Maize (*Zea mays* L.) is the most popular crop grown in the world. It is a staple food for millions of people living in the developing world including Ethiopia. Maize grows in nearly all agro-ecological zones (FAO, 2011). African farmers grow maize more than any other cereals as maize can adapt to various agro-ecology from lowland to highland and due to its lucrative yield. Maize accounts for over 30% of poor farmers' income and contributes to 60% of dietary calories and 50% of protein intake in Africa (IITA, 2009). In Ethiopia, maize grows across varied agro ecological zones (Emana Getu *et al*., 2006). Since its arrival to Ethiopia between 1600 and 1700 centuries probably from Mexico, maize grows well between 500 to 2400 meters above sea level (m.a.s.l.) (Emana Getu *et al*., 2006). Maize production received a great attention in Ethiopia because of several reasons such as high productivity (12 tons ha^{-1}), short growth period (3-5 months) and its suitability for different dietary forms among others (CSA, 2013). However, the high yielding potential of maize is constrained by a number of factors including insect pests and diseases.

From the insect pests, the damage inflicted by termites is tremendous (30-100%) in Ethiopia in general and western Ethiopia in particular (Emana Getu *et al*., 2006; Sileshi Gebre *et a*l., 2005; Ketema Hirpa and Tufa Bulto, 2016). Termites damage maize starting from the early stage of sowing to the maturity stage of the crop and in the store. Termite genera involved in the infestation of maize in western Ethiopia include *Macrotermes*, *Odontotermes* and *Pseudacanthotermes* (Abdurahaman Abdulahi, 1990; Emana Getu *et al*., 2006). Different control options of termites are available including queen removal and use of termiticide such as fipronil, imidacloprid and chlorantraniliprole (Thomas *et al*., 2011; Emana Getu *et al*., 2006; Mulatu Wagari and Emana Getu, 2015). The use of queen removal proved to be in effective as secondary female reproductive from the colony can immediately replace the mother and rescue the colony unless the operation is immediately followed by flooding and poisoning using termiticide (Emana Getu *et al*., 2006).

The use of termiticide has different negative impacts including environmental pollution, non-target effect, high cost and resistance development among others (Grdisa and Grsic, 2013). Thus, looking for alternative termite control method is crucial. Due to its availability at users premise and its low negative impacts a number of scientists recommended the use of botanical plants as an alternative to the use of pesticides in general and termiticide in particular (Nyeko *et al*., 2010). Farmers of western Ethiopia rectified the failure of termiticide under use in controlling termites (Temesgen Beyene, unpublished data).

In Ethiopia, termite management with botanicals were widely practiced in the laboratory, There is little or scares document on field practice for botanical termite management on irrigated or rainfed trend maize production in Easter Wollega zone, Western Ethiopia. Therefore; this study was designed with the following objectives;

- To determine the available termite genera composition in the study site
- To evaluate the efficiency of botanicals leaf extract separately used against termites on maize under field condition.
- To determine the potency of combined used botanicals leaf extract against termites on maize under field condition.

6.2. Materials and Methods

6.2.1 Description of the study area

The study was conducted at Wollega University (WU) on station Research site located in Nekemte town and WU Uke sub-station (Figure 6.1). From November 2018 to July 2019 during dry and rainy season respectively. Both study sites were found in East Wollega zone. Detail descriptions of the study sites are presented in (Table 6.1; Appendices 6.1-6.3)

Table 6 1.Coordinates, elevations, mean annual rainfall, relative humidity and

Temperatures of the study sites

Location	Coordinates	*Elevation (m.a.s.l.)	Mean annual rainfall mm)	Relative humidity (%)	Mean annual Temperature (^{0}C)	
					Maximum	Minimum
Nekemte	$9^O5'.887''N, 36^O34.647'E$	2080.00	1862.33	55.45	21.66	13.62
Uke	$8^O11'52''N, 0^O94'44''E$	1500-1700	1666.00	50.02	31.00	16.00

Source: National Meteorological Agency of Ethiopia (Average of 10 years).

*meters above sea level

Wollega University on station field is located in the western direction of Nekemte town. Nekemte is located 335 km away from Addis Ababa to the West. Uke sub-station field site is found 375 km away from Addis Ababa and 44 km away from Nekemte on Nekemte to Burae- Bahirdar road. The soil type of the study areas is loam, clay and sandy which favour the growth of different types of crops including maize. Maize and sorghum are the major crops grown in the study areas. Savannah type grasses and forest trees are dominating the areas. The socio-economy of the study areas is predominantly mixed farming. Cows, sheep, Goat and Equines are dominating the livestock sector.

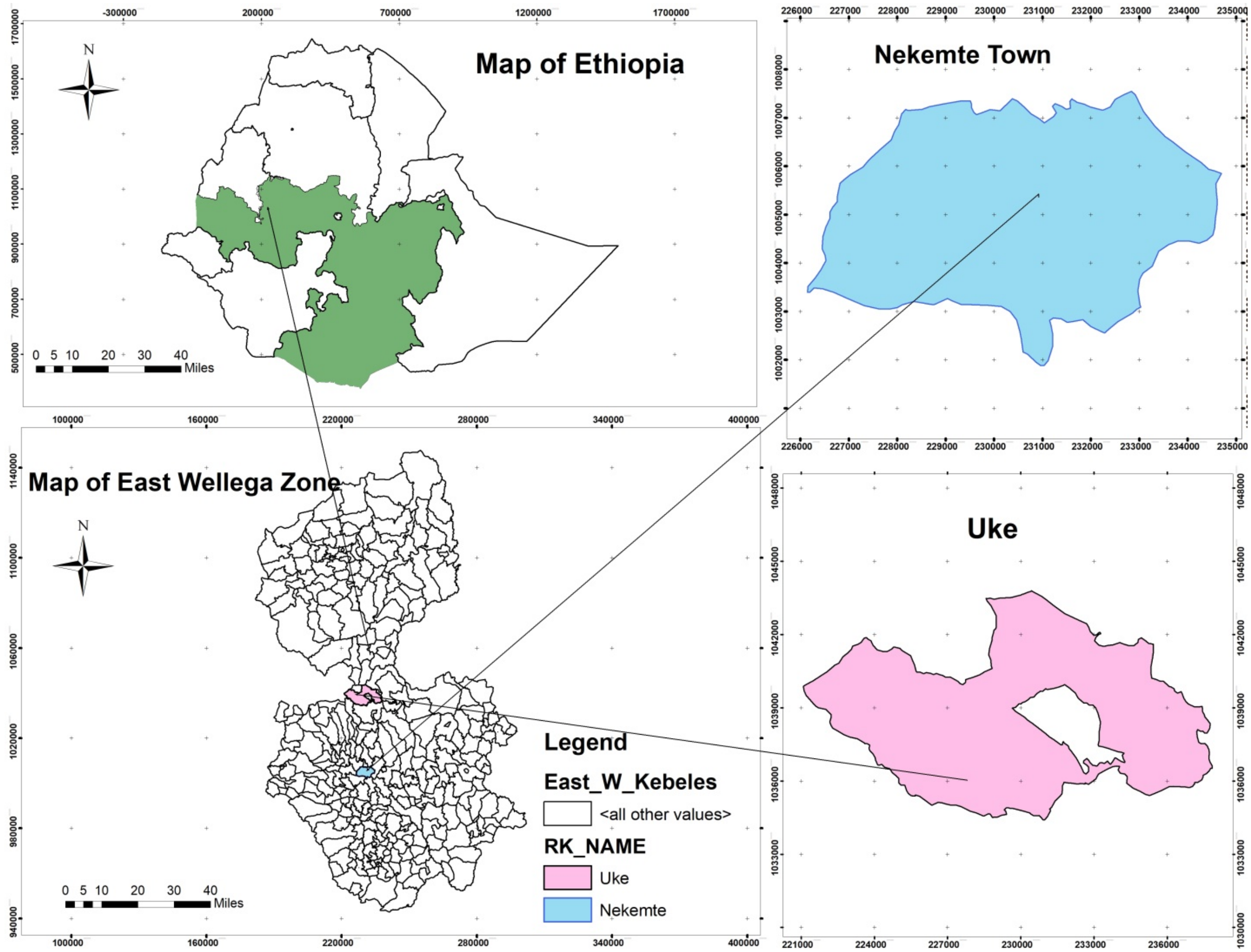

Figure 6. 1 Map of the study areas

6.2.2. Study design and sampling procedure

6.2.2.1. Termite Identification

Termite solider sample involved in the infestation were collected and preserved in a vial containing 80% alcohol (Abdurahaman Abdulahi, 1990; Daniel Getahun and Bekele Jembere, 2006). The specimens were taken to Addis Ababa University, Insect Science Laboratory for identification. Identification Keys for the Genera of Ethiopian Termites, books, pictures and reference collections were used for the identification (Emana Getu *et al.*, 2008).

6.2.2.2. Experimental materials

Three botanical plants: *Croton macrostachys* (*Hochst*)*, Phytolacca dodecandra* L. *and Jatropha curcas* L. were selected based on their social ties to the community in terms of their use and availability (Weldesenbet Beze *et al.,* 2019). The botanicals used for the study were collected from Wollega University campus and Diga district in Eastern Wollega zone. Maize variety, BH-661 obtained from Bako Research Centre was used for the experiment (Addisu and Sileshi *et al*., 2013).

6.2.2.3 .Preparation of Botanical Extracts

Leaves of each botanical were dried under shade for three weeks in Wollega University Biology laboratory section before extraction (Addisu and Silesh *et al*., 2014; Cynthia *et al.,* 2016; Ali *et al*., 2018). The dried leaves were grounded in to a fine powder using a small hand-operated manual grinder. The powder was further sliced with analytical mill and sieved through a 0.25 mm pore size mesh to make uniform fine dust particle. Each sieved botanical powder was collected in polythene bag and separately stored on shelf at room temperature prior to use.

Plate 6 1 Botanical powder collected   Plate 6 2 Sieving and measuring the powder

6.2.2.4. Experimental Design and treatments

The experimental fields were prepared as per the recommendation for maize planting in the study areas (2-3 times ploughing).Maize varieties, BH-661 was planted on a plot size of 3 mx7.5m with intra and inter spacing of 0.30 m and 0.75 m, respectively. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications. Spacing between plots and blocks were 1m and 2m, respectively. The on station experiment was conducted using irrigation, while the Uke was in rain fed condition. DAP and UREA were used at the rates of 100 kg/ha and 200 kg/ha, respectively. DAP was applied at planting, while UREA was applied both at two leaf stage and knee height of maize plant. The botanicals used were *C. macrostachys*, *P. dodecandra, J. curcas, C. macrostachys* + *P. dodecandra, C. macrostachys* +*J. curcas, P. dodecandra* + *J. curcas, C. macrostachys* + *P. dodecandra* + *J. curcas*. Untreated check was used for comparison.

6.2.2.5. Treatment preparation and Application

From the stored botanical powder of each botanical 300 g was weighed and soaked in 1000 ml distilled water in flask of 1500 ml capacity and shacked to mix thoroughly. The mixtures were kept for 72 hrs. The mixtures were filtered with clean cheese cloth and stored in a beaker of 250 ml capacity. This method was adopted from Addisu and Sileshi *et al*. (2013) with minor modification. Planting holes were prepared on each row at the distance of 0.30 m. From the stock solution of each treatment, 20 ml was drenched to each hole 10 days before planting. Similar amounts of single and mixed treatments were applied at different growth stages of maize by making drench at the base of maize plants. For the application of the treatments, 30 ml capacity calibrated syringe was used (Weldesenbet Beza *et al*., 2019).

Plate 6.3. Stock solution of leaf extract

Plate 6.4.Filtering and measuring leaf extract

Plate 6. 5 Drenching the soil

6.2.2.6. Data collection

Data on the number of foraging termites, foraging galleries and mounds were recorded two days before planting and every two days after treatment application at all growth stages of maize plant (Daniel Getahun and Emana Getu, 2014). At harvesting stand counts were recorded from two central rows of each plot and maize cobs were collected from each plot and weighed. For analysis yield per plot (kg/plot) was converted to yield per hectare (kg ha^{-1}).

6.2.2.7 Data Analysis

ANOVA was employed for the analysis of data using SAS software version 9.1. Significant means ($P<0.05$) were separated using Tukey's Studentized Range test (HSD) (SAS, 1999).

6.3. Results

6.3.1. Termite's Genera composition

Genera composition of termites of Nekemte irrigation site and Uke substation rain fed site are shown in Table 6. 2. Out of the 2000 solider samples collected from the two sites, the genus *Macrotermes*, *Odontotermes* and *Pseudocanthermes* were identified. However, 60% and 80% of the termites were from the Genus Macrotermes in Nekemte and Uke site respectively.

Table 6. 2Termites' Genera composition of Nekemte and Uke sites

Location	Termite Genera	% Genera composition	No. of termite soldiers sampled per location
Nekemte	Macrotermes	60	
	Odontotermes	16	
	Pseuducanthotermes	24	800
Uke	Macrotermes	80	
	Odontotermes	12	
	Pseuducanthotermes	8	1200

6.3.2. Efficacy of botanical extracts for the management of termites on irrigated maize at Nekemte

The effect of pre-planting botanical extracts on mean number of foraging termites, number of termite galleries and termite mound on irrigated field at Nekemte is shown in Table 6.3. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received 3 botanicals mixed treatment, while the highest was recorded on the untreated check plots. Plots that received the 2 mixed botanicals were found to be more effective than the plots that received single botanical treatment in the management of termites. (Table 6.3: Appendixes 6.2-6.4).

Table 6.3 Effect of pre-planting botanical application on mean (±se) of termites and their Symptoms in irrigated field 8 days before planting**.**

Treatments	Number of termites and their symptoms		
	Number of foraging termites	Number of termite galleries	Number of termite mound
Untreated check	116.7 ± 1.05^{f}	32.3 ± 1.35^{f}	4.3 ± 1.23^{b}
C. macrostachys	85.00 ± 2.06^{e}	27.7 ± 1.96^{e}	2.0 ± 0.23^{c}
P. dodecandra	78.30 ± 2.30^{d}	25.0 ± 2.23^{bd}	0.0 ± 0.00^{a}
J. curcas	57.70 ± 2.59^{c}	23.0 ± 2.22^{d}	0.0 ± 0.00^{a}
C. macrostachys +P. Dodecandra	48.70 ± 2.89^{bc}	22.7 ± 2.24^{cd}	0.0 ± 0.00^{a}
C. macrostachys + J. curcas	44.00 ± 3.05^{ab}	20.0 ± 2.50^{c}	0.0 ± 0.00^{a}
P. dodecandra + J. curcas	38.33 ± 3.00^{b}	16.0 ± 2.96^{b}	0.0 ± 0.00^{a}
C. macrostachys + P. dodecandra + J. curcas	26.33 ± 3.555^{a}	10.7 ± 3.00^{a}	0.0 ± 0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Tukey's Studentized Range test (HSD).

6.3.3. Effect of botanical application on mean number of termites and their symptoms at seedling stage.

The effect of botanical application on mean number of termites and their symptoms at seedling stage is shown in Table 6. 4. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the 3 botanicals mixture treatment, while the highest was recorded on the untreated check plot. Plots that received the 2 botanicals mixture treatments were found more effective in the management of termites than plots that received single botanical treatments.

Table 6. 4 The effect of botanical applications on mean (±se) number of termites and their symptoms at seedling stage on irrigated maize**.**

Treatments	Number of termites and their symptoms		
	number of foraging termites	number of termite galleries	number of termite mound
Untreated check	120 ± 0.65^{g}	31.7 ± 0.70^{f}	4.0 ± 0.25^{b}
Croton macrostachys	93 ± 0.80^{f}	27.7 ± 0.74^{e}	2.0 ±0.20^{c}
Phytolacca dodecandra	87 ± 0.89^{e}	25 ± 0.78^{de}	0.0±0.00^{a}
Jatropha curcas	78 ±1.04^{d}	23 ± 0.80^{d}	0.0±0.00^{a}
C. macrostachys+ P. Dodecandra	67.7 ± 1.14^{c}	22.7 ± 0.85^{cd}	0.0±0.00^{a}
C. macrostachys + J. curcas	47 ± 1.44^{b}	16 ± 0.90^{c}	0.0±0.00^{a}
P. dodecandra + J. curcas	44 ± 1.64^{ab}	20 ± 0.95^{b}	0.0±0.00^{a}
C. macrostachys + P. dodecandra + J. curcas	36.33 ±1.84^{a}	10.7 ± 0.99^{a}	0.0±0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.4. Effect of botanical application on mean number of termites and their symptoms at vegetative stage

As shown in Table 6. 5, the effect of botanical application on mean number of termites and their symptoms at vegetative stage is significantly different ($P<0.05$). The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the 3 botanical mixtures, while the highest was recorded on the untreated check plot. Plots that received P. *Dodecandra + J. curcas* were found to be more effective in the management of termites than single botanical treatments.

Table 6.5 Effect of botanical treatments on mean (±se) number of termites and their symptoms at vegetative stage on irrigated maize at Nekemte site.

Treatments	Number of termites and their symptoms		
	number of foraging termites	number of foraging galleries	number of termite mound
Untreated check	89.7±1.22[h]	26.7±0.22[g]	3.7±0.12[b]
Croton macrostachys	85±1.32[g]	23.7±0.35[f]	0±0.00[a]
Phytolacca dodecandra	77±1.50[f]	21.0±0.50[e]	0±0.00[a]
Jatropha curcas	62.7±1.60[e]	17.0±0.60[d]	0±0.00[a]
C. macrostachys+ .Dodecandra	49.7±1.65[d]	14.3±0.70[cd]	0±0.00[a]
C. macrostachys + J. curcas	42.7±1.70[c]	11.7±0.75[c]	0±0.00[a]
P. dodecandra + J. curcas	36.7±1.75[b]	8.7±0.90[b]	0±0.00[a]
C. macrostachys + P.dodecandra + J. Curcas	24.7±1.81[a]	6.0±0.91[a]	0±0.00[a]

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.5. Effect of botanical application on mean (±se) number of termites and their symptoms at flowering stage of maize on irrigated maize

The mean number of termites and their symptoms are shown in Table 6.6.The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received *C. macrostachys* + *P. dodecandra* + *J. curcas*, while the highest was recorded on the untreated plot. All plots that received the 2 treatments combinations were found to be effective in the management of termites when compared to a single botanical treatment.

Table 6. 6 The effect of botanical application on mean (±se) number of termites and their symptoms at flowering stage of maize on irrigated maize at Nekemte**.**

Treatments	Number of termites and their symptoms		
	number of foraging termites	number of termite galleries	number of termite mounds
Untreated check	89.7± 1.10^{h}	26.7± 0.24^{g}	3.7± 0.12^{b}
Croton macrostachys	85.0± 1.20^{g}	23.7± 0.42^{f}	0±0.00^{a}
Phytolacca dodecandra	77.0± 1.28^{f}	21.0± 0.54^{e}	0±0.00^{a}
Jatropha curcas	62.7± 1.35^{e}	17.0 ± 0.62^{d}	0±0.00^{a}
C. macrostachys + P. Dodecandra	49.7± 1.54^{d}	14.3± 0. 68^{cd}	0±0.00^{a}
C. macrostachys + J. curcas	42.7± 1.60^{c}	11.7±_0.70^{c}	0±0.00^{a}
P. dodecandra + J. curcas	36.7± 1.70^{b}	8.70± 0.80^{b}	0±0.00^{a}
C. macrostachys + P. dodecandra + J. Curcas	24.7± 1.81^{a}	6.0± 0.91^{a}	0±0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.6. Effects of botanical application on mean (±se) termite symptoms and yield &yield components at harvesting stage on irrigated maize

The analysis of variance for mean of termite symptoms and yield & yield components in irrigated field showed statistically significant ($p<0.05$) differences among the treatments applied separately or in combination (Table 6. 7).The result revealed that there was high termite symptom and low yield and yield components from the untreated check plot and low termite symptoms and high yield and yield components from the plot that received three treatments combination. Plots that received the two treatments combination were found to be effective in the management of termites when compared to single botanical treatment. The three mixture treatments provide high protection by repelling termite from maize plant. Consequently maize plant performance increased and more yields obtained.

Table 6.7 The effects of botanical application on mean (±se) termite symptoms and yield. &yield components at harvesting stage on irrigated maize at Nekemte

Treatment	Number of termites and their symptoms			yield & yield components			
	Foraging termites	Foraging tunnel	Mound	Plant height	Stand count	Number of cobs/plot	Yield (kg/ha)
C. macrostachys	127.5.5^{b}	51.3±0.1^{b}	2.0±1^{bc}	3.5±1^{a}	49.5±2^{b}	86.3±3^{d}	3813±9^{bc}
P. dodecandra	91.±.3^{c}	28.8±0.5^{c}	1.8±1^{c}	3.6±1^{a}	52.3±2^{a}	117.3±5^{c}	6042±^{bc}
J. curcas	91±.3^{c}	27.5±0.5^{c}	2.0±1^{bc}	3.6±1^{a}	52.0±2^{ab}	130.0±4^{b}	6708±9^{a}
C. macrostachys + *P.*	55±2^{d}	28.0±0.5^{c}	2.3±1^{b}	3.5±1^{a}	50.5±2^{ab}	125.5±4.6^{bc}	5583±9^{abc}
C. macrostachys + *J.*	55±2^{d}	24.3±0.3^{d}	1.8±1^{c}	3.6±1^{a}	52.3±2^{ab}	130.5±4^{b}	6771±9^{ab}
P. dodecandra + *J.*	47 ±1^{d}	19.8±0.2^{e}	1.8±1^{c}	3.5±1^{a}	52±2^{ab}	129.8±4^{b}	6667±9^{ab}
C. macrostachys + *P. dodecandra* + *J. curcas*	15 ±0.1^{e}	7.50±0.1^{ef}	0.3±0^{d}	3.6±1^{a}	52.8±2^{a}	144.8±6^{a}	7333±9^{a}
Untreated check	192. ±5.8^{a}	71± 0.30^{a}	9.3±1.5^{a}	3.5±1.5^{a}	44.8±2^{c}	89.5±3^{cd}	3646±9^{c}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.7 Efficacy of botanical extracts on the management of termites on rain fed maize at Uke site.

The effect of pre-planting botanical application on mean number of termites and their symptoms on rain fed maize at Uke is presented in Table 6.3.7Appendix 6.4. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the three botanicals combination, while the highest was recorded on the untreated check plot. All plots that received the two treatments combinations were found to be more effective in the management of termites than plots that received single botanical treatments.

Table 6. 8.Effect of pre-planting botanical application on mean (±se) number of termites and their symptoms on rain fed maize 8 days before planting**.**

Treatment	Number of termites and their symptoms		
	number of foraging termites	number of termite galleries	Number of termite Mounds
Untreated check	60.5 ± 0.12^{h}	16.75 ± 0.1^{a}	1.5 ± 0.32^{a}
Croton macrostachys	55.5 ± 0.18^{g}	10.5 ± 0.2^{b}	0.75 ± 0.42^{b}
Phytolacca dodecandra	45.5 ± 0.22^{f}	8.5 ± 0.45^{bc}	0.55 ± 0.02^{ab}
Jatropha curcas	40.5 ± 0.30^{e}	7.5 ± 0.35^{bc}	0.45 ± 0.01^{ab}
C. macrostachys+ P. Dodecandra	30.5 ± 0.45^{d}	6.25 ± 0.3^{c}	0.25 ± 0.10^{bc}
C. macrostachys + J. curcas	25.5 ± 0.55^{c}	5.25 ± 0.4^{cd}	0.2 ± 0.1^{c}
P. dodecandra + J. curcas	14.5 ± 0.60^{b}	3.75 ± 0.4^{d}	0.05 ± 0.22^{d}
C. macrostachys + P. dodecandra + J. Curcas	10.5 ± 0.71^{a}	2.25 ± 0.7^{e}	0.05 ± 0.12^{d}

Means followed by the same letter within a column are not significantly different from each there at 5% level, Turkey's Studentized Range test (HSD).

6.3.8 Effect of botanical application on mean (±se) number of termites and their symptoms at seedling stage on rain fed maize at Uke site.

The effect of botanical application on mean number of termites and their symptoms at seedling stage of maize at rain fed is shown in Table 6. 9. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the three treatments combination, while the maximum number was recorded on the untreated check plot. All plots that received the two treatments combination were found to be more effective in the management of termites than the plots that received single botanical treatment.

Table 6. 9 The effect of botanical application on mean (±se) number of termites and their symptoms at seedling stage on rain fed maize at Uke site.

Treatments	Number of termites and their symptoms		
	number of foraging termite	number of foraging galleries	number of termite mounds
Untreated check	72.7± 0.55^{h}	7.75± 0.22^{d}	1.25± 0.06^{e}
Croton macrostachys(Cr)	61.5± 0.60^{g}	6.75± 0.20^{d}	0.77± 0.08^{d}
Phytolacca dodecandra (Ph),	50.7±0.65^{f}	4.50± 0.28^{c}	0.7± 0.09^{c}
Jatropha curcas (Ja)	41.2± 0.70^{e}	4.25± 0.28^{c}	0.55± 0.10^{bc}
C. macrostachys+ P. Dodecandra	34.5± 0.76^{d}	2.25±0.32^{bc}	0.15± 0.11^{ab}
C. macrostachys + J. curcas	29.5± 0.70^{c}	2.50± 0.32^{bc}	0.25±0.12^{ab}
P. dodecandra + J. Curcas	20.7± 0.78^{b}	3.00± 0.34^{b}	0.00^{c}
C. macrostachys + P. dodecandra + J. Curcas	12.5± 0.86^{a}	1.50± 0.38^{a}	0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.9. Effect of botanical application on mean (±se) of termite symptoms at knee height/vegetative stage on rain-fed maize

The effect of botanical application on mean number of termites and their symptoms at knee height/vegetative stage on rain-fed maize is shown in Table 6.10. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the three treatments combinations, while the highest was recorded on the untreated check plot. Plots that received all the two treatments combinations were found to be more effective in the management of termites than single botanical treatments.

Table 6.10 The effect of botanical application on mean (±se) of termite symptoms at knee height/vegetative stage on rain-fed maize.

Treatments	Number of termites and their symptoms		
	number of foraging termites	number of termite galleries	number of termite mounds
Untreated check	51.5± 0.32^{h}	13± 0.80^{e}	1.50± 0.04^{c}
Croton macrostachys (Cr)	41.5±0.45^{g}	8.75± 0.12^{d}	0.87± 0.03^{b}
Phytolacca dodecandra Ph)	35.5± 0.55^{f}	4.00± 0.16^{de}	0.67± 0.02^{bc}
Jatropha curcas(Ja)	25.75±0.60^{e}	3.0± 0.18^{de}	0.47± 0.01^{ab}
C. macrostachys+ P. Dodecandra	19.75±0.65^{d}	2.50±0.22^{c}	0.35± 0.01^{ab}
C. macrostachys + J. curcas	19.25±0.75^{c}	4.25± 0.30^{b}	0.25± 0.01^{ab}
P. dodecandra + J. Curcas	16.75±0.80^{b}	4.00± 0.32^{ab}	0.25± 0.01^{ab}
C. macrostachys + P. dodecandra + J. Curcas	10.75± .85^{a}	0.25± 0.42^{a}	0.0± 0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD).

6.3.10. Effects of botanical application on mean (±se) number of termites and their symptoms at flowering stage on rain fed maize at Uke site

The effect of botanical application on mean number of termites and their symptoms at the flowering stage of maize is shown in Table 6.11. The lowest mean number of foraging termites, termite galleries and number of mounds were recorded on the plots that received the three treatments combination, while the highest was recorded on the untreated check plot. All plots that received the two treatments combination were found to be more effective in the management of termites than a single botanical treatment.

Table 6.11 The effects of botanical application on mean (±se) number of termites and their symptoms at flowering stage on rain fed maize at Uke.

Treatments	Number of termites and their symptoms		
	N0. of foraging termite	No. of termite galleries	N0. of termite mounds
Untreated check	40.5±0.59^{g}	14.2± 0.15^{f}	1.00± 0.00^{c}
C. macrostachys	29.7±0.80^{f}	10.0 ± 0.20^{e}	0.50± 0.12^{b}
P. dodecandra	28.0± 0.87^{e}	9.25± 0.24^{d}	0.00± 0.00^{a}
J. curcas	24.7± 1.00^{d}	4.75± 0.30^{cd}	0.00± 0.00^{a}
C. macrostachys+ P. Dodecandra	10.7± 1.02^{c}	3.50± 0.34^{bc}	0.00± 0.00^{a}
C. macrostachys + J. curcas	6.25± 1.04^{b}	2.25± 0.40^{bc}	0.00± 0.00^{a}
P. dodecandra + J. Curcas	4.50± 1.06^{ab}	1.10± 0.44^{b}	0.00± 0.00^{a}
C. macrostachys + P. dodecandra + J. curcas	3.00± 1.08^{a}	1.00± 0.54^{a}	0.00± 0.00^{a}

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD

6.3.11. Effects of botanical application on mean (±se) number of termites and their symptoms, yield and yield components at harvesting on rain fed maize

As shown in Table 6.12, the mean number of termites and their symptoms, yield and yield components at harvesting stage of rain fed maize at UKE are significantly different

($p<0.05$) due to different treatments. The results obtained revealed that there was low number of termites and their symptoms, and high yield and yield components in plot that received the three treatments combination and high number of termites and their symptoms, and low yield and yield components in the untreated check plot. These results depict inverse relationship between termite symptoms and yield and yield components. All plots that received the two botanical treatments combinations were more effective than a single botanical treatment.

Table 6.12.The effects of botanical application on mean (±se) number of termites and their symptoms yield and yield components at harvesting on rain fed maize.

Treatments	Number of termites and their symptoms			Yield and yield components			
	Foraging termites	Foraging tunnel	Mound	Plant height	Stand count	No.cob/plot	Yield(kg)/ha
C. macrostachys	127.5±5^{b}	51.3±3^{b}	2.0±1^{b}	3.6±1^{a}	49.5±3^{b}	86.3±3^{c}	3813±8^{bc}
P. dodecandra	91.5±3^{c}	28.7±1.2^{c}	2.0±1^{b}	3.5±1^{a}	52.3±3^{a}	117±5^{abc}	6042±8^{ab}
J. curcas	91.7±3^{c}	27.5±1,2^{c}	2.0±1^{b}	3.6±1^{a}	52.0±3^{a}	130.±6^{a}	6708±8^{a}
*Cm+ P*d	47.5±3^{e}	28.0±1.2^{c}	2.3±1^{b}	3.5±1^{a}	50.5±3^{ab}	125.5±6^{ab}	5583±8^{abc}
Cm + Jc	55.0±3^{d}	24.3±2^{d}	1.8±1^{b}	3.6±1^{a}	52.3±3^{a}	130.5±6^{a}	6777±8^{a}
Pd+ Jc	47.5±3^{e}	19.8±2^{c}	1.8±1^{b}	3.5±1^{a}	52±3^{a}	129.8±6^{a}	6667±8^{a}
Cm+ Pd + Jc	15.0±2^{f}	7.5±1.0^{d}	0.3±0^{b}	3.6±1^{a}	52.8±3^{a}	144.8±7^{a}	7333±8^{a}
Untreated check	192.5±7^{a}	71.3±5^{a}	9.2±1^{a}	3.5±1^{a}	44.8±3^{c}	89.5b±5^{c}	3646±8^{c}

- Cm= *C. macrostachys. Pd= P. dodecandra, Jc= J. curcas*

Means followed by the same letter within a column are not significantly different from each other at 5% level, Turkey's Studentized Range test (HSD)

6.4. Discussion

Mixture application of *C. macrostachys, P. dodecandra* and *J. curcas* leaf extracts were found to be highly effective in the management of termites on maize when the termites species composition are *Macrotermes*, *Odontotermes* and *Pseudacanthotermes*. The fact that single botanical treatments are less effective than both the two botanicals mixture treatments and the three botanicals mixture treatment implies that botanicals combination has a synergetic effect in controlling termites. The synergetic effect was demonstrated by the fact that plots that received botanicals treatment at 2 levels and 3 levels highly reduced the number of foraging termites, foraging galleries and number of termite mounds. The synergetic effect also increased the number of standing plants at harvesting.

Moreover, it has increased the yield and yield components. The current findings is in line with Cynthia *et al*. (2016) who reported mixing of *Zingiber officinale* and *Allium sativum* significantly reduced termite damage on hot peppers. In the study, maximum termites and their symptoms reduction realized on the plots that received mixtures of *C. macrostachys, P. dodecandra* and *J. Curcus.* Tadele Shiberu *et al*. (2014) reported that the combination of *P. dodecandra* and *J. Curcas* gave 100% termites mortality in 2 hrs exposure time in the laboratory. Simon Kebede and Nnah (2018) and Qwarse Michael *et al*. (2017) demonstrated the effects of some botanicals applied in the soil hinder termites from forming extensive galleries. Ahmed Ibrahim and Girma Demisse (2013) compared the seed and leaf extracts of C. *macrostachys* and found out that seed extract significantly shortened termites galleries. Ibe *et al*. (2018) demonstrated the efficacy of *J. Curcas* applied to the soil significantly prevent subterranean termites from making of tunnels. Tilahun Mola (2018) reported that Chomo grass (*Brachiaria humidicola* (Rendle) Schweick)) hinder termite further infestation by reducing the formation of tunnels. Moreover, the extent of termites' galleries formation depends on the potential of each botanical extract (Shahid *et al*., 2012).

6.5. Conclusion

The findings of this study showed that application of leaf extracts of *C. macrostachys*, *P. dodecandra* and *J. curcas* applied alone and in mixtures at the rate of 20ml/plant significantly reduced number of termites particularly Macrotermes, Odontotermes and Pseudacanthotermes. This ultimately lead to subsequent reduction of termite galleries and mounds under irrigated and rain fed conditions before planting, at seedling, flowering and at harvesting stages of maize plants. From the current study it can be concluded that the tested botanicals in mixture or singly can be considered as an alternative termites control where multiple species of termites occur in maize culture.

CHAPTER 7

General Conclusions and Recommendations

7.1 Conclusions

- Traditionally Identified termites genera are in accordance with scientific knowledge. All of them are from West Wollega and are claimed threaten production more than other pests

- Termites are perceived as minor pests as their damage is gradually escalating and heir damage is not sever and traditionally controlled. This kind of farmer's perception would assist to determine thresh hold strategy for termite control.

- Agrecology and land use significantly influence termite species composition and abundance. Both similar and different compositions are found in same or different land use system.

- Peak termite infestation in low agroecology grazing land use than in high agroecology. However, the local termite's composition was similar for agrecology and land use system

- A total of 295 termite species sample collected were from one family Termitidae, comprising of four sub-families and nine genera; *, Termitinae, Nasutitermitinae, and Apicotermitinae under nine genera; Macrotermes, Microtermes, Odontotermes, Pseudacanthotermes Amitermes, Microcerotermes, Angulitermes, Trinervitermes* and *Apicotermitinaee.* Except, *Apicotermitinae* all are recorded from grazing, cultivated and disturbed forest lands of the three districts (Nunuqumba, Diga and Limu).

- *Macrotermes, Odontotermes* and *Pseudacanthotermes* termites were sampled from the mounds under study, may be they were mound constructing termites as reported elsewhere

- Termite symptom; were high in grazing land than in cultivated and disturbed forest land use system
- Analyzed some physiochemical properties of mound soil show fitting value of soil (bulk density, moisture content and porosity) and high soil; OM, OC, TN, (av) P, pH, ex Ca, Mg and K than adjacent and non-mound soil,
- .Mound soil with better soil texture and high mineral content are rated as moderate agricultural soil
- More maize plant growth trait was attained from the combined treatment (growth inputs) (MS+AS+NPK+ NMS) than non-mound soil.
- However, extra ordinary growth when MS+NPK used, thus MS is not recommended with NPK
- Maize plant growth trait confronts pest termites damage at all growth stages(seedling vegetative flowering and at harvest) in both irrigation and rainfed condition
- Termite management mainly relay on indigenous management practices (mound destruction) and use of various insecticides were continued as believed to have minimized termite infestation.
- Plant growth trait significantly higher from mound soil and more growth was attained from (MS+AS+NPK+ NMS) than non-mound soil. Subsequently this growth induce cob to retain more yield per plant
- Termite symptoms at both irrigation and rainfed conditions can be managed with applications of separate or combined botanical leaf extracts.
- Termite buildup, galleries formation and mounds construction under irrigated and rain fed conditions before planting, at seedling, flowering and at harvesting stages of maize plants was managed with applications of botanicals Significant termite control was done when three combined botanicals were used

- Botanically managed maize plant can give butter performed maize stand count, more number cobs and yield per plot than untreated plot .

- Thus further mixture of botanicals ***C.*** *macrostachys, J. curcas and P. dodecandra* could be used as part of an integrated termites' management

7.2 Recommendations

- Further study;
- on termite composition in agroecology and land use
- on farmer's termite knowledge
- on physicochemical properties of mound soil and its fertilizer potential for plant growth
- on large scale use of botanicals extracts for termite management
- Providing awareness for small-holder farmers in the available termite mound area how to use termite mound soil as fertilizer to compensate the high expense of commercial fertilizer for crop production
- Cultural practices such as mound destruction, consistent scouting for termite's infestation, removal of infested parts and tunnels are essential management practices that farmers should practiced
- Following high termite incidence, the best period for application of botanicals for the control of termites need to be identified and scheduled for plant growth traits starting from seed to harvest
- The current effective and safer termite control methods need to be explored, tasted and adapted in the study area
- Farmer's participation in technology generation and evaluation which would help harness their indigenous knowledge in tackling the termite problems should be supported
- Termites issue problem need the control method which include resource poor farmer's
- Integrated Termite Management (ITM) should be implemented for the control of termite

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9. Appendices

Appendix 3 1.Questionnaire used to gather baseline information on termites

Questionnaire used to gather baseline information on Termites in Nunuqumba ,Diga and limu Districts East Wollega Zone ,western Ethiopia This questionnaire has been designed to gather baseline information from household farmer regarding their knowledge about termite's and its impact on production, knowledge of termite management

Information obtained through this questionnaire will be kept confidential and used only for the purpose of academic research.

We would like to thank in advance for your kind cooperation

I. Demographic data

1. District Nunu , Diga ,Limu
2. Kebele(lowest administration)harogudatu,korbu saqa , wama dirre,Gamachis, biqila, qarsa dako, warsu, malkalami,fitbako
3. Occupation farming, mixed farming laborer
4. Land holding 1ha,11/2ha ,2ha, >2ha
5. Agro ecology High, mid low land

II. Termite species composition

7. Constraints of production Disease, Weevils Locust Termites,

8. Farmer's knowledge of termites; King/Motii, Queen/Giifitii Worker and Soldier/Waraa, Immigrants/Rirma marmartu, Dung dwellers/Rirma dikee

9. Agro ecology/altitude class favoring termite prevalence

a/ High b/ Medium c/ low

10. Farmer's knowledge of termite infestation label by land use a/ grazing, b/cultivated, c/disturbed forest d/ built-up land

11. Reason for the abundance of termite in grazing land was contributed a/ food source. B/climate c/ farming practice d/absence of natural enemies

12. Status of land use infestation, rank a/ grazing land b/ cultivated c/ disturbed forest

13. The label of pest increase in grazing land use due to a/ overgrazing. B/Agricultural practices like; monoculture, non-fallow farming, c/ deforestations

14.termites in the study area are a/ minor pests (less number /density, their damage is not devastating,), b/ sporadic pest (termite's which occurs irregularly, don't found all the time) c/ major pest termite that cause significant damage when they are large in number, d/, fail to locate termite pest status

III. **Termite management practice**

15. Farmers 'management practice for the control of termite a/ cultural managements. b/ chemicals for termite management. c/ biological/botanical means. d/ fail to locate termite management practice

16. Widely used cultural practice for termite control were; a/mound demolition b/Flooding mound, c/Removing galleries, d/botanical leaves and extracts e/ termite resistant plants. f/ all

Appendix 3.2 Termite symptom sampled within the three land-uses patch's from the quadrat sampling methods at Nunuqumba districts, 2019

Duration of collection	Woreda	Land use	Encounters	Gallery	Mounds

One month	Nunuqumba	Cultivated land	105	106	10
		Range land	95	47	5
		forest land	74	46	5
	Nunuqumba	Cultivated land	79	28	5
		Range land	103	44	9
		forest land	83	25	4
	Nunuqumba	Cultivated land	83	110	8
		Range land	69	57	10
		forest land	71	50	8

Appendix 3 3 Termite symptom sampled within the three land-uses patch's from the quadrat sampling methods at Diga districts, 2019

duration of collection	Woreda	Land use	encounters	Gallery	mound
One month	Diga	Cultivated land	72	31	2
		Range land	103	28	5
		forest land	26	27	6
	Diga	Cultivated land	116	29	6
		Range land	78	26	6
		forest land	146	27	6
	Diga	Cultivated land	118	29	4
		Range land	136	30	6
		forest land	128	30	5

Appendix 3 4.Termite symptom sampled within the three land-uses patch's from the quadrat sampling methods at limu districts, 2019

duration of collection	Woreda	Land use	encounters	Gallery	mound
One month	Limu	Cultivated land	98	66	2
		Range land	82	44	5
		forest land	109	41	5
		Cultivated land	71	20	5
		Range land	89	29	10

	Limu	forest land	91	25	5
	Limu	Cultivated land	91	107	10
		Range land	84	49	10
		forest land	74	50	5

Laboratory result for soil sample collected from Limu, Fitbako *kebele.* by Agricultural Research Institute Bako Agricultural Research Centre Soil fertility Improvement Research case Team. Soil Lab test result Mr.Temesgen Beyene, Prepared by Bayisa Baye)

Appendix 4. 1 Laboratory result for Soil Physical property

Lab No	Analyzed soil sample	Moisture content (%)	Bulk .D (g/cm3)	Porosity (%)
1	Grazing land-Top	12.3	1.10	57.79
2	Grazing land-mid	13.9	1.23	52.65
3	Grazing land-bottom	13.3	1.39	46.61
4	Built-upland Top	14	12.1	48.89
5	Built-up land_mid	15.7	1.23	52.53
6	Built-up land bottom	17.9	1.32	49.32
7	Cultivated land –Top	12.8	1.38	47.08
8	Cultivated land –mid	8.5	1.38	47.08
9	Cultivated land –bottom	1.89	0.86	86.09
10	Disturbed forest-top	10.9	1.30	49.53

11	Disturbed forest-mid	11.8	1.33	49.89
12	Disturbed forest-bottom	12.7	1.36	53.4

Analysis of variance (ANOVA) table for selected soil physical property collected from Limu, Fitbako *kebele*

Appendix 4.2 Analysis of variance (ANOVA) table for mean bulk density of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Bulk density

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	6.69882515	0.39404854	3.77	0.0008
Error	29	3.03086847	0.10451271		
Corrected Total	46	9.72969362			

Appendix 4.3 Analysis of variance (ANOVA) table for mean porosity of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: porosity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1211.491522	71.264207	0.68	0.7977
Error	29	3046.417665	105.048885		
Corrected Total	46	4257.909187			

Appendix 4.4 Analysis of variance (ANOVA) tables for mean moisture content of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Moisture content

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	71.9786872	4.2340404	0.56	0.8937
Error	29	218.9786958	7.5509895		
Corrected Total	46	290.9573830			

ANOVA table for soil chemical property collected from Limu, Fitbako *kebele*

Appendix 4.5 Laboratory result for soil chemical property

Lab No	Analyzed soil sample	pH(1:1.25) H_2O	%OC	%OM	%TN	Av.P (PPM)	Ex.K (cmol/Kg soil)	Ex.Ca (meq/100g)soil	Ex.Mg (meq/100g)soil
1	Forest land-Top	6.51	2.03	3.51	0.18	9	1.55	14.9	23.7
2	Forest land-mid	6.8	2.03	3.5	0.18	10	1.58	21.7	30.4
3	Forest land-bottom	7.09	2.02	3.48	0.17	21	1.60	28.5	35.1
4	Grazing land-Top	5.02	0.95	1.60	0.08	7	0.81	9	3
5	Grazing land-mid	5.27	0.82	1.42	0.07	7	0.80	7	1.5
6	Grazing land-bottom	5.01	0.50	0.86	0.04	8	1.23	6	1.2
7	Buit-upland_Top	5.63	1.37	2.31	0.12	9	1.29	6.2	3
8	Buit-upland_mid	5.32	1.31	2.26	0.11	8	1.21	5.6	2
9	Buit-upland_bottom	5.49	0.96	1.66	0.08	9	1.55	6.2	2.5
10	Cultivated land -Top	5.02	2.23	3.85	0.19	12	0.81	10	2
11	Cultivated land –mid	5.61	2.1	3.62	0.18	8	1.18	6.5	2.5
12	Cultivated land -bottom	5.68	2.5	1.03	0.05	7	1.60	6.6	1.1

Appendix 4.2 Analysis of variance (ANOVA) table for mean PH of soil collected from Limu, Fitbako *kebele*

The GLM Procedure Dependent Variable: PH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1211.491522	71.264207	0.68	0.7977
Error	29	3046.417665	105.048885		
Corrected Total	46	4257.909187			

Appendix 4.3 Analysis of variance (ANOVA) table for mean Organic carbon (OC) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure Dependent Variable: Organic carbon (OC)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1211.491522	71.264207	0.68	0.7977
Error	29	3046.417665	105.048885		
Corrected Total	46	4257.909187			

Appendix 4. 4. Analysis of variance (ANOVA) table for mean available phosphorous (A v.P) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Available phosphorous(av.P)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	260.5832650	14.4768481	1.10	0.4009
Error	29	382.5128662	13.1900988		
Corrected Total	47	643.0961313			

Appendix 4. 5 Analysis of variance (ANOVA) table for mean Organic Matter (OM) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Organic matter (OM)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	26.55368468	1.47520470	1.14	0.3636
Error	29	37.38864032	1.28926346		
Corrected Total	47	63.94232500			

Appendix 4. 6 Analysis of variance (ANOVA) table for mean Available potassium (Av.K) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Available potassium (Av.K)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	3.77609245	0.20978291	1.02	0.4727
Error	29	5.99247422	0.20663704		
Corrected Total	47	9.76856667			

Appendix 4.7 Analysis of variance (ANOVA) table for mean Exchangeable Calcium (Ex. Ca) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Exchangeable Calcium (Ex. Ca)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	970.373891	53.909661	1.44	0.1860
Error	29	1085.913790	37.445303		
Corrected Total	47	2056.287681			

Appendix 4. 8 Analysis of variance (ANOVA) table for mean Exchangeable magnesium (Ex. Mg) of soil collected from Limu, Fitbako *kebele*

The GLM Procedure

Dependent Variable: Exchangeable magnesium (Ex. Mg)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	18	970.373891	53.909661	1.44	0.1860
Error	29	1085.913790	37.445303		
Corrected Total	47	2056.287681			

Appendix 5 1.Laboratory result for Soil Physical property

Lab No	Analyzed soil sample	Moisture content (%)	Bulk .D (g/cm3)	Porosity (%)
1	Cultivated land –Top	12.8	1.38	47.08
2	Cultivated land –mid	8.5	1.38	47.08
3	Cultivated land –bottom	1.89	0.86	86.09

Appendix 5 2.Laboratory result for soil chemical property

Lab No	Analyzed soil sample	pH(1:1.25)H_2O	%Oc	%OM	%TN	Av.P (PPM)	Ex.K (cmol/Kg soil)	Ex.Ca (meq/100g) soil	Ex.Mg (meq/100g)soil
10	Cultivated land -Top	5.02	2.23	3.85	0.19	12	0.81	10	2

11	Cultivated land –mid	5.61	2.1	3.62	0.18	8	1.18	6.5	2.5
12	Cultivated land -bottom	5.68	2.5	1.03	0.05	7	1.60	6.6	1.1

Appendix 5 Analysis of variance (ANOVA) for mean plant growth trait at 2, 4, and 8 weeks

Appendix 5 3.Analysis of variance (ANOVA) table for mean plant height at 2, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	205.8333333	41.1666667	7.52	0.0145
Error	6	32.8333333	5.4722222		
Corrected Total	11	238.6666667			

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Appendix 5. 4 Analysis of variance (ANOVA) table for mean plant stem width at 2, weeks

Source	Df	Sum of square	Mean square	F Value	Pr>F
Model	5	9.68500000	1.93700000	6.78	0.0187
Error	6	1.71500000	0.28583333		
Corrected Total	11	11.40000000			

Appendix 5 5.Analysis of variance (ANOVA) table for mean plant leaf width at 2, weeks

Source	Df	Sum of square	Mean square	F Value	Pr>F

Model	5	2.75416667	0.55083333	11.20	0.0053
Error	6	0.29500000	0.04916667		
Corrected Total	11	3.04916667			

Appendix 5. 6 Analysis of variance (ANOVA) table for mean plant height at 4, weeks

Source	Df	Sum of square	Mean square	F Value	Pr>F
Model	5	5818.083333	163.616667	2.81	0.1200
Error	6	348.833333	58.138889		
Corrected Total	11	1166.916667			

Appendix 5. 7 Analysis of variance (ANOVA) table for mean plant stem width at 4, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	20.70000000	4.14000000	2.46	0.1516
Error	6	10.08666667	1.68111111		
Corrected Total	11	30.78666667			

Appendix 5.8 Analysis of variance (ANOVA) table for mean plant leaf width at 4, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	16.10000000	3.22000000	4.73	0.0426
Error	6	4.08666667	0.68111111		
Corrected Total	11	20.18666667			

Appendix 5. 9 Analysis of variance (ANOVA) table for mean plant leaf number at 4, weeks

		Sum of			

Source	DF	Squares	Mean Square	F Value	Pr> F
Model	5	2.25000000	0.45000000	0.31	0.8893
Error	6	8.66666667	1.44444444		
Corrected Total	11	10.91666667			

Appendix 5.10 Analysis of variance (ANOVA) table for mean plant height at 8, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	0.14494167	0.02898833	1.72	0.2642
Error	6	0.10135000	0.01689167		
Corrected Total	11	0.24629167			

Appendix 5.11 Analysis of variance (ANOVA) table for mean plant stem width at 8, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	22.08333333	4.41666667	3.00	0.1068
Error	6	8.83333333	1.47222222		
Corrected Total	11	30.91666667			

Appendix 5.12 Analysis of variance (ANOVA) table for mean plant leaf width at 8, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	23.04750000	4.60950000	4.48	0.0478
Error	6	6.17500000	1.02916667		
Corrected Total	11	29.22250000			

Appendix 5. 13 Analysis of variance (ANOVA) table for mean plant leaf number at 8, weeks

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	5	5.33333333	1.06666667	0.87	0.5498
Error	6	7.33333333	1.22222222		
Corrected Total	11	12.66666667			

Appendix 6 Analysis of variance (ANOVA) table for mean of termite symptom in maize growth field under Irrigation condition

Appendix 6 1.Analysis of variance (ANOVA) table for mean for foraging termite density in maize growth field under Irrigation condition

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	18410.62500	2630.08929	74.88	<.0001
Error	16	562.00000	35.12500		
Corrected Total	23	18972.62500			

Appendix 6 2.Analysis of variance (ANOVA) table for mean of Foraging termite Galleries in maize growth field under Irrigation condition

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	952.6666667	136.0952381	51.04	<.0001
Error	16	42.6666667	2.6666667		
Corrected Total	23	995.3333333			

Appendix 6 3.Analysis of variance (ANOVA) table for mean of termite constructed mound in maize growth field under irrigation condition

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	53.29166667	7.61309524	45.68	<.0001
Error	16	2.66666667	0.16666667		
Corrected total	23	55.95833333			

Appendix 6 Analysis of variance (ANOVA) table for mean of termite symptom in maize growth field under rain fed condition

Appendix 6.4 Analysis of variance (ANOVA) table for mean of Foraging termite density in maize growth field under rain fed condition

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	9363.500000	1337.642857	668.82	<.0001

Error	24	48.000000	2.000000
Corrected Total	31	9411.500000	

6. 5 Analysis of variance (ANOVA) table for mean of foraging termite Galleries in maize growth field under rain fed condition

Source	DF	Sum Squares	Mean Square	F Value	Pr > F
Model	7	574.9687500	82.1383929	42.17	<.0001
Error	24	46.7500000	1.9479167		
Corrected Total	31	621.7187500			

Appendix 6 6.Analysis of variance (ANOVA) table for mean of termite constructed mound in maize growth field under rain fed condition

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6.36528750	0.90932679	17.31	<.0001
Error	24	1.26070000	0.05252917		
Corrected Total	31	7.62598750			

Appendix 7 1.Published article

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Efficacy of botanical extracts against termites on maize (*Zea mays* (L.)) under field condition in western Ethiopia

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ABSTRACT*:* Maize *(Zea mays L.)* is grown popularly in the world. It is severely attacked by termites. Insecticides are widely used to control, but could not minimize termites' damage mainly because of resistance development and easily break down of the active ingredients. Hence, field experiment was conducted with the aim of evaluating different botanical crude extracts from leaves of *Croton macrostachys* (*Hochst*), *Jatropha curcas L. and Phytolacca dodecandra L.* for the management of termites. The experiment was conducted at Wollega University (WU) under irrigation and rain fed conditions. Leaves of the botanicals were collected from experimental sites in western Ethiopia and dried under shade. The dried leaves were grounded to a fine powder using a small hand-operated manual grinder and the powder was further sliced with analytical mill and sieved through a 0.25 mm pore size mesh to make uniform fine dust particle. The treatments were *C. macrostachys, P. dodecandra, J. curcas, C. macrostachys + P. dodecandra, C. macrostachys +J. curcas, P. dodecandra + J. curcas, C. macrostachys + P. dodecandra + J. curcas*. Untreated check was used for comparison. For treatment preparation, 300 g. of each botanical leaf powder was soaked in 1000 ml distilled water for 72 hrs. The mixtures were filtered with clean cheese cloth and stored in a beaker of 250 ml capacity. The experiment was laid-out in a Randomized Complete Block Design (RCBD) in four replications. Shallow holes for maize seed planting were prepared well ahead of planting on the experimental plots. From the stock solution of each botanical, 20 ml was drenched to each planting hole 10 days before planting and continued at all maize growth stages. Treatments were applied using 30 ml capacity Syringe. Data on termite damage symptoms were collected two days before planting and two days after treatment application at every growth stage. The results revealed that mixed botanicals treatments were significantly ($p<0.05$) superior to non-mixed botanical treatments in the management of termites. The highest number of foraging termites, galleries and mounds were recorded in the untreated check plot, while the lowest was recorded in the mixed botanical treatments. Moreover, the highest number of maize stand count, maize cobs and maize yield were recorded from plots that received mixed botanicals and the lowest were recorded from the untreated plot. In conclusion, mixtures of *C. macrostachys, J. curcas and P. dodecandra* can be used as part of an integrated termites' management.

Keywords/Phrases: ***Croton macrostachys, Foraging termite, Foraging tunnel, Jatropha curcas,Phytolacca dodecandra.***

Appendix 7 2.Published article

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Some physiochemical properties of termite mound soil and its effect on yield and yield components of maize (*Zea mays L.*) Under Greenhouse condition at Nekemte, western Ethiopia

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ABSTRACT: Termite mound soil amends soil fertility and utilized as an alternative to NPK fertilizers by smallholder farmers in Africa. Experiment was conducted in western Ethiopia to compare selected physical and chemical properties of mound soil (ms), Adjacent soil (AS) and non-mound soil (NMS) and the effect of these soils on maize plant growth and yield in the Greenhouse. In Limu district, Fitbako kebele, cultivated land was purposively selected for sampling. In the cultivated land, a plot of 100m x100m was delineated and three mounds within the plot were also purposively selected to collect composite soil sample for soil analysis and Greenhouse pot experiment. From each mound, 10kg soil each from bottom, middle and top (total= 30 kg) were collected and mixed to obtain working sample of 10 kg. About 30kg of adjacent soil 5m away from mound soils and Non-mound soil at the distance of 20 m away from mound soil at the depth of 0-30cm were collected and thoroughly mixed to make working sample of 10kg from each soil type. Three kilograms of mound soil, adjacent soil and non-mound soil each was put in separate plastic bucket for greenhouse pot experiment. About 100 gm of each soil type was used for selected physical and chemical properties analyses. The result obtained demonstrated that termite mound soil was significantly ($P<0.05$) high in bulk density (BD), moisture contents (MC), porosity (P), Soil pH, percent organic carbon (% OC) and percent organic matter (% OM). Total Nitrogen (TN), average (av.) P, av. K, Exch. Ca and Exch. Mg were also significantly ($P<0.05$) higher in mound soil in comparison with adjacent soil and non-mound soil. Maize plant growth traits and yield were significantly ($P<0.05$) high in mound soil. From the current study, it can be concluded that the use of NPK fertilizer on plots having termite mound is not recommended. However, further research is needed on how to use mound soil on large plot of land.

Key words/Phrases: Adjacent soil, Chemical property of soil, Non-mound soil, Soil texture, Termite mound soil