The Importance and Management of Termites in Ethiopia: A Review

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Introduction

Termites are major pests in the semi-arid and sub-humid tropics (Harris 1971, Wood and Johnson 1986, Wood 1991). Since Ethiopia lies in the tropics termites pose a serious threat to agricultural crops, forestry seedlings, rangelands and wooden structures. Termite problem is particularly serious in the western parts of the country.

Damage caused by termites to agricultural crops and wooden material have been long recognized in Ethiopia. The first report of termite damage was from Kiltu Kara (near Ghimbi) in 1938 (Abdurahman and Adugna 1986). Later more consistent and serious reports of termite damage to crops, forestry trees and rangelands came in early 1970s (Sanna 1973, Sands 1976, Wood 1986a). Effective management of termites is of paramount importance to ensure food security in the country and to improve availability of raw material for local industry and export markets.

In the past, several attempts were made to reduce damage caused by termites in the country. The control measures undertaken include extensive termite mound poisoning campaigns that were conducted in some parts of western Ethiopia by the Ministry of Agriculture in 1983, the Relief and Rehabilitation Commission (RRC) in 1984 and the Ministry of Coffee and Tea Development in 1988. The Institute of Agricultural Research (IAR) also executed several termite research programs to develop effective control measures, including the development of resistant forage grasses (Abraham Tadesse, pers.com.). Moreover, in 1986, a consulting entomologist from the Tropical Development and Research Institute (TDRI), London, was funded by the World Bank to assess the termite problem in the country and recommend short and long term management strategies (Wood 1986a, 1986b).

In this paper attempts are made to collate information on the species of termites recorded in Ethiopia, their distribution, economic importance, damage and management options scattered over published and unpublished sources and avail them for use by researchers and development workers on termite problem in the country. This paper is also believed to identify research gaps that need to be addressed.

Termite Species Recorded in Ethiopia

To date, over 2600 species of termites in seven families and 15 subfamilies are known worldwide. Six of the families are referred to as lower termites. Termites in this group possess intestinal protozoa which help in the digestion of wood. The seventh family, the Termitidae, which includes 75% of all living termite species, is known as higher termites. With over 660 species, Africa is considered the richest continent in termite diversity (Eggleton 2000).

Over 80% of the known genera and the species that damage crops, trees and rangelands belong to the family Termitidae. Although the exact number of termite species is not known, it is estimated that less than 20% of the species in the family Termitidae are serious pests (Pomeroy *et al*.1991, Mitchell 2002). Over 90% of the termite damage in agriculture, forestry and urban settings is attributed to members of the subfamily

Macrotermitinae (Pomeroy *et a*l. 1991, Mitchell 2002), which build large mounds that form the spectacular features of the African landscape (Glover 1967, Malaisse 1978). The association of termites as crop pests is also related to the presence of termiteria in crop fields and near trees.
The termite fauna of Ethiopia is not well known. At present, 62 species belonging to 25 genera and four families have been recorded and 10 of the species are endemic (Cowie *et al.* 1990). About 25% of these species are pests of agricultural crops, forestry seedlings and grazing lands. The four families that contain the pest species are Kalotermitidae, Hodotermitidae, Rhinotermitidae and Termitidae.

The Kalotermitidae are commonly known as dry – wood termites, as they live and feed entirely on woody materials without any contact with the soil. Such feeding habits restrict their damage entirely to woody perennial plants such as tea, cocoa, coconut and citrus (Sands 1973). The Kalotermitidae species recorded in Ethiopia are: *Neotermes erythraeus* Silvestri, *N. superans* Silvestri, N. *aridus* Wilkinson and *Epicalotermes aethiopicus* Sjostedt (Cowie *et al.* 1990). Only the latter species was reported attacking acacia trees in eastern Ethiopia (Hill 1965).

The Hodotermitidae are known as harvester termites and feed mainly on grass and grass litter which they collect during the night or cooler hours of the day. Occasionally, they may feed on non graminaceous plant material and herbivore dung (Harris 1969). The species reported in Ethiopia are: *Hodotermes mossambicus* (Hagen) and *H. erithreensis* Sjostedt, which is an endemic species (Cowie *et a*l. 1990). Only the latter species was recorded causing damage on plants (Harris 1969, 1971).

The family Rhinotermitidae is subterranean and moist wood termites and consists of several species that cause damage, mainly on non staple food crops such as tree crops, sugarcane and tea. The only staple food crops attacked are potatoes in Jamaica and various root crops and groundnut in China (Sands 1973). The species recorded in Ethiopia are: *Coptotermes amanii* (Sjostedt), *Psammotermes hybostoma* (Sjostedt), *Heterotermes aethiopicus* (Sjostedt) (Sands 1976, Cowie *et al.* 1990, Hill 1965). Only the latter species was reported attacking acacia trees in eastern Ethiopia.

The family Termitidae consists of four subfamilies and over 85% of the termite species recorded in Ethiopia belongs to this family (Cowie *et al.* 1990). However, most of these species are considered harmless; feeding on dead plant material, soil organic matter or herbivore dung. The species recorded attacking growing plants are in the genera *Macrotermes*, *Microtermes*, *Odontotermes*, *Pseudacanthrotermes*, *Ansistrotermes and Amitermes.*

The genus Macrotermes is represented in Ethiopia by *Macrotermes subhyalinus* (Rambur) and *M. herus* (Sjostedt) (Ruelle 1970, Sands 1976). *M. subhyalinus* is considered an important pest species in several parts of Wollega and Asossa zones particularly in Mendi area (Crowe *et al.* 1977). Perhaps that is why it is known locally as the Mendi termite. It has been reported causing damage on maize, tef, Eucalyptus and grasses (Sands 1973, 1976, Wood 1986b), wheat and barley (Adugna and Kemal 1986); pepper, tomato and other vegetable crops (Popov *et al.* 1982). *M. herus* has been reported causing 50% pre-and-post- harvest damage on maize and pepper and serious damage on young Eucalyptus trees in the Asossa and Anger Gutin settlement areas (FAO 1984). This species is very likely to be similar to the former as the identification of species is notoriously difficult (Ruelle 1970, Bagine *et al.* 1989).

Five species of *Microtermes* have been reported in Ethiopia and these are: *M. aethiopicus* Barnett et al., *M. magnocellus* (Sjostedt), *M. neghelliensis* Ghidini, *M. tragardhi* (Sjostedt) and *M.* nr. *Vadschaggue* (Cowie *et al.* 990).

Microtermes aethiopicus Barnett et al. is known only from Ethiopia (Barnett *et al.* 1987, 1988). *Microtermes* attack has been recorded on standing maize in western Ethiopia (Wood 1986a), on groundnut in Bako (Schumutterer, 1971), on Swiss chard in eastern Ethiopia (Hill 1965), on haricot beans and cowpea in Melkasa area (Tsedeke et. al. 1982, Schumutterer 1971) and on wheat in the IAR station at Melka Werer (Wood 1986a). *Microtermes magnocellus* (Sjostedt) was recorded on crop residue in western Ethiopia (Sands 1976) but it is not known whether it is a crop pest or not.

In earlier reports four species of *Odontotermes* have been reported causing crop damage in Ethiopia. *O. anceps* (Sjostedt) has been reported attacking groundnut (Schumutterer 1971, Crowe et al. 1977) and wheat (Adugna and Kemal 1986). Abushama and Cloudsley-Thompson (1968) also reported the occurrence of this species in shores of Lake Ziway in central Ethiopia, but have not indicated whether it was causing crop damage or not. *O. montanus* (Harris) and *O. classicus* (Sjostedt) damage were recorded on wheat (Adugna and Kemal 1986, Crowe *et al.* 1977). The former species was also recorded on *Milletia ferruginea* (Hohest) in eastern Ethiopia (Hill 1965). *O. badius* (Haviland) was reported as a pest of gardens in high altitudes (Crowe et al. 1977). Various species of *Odontotermes* have been reported also feeding on grasslands (Sands 1976, Wood, 1986a).

Pseudacanthotermes militaris (Hagen) has been recorded causing damage on badly denuded grasslands in Wollega (Sands 1976, Wood, 1986a) and on maize in Gamo Goffa region (Cowie *et al.* 1990).

Three species of *Ancistrotermes* have been reported in Asossa, Gambella and southwestern Ethiopia (Barnett et al. 1987). *A. crucifer* (Sjostedt) and *A. periphrasis* (Sjostedt) were recorded attacking growing crops, especially maize in Gamo Goffa. *A. latinotus* (Holmgren) was known only on dead plant materials, such as maize stubble and logs.

Microcerotermes parvus (Haviland) and *M. parvulus* (Sjostedt) have been recorded on maize and sorghum residue, but it is not known whether they can attack food crops or not (Barnett *et al.* 1987). However, the former species was recorded causing damage on forestry seedlings in Shoa region (Cowie *et al.* 1990).

Amitermes sciangallorum Ghidini has been recorded feeding on the roots of young cotton plants in the IAR station at Melka Werer (Schmutterer 1971).

Unidentified termites have been also reported in western Ethiopia attacking hot pepper (Tsedeke 1986), groundnut (Kemal et al. 1986) and coffee (Crowe and Tadesse 1984).

Abdurahman (1990) identified 12 species of termites belonging to nine genera and two subfamilies in the Wollega and Asossa zones in western Ethiopia. Seven of the species in the subfamily Macrotermitinae were observed attacking crops. These were *Macrotermes subhyalinus* (Rambur), *Microtermes* nr. *vadschaggae* (Sjostedt), *Microtermes aethiopicus* Barnett et al., *Odontotermes* species D, E and I and *Pseudacanthotermes militaris* (Hagen). *Odontotermes* species I is possibly a new species as it has never been reported in any of the previous studies.

Abraham (1987b) recorded termites in the genera *Macrotermes, Odontotermes, Microtermes*, soldierless termites, *Amitermes, Microcerotermes*, and *Angulitermes* on maize stubble, natural rangeland and Eucalyptus plants in Ziway area in 1986. *Angulitermes* and soldierless termites are soil feeders causing no damage to crops. *Microcerotermes* feed only on dead plant materials.

Many of the records available lack the necessary details regarding the stage of crops attacked and the extent of damage caused by the different species of termites. Some of the studies even did not report the name of the species responsible for crop damage. Such information is vital to understand the economic importance of the species found in the area, so that studies on their biology and control may be directed at the most important species. The taxonomy of some of the genera such as *Odontotermes* and *Microtermes* are poorly known and there are no identification keys that can be used to identify the different species. All the identification works that have been done regarding the Ethiopian fauna were based on the fauna of other parts of Africa (Barnett *et al.* 1987). These limitations clearly show some of the challenges in studying the Ethiopian termite fauna.

Termite identification is generally based on the alates (winged – form) or major soldier characters. Alates are found only at certain periods of the year during swarming. As a result they are not widely used, but soldier castes which are found throughout the year are more commonly used in termite identification (Abdurahman 1991b). This conventional method is not always reliable, especially when the similarities between different species are very close (Bagine et al. 1989, cited by Abdurahman 1991a). Barnett et al. (1987) indicated that species identification in termites is very difficult for many reasons, and for many genera identification key has not been worked out. Wood (1991) also indicated that lack of taxonomic understanding has been a major impediment to the study and management of tropical termites. Species numbers are high and many of those are undescribed or poorly described. According to the review of Abdurahman (1991a), other techniques such as isoenzyme electrophoresis, differences in the secretions of soldier castes and morphometric analysis were used to identify closely related species.

Termite Distribution in Ethiopia

Termites are mainly tropical and subtropical insects; however, their distribution extends to the temperate regions up to 45^0 N and S latitudes (Harris 1969, Wood and Sands 1977). Low temperature is the most important factor limiting the distribution of termites in colder temperate regions. However, with the expansion of central heating system and the construction of houses with concrete slab on the ground termites that infest buildings have started spreading to the warmer temperate regions (Johnson 1981, Edwards and Mill 1986). Termite distribution is also limited by high elevation (over 3000 masl) where it is cold and in deserts where there is no food. However, termites live in all types of soils except in some permeable water logged areas and in certain deeply cracking vertisols (Wood 1988).

The Ethiopian zoogeographical region is the richest in termite fauna and the center of origin for many termite genera. Bouillon (1970) reported the occurrence of 570 species in 89 genera. However, the dominant termites (*Macrotermes*, *Microtermes* and *Odontotermes*) in the region are the non-endemic genera.

The range of termite genera found in a typical savanna in western Ethiopia is reported by Wood (1991). The dominant species in natural ecosystems belong to the subfamily Macrotermitinae, and include various species of *Macrotermes*, *Odontotermes*, *Pseudacanthotermes*, *Ancistrotermes* and *Microtermes*. Most of these species are found throughout the savanna and wooded steppes of tropical Africa, below altitudes of 1800-2000 m. Above 2000 m there are fewer species, mainly soil feeders and a few *Odontotermes*. Clearing trees from such areas and subsequent cultivation usually destroys the nests of species building small mounds (e.g. *Trinervitermes*) and those with shallow, subterranean nests (e.g. many soil feeders). Species that depend on trees or woody litter (e.g. *Coptotermes*) also tend to disappear. However, species with deep subterranean nests and with the ability to survive on crops and crop residue remain (e.g. *Microtermes*, *Ancistrotermes*), often increase in abundance and some may become crop pests (Wood 1991).

Although termites are abundant and widely distributed throughout tropical and sub-tropical regions of Ethiopia (Wood 1991), the majority of reports of termite damage in the country come from Wollega, Benishangul Gumuz, Illubabor, Gambella, Sidama, Gamo Goffa, Shoa, Keffa, Hararghe and Somali regions/zones where they are reported to cause damage to a variety of agricultural crops, forage grasses, young and mature trees and all kinds of wooden structures (Wood 1986a). Termite problem is particularly prevalent in the western part of the country (Wollega zone of Oromia region and Benishangul Gumuz region), where it has been well known for many years and has received wide publicity. According to Wood (1986a), losses on maize were greater in Wollega than in Sidama and Gamo Goffa. FAO (1984) reported 50% damage by *Macrotermes* species in maize and pepper in Wollega.

Seven genera of termites were reported in maize fields in Metekel Zone of Benishangul Gumuz Region. These were: *Coptotermes*, *Microtermes*, *Odontotermes*, *Pseudacanthotermes*, *Macrotermes*, *Microcerotermes*, and *Trinervitermes*. *Macrotermes subhyalinus* was the dominant species in the region at altitudes below 2000 masl (Tizazu 2011).

Economic Importance

Termites can cause damage to all crops, and the damage can occur from seedling to harvest stage. However, credible information on the economic losses is difficult to obtain. Termite damage to crops is generally expressed as percentage of plants attacked or plant mortality, and degree of plant damage. However, yield loss may not necessarily be significant, but a relationship between the percentage damage by termites and yield losses have been reported in some crops.

Estimates of losses due to termites vary widely. In East Africa, severe losses (50-100%) due to termites have been reported on various crops and tree species (Sekamatte 2001, Nyeko and Olumbayo 2005). Yield loss assessment studies in teff using aldrin treated and untreated plots in Wollega showed yield increase in treated plots from 0 to 85% (Wood 1986a). Wood (1986b) indicated that farmers and extension workers estimated losses in millet and teff to range between 20 to over 50%; and in pepper and groundnut to be 20-25%. According to Abraham (1991), damage to maize was more serious when termite attack was severe enough to cause lodging or when the attack occurred after the plants were lodged. In some localities farmers ceased to grow improved varieties of maize and had reverted to local varieties which lodge less. Damage to teff was claimed to be up to 20% in Sidama and Gamo Goffa, and 100% in Wollega peasant farms (Wood 1986b). According to Wood (1986a), although there was some evidence of significant losses in some of the fields visited, losses due to termites were exaggerated by farmers in some localities. The problem is that it is difficult to differentiate between the significance of termites feeding on dead plants or crop residue and termites feeding on living plants resulting in yield losses. A common concept was that if termites were present then they must be causing damage, particularly if mounds were present.

Termites can also cause damage to non-cellulose materials such as dam linings and electrical cables. Surface soil mounds can also interfere with ploughing and grazing.

Ancistrotermes, Macrotermes, Microtermes, Odontotermes, Pseudacanthotermes and Trinervitermes are major termite species that cause damage on maize, teff, sorghum and rangelands in Manasibu District in western Ethiopia (Ofgaa et al. 2007).

Abdurahman (1990) reported that *Macrotermes* caused 4.85% damage on maize at vegetative stage and 2.8% damage to young cob stage by cutting stems. *Microtermes vadschaggae* caused 63.7% damage to maize at harvesting stage in western Ethiopia. *Odontotermes* species was recorded to cause 3% damage on maize at maturity and 4% at seedling stage. *Pseudacanthotermes militaris* is recorded to cause 2% damage on maize at seedling stage and 1% damage at maturity by feeding on the root.

Termites are one of the major agro forestry pests in the tropics. The study conducted at Pawe Research Center in Ethiopia showed that subterranean termites were important agents of biodeterirotion. Underground parts of all the untreated stakes of *Croton macrostachys* were completely (100%) degraded and fell down to the ground by subterranean termites attack during the first year field exposure period (Behailu *et al.* 2011).

Damage Caused by Termites

Damage to crops and trees - There are basically two types of damage, namely complete or partial cutting of stems and excavating roots and stems.

Macrotermes, *Odontotermes* and *Pseudacanthotermes* have large nests with long galleries running just below the soil surface for distances of up to 50 m from the nests. The attack begins just below or at the soil surface and often results in a thin layer of soil being constructed over the plant above ground. This damage results in ring barking of young trees, which almost inevitably die, and the complete or partial cutting of the stems of crop plants. In the former case the trees may die some months after ring barking and death may be attributed to other causes (e.g. root rots). In the latter case compensatory growth of adjacent crop plants will tend to maintain yields and stand losses are not necessarily reflected in yield losses (Wood 1991).

Microtermes and *Ancistrotermes* have smaller, diffuse, subterranean nests with numerous galleries extending from deep in the soil towards the soil surface. They damage plants by penetrating and excavating the roots and continuing the excavation upwards within the stem. This damage reduces the translocation of nutrients and water, but being obscured is often overlooked unless the stem, usually towards maturity is severely weakened, breaks and lodges. At this stage compensatory growth and yield response from unattacked plants is not possible (Wood 1991).

Damage symptoms in maize - Seedling maize is either cut by *Macrotermes* just below the soil surface or just above the soil surface with access from soil covered galleries impinging on the base of the plant. Usually seedlings are completely severed, resulting in lowered plant population. *Microtermes* attack maize by penetrating roots when plants are at the tasseling or young cob stage; continued penetration results excavation of the root system and base of stem, resulting in lodging. The stem can be excavated and packed with soil to heights of over one meter in intensive attack (Wood *et al.* 1980). The only evidence of these subterranean attacks broken prop roots or lodging due to weakened root system or weakening of the stems. However, frequently no symptom is evident despite the occurrence of heavy attack. Wood *et al.* (1980) reported that the subterranean termite, Odontotermes start their attack on matured maize by covering the base of the stem with a thin layer of soil under which they consume dead leaf sheathes. Eventually the entire stem and cobs covered in a layer of soil and the cobs destroyed. This type of damage is rare and confined to drier regions.

Damage to rangeland - Throughout tropical Africa several species of Macrotermitinae consume grass litter as a significant part of their diet and in Ethiopia the most common genera that damage crops belong to the genera *Macrotermes*, *Odontotermes* and *Pseudacanthotermes*. Typical foraging is characterized by subterranean galleries leading to surface 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 can have up to 55 foraging holes per m^2 (Cowie and Wood 1989). However, the primary cause of denudation is overgrazing. Livestock are resident during the wet season and were observed grazing green grass down to ground level. In one district in western Ethiopia with an estimated grass production of 2000 kg ha^{-1} stocking rates were approximately 4.7 ha^{-1} compared with recommended rates of 1 ha^{-1} (Wood 1986a, 1986b). Studies in Kenyan rangeland have shown that in the absence of overgrazing the grass consumed by termites was insignificant and had no effect on subsequent grass production (Collins 1981). On overgrazed land in Ethiopia the termites remove the remaining dry grass and grass litter leaving the soil bare and the false impression that they are the primary cause of denudation (Wood 1991).

The large pasturing zones in western Ethiopia are subjected to degradation by Macrotermes, Odontotermes and Pseudacanthotermes, which take away both standing grass and lying litter in the wake of cattle grazing (Cowie and Wood 1989)..

Damage to rural dwellings and food stores - The wood/straw thatch buildings, characteristic of farming communities in Ethiopia and much of sub-Saharan Africa are susceptible to termite damage, particularly in the tropical savanna areas where Macrotermitinae are abundant. Other wood-feeding termites, such as *Amitermes* spp. and *Microcerotermes* spp. also cause damage and the net effect necessitates constant repair and rebuilding (Wood 1991). Termite damage to stored products generally results in invasion by *Aspergillus*, which causes indirect yield losses and contamination with aflatoxin.

Termite Management Options

There are several species of termites that cause damage to agricultural crops, forestry trees, wooden structures and rangeland grasses. The foraging behavior and feeding habits of these termites are completely different. Therefore, it is important to identify the pest species correctly before any control measures are undertaken as the choice of control measures vary, depending on termite species causing damage and the nature of damage they cause.

Termite management options that are currently practised in the country are presented as follows:

Physical/Mechanical Methods

Mound destruction and poisoning

The destruction of termite nests for controlling mound-building termites is a frequently used practice in the country. Mounds are physically destroyed and then either poisoned with chemicals or flooded or straw burnt on the top of the mound to suffocate and kill the colony. Moreover, breaking up of termite galleries by deep plowing and regular cultivation around the plants are also practised to reduce termite population.

Very extensive termite mound poisoning campaigns were conducted by the Ministry of Agriculture in 1983 in Menesibu and certain parts of Nedjo – Jarso districts in western Ethiopia in collaboration with All Ethiopian Peasant Association. Every visible mound in the cultivated field and grazing land were destroyed and poisoned with aldrin 40% WP at the rate of 12.5 g or 25 g product per mound depending on the size of the mounds (Abdurahman 1983, Abdurahman 1990). The details of mound poisoning campaigns are shown in Table 1.

Table 1: Number of mounds poisoned, insecticides applied and labour force utilized in Menesibu and Jarso districts

Item	Menesibu	Nedjo-Jarso
Mounds treated (number)	510,661	125,247
Aldrin 40% WP applied (kg)	9,572	2,506
Labour (man-days)	152,238	56,400
Cost (US$)	62,980	15,974

Similar campaigns were also conducted at Assosa and Anger Gutin settlement areas by the Relief and Rehabilitation Commission (RRC) with Technical Cooperation Programme (TCP/ETH/2312) funded by the United Nations Food and Agriculture Organization. The number of termite mounds treated in Assosa and Anger Gutin were 1,838 and 307, respectively. Similarly, the quantity of aldrin 40% WP applied was 155 kg at Assosa and 46 kg at Anger Gutin settlement areas (FAO 1984).

The Ministry of Coffee and Tea Development also conducted similar mound poisoning campaigns in Menesibu, Ghimbi, Ayra-Guliso and partially in Nedjo-Jarso and Yubdo districts during 1988 crop season as shown in Table 2 (Ministry of Coffee and Tea Development, unpublished, Abdurahman 1990).

Table 2: Number of mounds poisoned and insecticides applied in five districts in western Ethiopia

Districts	Mounds treated	Heptachlor 40% WP (kg)	Labour man-days
Menesibu	449,296	10,344	23,106
Nedjo-Jarso	44,719	1,106	22,025
Ghimbi	31,325	842	7,065
Ayra-Guliso	24,761	619	20,927
Yubdo	7,462	166	6,074
Total	557,563	13,077	79,197

Studies have been conducted to evaluate the efficacy of insecticides against termite mounds. Sanna (1973) evaluated aldrin at 12.5, 25, 50 and 100 g per mound in 10 lt of water, BHC smoke generators, Thiodan, Phostoxin and hydrogen phosphide ('Detia Gas Ex-B'), and found only aldrin and phostoxin to be effective (Wood 1986a).

Following the complaints that chlordane 40% used in the mound poisoning campaign in 1984/85 did not provide the desired degree of control, Adugna et al. (1985) compared the efficacy of aldrin and chlordane for mound poisoning and found out that chlordane was not effective.

Chlorpyrifos 48% EC at the rate of 200 ml/ha were also used to poison the mound. Diazinon 60% EC at the rate of 2 l/ha was effective to poison the mound and surface spraying/application (Girma, 2009).

There are different opinions regarding the effectiveness of mound poisoning method. Wood (1991) believes that human perceptions of the pest status of *Macrotermes* have led to expensive campaigns on denuded and eroded rangeland where the primary problem is overgrazing.

Generally, mound poisoning is relatively simple to carry out and less likely to pollute the environment since small amount of insecticide is applied per nest. However, it is very difficult to implement in areas where there is shortage of water since large amount of water is required for mixing the insecticide. It is also very difficult to carry out during the dry season as the mounds get too hard to dig. However, the most important limitation of mound poisoning is that it can be used only against the species that build mounds, so that in areas with several termite species only partial control can be obtained and the subterranean species will continue to damage crops.

Queen Removal

Guachan *et al.* (1998) reported that digging a mound and removal of queen exposes the other castes to direct sunshine, birds and other predators and thereby prevents their access to crops. The queen must be dug out of nests to ensure that the colony cannot recover.

Queen removal is practised to some extent against mound building termites in western Ethiopia. Western Synod branch based at Tchallia, small town in Ayra-Guliso district in western Ethiopia, participated in termite control program by offering financial incentive for small farmers who brought termite queen. At first farmers were paid US 48 cents for every termite queen they brought, but later the payment was reduced by half since several farmers participated in the program. From September 1987 to September 1988, over 23,000 *Macrotermes* queens were handed in and US$ 19,592.27 was paid to farmers (Markos unpublished, Abdurahman 1990).

Digging out of queen is often laborious and time consuming. It does not provide the desired level of control since certain species have the ability to develop substitute queens under favourable conditions (Harris 1971). Furthermore, occasionally several queens may be found in one colony either due to the replacement of the original queen or merging of two or more colonies (Darlington 1985). Removal of a queen, therefore, does not necessarily lead to colony mortality.

Cultural Control

Good agricultural practices (plowing, cultivation, weeding, appropriate fertilization, quality seed, avoiding mechanical damage to plants, density of sowing, early planting and use of short season varieties, immediate/ prompt harvesting and sowing lodging resistant maize) that result in vigorous plant growth are generally recommended for the control of termites.

Seed quality, planting methods and plantation conditions all affect plant health. For example, seedlings that are not planted upright are more likely to be attacked by termites in Uganda (Logan *et al.* 1990). Flooding, intercropping, hoeing, organic amendments, use of fully decomposed farm yard manure etc. are also used to control termites. Rates of attack can depend on hydrological conditions; high rainfall favors termite attack on tea and groundnut through increased foraging, and also promotes mildew, producing even greater losses (Reddy and Ghewande 1986). On the other hand, evidence from cotton, groundnut and eucalyptus plantations shows that vulnerability to termites is increased in dry zones, where drought conditions prevail or between irrigations (Cowie and Wood 1989). Singh and Singh (2003) reported that irrigation and hoeing at an interval of one and two months decreased termite population by 85 % in five months period.

Sileshi et al. (2009) also reported that African subsistence farmers use various traditional termite control methods, including queen removal, intercropping, crop rotation, and use of plant extracts, but often with limited success. For such small-scale farmers who cannot afford expensive chemicals, a safe alternative solutions need to be developed.

Some of the cultural methods that can be practised to discourage the buildup of large populations of termites are discussed below:

Rendering Plants Less Susceptible to Termite Attack

Although termites may damage healthy plants, unhealthy and stressed plants are generally more susceptible to termite attack. Therefore, cultural practices should aim at maintaining or enhancing plant vigor.

Intensive cultivation, and in particular monoculture, reduces soil fertility and modifies soil structure (Black and Okwakol 1997). Studies have shown that less vigorous maize in Ethiopia and trees in Zambia were more susceptible to termite attack (Cowie and Wood 1989, Sileshi *et al.* 2005). Competition from weeds, low light levels and low water availability were all stress factors for crops and young trees, which equally increase susceptibility to termite attack (Black and Okwakol 1997).

Deficiency or excess of water may stress plants; hence, frequent irrigation practices and other measures to reduce water stress are useful to make plants less susceptible to termite attack.

The use of inorganic fertilizers enhances plant vigor and hence the ability to withstand pest damage. Fertilizer can restore vigour and reduce vulnerability (Wardell 1990).

Adding Organic Matter to the Soil/ Removal

Fungus growing termites prefer to feed on dead plant material. Their attacks are thought to be related to soils with low organic matter content. This is because such soils do not contain enough food for termites to live and hence they resort to feeding on living plant material. Adding compost or well-rotted manure to the soil and sowing green manures help to increase the organic matter in the soil. Farmers should avoid having bare, dry soil around crops. Mulching with items such as hay, manure, wood ash, or threshed maize cobs has shown in South Africa and Uganda to dramatically decrease termite attacks. However, offering a substitute food may also attract termites to the area and increase the overall damage to trees and crops. Ahmed *et al.* (2009, 2011) found that application of maize stover, grass or haricot bean residue as a mulch at about 0.56 t ha^{-1} reduced the amount of termite damage on hot pepper comparable to that of standard insecticide diazinon 60% EC at 2 lt ha^{-1} Each case is likely to be different and dependent on the species of termites involved and crops/trees attacked. Therefore, this method should be applied with utmost care.

Encouraging Predators

Termites have many predators such as ants, birds, lizards, etc. Encouraging these predators will help to reduce the number of termites. Bushes and trees are a habitat for many of these predators. These areas of natural habitat can be left around crop fields. If these areas are destroyed then there is an imbalance between the population of predator and pest. This can increase termite problem in the area.

Crop Rotation

Planting the same crop on the same land year after year reduces soil fertility and structure. Crops growing in such conditions will be weaker and susceptible to termite attack.

Ideally the farmers should rotate crops so that the same crop is not planed the following season. The rotation should include a crop which is tolerant or resistant to termite infestations. For example as a contrast to cereal crops, cotton is regarded as highly beneficial in the rotation, especially as insecticides applied against other cotton pests may also help to reduce damage caused by termites (Johnson and Wood 1980, Johnson 1981).

Intensive mono-cropping for a long period also reduces soil fertility and structure. Rotation with less susceptible crops can help to reduce termite damage. Rotation of crops, including a period of fallow to remedy changes to soil structure, is therefore recommended to manage termites.

Intercropping and Mulching

Intercropping maize with sorghum/legumes was found to reduce termite damage at Bako, Ethiopia (Girma *et al.* 2009). Soybean (IPB-81-EP-7) planted at 12.5 cm between plants and 25 cm between rows and maize variety BH-540 at spacing of 75 cm between rows and 30 cm between plants was observed to reduce termite damage. In each intercropped plot, two rows of soybean were planted between two rows of maize. Moreover, maize stover and neem seed powder were applied three weeks after seedling emergence. The result showed that the integration of mulching and intercropping significantly reduced termite damage (Girma *et al.* 2009).

Destroying Crop Residue

Clearing and burning of crop residue are useful to destroy food resources of termites. Unfortunately, this method also takes time and energy. In some areas farmers can remove crop residue and plough the land immediately after harvest to deprive termites their food (Sands 1977). This is not always possible in arid zones if the soil is too hard.

It should be noted that adding organic matter to soil also helps to control fungus growing termites. Hence, before this method is used the termite species that cause damage in the area needs to be identified.

Hoe Weeding or Ridging

Hoe weeding or ridging soon after rain is also considered beneficial for destroying the foraging galleries that run near soil surface and disturbing termites that are foraging (Johnson and Wood 1980).

Area Enclosure

Significant damage to rangeland was observed only in the western part of the country and the problem seemed to be aggravated by over grazing. This conclusion was suggested by observation on an area of rangeland at Mendi in early 1980s (Bako Research Center trial site). In part of this area various forage grasses had been planted for evaluation against termites; livestock had been kept out of the research area by fencing the trial site. A complete grass cover was observed in the enclosed area while the adjacent area where grazing had been permitted the grass had been grazed to ground level and many areas were bare. This was latter confirmed by a consulting entomologist who indicated that although foraging by *Macrotermes*, *Odontotermes* and *Pseudacanthotermes* in the dry season removes the little remaining dry grass and grass litter from overgrazed rangeland leaving the soil bare and susceptible to accelerated erosion. Farmers and government officials are reluctant to accept overgrazing as the primary and major cause of denudation. Instead they regard termites as the major problem, hence the repeated attempts to control them by mound-poisoning (Wood 1991). Therefore, termite control in rangeland should target mainly on stock management or avoidance of overgrazing.

Use of Resistant Plants

Varieties of crops may differ in their susceptibility to termite attack, but this variation has not been exploited to a great extent in termite control. In Pakistan, termites that cause damage to cotton have been successfully controlled by changing the variety grown in the problem areas from Egyptian cotton (*Gossypium barbadense*) to American long staple (Harris 1954).

Planting larger pieces of sugar cane that germinate more rapidly have been found to suffer less termite damage than the short pieces (Abushama and Kambal 1977).

Crops are more susceptible at maturity probably because they have more woody tissues than young plants. A useful strategy to reduce this type of damage is to grow earlier maturing varieties that can be harvested as soon as they reach maturity.

This technique has been successful with sunflower (Harris 1971).

The research conducted by the Institute of Agricultural Research (IAR) in 1980s had shown that elephant grass and a *Pennisetum purpureum* x Typhoides hybrid are resistant to termite damage (Abraham Tadesse, pers. com).

Lodged maize plants were found to be more attacked by termites than standing plants. Moreover, delay in harvesting crops such as maize give ample opportunity for subterranean termites to cause damage. Hence use of lodging resistant varieties and prompt harvesting are useful to prevent or reduce damage caused by termites.
Generally, indigenous crops are more resistant to termites than exotic crops. For instance, in Africa, sorghum and millet are more resistant than maize and cowpea. The same is true for trees (Wood 1986a, 1986b, Logan et al. 1990).
Heartwoods of Atlantic white cedar *Chamecyparis thyoides*; juniper, *Juniperus* spp.; erisma, *Erisma* spp.; and ipe, *Tabebuia* spp. are naturally resistant to *Reticulitermes flavis* (Arango *et al.* 2006). Teak wood is naturally resistant to termite attack. Heartwood of *Caesalpinia echinata* Lam. is highly resistant to the dry wood termite, *C. brevis* (Silva *et al.* 2007).

Botanical Insecticides and other Materials

Plant parts and plant extracts can be used for termite control. Various parts of plants and plant extracts are known to be either toxic or repellent to pests of agriculture, and are widely used in rural settings. However, no specific recommendations have been made for their large-scale utilization. Some of these extracts have been investigated in the laboratory and proven effective against termites. Elsewhere, plant extracts, such as those of neem, wild tobacco and dried chili, have been used to control termites in the field and storage warehouses.

Wardell (1987) reported that leaf mulch of neem can be used to reduce termite activity in tree nursery.

Wood ash heaped around the base of the trunk of coffee bushes has been recorded to prevent termite infestations. Wood ash has also been reported to repel termites from date palm and protect stored yam, maize straw, tree seedlings, when it is mixed into plant nursery beds or applied as a layer. However, the potential benefits of using wood ash for termite management require further verification. *Maesa lanceolata* leaf powder at 40 kg/ha (basal application), *Azadirachta indica* seed powder at 40 kg/ha (basal application) were found to have anti-feedant effect against termites attacking hot pepper in Bako area, West Shoa, Ethiopia (Aschalew et al. 2008).

A neem insecticide formulation, Margosan-O, containing 0.3% azadirachtin and 14% neem oil, was observed to be toxic against the Formosan subterranean termite (Grace and Yates 1992).
In filter paper bioassay conducted in Ethiopia, 10, 25 and 40 % w/v *birbira* (*Milletia sp.*) seed crude extract caused 100% mortality in all castes of *Macrotermes spp.* except 10% w/v in which 93% alate caste mortality was recorded. In saw/dust bioassay 10% w/v *birbira* seed extract caused 100% mortality of all castes of *Macrotermes* termite. In the mound poisoning experiment against *Macrotermes*, *birbira* seed extract 10% w/v caused 22.96% mortality of soldiers and 19.35% of workers in Meki, Ethiopia (Daniel and Bekele 2006).

Biological Control

Biological control of termites includes the use of natural enemies such as predators, parasites and pathogens. Termites can be preyed upon by a wide variety of predators such as birds, lizards, frogs, spiders, bats, other mammals and ants. These natural enemies can destroy many swarming males and females when they leave the nests or during the flight. Humans, in some parts of the world may also feed on the winged forms. Ants are also natural enemies of termites, which can have great potential as biological control agents (Su and Scheffran 1998).

Entomopathogenic fungi: Biological control of termites has largely focused on two fungal species, *Beauveria bassiana* (Balsamo)

Vuillemin and *Metarhizium anisopliae* (Metchnikoff) Sorokin and recently also *Paecilomyces fumosoroseus* (Wright *et al.* 2005).

A study conducted on the management of termites in Metekel zone in Ethiopia, in 2010/11 showed very encouraging results. Vetiver 20% and *birbira* 20% provided effective control up to 60 days after application. Vetiver 10% and b*irbira* 10% provided effective control up to 30 days after application (Tizazu 2011).

Beauveria bassiana and *Metarhizium anisopliae* were less effective in the beginning, but their effectiveness increased gradually and was better than botanicals (Fig. 1). Mounds were found dead 75 days after the application of fungi. This was possible to cause a reduction in termite activity, indicating ongoing epizootics in the remaining treated colonies (Tizazu 2011). Increase of disease persistence on termites started 60 days after application of entomopathogenic fungi (Haimanot 2002). The gradual increase of effectiveness of entomopathogenic fungi was also observed in Ambo Plant Protection Center (APPRC 2009, 2011).

According to Haimanot (2002), the Ethiopian *M. anisopliae* isolates (obtained from Ambo Plant Protection Research Center) were as virulent as the standard isolate (ICIPE30) both under field condition at Lekemt Zuria and Sasiga, in the Eastern Wellega zone, Oromia regional state and laboratory conditions. The *M. anisopliae* isolate, MM was found to be the most virulent isolate tested against *M. subhyalinus*, and had relatively lower LD50 values.

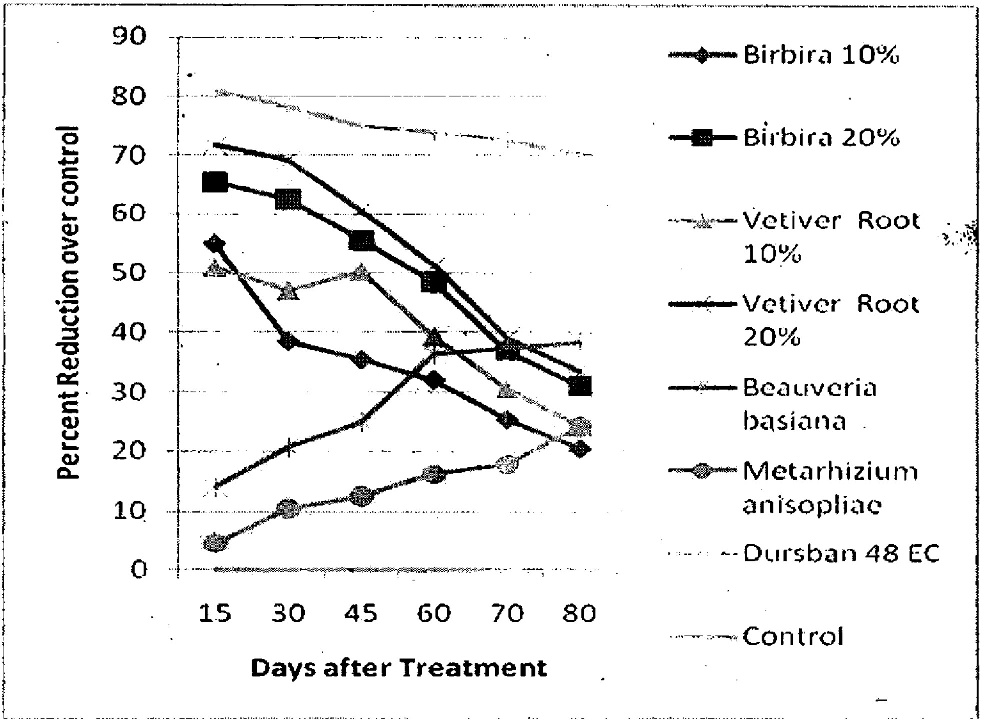

Figure 1: Percent reduction of termite population over control in different dates after treatment Metekel zone, Ethiopia, 2011 (Source - Tizazu 2011)

Studies conducted in Kenya showed the effectiveness of *M. anisopliae*, strain ICIPE 30, for the control of termites in pastures, nursery trees and mounds in Kenya (ICIPE 1997). Field studies with *M. anisopliae* isolate ICIPE 30 on maize in Uganda and Kenya showed significant increase in maize yield (Sekamatte 2001, Maniania *et al.* 2002). The fungus formulated as granules and applied as seed treatment resulted in reduction of plant lodging and subsequent increase in maize yield comparable to that of the chemical insecticide, lindane. *M. anisopliae* has been developed for control of termites in the USA and Australia (Milner 2000).

Dong *et al.* (2007) reported that they have found efficient new virulent *M. anisopliae* in China. It was highly infectious and virulent against *Odontotermes formosanus*. It caused almost100% mortality to the termites after three days post inoculation with concentration of $3x10^8$ conidia/ml. Trophallaxis (the exchange of regurgitated food), proctodeal trophallaxis (the consumption of anal excretions) and grooming are regular, necessary colony functions. It is through this grooming behavior that the infective propagules of *M. anisopliae* can be transferred from one individual to another (Haimanot 2002). To create a high level of infection (an epizootic), a percentage of the colony would have to be removed from the site of infestation, dusted with conidia, and released back into the colony. The grooming and other social interactions between termites are seen to have the potential to spread the fungus throughout the colony, allowing for colony control by treatment or remote feeding sites. However, factors such as avoidance of the fungus conidia by the termites, the removal and burial of fungus-killed termites, together with hormonal resistance may limit the spread of disease in the colony (Rath 2000). In other studies, the efficacy of a new virulent *M. anisopliae* strain (SRRC 2558) was evaluated against the eastern subterranean termite, *R. falvipes* and the formosanus subterranean termite *C. formosanus* and was found to be highly infectious against the termites. It caused 100% mortality to groups of 100 *R. flavipes* workers at a concentration of $\geq 3 \times 10^3$ conidia / cm^2 (Wang and Powell 2004).

However, factors such as repellency of fungal conidia, the removal and burial of fungus-killed termites, and behavioral changes in infested termites (in the case of *Metarhizium* they congregate at the base of a nest where they are easier to quarantine by nest mates) may limit the spread of the disease in the colony. Application methods to overcome some of the limitations include inundating of termite nests or sites of high termite activity with formulated products, and use of low doses of the insecticide imidacloprid in combination with the fungus. The insecticide has a synergistic effect. More termites die from the combined treatment than from the combined mortality caused by each agent alone.

In other countries, nematodes (Mix 1985) and a nuclear polyhedrosis virus (Al-Fazairy and Hassan 1988) were found to be effective against termites under laboratory conditions, but failed to provide satisfactory control under field conditions. Unfortunately, nematodes are susceptible to both high and low temperatures and drying (Mix 1986). According to Sands (1973) the major limitation to the use of biocontrol agents is the difficulty of applying sufficient biocontrol agents on termites without loosing their efficacy. In particular termites in the nests and moving in subterranean galleries are so protected that it is very difficult to apply biocontrol agents. Walling of dead bodies and cannibalism on dead individuals as a means of nest sanitation (Lee and Wood 1971) could also limit the use of biocontrol agents on termites. Thus a concentrated research is required to overcome these limitations.

Chemical Control

The use of persistent organochlorine (cyclodiene) insecticides has been the cornerstone of termite control in the tropics. No other insecticides have the required degree of persistence in the field to protect crops and forestry trees. The principal persistent organochlorine insecticides, and in Ethiopia aldrin was the most widely used. The potential health and environmental hazards of these compounds are well known (Wood 1991); which caused their use to be banned or under serious restrictions.

Until its banning aldrin was used as plant hole or furrow applications, dipping roots of pepper seedlings with or without ball of earth, seed dressing or fertilizer dressing of maize, teff and forage grasses were tested and recommended against termites in western parts of the country (Sanna 1973, Abraham 1986, 1987a, 1993, Abraham and Adane 1993, Adhanom and Abraham 1985).

Following the banning of persistent organic pollutants less persistent insecticides, such as organophosphates (chlorpyrifos, iodofenphos, isofenphos), carbamates (carbosulfan, carbofuran), and pyrethroids (permethrin, decamethrin, deltamethrin), have been used as alternatives elsewhere in Africa; however, their low persistence often necessitates repeated applications. Recently, controlled-release formulations of some non-persistent insecticides were tried and found to be effective and long-lasting. However, these formulations are not cost-effective for the majority of low-income farmers in developing countries (Logan *et al.* 1990)

Recently, several termiticides containing active ingredients: bifenthrin, chlorfenapyr, cypermethrin, fipronil, imidacloprid and permethrin were developed under various brand names for termite control (Scheffrahn *et al.* 1997). Other chemicals such as spinosad, disodium octaborate tetrahydrate (DOT), calcium arsenate, and chlorpyriphos are also recommended for termite control. Their chemical toxicity, formulation and application method, as well as termite behavior and gallery system architecture influenced the performance of chemical treatments (Scheffrahn *et al.* 1997).

Different methods of insecticide application are used for termite control in crops. The most commonly used methods are seed treatment, soil treatments and mound poisoning.

Seed Treatment

Seed treatment has been known as long as 50 AD; but its use has been much more extensive since the introduction of organochlorine insecticides in the late 1940's (Griffiths 1986). Seed treatment is considered effective against soil borne insects that attack seeds and seedlings (Hewett and Griffiths 1986). Its major advantage is that small amount of insecticides are used and it is relatively simple and economic to use. The small quantity targeted to protect the seed makes the insecticide less hazardous to beneficial insects and soil microorganisms.

Different trials were conducted with different rates of aldrin (5, 10 and 20 g kg^{-1} seed) each rate being with and without different stickers (cittowet, sugar solution and wheat flour) on maize at Bako and Anger Didissa from 1977 to 1982. Results indicated that differences in maize grain yield were not significant between treatments except for plots where maize plants were lodged. It was observed that when termite infestations came late (after crop maturity) yield losses occurred only when cobs of lodged plants were attacked. It was found that higher rates of aldrin without stickers or the lower rate with cittowet or sugar solution as stickers were found to be relatively better than the other treatments. However, it was apparent that the plot sizes used for the trials were too small (14-27m^2) to get adequate termite infestation to reveal significant treatment differences (Abraham 1986).

In Ethiopia, aldrin 40% WP seed treatment was standard recommendation for termite control on staple food crops (Crowe and Shitaye 1977, Sands 1976, Wood 1986 a, b). However, studies of aldrin treated maize seed showed no significant improvement in grain yields (IAR 1983). No significant differences in grain yield and in crop infestation were observed in tef when aldrin was applied as seed or soil treatment or with fertilizer (Abraham 1987a, IAR 1985, 1986).

Recently, Asogwa *et al.* (2009) found that Chlorpyrifos 48 EC, Endosulfan 35 EC, Dichlorvos 1000 EC and Diazinon 600 EC applied at the rate of 0.25% active ingredient provided effective control of termites in southwestern Nigeria. Recently introduced chemicals, imidacloprid and fipronil, which are less toxic to humans and other mammals than the old chemicals are now available. Seed dressing of maize seed/teff with Fipronil (Reagent 500FS) at the rate of 10 – 11.7 ml/kg and imdacloprid (gaucho) were found effective against termites around Bako area, Ethiopia (Girma 2009).

Soil Treatment

Soil treatment is the second most commonly used method of insecticide application for termite control in agriculture. Insecticides may be applied along the furrow, in individual planting holes or broadcast over the soils and in each case the chemical can be incorporated and covered by soil. These methods are considered more effective than seed treatment.

The effectiveness of soil treatment depends on the method of application used. Furrow treatment with heptachlor, chlordane, lindane and HCH was found to be more effective against *Odontotermes obesus* Rambur on groundnut compared with a broadcast application at the time of sowing or by application around plants followed by earthing after sowing (Rawat *et al*. 1970).

Timing of soil treatment is also important. In Gizan area of Saudi Arabia, insecticides applied five days before planting was more effective against *Microtermes najdensis* than one week after planting green peppers (Badawi and Faragalla 1986).

Soil treatment requires large amount of insecticides and so the method is relatively more expensive compared to seed treatments.

Soil treatment and the treatment of seedlings before transplanting have been used as classical methods of control and prevention of subterranean, arboreal and dry wood termites in many regions of the world for many years. These methods of control have a high environmental impact because of the large amounts of insecticides that have to be applied in open areas that are exposed to leaching. In recent years, new generation insecticides that are active at very low doses have become available. Examples of these new generation insecticides are imidacloprid and fipronil. However, before adopting a chemical means of control, alternative, traditional methods of control need to be explored.

Conclusions and Recommendations

i) Termite problem is more serious in Ethiopia now than it was in the past and it will continue to be a problem in the future unless more effective, economical, safe and easily applicable methods of control are worked out.
ii) Farmers and extension personnel often lack proper training. Very few specialists are able to identify tropical termites to species level and many of the economically important groups lack proper taxonomic revision, resulting in a large number of incorrect, doubtful or incomplete identifications. Under these conditions it is very difficult to accurately collect information on the biology and economic importance of termite species. Therefore, it is strongly recommended to establish and develop regional reference collections, identification guides and training programs for extension staff.
iii) It is important to know termite species that cause crop damage and their abundance, type and magnitude of damage, loss assessment studies and relationship of damage and loss to develop more effective and efficient management strategies.
iv) The first principle of termite control is to decide whether control is both desirable and economically feasible. For the latter, yield loss estimates are essential – damage levels may be only poor indicators of ultimate yield loss. For example, in maize, compensatory growth by surviving plants following early season attack, harvest of cobs on the ground from plants lodged late in the season, and damage to vegetative parts occurring after cob formation will result collectively in over-estimates of yield loss if they are based only on attack or damage scores.
v) A basic understanding of termite diversity and biology is a prerequisite for adequate management of termites.
vi) Termite control for use by resource poor farmers should mainly depend on non-chemical techniques, which include a range of mechanical methods, cultural practices,

biological control, use of resistant crops/ trees and a number of other measures.

vii) Best termite control methods that are currently practised in other countries with similar climatic conditions need to be explored and tested in the country in order to come up with effective, affordable and safer termite control measures.

viii) The effectiveness of new generation insecticides should be evaluated against major termite species in areas where termites are major pests. The study also should focus on method of applications since this area also requires much improvement.

ix) The use of *Metarhizium anisopliae* provides an opportunity for sustainable control of termites in agro-ecosystems. Its production is cheap and facile, and can be formulated in a variety of ways. However, information pertaining to the optimum application rates, persistence and compatibility of the fungus with other termite control methods require due emphasis since the fungus has a high potential for exploitation into commercial bio-pesticides in Africa.

x) Overgrazing is the primary and major cause of denudation in the rangelands in the country. Therefore, termite control in rangeland should target mainly stock management or avoidance of overgrazing rather than on termite control.

References

Abdurahman Abdulahi. 1983. Termite control campaign in Wellega. Committee of Ethiopian Entomologists (CEE) Newsletter 3(2): 6-7.

Abdurahman Abdulahi. 1990. Foraging activity and control of termites in Western Ethiopia. Ph.D. dissertation, Imperial College, University of London. Pp 277.

Abdurahman Abdulahi. 1991a. Recent advances in the biology, ecology and control of termites. P. 15-19. In: Tsedeke Abate, Teferi Gemechu and Abdurahman Abdulahi (eds.). Proceedings of the 11th Committee of Ethiopian Entomologists (CEE), Addis Ababa.

Abdurahman Abdulahi. 1991b. Keys to the genera of Ethiopian termites. Crop Protection Bull.No.1. Crop Protection and Regulatory Dept., Ministry of Agriculture, Addis Ababa. Pp 12.

Abdurahman Abdulahi and Adugna Haile. 1986. Survey of termite problems in Wollega Administrative Region. CEE Newsletter 5: 4-9.

Abraham Tadesse. 1986. Termites as an agricultural pest in Ethiopia with particular emphasis to its control on maize in western region. Paper presented at the 6th Annual Conference of CEE, 7 March 1986, Addis Ababa.

Abraham Tadesse. 1987a. Method and rate of aldrin application on teff to control termite infestation at Bako. Pp. 217-221. In: Proceedings of the 18th National Crop Improvement Conference (NCIC), 24-26 April 1986. Addis Ababa, Ethiopia.

Abraham Tadesse. 1987b. Survey and identification of termite species at Ziway area and their suggested control methods. A paper submitted to Prof. Dr. D. S. Hill (instructor) in partial fulfillment of the course on Principles of Pest Management Pl. Sc. 551). Department of Plant Sciences, Alemaya University of Agriculture, Alemaya.

Abraham Tadesse. 1991. Termites: Problems and possible methods for their control in agriculture with reference to Ethiopian conditions. P. 50-74. In: Proceedings of the 10th Annual Meeting of the Committee of Ethiopian Entomologists (CEE), 7-9 February 1990, Addis Ababa, Ethiopia.

Abraham Tadesse. 1993. Soil pests of maize, their control and damage assessment methods. A training course on disease and insect pests of maize and their control, 17-26 August 1993. Organized by the National Maize Research Program of IAR, Bako. Held at Awassa College of Agriculture (unpublished).

Abraham Tadesse and Adane Kassa. 1993. The effect of seed dressing with aldrin on termite control on maize in western Ethiopia. Paper presented at the First Crop Protection Society of Ethiopia Annual Conference, Feb. 25-26, 1993. Addis Ababa.

Abushama, F.T. and Kambal, M.A. 1977. Field observation on the attack of sugar cane by the termite *Microtermes tragardhi* (Sjost.). Z. ang. Ent. 82, 355-359.

Adhanom Negassi and Abraham Tadesse. 1985. Insect problems of maize and sorghum and their control in Ethiopia. In: Tsedeke Abate (ed). Proceedings of the First Crop Protection Symposium, February 4-7, 1985, Addis Ababa.

Adugna Haile, Bisrat G/Kal and Aynekulu Yemane. 1985. Comparison of termite mound control with aldrin 40% WP and Chlordane 40% WP in Sasiga, Wollega Adminstrative region. CEE Newsletter 5(1): 15-18.

Adugna Haile and Kemal Ali. 1986. A review of research on the control of insect pests of small cereals in Ethiopia. P. 57-77. In: Tsedeke Abate (ed.). A review of crop protection research in Ethiopia. Proceedings of the First Crop Protection Symposium, February 4-7, 1985. Institute of Agricultural Research, Addis Ababa.

Ahmed Ibrahim, Tadesse Berhanu, Teshome Bogale and Abraham Tadesse. 2009. Termite management with mulches of plant materials in hot pepper in the Bako area of western Ethiopia. Pest Management Journal of Ethiopia (PMJoE) 13: 33-37.

Ahmed Ibrahim, Tadesse Berhanu, Teshome Bogale and Abraham Tadesse. 2011. Management of termites on hot pepper using different plants as mulch at Bako, West Shoa, Ethiopia. P. 209-216.In: Kebebew Assefa and Woldeyesus Sinebo (eds.). Proceedings of the 13th Biennia Conference of the Crop Science Society of Ethiopia (CSSE), 31 December – 2 Jan. 2008, Addis Ababa, Ethiopia. CSSE, Addis Ababa, Ethiopia.

AL-Fazairy, A.A. and Hassan, F.A. 1988. Infection of termites by *Spodoptera littoralis* nuclear polyhedrosis virus. Insect Sci. Applic. 1: 37-39.

Ambo Plant Protection Research Center (APPRC). 2009. Progress report. Ambo, Ethiopia.

Ambo Plant Protection Research Center (APPRC). 2010. Progress report Ambo, Ethiopia.

Arango, R.A., Green III F., Hintz K., Lebow P.K. and Miller R.B., 2006. Natural durability of tropical and native wood against termite damage by *Reticulitermes flavis* (Kollar). *ternational Biodeterioration & Biodegradation* 57:146.150.

Aschalew Sisay, Ahmed Ibrahim and Tadele Tefera. 2008. Managememnt of termite (*Microtermes vadschanggae*) on hot pepper using powdered leaves and seeds of some plant species at Bako, western Ethiopia. East African Journal of Sciences, 2(1)..41-44. *Maesa lansolata* and Azadrachata indicaneem reduced termite damage as did diazinon at 2.5 l ha^{-1} on hot pepper at Bako.

Asogwa, E. U.; Okelana, F. A.; Ndubuaku, T. C. N.; and Mokwunye, I. U. 2009. The termiticidal effects of Chlorpyrifos 48 EC, Endosulfan 35 EC, Dichlorvos 1000 EC and Diazinon 600 EC against termites in southwest Nigeria. African Journal of Biotechnology 8(1): 048-052. http://www.academicjournals.org/AJB.

Badawi, A. and Faragalla, A.A. 1986. Evaluation of different chemicals against *Microtermes najdensis* Harris (Termitidae, Isoptera) attacking green pepper in Jizan area, Saudi Arabia. Tropical Pest Management 32, 130-133.

Bagine, R.K.N., Darlington, J.P.E.C., Kat, P. and Riche, J.M. 1989. Nest structure, population structure and genetic differentiation of some morphologically similar species of Macrotermes in Kenya. Sociobiology 15, 125-132.

Barnett, E. A.; Cowie, R. H.; Sands, W. A. and Wood, T. G. 1987. Identification of termites collected in Ethiopia in January to February and July 1986. Report No. CO696. TDRI, London.

Barnett, E.A., Cowie, R.H., and Wood, T.G. 1988. *Microtermes aethiopicus* sp. n., a fungus – growing termites (Isoptera: Termitidae: Macrotermitinae) from Ethiopia. Systematic Entomology 13, 133-141.

Behailu Kebede, Yigremachew Seyoum, Getachew Desalegn, Melaku Abegaz and Demelash Alem. 2011. Performance of traditional wood protection measures in controlling termite and fungal attack in Pawe Wereda. Research Report 92. EIAR, Addis Ababa.

Bekele Jembere, Daniel Getahun, Merid Negash and Emiru Seyoum, 2002. Toxicity of Birbira (*Milletia ferruginea*) seed crude extracts to some insect pests as compared to other botanical and synthetic insecticides. Pp. 88-96, 11th NAPRECA Symposium Book of Proceedings, Antananarivo, Madagascar.

Black, H. I. J., and M. J. N. Okwakol. 1997. Agricultural intensification, soil biodiversity and agro ecosystem function in the tropics: the role of termites. *Applied Soil Ecology* 6(1):37–53.

Bouillon, E. 1970. Termites of the Ethiopian

Region. P. 153-280. In: K. Krishna and F. M. Wesner (eds.). Biology of termites, Volume 2. New York Academic Press.

Collins, N.M. 1981. The role of termites in the decomposition of wood and leaf litter in the southern guinea savannah of Nigeria. Oecologia 55: 389-399.

Cowie, R. H. and Wood, T. G. 1989. Damage to crops, forestry and rangeland by fungus growing termites (Termitidae: Macrotermitinae) in Ethiopia. Sociobiology 15, 139-153.

Cowie, R. H., Wood, T. G.; Barnett, E. A. Sands, W. A. and. Black. H. I. J. 1990. A checklist of termites of Ethiopia with a review of their biology, distribution and pest status. Afr. J. Ecol. 28: 21-33.

Crowe , T.G. and Shitaye G. Medhin. 1977. Crop Pest Handbook. Third (revised) ed. Institute of Agricultural Research, Addis Ababa, 55 pp.

Crowe, T. G., Tadesse, G.M. and Tsedeke, A. 1977. An annotated list of insect pests of field crops in Ethiopia. Institute of Agricultural Research, Addis Ababa, 71 pp.

Crowe, T.G. and Tadesse, G.M. 1984. Coffee pests in Ethiopia: their biology and control. IAR, Addis Ababa, 45 pp.

Daniel Getahun and Bekele Jembere, 2006. Evaluation of toxicity of crude extracts of some botanicals on Different Castes of *Macrotermes* Termite. *Pest Mgt. J. Eth.* 10:15-23.

Darlington, J.P.E.C. 1985. Multiple primary reproductives in the termite *Macrotermes michaelseni* (Sjostedt). In, Caste differentiation in social insects (J.A.L. Wats, B.M. Okot-Kotber and CH. Noirot, eds.), pp 187 – 200, Pergamon Press, Oxford.

Dong, C., J. Zhang, W. Chen, H. Huang & Y. Hu. 2007. Characterization of a newly discovered China variety of *Metarhizium anisopliae (M. anisopliae var. dcjhyium*) for virulence to termites, isoenzyme, and phylogenic analysis. Microbial Res. 162: 53–61.

Edwards, R. and Mill, A.E. 1986. Termites in buildings: their biology and control. Rentokil Library Series. Rentokil Ltd. 261 pp.

Eggleton, P. 2000. Global patterns of termite diversity. Pages 25–51. *In:* T. Abe, D. E. Bignell, and M. Higashi, editions. *Termites: evolution, sociality, symbioses, ecology.* Kluwer Academic Publishers, Dordrecht, the Netherlands.

FAO. 1984. Emergency assistance to control ants and termites in settlements of the Relief and Rehabilitation Commission, Ethiopia. Rome, FAO TCP/Eth/2312. Pp 21.

Girma Demissie, Addis Teshome and Tadele Tefera. 2009. Effect of mulching and intercropping on termite damage to maize at Bako, western Ethiopia. Pest Management Journal of Ethiopia. 13: 38-43.

Grace, J.K. and Yates J.R., 1992. Behavioural effects of a neem insecticide on *Coptotermes formosanus* (Isoptera: Rhinotermitidae). *Tropical Pest Management* 38:176.180.

Griffiths, D.C. 1986. Insecticidal treatment of cereal seeds. In, Seed treatment (K.A. Jeffs, eds.) 2nd ed. Pp113-137. BCPC.

Haimanot Abebe. 2002. Potential of entomopathogenic fungi for the control of *Macrotermes subhyalinus* (Isoptera: Termitidae). Ph D Thesis, geboren am 08. März 1957 in Äthiopien.

Harris, W.V. 1969. Termites as pests of crops and trees. Commonwealth Institute of Entomology. London, 41 pp.

Harris, W. V. 1971. Termites, their recognition and control (second ed.), Longman, London.

Hill, B.G. 1965. The insect pests of vegetables in Harar Province, Ethiopia 1960 – 1964. Exp. Stat. Bull. 36, Imp. Ethiop. Coll. Agric. Mech. Arts, Dire Dawa.

Hewett, P.D. and Griffiths, D.C. 1986. Biology of seed treatment. In, Seed treatment (K.A. Jeffs, ed.) 2nd ed. Pp 7-15.BCPC.

ICIPE. 1997. Annual scientific report, 1995-1997. International Center of Insect Physiology and Ecology, Nairobi, Kenya.

Institute of Agricultural Research (IAR). 1983. Crop Protection Department progress report for the period 1979/1980. Addis Ababa, pp 147-148.

Institute of Agricultural Research (IAR). 1985. Crop Protection Department progress report for the period 1980/81 – 1982/1983. Addis Ababa, pp 45.

Institute of Agricultural Research (IAR). 1986. Crop Protection Department progress report for the period 1984/85. Addis Ababa, pp 44-45.

Johsnson, R.A. 1981. Termites: damage and control reviewed. Span 24, 108-110.

Johnson, R.A. and Wood, T.G. 1980. Combating termites. West African Farm. Food Proc. (March-April), pp 41-42.

Lee, K.E. and Wood. T.G. 1971. Termites and soils. London and New York, Academic Press, 251 pp.

Logan, J. M. W.; Cowie, R. H. and Wood, T. G. 1990. Termite (Isoptera) control in agriculture and forestry by non-chemical methods: A review. Bull. Entomol. Res. 80: 309-330.

Kemal A., Alemayehou R. and Adhanom N. 1986. A review of oil crop Entomology in Ethiopia. P. 282-289. In: Tsedeke A. (ed). A review of crop protection research in Ethiopia. Proceedings of the First crop Protection Symposium, 4-7 February 1985. IAR, Addis Ababa.

Malaisse, F. 1978. High termitaria. Pages 1279–1300 *in* M. J. A. Werger, editor. *Biogeography and ecology of Southern Africa.* Dr. W. Junk b.v., The Hague, The Netherlands.

Maniania, N. K.; Ekes, S. and Songa, J. M. 2002. Managing termites in maize with the entomopathogenic fungi M. anisopliae. Insect Sc. Appl. 22: 41-47.

Milner, R. J. 2000. Current status of *Metarhizium* as a mycoinsecticide in Australia. Biocontrol News and Information 21: 47N-50N.

Mitchell, J. D. 2002. Termites as pests of crops, forestry, rangeland and structures in southern Africa and their control. *Sociobiology* 40:47–69.

Mix, J. 1985. Can nematodes halt subterranean termites? Pest Control 53, 22-23.

Mix, J. 1986. Nematodes flung again. Pest Control 54, 48- 54.

Nyeko, P. and Olumbayo, F. M. 2005. Participatory assessment of farmers experiences on termite problems in agro-forestry in Tororo district, Uganda. Agricultural Research and Extension (AgREN) paper No. 143.

Ofgaa Djirata, Bekele Jembere, Emana Getu. and Seyoum Mengistou. 2007. Prevalence of termites and level of damage on major field crops and range lands in Manasibu District, Western Ethiopia. Journal of Biological Sciences, 6(2): 115 – 128. Addis Ababa, Ethiopia.

Pomeroy, D. E., R. K. Bagine, and J. P. E. C. Darlington. 1991. Fungus-growing termites in East African Savannas. Pages 41–50 *in* F. I. B. Kayanja and E. L. Edroma, editions. *African wild research and management.* International Council of Scientific Unions, Paris, France.

Popov, G.B., Mitchell, G. and Farah, M.A. 1982. Ethiopia, report of a survey on plant protection, 7 April – 2 May, 1981, Rome, FAO. 98 pp (FAO report AGB: Ipp/81/12).

Rath, A. C. 2000. The use of entomopathogenic fungi for control of termites. Biocontrol Sci. Technol. 10: 563–581.

Rawat, R.R., Deshpande, R.R. and Kaushal, P.K. 1970. Comparative efficacy of different modern insecticides and their methods of application for the control of termites *Odontotermes obesus* Rambur in groundnut – *Arachis hypogea.* Madras agric. J. 57, 83-87.

Reddy, P.S., Ghewande M.P., 1986. Major insect pests of groundnut and their management. *Pesticides* 20:52.56.

Ruelle, J.E. 1970. A revision of the termites of the genus Macrotermes from the Ethiopian region (Isoptera: Termitidae). Bull. Br. Mus. (Nat. Hist.), Entomol. 24, 365-444.

Sands, W. A. 1973. Termites as pests of tropical food crops. PANS 19, 167 – 177.

Sands, W. A. 1976. A visit to Ethiopia to examine termite problems in Wellega province, 17-26 may 1976. Report No. CVR/76/10, Center for Overseas Pest research, London. 11 pp.

Sands, W.A. 1977. The role of termites in tropical agriculture. Outlook on Agriculture 9, 136-143.

Sanna, E. 1973. Termite as agricultural pests in western Wollega. Appropriate Technology Unit, CROA, Addis Ababa.

Scheffrahn, R.H., Su N.Y. and Busey P., 1997. Laboratory and field evaluation of selected chemical treatment for control of dry wood and field evaluation of selected chemical treatment for control of dry wood termites (Isoptera: Kalotermitidae), *Journal of Economic Entomology* 90:492.502.

Schmutterer, H. 1971. Contribution to the knowledge of the crop pest fauna in Ethiopia, Z. ang. Ent. 67, 371-389.

Sekamatte, M.B. 2001. Options for integrated management of termites (Isoptera: Termitidae) in smallholder maize-based cropping systems in

Uganda. PhD thesis. Kampala: Makerere University.

Sileshi, G., Mafongoya P.L., Kwesiga F., Nkunika P. 2005. Termite damage to maize grown in agro forestry systems, traditional fallows and monoculture on nitrogen-limited soils in eastern Zambia. *Agric Forest Entomol* 7:61- 69.

Sileshi, G. W.; Nyeko, P.; Nkunika, P. O. Y.; Sekamatte, B. M.; Akinnifesi, F. K. and Ajayi, O.C. 2009. Integrating ethno-ecological and scientific knowledge of termites for sustainable termite management and human welfare in Africa. Ecology and Society 14(1): 48.

Silva, A.C., Monteiro M.B.B., Brazolin S., Lopez G.A.C., Richter A. and Braga M.R., 2007. Biodeterioration of brazil wood *Caesalpinia echinata* Lam. (Leguminosae.Caesalpinioideae) by rot fungi and termites. *International Biodeterioration & Biodegradation* 60:285.292.

Singh, S. K. and Singh G. 2003. Management of Termite infestation in mango orchard by cultural practices and organic amendments. *Ind. J.Agrl. Research*. **37** (2): 148-150.

Su, N.Y. and Scheffrahn, R.H. 1998. A review of subterranean termite control practices and prospects for integrated pest management programs. Integrated Pest Management Reviews. 3: 1-13.

Tizazu Degu. 2011. Mound distribution and management of termites using botanicals and entomopathogenic fungi in Metekel Zone. MSc thesis. Ambo University, Ambo.

Tsedeke, A., Tadesse, G.M. and Kemal, A. 1982. Arthropod pests of grain legumes in Ethiopia: their importance distribution. IAR , Addis Ababa, 52 pp.

Tsedeke, A. 1986. A review of vegetable insect and mite pest management research in Ethiopia. In, a review of crop protection research in Ethiopia (Tsedeke, A. ed.) pp 479-493. IAR, Addis Ababa.

Wang, C. and Powell, J.E., 2004. Cellulose bait improves the effectiveness of *M. anisopliae* as a microbial control of termites (Isoptera: Rhinotermitidae). *Biol. Control*, **30**: 523-529.

Wardell, D.A., 1987. Control of termites in nurseries and young plantations in Africa: established practices and alternative courses of action. *Common Forest Rev* 66:77.89

Wardell, D.A., 1990. The African termite: peaceful coexistence or total war? Agro forest Today 2:4.6.

Wood, T. G. 1986a. Assessment of termite damage in Ethiopia and recommendations for short-term control and development of long-term pest management practices. TDRI, London. Report for the World Bank and Ministry of Agriculture. Addis Ababa, unpublished.

Wood, T. G. 1986b. Report on a visit to Ethiopia to advice on assessment of termite damage to crops. 27 June -8 August 1986. R1347(R). Project No. A1639. TDRI. Overseas Devt. Administration. 127 Clerkenwell Road, London ECIR 508. 20 pp.

Wood, T. G. 1988. Termites and soil environment. Biol. Fertil. Soils 6: 228-236.

Wood, T. G. 1991. Termites in Ethiopia: The environmental impact of their damage and resultant control measures. Ambio 20(3/4): 136-138.

Wood, T. G. and Johnson, R. A. 1986. The biology, physiology and ecology of termites. In: S. B. Vinson (ed.). Economic impact and control of social insects. Praeger, New York.

Wood, T. G.; Johnson, R. A. and Ohiagu, C. E. 1980. Termite damage and crop loss studies in Nigeria – a review of termite (Isoptera) damage to maize and estimation of damage, loss in yield and termite (Microtermes) abundance at Mokwa. Tropical Pest Management 26, 242-253.

Wood, T.G. and Sands, W.A. 1977. The role of termites in ecosystems. Brian Production Ecology of Ants and Termites, International Biological Programme 13. Wright, M.S., A.K. Raina and A.R.Lax, 2005. A Strain of the Fungus *Metarhizium anisopliae* for controlling subterranean termites. J. *Econ. Entomol.*, 98: 1451–1458.