FORAGING ACTIVITY AND CONTROL

OF TERMITES

IN WESTERN ETHIOPIA

By

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A thesis submitted for the degree of

Doctor of Philosophy of the University of London

and for the Diploma of Imperial College

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Silwood Park

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February 1990

ABSTRACT

The termite species identified as crop pests in western Ethiopia belong to the subfamily Macrotermitinae and to the genera *Macrotermes*, *Microtermes*, *Odontotermes* and *Pseudacanthotermes*; however, only *Macrotermes* was economically important.

Macrotermes subhyalinus (Rambur) foraged throughout the year while the main activity of *Microtermes* was during the rainy season and that of *Pseudacanthotermes* during the dry season. During the wet season *Microtermes* foraging activity occurred throughout the day and night while the activity of *Pseudacanthotermes* was restricted to certain specific periods of the day or night both during dry and wet seasons.

Studies on *Microtermes* showed no relationship between the number of plants attacked and yields of maize and sunflower; peppers on farmers fields were not infested and yield losses were principally in haricot beans, and ranged from 4.5 to 12.8%.

Simulation of *Macrotermes* damage in maize showed that yield loss depends on the extent of stand reduction and the growth stage of the crop. Stand reduction at the early stage had no effect until more than 30% of the plants were removed. The yield reduction of 40 per cent was obtained when 45% of the plant population was removed at the tasselling stage.

The incidence of *Microtermes* attack was unaffected by applying fertilizer. Doubling the recommended sowing rate reduced maize yield by about 40%. Seed treatment with chlorpyrifos, isofenphos or aldrin or furrow treatment before sowing or a combination of both gave no protection against *Microtermes* or *Macrotermes*.

The application of chlorpyrifos at the rate of 20.2 g a.i. per mound effectively killed *Macrotermes* colonies, but the use of diazinon and removing the queen from the nest gave only partial success. No significant yield difference was found in tef between areas where mounds were treated and untreated due to the presence of young colonies that have not yet built mounds.

Studies including morphometric analysis on *Macrotermes* in western Ethiopia indicated that two distinct populations exist with different mound building behaviour. Whether these differences indicate different species or not is not yet known. There was no evidence that crop damage is due to the removal of natural vegetation.

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CHAPTER ONE : GENERAL INTRODUCTION

1.1 CHARACTERISTICS OF TERMITES

Termites are polymorphic social insects that live in colonies consisting from a few thousand to several million individuals. Fossils found in several areas have shown that termites are relatively primitive insects. The fossils discovered in southern England, showed that *Valditermes brenanae* is about 120 million years old and was not much different from the present day termites (Wood and Johnson, 1986). This clearly indicates little change has occurred in the morphology of termites for the past several million years.

At certain times of the year a termite colony consists of both winged and wingless individuals. The winged individuals, alates, have two pairs of wings which are similar in size and shape; hence, termites are in the order, Isoptera, which means equal wings in Greek (Borror and Delong, 1971). The major characteristic features that distinguish termites and other social insects from solitary insects are that they live in colonies and there is a division of labour, based on a caste system whereby each individual has specific task. In contrast, certain insects such as locusts and caterpillars may aggregate temporarily but they have not developed a division of labour which is an important characteristic feature of social insects (Snyder, 1948).

The Romans named termites as 'termes' which means literally 'woodworm' (Douglass, 1982). This name appropriately describes the destructive nature of termites which live in and feed on woody materials. Hence, the name 'termes' is suffixed with the scientific names of nearly all termite genera described. In contrast, the early European travellers returning from tropical and subtropical parts of the world mistakenly named termites that destroyed their properties and tools as 'white ants' (Hickin, 1971). Morphological and behaviourial features clearly distinguish termites from true ants. Whereas termites have an incomplete metamorphosis ants in the order Hymenoptera have complete metamorphosis. Termites have generally light-coloured soft bodies while ants have dark coloured hard bodies. The alates of both termites and ants have two pairs of wings but unlike termites ant fore-wings are much larger than the hind wings. The abdomen of termites is broadly joined to the thorax while that of ants is narrowly joined. The antennae of termites are moniliform or filiform but that of ants are elbowed (Borror and Delong, 1971). The most important behaviourial feature that distinguishes termites from ants is the life span of the males or kings. In ants the male dies once he has mated with the queen but in termites the king lives as long as the queen and mating can occur throughout their life span (Snyder, 1948; Bodenheimer, 1937).

The most primitive living termite, *Mastotermes darwiniensis* Froggatt of Australia, has wing structures similar to that of cockroaches and carry its egg masses like cockroaches. Similarly the primitive wingless brown cockroach, *Cryptocercus punctulatus* Scudder burrows into decayed wood for food and shelter and also depends on protozoans found in its hind-gut for the digestion of its food just like the lower termites (Snyder, 1948). Thus termites are more closely related to cockroaches than ants.

1.2 CLASSIFICATION

Currently 2231 living and 60 fossil termite species are known (Wood and Johnson, 1986). These species are grouped according to their morphological characteristics. There have been changes in the way the Isoptera have been classified. Earlier classifications grouped termite species into five families (Light, 1946; Snyder; 1948; Webb, 1961), whereas Krishna (1969) considered that there were six families, while Roonwal (Verma and Kashyap, 1980), grouped termite species into nine families. Later Wood and Johnson (1986) revised these earlier studies and classified known termite species into seven families, namely Mastotermitidae, Kalotermitidae, Termopsidae, Hodotermitidae, Rhinotermitidae, Serritermitidae and Termitidae.

The first six families are collectively known as lower termites. One major characteristic feature of lower termites is the presence of protozoans in their hind gut on which they depend for the digestion of cellulose which is their main diet. The seventh family, Termitidae which consists of over 80% of the genera and 74% of termite species so far described (Wood and Johnson, 1986), are called higher termites because of their highly advanced social behaviour (Bignell *et al.*, 1983). Their major characteristics are lack of symbiotic intestinal protozoans, large colonies (100,000's or millions) and the presence of worker caste that has completed its development (Sands, 1977a). In the lower termites the worker caste is not permanent and is capable of further development (Wood and Johnson, 1986).

The family Termitidae consists of four subfamilies known as Apicotermitinae, Termitinae, Macrotermitinae and Nasutitermitinae. The subfamily Macrotermitinae is also known as fungus-growing termites. It represents 20% of the family Termitidae (Cowie, 1988) and contains 13 genera and 288 species some of which are important pests in Africa and Asia (Wood and Johnson, 1986). The Macrotermitinae cultivate a Basidiomycete fungus, *Termitomyces*, on the comb within the nest (Sands, 1956). Wood and Thomas (1989) recently reviewed the association between Macrotermitinae and Termitomyces.

The food consumed by the workers passes through the gut relatively unchanged and is used for the construction of fungus comb on which *Termitomyces* is grown. The inoculation of new nests by *Termitomyces* has been found to be due to the carriage of spores by the swarming alates in the genus *Microtermes* and *Macrotermes bellicosus*; in other Macrotermitinae, it is suspected that the first foraging workers bring basidiospore to the nest (Johnson 1981a; Thomas, 1981). The fungus breaks down lignin and cellulose and also produces spores which are ingested by the termite. Thomas (1981) has shown that *Termitomyces* degrades nitrogen-poor food and provides termites with a relatively nitrogen rich food. Abo-Khatwa (1977) also showed that the fungus provides termites with vitamins and nitrogen. Fungus comb is partly digested food and when ingested by termites further digestion occurs in the gut by the enzymes such as C_x cellulases and B-glucosidase produced partly by ingesting fungal material and partly by the midgut epithelium and salivary glands (Wood and Thomas, 1989). Josens (Wood and Thomas, 1989) showed that the turnover time of the fungus comb is five to eight weeks.

1.3 GEOGRAPHICAL DISTRIBUTION

Termites are mainly tropical and subtropical insects; however, their distribution extends to the temperate regions up to 45^0 N and S latitudes (Harris, 1965, 1969; Wood and Sands, 1978). Low temperature is the most important factor determining the absence of termites in the 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, 1981b; Edwards and Mill, 1986; Osmun and Butts, 1966).

According to Wood and Johnson (1986) the areas in which termites occur, extend over two-thirds of the land mass, involving some 100 countries with total human population of over 3 billion. Most of these countries are developing countries and over half of them have a gross national product (GNP) of less than US $ 500. Within these areas termites are not found at altitudes above 3000 m, in extremely dry areas and where there is no vegetation. Termites have been found in all types of soils except in semi-permanently water logged areas and in certain deeply cracking vertisols (Wood, 1988).

The diversity of termite species increases close to the equator and at lower altitudes, except in Australia where an equal number of termite species are found both north and south of the Tropic of Capricorn (Wood and Sands, 1978). The increase in the number of termite species is apparently due to high temperature which is favourable for termites.

The Ethiopian zoogeographical region is the richest in termite fauna and the centre of origin for many termite genera. Bouillon (1970) reported the occurrence of 89 genera and 570 species in the region. Of these 67% of the genera and 87.5% of the species are endemic. It also contains 10 genera of Macrotermitinae of which 7 are endemic. Surprisingly, the dominant termites in the region are the non-endemic genera, *Macrotermes*, *Microtermes* and *Odontotermes* (Bouillon, 1970). Macrotermitinae is widely spread throughout the Ethiopian and Indo-Malayan regions (Ruelle, 1970; Sen-Serma, 1974). The zoogeographical composition of termite species found in Ethiopia has been discussed by Cowie *et al.* (in press). Commonest termites of western Ethiopia consists of pan-African, West African, East African and endemic species. *Macrotermes subhyalinus* (Rambur) and *Pseudacanthotermes militaris* (Hagen) are pan-African;

Astratotermes sp. nr. *pacatus* (Silvestri) is West African; *Microtermes* sp. nr. *vadschaggae* (Sjostedt), *Adaiphrotermes* sp. nr. *scapheutes* Sands, *Alyscotermes trestus* Sands and *Ateuchotermes rastratus* Sands are East African; *Microtermes aethiopicus* Barnett *et al.* and *Firmitermes abyssinicus* (Sjostedt) are endemic (Cowie *et al.*, in press; Sands, 1976; Emerson, 1959).

1.4 BIOLOGY OF TERMITES

A termite colony is made up of functional reproductives, workers, soldiers and relatively large number of immature individuals in various stages of development. The proportion of the different castes varies depending on the species and the age of the colony. The mean percentage of different castes recorded in mature *Macrotermes bellicosus* colony are 1.6% major soldiers, 2.4% minor soldiers, 35.6% major workers and 60.5% minor workers (Bagine *et al.* 1989).

There are two types of functional reproductives, primary and supplementary. The primary reproductives, the king and the queen, develop from the winged alates that have shed their wings and established a colony. They have highly sclerotized and pigmented bodies. Generally a single pair of the primary reproductives are found in a colony; however, in certain termite species multiple primary reproductives may be found. For instance, in *Odontotermes obesus* two kings and two queens were recorded (Roonwal, 1970). In *Macrotermes michaelseni* colonies examined in semi-arid range land at Kajiado, multiple queens and multiple kings were observed in about 25% and 5% of the nests respectively (Darlington, 1985). In termite species that have large colonies the queen's abdomen grows considerably to accommodate large number of eggs developing. Such growth reaches its maximum in the genus *Macrotermes*. For example, in *Macrotermes natalensis* (Haviland), the queen may expand from 35 mm to 140 mm and weigh 125 times as much as the original queen (Howse, 1970). The egg laying capacity of the queen varies depending on the species. The mature queen of *Macrotermes natalensis* and *Odontotermes badius* (Haviland) have been recorded to lay about 40,000 eggs per day which is equivalent to one egg every two seconds (Bouillon, 1970).

The supplementary reproductives develop when either one of the primary reproductives die or the egg laying capacity of the queen drops below a certain minimum level. In Macrotermitinae, the queen is also replaced when she gets old (Harris, 1961). Three types of supplementary reproductives are known. These are adultoids which develop from imagoes, nymphoids which develop from nymphs and ergatoids which develop from workers. In higher termites of the family Termitidae, all the three types of replacement reproductives are known; however, in the subfamily Macrotermitinae only adultoid replacement reproductives have been recorded (Sieber, 1985). Since the supplementary reproductives are not as fecund as the original queen often several of them may be found in a colony. According to Harris (1971), Coaton reported 50 supplementary reproductives in *Hodotermes* colony in South Africa.

The workers are the most numerous caste in a colony. They are sterile, wingless and in most species they are also blind. Fully developed workers have sclerotized mandibles and lightly sclerotized heads. In the higher termites the workers are sterile and incapable of further development, but in lower termites the worker caste has not reached its final stage of development and can further develop into reproductives or soldiers. In the lower termites the functions of the worker caste is carried out by the immature individuals known as pseudergates or pseudoworkers. In certain Termitidae, there are two types of workers: major (large) and minor (small). In the Macrotermitinae, the major workers are males and forage outside the nest, whereas the minor workers are females and work in the nest. The functions of the worker caste include foraging for food, feeding and cleaning individuals of other castes, building and repairing nests. In the Macrotermitinae, the workers are also responsible for maintaining the fungus gardens (Wood and Johnson, 1986).

The soldiers are the second numerous caste in many termite species. As in the workers, they are sterile, wingless and in most species blind. They are characterized by having long and powerful mandibles or other structural modifications on the head that can be used to defend the colony against predators. Dimorphism is common among many termite species, and in certain Macrotermitinae and Nasutitermitinae a third type is also known (Noirot, 1969). In most Macrotermitinae, the soldiers are females. The minor soldiers defend the foraging workers outside the nest, whereas the majors defend the colony in the nest (Wood and Johnson, 1986).

The immature individuals could develop into any of the castes depending upon the requirements of the colony. The direction of development is not determined by genetic factors but rather by hormones and pheromones. In *Macrotermes michaelseni* JHA (juvenile hormone analogues) externally applied on the larvae induced soldier development which would have normally developed into workers (Okot-Kotber, 1985). Inhibitory pheromones have been also shown to prevent the development of supplementary reproductives and soldiers. In *Nasutitermes lujae*, the rate of soldier production was reduced by the application of organic extracts from soldier frontal glands; In *Macrotermes bellicosus* the removal of royal pair has been shown to induce the development of nymphs which would develop into supplementary reproductives (Bordereau, 1975).

One of the reasons for the success of termites seems due to their ability to regulate the proportion of different castes in the colony to maximize the survival of the colony. Understanding this complex mechanisms would help to identify the weak parts in the system and develop effective pest management strategies.

1.5 ECONOMIC SIGNIFICANCE

About 15% of the known termite species have been recorded attacking agricultural crops and buildings, and this is considered relatively high compared to other social insects (Sands, 1977b). The rest are considered harmless either feeding on dead plant material, herbivore dung or soil organic matter. The subfamily Macrotermitinae contains the most important species that cause damage to agricultural crops, forestry trees, buildings and wooden structures in Africa and Indo-malaya regions. The most important genera in Africa are *Macrotermes*, *Microtermes*, *Odontotermes*, *Pseudacanthotermes*, *Ancistrotermes* and *Allodontermes*.

The genus *Macrotermes* are widely spread throughout Africa (Ruelle, 1970). They build mounds that reach several metres high. Generally they have large colonies consisting several million individuals. A colony of *Macrotermes michaelseni*, for example, was recorded to have a population of over 5.25 million individuals at Kajiado, Kenya (Darlington, 1982a). Because of very high population the food requirements of *Macrotermes* is also proportionately high. As a result they are more likely to cause widespread damage compared to those genera that have low populations. Their basic food consists of grass and grass litter, but in some areas they also attack growing plants and cause significant damage (Lepage, 1981). The major species recorded causing damage on agricultural crops and forestry trees in Africa are shown in Table 1.1

The genus *Microtermes* is widely distributed in Africa and Asia and is also the smallest genus (in size) of the fungus-growing termites (Johnson, 1981b). It has not been recorded in deserts (Badawi *et al.*, 1986) perhaps due to lack of food and high temperature. At present 40 species have been described in Africa (Wood *et al.*, 1986) and one new species recently in Ethiopia (Barnett *et al.*, 1987). They build diffuse subterranean nests which consists of chambers 3-4 cm in diameter interconnected by narrow galleries and they usually feed on wood or woody litter on the soil surface and plant roots (Wood and Johnson, 1978). They attack plants at or below ground level and usually penetrate towards the stem filling the attacked parts with soil particles. The major species recorded as pests of agricultural crops in Africa are shown in Table 1.2.

Odontotermes are commonly found in several parts of Africa. In Africa, they are generally subterranean, but occasionally build mounds. They mainly feed on dead wood, dead grass and tree barks, but sometimes can feed on growing plants. Different species reported causing damage in Africa are shown in Table 1.3. The taxonomy of *Odontotermes* is extremely difficult and may require further identification.

The genera *Pseudacanthotermes*, *Ancistrotermes* and *Allodontermes* are minor pests in Africa. *Pseudacanthotermes* is pan-African, whereas the other two genera are both West and East African (Cowie *et al.*, in press). Generally, they feed on dead plant materials but occasionally can feed on growing plants and could cause damage. Crops attacked by the various species of these genera are shown in Table 1.4.

Table 1.1 *Macrotermes* damage to crops and young trees in different countries in Africa.

species	Crop/plant	Country	Author
Macrotermes bellicosus (Smeathman)	maize	Nigeria	Wood *et al.* (1980)
	rice	Nigeria	Harris (1969)
	sugar cane	Nigeria	Harris (1969)
	groundnuts	Sudan	Harris (1969)
	coffee	Uganda	Harris (1969)
	clove	Tanzania	Harris (1961)
	coconut	Nigeria	Aisagbonhi (1989)
natalensis (Haviland)	rice	Nigeria	Harris (1969)
	citrus	Nigeria	Harris (1969)
	Acacia	S. Africa	Harris (1969)
	young trees	Uganda	Harris (1969)
nigeriensis (Sjostedt)	coconuts	Nigeria	Harris (1969)
subhyalinus (Rambur)	maize	Nigeria	Wood *etal.*(1980)
	rice	Nigeria	Harris (1971)
	sugar cane	Nigeria	Collins (1984)
	groundnuts	Sudan	Harris (1971)
	coconuts	Nigeria	Harris (1971)
	cocoa	Nigeria	Harris (1971)
spp.	maize	Nigeria	Johnson & Wood (1979)
	Maize	Ethiopia	Crowe & Shitaye (1977); Sands (1976), Wood (1986a,b)
	Sorghum	Ethiopia	Wood (1986a,b)
	Millet	Ethiopia	Wood (1986a,b)
	Barley	Ethiopia	Wood (1986a,b)
	Tef	Ethiopia	Crowe & Shitaye (1977); Wood (1986a,b)
	cotton	E. Africa	Harris (1961)

Table 1.2 *Microtermes* damage to crops in different countries in Africa

species	Crop/plant	Country	Author
Microtermes			
albopartitus (Sjostedt)	food crops	Tanzania	Harris (1969)
	maize	Tanzania	Bigger (1966)
aluco (Sjostedt)	cotton	W. Africa	Harris (1969)
Kasaiensis (Sjostedt)	cotton	Zambia	Harris (1961)
lepidus Sjostedt	groundnuts	Nigeria	Johnson *et al.* (1981)
najdensis Harris	cotton	Sudan	Tiben (1985)
			Pearce *et al.* (1986)
redenianus (Sjostedt)	food crops	Tanzania	Harris (1969)
	maize	Tanzania	Bigger (1966)
thoracalis (Sjostedt)	groundnuts	Sudan	Harris (1969)
	cotton	Sudan	Harris (1969)
tragardhi Sjostedt	sugar cane	Sudan	Abushama & Kambal (1977)
vadschaggae (Sjostedt)	wheat	Tanzania	Harris (1969)
spp.	cotton	Tanzania	Harris (1969)
	maize	Nigeria	Wood *et al.* (1977)
	sugar cane	Nigeria	,,
	groundnuts	,,	,,
	yam	,,	,,
	sweet potato	,,	,,
	wheat	Tanzania	Sands (1977a)

Table 1.3 *Odontotermes* damage to crops and forestry seedlings in different parts of Africa

Species	Crop/plant	Country	Author
Odontotermes			
amanicus	clove	Tanzania	Harris (1961)
badius	groundnuts	S. Africa	Harris (1969)
(Haviland)	sugar cane	S. Africa	,,
classicus	sugar cane	Somalia	,,
(Sjostedt)	coconut	Somalia	,,
latericius	cotton	Mozambique	,,
(Haviland)	citrus	Mozambique	,,
	groundnuts	S. Africa	,,
	acacia	S. Africa	,,
	food crops	Tanzania	,,
nilensis	groundnuts	Sudan	,,
Emerson	date palm	Sudan	,,
smeathmanni (Fuller)	sugar cane	Nigeria	Collins (1984); Wood *et al.* (1977)
	maize	Nigeria	Wood *et al.* (1977)
sudanensis (Sjostedt)	groundnuts	Sudan	Harris (1961)
transvalensis (Sjostedt)	tea	Zimbabwe	Harris (1969)
vulgaris (Haviland)	groundnuts	Senegal	Harris (1969)
zambesiensis (Sjostedt)	food crops	Tanzania	Harris (1969)
spp.	groundnuts	Africa	Wightman & Amin (1988)
		Nigeria	Wood *et al.* (1980)
	tuber crops	W. Africa	Sands (1977a)
	cotton	Congo	Harris (1961)
	date palm	Sudan	Wood & Kambal (1984)
	tobacco	Zimbabwe	Harris (1961)
	sugar cane	Nigeria	Malaka (1983)

Table 1.4 *Pseudacanthotermes*, *Ancistrotermes* and *Allondontermes* damage to crops in Africa

Species	Crop/plant	Country	Author
Pseudacanthotermes			
militaris	cocoa	Nigeria	Harris (1969)
(Hagen)	food crops	Nigeria	,,
	sugar cane	Kenya	,,
	tea	Malawi	,,
	young trees	Nigeria	,,
	maize	Nigeria	Wood *et al.* (1980)
Allodontermes			
giffardi Silvestri	maize	Nigeria	Wood *et al* (1980)
morogorensis Harris	coconut	Tanzania	Harris (1969)
tenax (Sivestri)	maize	Tanzania	Bigger (1966)
Ancistrotermes			
amphidon (Sjostedt)	cotton	Uganda	Harris (1961)
cavithorax	young trees	Uganda	Harris (1971)
(Sjostedt)	maize	Nigeria	Wood *et al.* (1980)
crucifer	young trees	Nigeria	Harris (1971)
(Sjostedt)	groundnuts	Gambia	Harris (1961)
equatorius Harris	cotton	Uganda	Harris (1971)
guineense (Silvestri)	rubber	Nigeria	Harris (1969)
latinotus	coffee	Zambia, Congo	
(Holmgren)		Tanzania	Harris (1969)
	maize	Tanzania	Bigger (1966)
	cotton	Zimbabwe	
		Congo	Harris (1969)
	sugar cane	Congo	Harris (1969)
	groundnuts	,,	,,
	tobacco	,,	,,
	food crops	Tanzania	,,
	young trees	Zambia	,,
spp.	sugar cane	Nigeria	Malaka (1983)
	tobacco	Zimbabwe	Tobacco Res. Board (1988)

Termites also attack mulches and crop residues which would otherwise be available to growing crops. Harris (1954) believes that termite damage is greatest in areas which would benefit most from the application of manure and mulches.

Termites are important pests in tropical forestry, especially in areas where exotic forestry trees are planted. Damage is particularly serious on *Eucalyptus* seedlings during the first three years after transplanting (Nair and Varma, 1981; FAO, 1985; Cowie *et al.* 1989; Harris, 1966; Thakur, 1977). Termites cause damage to the transplanted seedlings by cutting the stem at or near the ground level (eg. *Macrotermes*), ring-bark the stem at the base or severe the tap root (eg. *Macrotermes*) or attack the root system (eg. *Microtermes*) (Cowie and Wood, 1989). The attacked plants wilt and die (Coaton, 1950). Termites that forage on well established trees (more than 3 years old) usually do not cause damage since they feed only on barks and dead tissues (Cowie *et al.* 1989).

In the tropics and subtropics grass-feeding termites are widely spread on grasslands grazed by livestock (Cowie and Wood, 1989). Significant damage has been reported especially in South Africa and Australia. The species observed causing damage in South Africa are mainly harvester termites, *Trinervitermes*, *Hodotermes* and *Microhodotermes* (Coaton, 1950). Overgrazing was observed to increase their population and damage from 20% to 100% in a dry year. In Australia, termites such as *Drepanotermes* and *Amitermes* have been recognized as pests of certain grazing lands (Harris, 1969). In Nigeria, *Trinervitermes geminatus* (Wasmann) was reported to remove only about 3.1 % of net primary production (Ohiagu, 1979). Various species of Macrotermitinae are also widespread on grazing lands in Africa; however, they do not cause serious damage since they are litter feeders (Lepage, 1981). In areas where recommended stocking rate is followed, the termites feed on grass litter and competition will be insignificant (Collins, 1982). On the other hand, in areas where livestock is introduced at a rate much higher than the recommended, the problem arises mainly due to competition between grass-feeding termites and the livestock (Sands, 1977a; Wood, 1986a).

Several species of termites are also responsible for the destruction of buildings in the tropics and subtropics. They have started spreading to the warmer temperate regions because of building designs which create favourable environmental conditions for termites (Johnson, 1981b). In the rural areas of developing countries houses are built from grasses and woods without proper foundations. Such structures are susceptible to termites attacking buildings. Many species that attack forestry seedlings and crops can also attack buildings. The termite genera recorded causing significant damage on buildings in Africa are various species of *Cryptotermes*, *Coptotermes*, *Macrotermes*, *Odontotermes* and *Microcerotermes* (Harris, 1971). Even though termites are important pests of buildings not much study has been conducted to determine the extent of losses they cause. However, the information available for USA indicates $1.7 billion is spent annually for the prevention and control of termites damaging buildings and also destroy five times as many house as fire and cause more damage than tornadoes, hurricanes and windstorms combined (Granovsky, 1983).

Termites have been recorded causing damage on non-woody materials such as buried electrical power cables, rail road signal systems and telephone or telegraph communication circuits (Spear, 1970; Sternlicht, 1977). Damage has been reported on leather, rubber, packaging materials, documents, books, fabrics of cotton, linen, jute, silk as well as carpets (Harris, 1971).

1.6 TERMITE PROBLEM IN WESTERN ETHIOPIA

Termites have been reported as very serious pests in western Ethiopia, particularly in the Welega and Asosa administrative regions. Out of 20 provinces in the regions 12 have reported from mild to serious termite damage. The first damage report came in 1938 around Kiltu Kara, small town in the Asosa Administrative region (Menesibu Province administrator, pers. comm.). Most farmers interviewed in Menesibu Province believe termites that are threatening their crops and houses have spread from this area. The magnitude of the problem is not similar throughout the region. It seems very serious in Menesibu, Nedjo-Jarso, Ayra-Guliso and Ghimbi provinces.

Almost all the major annual crops grown in the region are attacked by one or more species of termites either throughout their growing season or at one stage of their development. Damage level was observed to be widespread and higher on maize and tef than sorghum. Significant yield losses were considered to be very common on crop stacks left in the field for drying. Complete loss occurs if stack is left in the field for a day without constructing above ground drying structures.

Termite damage on indigenous trees are insignificant. Serious damage is very common on exotic forestry trees especially on *Eucalyptus* one to three years after transplanting. In some localities up to 100% loss of seedlings was reported. Near Mendi, established trees, three to four years old, were also attacked; however, damage on established trees is generally not significant.

Widespread denudation is seen on grasslands in Menesibu, Nedjo-Jarso, Ghimbi and Ayra-Guliso Provinces. Farmers and extension agents believe termites are the cause of the denudation. However, Sands (1976) and Wood (1986a) believe that overgrazing by heavy cattle populations are the primary cause of this problem. In this study also similar observations were made near Mendi and Guliso, where grasslands protected from cattle grazing had a luxurious grass growth while the unprotected adjacent areas were barren and denuded even though conditions were the same. Studies showed that *Macrotermes* is mainly grass litter feeder and consumed about 23% of litter production in Kenya (Collins, 1982), 5.4-49.2% in Senegal (Lepage, 1972) and consumption by fungus-growing termites was estimated at 69% of grass litter in Northern Nigeria during dry season (Ohiagu and Wood, 1979).

It is a common practice in the region to build houses, stores and fences on untreated wood and grasses without proper stone foundations. Such structures provide favourable conditions for subterranean termite attack. The survey conducted by Abdurahman and Adugna (unpublished) by interviewing local farmers showed that thatched grass roof huts are destroyed after about five years while corrugated iron sheet roof houses survived about eight years after construction. In Asosa settlement alone about 50% of the houses require annual maintenance (Settlement head, pers. comm.). Stores, fences and wooden bridges crossing streams are also destroyed by termites. As a result trees are cut frequently to replace structures destroyed by termites. Such practice would undoubtedly lead to deforestation and ecological disaster. Farmers also often complain about termite damage on clothes kept in the house or when left in the field for more than two hours during weeding.

The local government officials and extension agents have reported that a large number of farmers have abandoned their lands and migrated to lowland areas where termite problem is less severe at present. Menesibu Province, Ministry of Agriculture office reported that 9,155 farmers or about 6% of the total farm population migrated to lowlands areas since the problem has become worst. This migration has exposed the farmers to deadly diseases such as malaria and their livestock to wild animal attack both of which are prevalent in lowlands areas.

As a short term solution, the Ethiopian Ministry of Agriculture conducted a very extensive mound poisoning campaign in 1983 in Menesibu and certain parts of Nedjo-Jarso provinces by mobilizing all members of farming community in the area. Every visible mound in the cultivated field and grazing land were destroyed and poisoned with aldrin 40% WP at the rate of 12.5 or 25 g product per mound depending on the size of mounds. The number of mounds poisoned, insecticides applied and the labour force utilized in the two provinces were as follows (Abdurahman, unpublished):

	Menesibu	Nedjo-Jarso
Mounds treated	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 Asosa 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 (FAO, 1984a). The number of termite mounds treated in these two settlement areas and resources used are shown below:

	Asosa	Anger Gutin
Mounds treated	1838	307
Aldrin 40% applied (kg)	155	46

Western Synod branch based at Tchallia, small town in Ayra-Guliso Province, also participated in termite control programme by offering financial incentive for 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 programme. Between September 1987 to September 1988, over 23,000 *Macrotermes* queens were handed in and US $ 19,592.27 were paid (Markos, unpublished).

The Ministry of Coffee and Tea Development which has taken over the extension activities of some of the termite affected areas from the Ministry of Agriculture has conducted similar mound poisoning campaign in Menesibu, Ghimbi, Ayra-Guliso and partially in Nedjo-Jarso and Yubdo Provinces during 1988 crop season. The number of mounds treated and insecticides applied are shown below (Ministry of Coffee and Tea Development, unpublished):

Province	Mounds treated	Heptachlor 40% applied (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

1.7 OBJECTIVES OF THE STUDY

Despite extensive control measures undertaken to alleviate termite problem in the Welega and Asosa regions, damage reports continued coming from farmers and extension agents. As a result this research programme was initiated in order to study the nature of the problem in depth and develop control measures suitable to small farmers. The main objectives of the research programme were:

(a) To identify economically important termite species causing crop damage in the region. Correct identification of the pest species is the basis of effective pest management and minimizing undesirable effects of control measures.

(b) To study the seasonal and diurnal foraging activity of economically important termites. Termites cause damage because of their foraging activities and feeding habits and an understanding of these would help to determine the best pest management practices including the timing of pesticide application.

(c) To study damage on major crops grown in the region and determine the relationship between damage and yield loss. The need for control or choice of control measure depends on the economics of yield loss.

(d) To develop control measures suitable for small farmers. The control measures developed for small farmers need to be inexpensive, easy to apply and appropriate to their needs.

(e) To assess the effect of *Macrotermes* mound poisoning on crop yield and on termite populations. Such programmes require tremendous resources and man-power. Therefore, it is important to evaluate the results of the method before any further mound poisoning is undertaken.

(f) To find out why *Macrotermes subhyalinus* causes widespread damage to agricultural crops in western Ethiopia, but to a lesser extent in other parts of the country.

CHAPTER TWO : STUDY SITES

2.1 LOCATION

Field studies were carried out at several sites, located in western Ethiopia in the Welega and Asosa administrative regions which lie between $34^{0}6'$ and $37^{0}38'$ east longitude and $8^{0}11'$ and $11^{0}16'$ north latitude. The sites and their distances from Addis Ababa by road are as follows:

Bako	250 Km
Sasiga	360 ,,
Didesa	380 ,,
Ghimbi	440 ,,
Henna	498 ,,
Nedjo	515 ,,
Mendi	590 ,,

All the study sites, except Sasiga, are located on the main road to Asosa. The site at Sasiga is located 30 km north-west of Nekempt, the regional capital of Welega Administrative Region (Figure 2.1). During the first year field trials were conducted at Sasiga and Ghimbi. However, during the second year the trial sites were expanded to include all sites except Sasiga where no significant termite damage was observed during the first year. In addition to the above sites, loss assessment studies and termite control trials were conducted in the settlement areas at Jarso and Keto as well as on farmers' fields at Jarso and Yubdo.

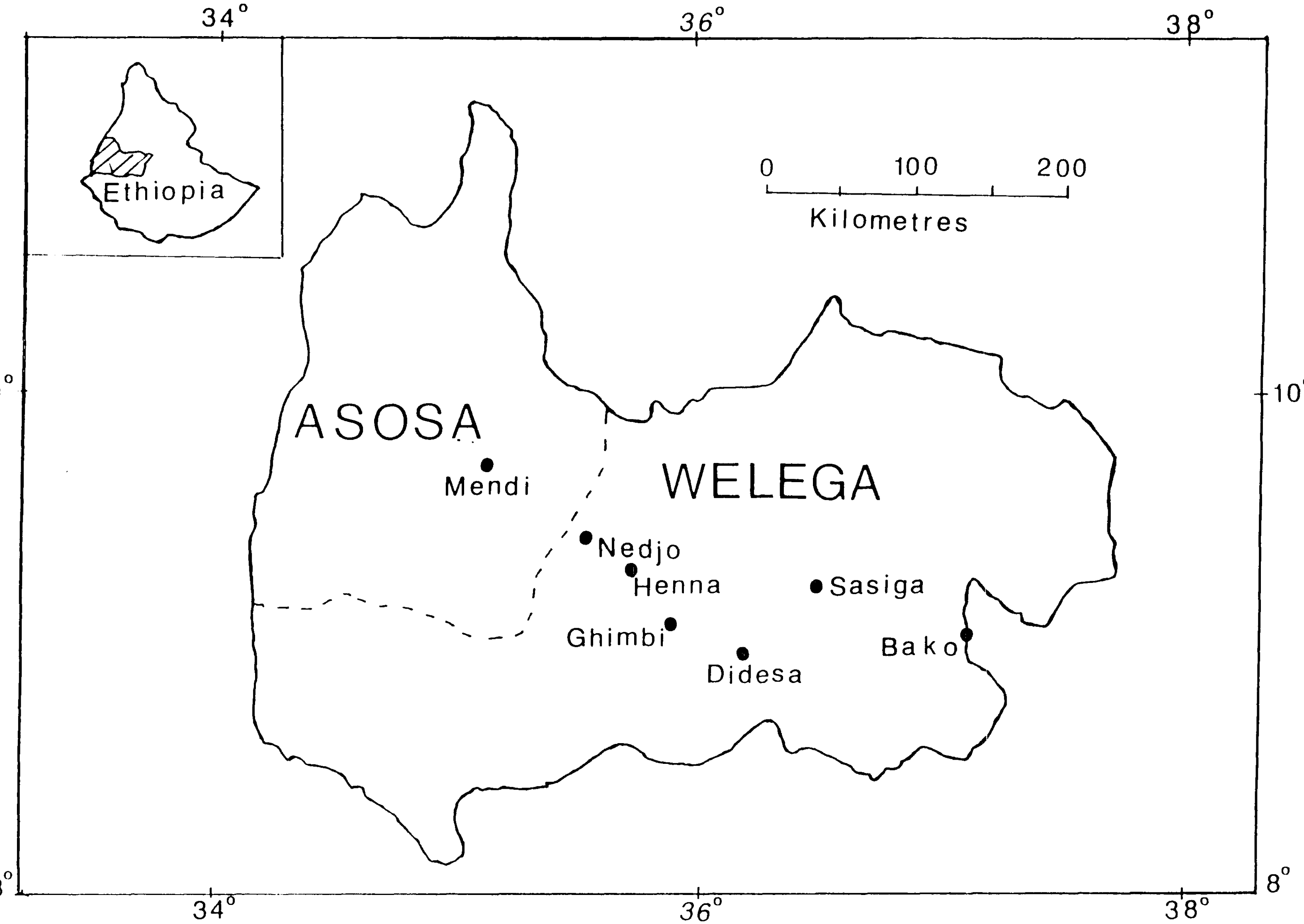


FIGURE 2.1 LOCATION OF STUDY SITES IN WESTERN ETHIOPIA

These study areas covered both lowland and temperate highlands. Generally, their topography was from gently to moderately sloping land with a westward slope, associated with drainage of major rivers towards the Sudan (Ethiopian Mapping Authority, 1988).

A survey of *Macrotermes* damage was also carried out in central Ethiopia around Meki-Ziway between 140-160 km south of Addis Ababa in order to get a wider perspective and understanding about the cause of the *Macrotermes* problem in western Ethiopia.

2.2 GEOLOGY

The geology of the area has been described by the Metal Mining Agency of Japan (1974) and the Ethiopian Mapping Authority (1988).

The basement rock on which all younger formations were formed consists of a complex of rocks formed during the Precambrian era some 600 million years ago. In certain areas where erosion has occurred, the basement rocks are visible and is known to contain different types of sedimentary, volcanic and intrusive rocks which have weathered to different degrees. In western Ethiopia considerable weathering has taken place because of the presence of granitic rocks and gneisses (Ethiopian Mapping Authority, 1988).

The intrusion of older granitic rocks caused regional metamorphism. This was followed by the deposition of upper Precambrian sediments, the intrusion of the middle stage granodiorites, ultrabasic bodies and the younger dioritic rocks. After a large scale orogenic movement and a low temperature metamorphism, mountains were formed. From the end of the Proterozoic to the late Palaeocene epoch erosion reduced the area to a plain and from the late Palaeocene to the late Eocene epoch the extrusion of the large scale plateau basalt took place (Metal Mining Agency of Japan, 1974).

2.3 CLIMATE

The area has a single rainy season from April to October lasting for seven months with the remaining months dry. The rainfall is transported by south westerly winds. At the beginning (April) and at the end of the rainy season (October) the rainfall is low, but gets very heavy from May to September (Daniel, 1977). Generally rainfall in western Ethiopia is higher than other parts of the country. The mean annual rainfall in the study areas varies from 1183.2 to 1796.8 mm (Table 2.1). During the 1988 season rainfall was slightly higher than the mean annual rainfall in all sites except at Bako.

The mean minimum monthly temperature ranges from 12.8 ^{o}C to 14.2 ^{o}C. Similarly mean maximum temperature ranges from 25.6 ^{o}C to 30.8 ^{o}C (Table 2.1).

Table 2.1 Altitude, annual rainfall, mean minimum and maximum temperatures in the study areas

Site year	Altitude (m)	Annual rainfall (mm)	Mean temperature °C minimum	maximum
Mendi				
1988	1680	1947.7	15.1	27.9
1987		1626.5	15.7	28.0
1955-86		1653.6	14.2	26.5
Nedjo				
1988	1830	1883.2	11.8	25.2
1987		1572.0	12.2	25.7
1952-86		1734.3	13.2	25.7
Henna				
1988	1890	2077.7	12.9	25.7
1987		1983.5	11.6	25.7
1978-86		1796.8	12.8	26.1
Ghimbi				
1988	1870	1949.9	14.8	25.9
1987		1803.8	15.2	26.2
1978-86		1649.7	13.5	25.6
Didesa				
1988	1250	2099.0	15.6	31.0
1987		1691.1	15.8	31.4
1971-86		1511.8	13.4	30.5
Bako				
1988	1650	1177.7	13.9	28.1
1987		1131.7	14.4	28.0
1974-86		1183.2	13.3	27.5
Sasiga				
1988	1520	1831.6	15.3	30.7
1987		1375.8	15.3	31.5
1972-86		1366.5	13.5	30.8

From National Meteorological Services Agency

2.4 SOILS

The soils of the study areas are predominantly Nitosols (Regional Office for Western Ethiopia, 1986). The most important diagnostic features of Nitosols are reddish brown to red in colour and clay in texture with an argillic B horizon without abrupt textural changes. They are found mainly on gently sloping to steep lands (FAO, 1984b).

Nitosols have generally a good potential for agriculture. They have good physical properties, a uniform profile, are porous, well drained, have a stable structure, high moisture holding capacity and a deep rooting volume (Ethiopian Mapping Authority, 1988).

However, an important limitation of these soils is that they are strongly acidic with pH values of less than 5.4 (Murphy, 1968; Adugna, 1984). They are highly deficient in available phosphorus (Murphy, 1968; Desta, 1982; Adugna, 1984), in exchangeable bases, CEC, organic matter, but high in exchangeable aluminium throughout the profile (Adugna, 1984). This indicates that the soil requires heavy fertilization especially with phosphorus and liberal addition of lime.

2.5 NATURAL VEGETATION

The natural vegetation is predominantly wooded-shrub grassland and shrub grassland with riverine forests stretching along the river banks. Because of differences in environmental conditions, composition of natural vegetation varies from one locality to another. However, the most widespread vegetation consists of medium sized trees and tall shrubs which include *Acacia* spp., *Albizia gummifera* (Gmel.), *Cordia africana* Lam., *Croton macrostachys* (Hochst), *Deinbollia kilimandscharica* (Roxb.), *Eckebergia capensis* Sparrman, *Ficus* spp. and *Syzygium guineense* (Willd.).

The dominant grass species are *Cynodon dactylon* (L.)Pers., *Eleusine jaegeri* Pilg., *Hyparrhenia* spp. and *Pennisetum polystachian* (L.). In the hot lowland areas *Hyparrhenia* spp. is the dominant grass usually growing over 3 m high. Fire outbreaks that occur annually between January and March burn the grass and herbaceous vegetation giving way for young nutritious grasses. Fires may destroy both terrestrial insect pests and their natural enemies, but do not affect subterranean insects directly.

Among various indigenous trees growing in the region Croton *macrostachys* (Hochst) is considered resistant to termite attack by many farmers. Some farmers even claim *Croton* leaves have a repellent effect against termites and are placed around harvested crop produce. However, during the study period no such use being made of *Croton* leaves has been witnessed in any of the study areas. A test on natural resistance of timber has shown that *Syzygium guineese* (Willd.) is moderately resistant to termite attack while *Eckebergia rueppliana* is very susceptible (Holmgren, 1963).

Recently a very extensive afforestation programme has been started in several parts of western Ethiopia as in other parts of the country where *Eucalyptus* and other tree species are planted. Although *Eucalyptus* is very susceptible to termite attack it is being planted in a very large scale because of its fast growing properties.

2.6 CROP PRODUCTION

The total land area of Welega and Asosa administrative regions are 66,516 sq. km (Anonymous, 1988). About 212,700 ha or 4.8% are covered with forests (Ministry of Agriculture, 1987b) and 700,000 ha or 10.5% are cultivated lands. Of the cultivated lands 88.8% represent small farms, 5.3% settlement farms and 5.9% the state farms.

Cereals such as tef (*Eragrostis tef* (Zucc.) Trotter), maize, sorghum, finger millet, barley, wheat and oats are the most important food crops grown in the area (Table 2.2). Tef originated in Ethiopia (Huffnagel, 1961), and at present Ethiopia is the only country in the world where tef is cultivated for human consumption. The cultivation of some species of tef has been reported in the United States, Australia and South Africa for hay and pasture (Huffnagel, 1961). It ranks first in the country in the basis of area of cultivation (Central Statistical Office, 1986). It is also the most widely grown grain crop in the Welega and Asosa administrative regions. It is grown in about 178,000 ha. which represents 28% of cultivated land in the region (Ministry of

Agriculture, 1987a). Farmers grow tef both as a cash crop and for domestic consumption.

Maize is the second important crop in farmers' fields, but ranks first in the state farms and settlement areas since these areas lie where environmental conditions are suitable for maize production. Maize is not an indigenous crop to Ethiopia; it was introduced by the Portuguese between 16th and 17th century (Huffnagel, 1961). It ranks first in the country in terms of yield per ha and total production; fourth in total area cultivated (Central Statistical Office, 1986).

The next widely grown are oil crops such as nigerseed (Noug), sesame, groundnuts, rapeseed and sunflower. Oil crops are grown mainly in the small farms and settlement areas. Various pulse crops such field peas, horsebeans, chickpeas, lentils and haricot beans are grown. Vegetable crops are not widely grown in the area except in some homestead farms and the state farms.

The settlement areas and state farms are located in flat lowland areas where land topography is suitable for mechanized agriculture. As a result land preparation is done fully by tractors in the state farms and partially in the settlement areas. In both these areas mound building termites are less of a problem, presumably due to the destruction of their nests and foraging galleries and crop damage is mainly due to subterranean termites. In contrast many of the small farms are located on hilly lands and ploughing is done either by oxen or hoe which does not destroy mound building termites. Under such farming systems crop damage may be caused both by mound building and subterranean species.

Table 2.2 Crop production in the Welega and Asosa administrative regions during 1987/88 crop season

	Area cultivated (ha)		
Crop	Farmers field[a]	Settlement farms[b]	State farms[c]
Cereals	550,724	32,680	36,920
Tef	178,190	979	
Maize	161,741	21,023	32,935
Sorghum	90,576	10,678	3,985
Millet	52,667		
Barley	48,362		
Wheat	19,036		
Oats	152		
Oil crops	37,534	1,258	178
Sesame			
Sunflower		27	178
Noog		989	
Groundnuts		242	
Pulses	32,047	3,202	3,394
Field peas			
Horse beans			
Haricot beans		1963	2957
Chick peas		163	
Lentils			
Soybeans		1076	437
Vegetables	7,735		
Pepper		336	209
Others			
Kenaf			1010
TOTAL	628,040	37,476	41,711

a = Welega region Ministry of Agriculture annual report for 1987
b = Annual report for settlement areas for 1988
c = Crop production in Welega region state farms for 1988

CHAPTER THREE : TERMITES OF AGRICULTURAL IMPORTANCE IN WESTERN ETHIOPIA

3.1 INTRODUCTION

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.*, in press). 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 species reported in Ethiopia are *Neotermes erythraeus* Silvestri, *N. superans* Silvestri, *N. aridus* Wilkinson and *Epicalotermes aethiopicus* Sjostedt (Cowie *et al.*, in press). Only the latter species was reported attacking acacia trees in eastern Ethiopia (Hill, 1965).

The Hodotermitidae are also 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 materials 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 al.*, in press). Only the latter species was recorded causing damage on plants (Harris, 1969, 1971).

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

Over 85% of the termite species recorded in Ethiopia belong to the family Termitidae (Cowie *et al.*, in press). 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 as follows:

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 in several parts of Welega and Asosa administrative regions, particularly in Mendi areas (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 (Sanna 1973; Sands, 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 Asosa and Anger Gutin settlement areas (FAO, 1984a). 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. *vadschaggae* (Cowie *et al.*, in press). *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), groundnuts in Bako (Schmutterer, 1971), swiss chard in eastern Ethiopia (Hill, 1965), haricot beans and cowpea in the Melkasa area (Tsedeke *et al.*, 1982; Schmutterer, 1971) and on wheat in the IAR station at Melka Werer (Wood, 1986a). In most of the literature the species responsible for causing damage have not been reported. *Microtermes magnocellus* (Sjostedt) has been recorded on crop residues 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 groundnuts (Schmutterer, 1971;

Crowe *et al.*, 1977) and wheat (Adugna and Kemal, 1986). Abushama *et al.* (1968) also reported the occurrence of this species in the 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 was recorded on wheat (Adugna and Kemal, 1986; Crowe *et al.*, 1977). The former species was also recorded on *Milletia ferruginea* (Hochst) 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 Welega (Sands, 1976; Wood, 1986a) and on maize in Gamo Gofa region (Cowie *et al.*, in press).

Three species of *Ancistrotermes* have been reported in Asosa, Gambela and south-western Ethiopia (Barnett *et al.*, 1987). *A. crucifer* (Sjostedt) and *A. periphrasis* (Sjostedt) were recorded attacking growing crops, especially maize in Gamo Gofa. *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 residues, but it is not known whether they can attack food crops or not (Barnett *et al.*, 1987). However, the former species was recorded causing localized damage on forestry seedlings in Shoa regions (Cowie *et al.*, in press).

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 peppers (Tsedeke, 1986), groundnuts (Kemal *et al.*, 1986) and coffee (Crowe and Tadesse, 1984).

Many of the records available lack the necessary information regarding the stage of crops attacked and the extent of damage caused by the different species. 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 an 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 work that has been done regarding the Ethiopian fauna was based on the fauna of other parts of Africa (Barnett *et al.*, 1987). These limitations clearly show some of the problems in studying the Ethiopian termite fauna.

For the past 20 years reports of termite damage have been coming to the Ethiopian Ministry of Agriculture from western Ethiopia, particularly from the Welega and Asosa administrative regions. Various attempts were made to identify the pest species that caused crop damage and concern among farmers and local government officials in the regions. Much progress has been made particularly during the past four years towards understanding the nature of termite problems in western Ethiopia.

The primary aim of the field surveys was to identify the most important termite species that are threatening crop production in the region and determine the extent of crop damage they cause. Secondary objectives examined various aspects of termite biology, such as timing of alate flight, abundance of *Macrotermes* mounds and foraging holes.

3.2 MATERIALS AND METHODS

Field surveys were conducted during both the 1987 and 1988 crop growing seasons in several areas in the Welega and Asosa administrative regions where serious termite problems had been reported. Each season two field surveys were conducted in all the major crops grown in the regions; the first at the early stage of crop development and the second towards crop maturity. In all areas where surveys were conducted, a field which represented the termite damage situation in the locality was selected for each crop with the help of farmers and local development (extension) agents. The termite species that are causing damage were identified and the extent of damage they cause was determined.

For termite species that cut plants either totally or partially at ground level, damage was assessed at the vegetative growth stage and after heading or podding by randomly selecting five sites per field at approximately 10 m intervals across the diagonal of the field. The number of plants cut by termites were determined by checking 20 consecutive plants per sampling site. The total of the five sampling sites were taken as the percentage of damage caused by that particular species in the locality. For the small cereals such as tef counting the number of plants cut by termites would be extremely difficult, so damage was assessed by visually estimating the percentage of plants cut in an area of 1 m^2 at five sampling sites per field. The mean of the five sampling sites were taken as the percentage of damage caused by the termite in the locality.

For the species that attack the root system, damage was assessed at maturity in the case of field crops and at the seedling stage for forestry seedlings by pulling out plants in a known area in five randomly selected sampling sites per field as described above. The roots were checked for the presence of termites and when no termites were seen the roots were tapped on a metal tray to ensure the presence or absence of termites in the root system. Plants were considered attacked when termites were seen feeding inside the root system.

Termite species that were actually seen causing crop damage as well as termites in the natural woodlands adjacent to the trial sites were collected and preserved in 70% alcohol. The necessary data on their habitat and stage of development of the crop when they were collected on crops were recorded. The specimens were later identified in the British Museum of Natural History using the reference collections, identification keys by Ruelle (1970), Sands (1972) and identification aids by Ahmad (1950) and Johnson (1979).

Observations on the swarming behaviour of some of the dominant genera were made in several localities in western Ethiopia. Beside recording the alate flight dates and times, specimens were also collected.

Nesting behaviour was identified by checking the presence or absence of termite mounds in the area. Where there was no mound, the nesting habit was considered subterranean. The density of *Macrotermes* mounds on cultivated land and grasslands were determined by using a questionnaire in 25 randomly selected peasant associations (PA) in Menesibu and Ayra-Guliso provinces where *Macrotermes* damage was reported to be very serious. The density was determined by dividing the total number of mounds on cultivated and grasslands by their respective areas.

In Ethiopia farmers are organized into PA's and each PA covers approximately 800 ha and the total cultivated land and the grasslands are generally known in each PA. In addition in western Ethiopia, particularly in Menesibu, Nedjo-Jarso, Ghimbi and Ayra - Guliso provinces the total number of termite mounds on cultivated land and grasslands in each PA were registered for the purpose of a termite mound destruction campaign. The density of mounds were determined physically in an area of five ha. in Gombo Ogyo PA in Menesibu province.

The density of *Macrotermes* foraging holes was determined on grasslands, grazed and ungrazed adjacent areas, in Gombo Ogyo PA and Chuta Gelel PA in Ghimbi province. In each locality eight sites were selected at 10 m intervals along the area dividing the grazed and ungrazed lands and the density of foraging holes was recorded in an area of 1 m^2 at a distance of 5m on either side of the eight sites.

3.3 RESULTS AND DISCUSSION

3.3.1 Termite Species

Over 400 samples of termites were collected on cultivated lands, woodlands, grasslands and from termite mounds. About 92% of the samples were collected in western Ethiopia, mostly on cultivated lands and the rest in the Meki-Ziway area of central Ethiopia from termite mounds. The collections included 12 species belonging to nine genera (Table 3.1). Of these, four of the genera belong to the subfamily Macrotermitinae and the rest to the subfamily Apicotermitinae.

The five species of Apicotermitinae were *Astratotermes* nr. *pacatus* (Silvestri), *Adaiphrotermes* nr. *scapheutes* Sands, *Alyscotermes trestus* Sands, *Ateuchotermes rastratus* Sands and *Firmitermes abyssinicus* (Sjostedt). The occurrence of these species in the regions were also reported by Barnett *et al.* (1987) and that of *F. abyssinicus* by Sands (1976). All are considered harmless since they live and feed in soil. They were most active during the rainy season or when the soil was wet. With the exception of *Firmitermes* they are all soldierless. According to Sands (1972) they are the second most abundant termites in the soil fauna next to *Microtermes*. Anderson and Wood (1984) reported that soil-feeding termites increase exchangeable K and available P by up to 76 times.

All the termite species observed causing crop damage in the regions belong to the subfamily Macrotermitinae and to the genera *Macrotermes* (1 species), *Microtermes* (2 species), *Odontotermes* (3 species) and *Pseudacanthotermes* (1 species). Only the first two genera were observed attacking crops in several parts of the region. The remaining two genera were not observed causing economically important damage in any of the surveyed areas.

Macrotermes subhyalinus was the dominant termite in several parts of the regions at altitudes below 2000 m. It builds short dome-shaped mounds and was commonly seen foraging in plant roots, base of stems, maize cobs, crop stacks and woody litter lying on the soil surface (Table 3.1). The most susceptible crops/plants were maize, tef, finger millet, pepper, sugar cane and *Eucalyptus* (Table 3.2). The highest level of attack was recorded on experimental sugar cane grown at Jarso settlement. Damage on sorghum was generally very low throughout the areas surveyed except in Jarso settlement during 1988 crop growing season where over 40% stand loss was recorded on an improved variety 'Bako Mash'.

The nature of *Macrotermes* attack varies from crop to crop. On field crops, such as maize the base of the stem is covered with soil and cut at ground level causing stand losses. In forestry seedlings, the base of stem below the soil surface is ring-barked and translocation of water and nutrients is prevented. It can also feed on the barks of young *Eucalyptus* and junipers up to a height of 2-3 m above ground. Completely ring-barked trees wilt and die, whereas partially debarked plants can heal debarked parts and recover. *Macrotermes* attacks the edible parts of head cabbage under soil cover and infestation on sugar cane occurs on the root system. The attacked sugar cane wilts and dies.

On field crops, stand losses were observed throughout the crop growing period from emergence to harvest; however, the period of heavy attack varied on different crops. For instance in maize, greater stand loss was recorded during the vegetative growth stage of the crop as compared to post-tasselling period. In contrast, in tef and finger millet greater damage was observed after the heading stage of the crop. The intensity of damage on sugar cane and head cabbage were greater towards the later part of their growth period than the early stages. On the contrary higher damage at the seedling stage were observed on sorghum, *Eucalyptus*, junipers and tobacco. Maize cobs that have fallen on the ground were also attacked after completely covered with soil layer.

Table 3.1 Termite species, their nesting habits and foraging sites in western Ethiopia

Species	Nesting type	Foraging site
Macrotermitinae		
Macrotermes subhyalinus (Rambur)	M	Plant roots and stem, maize cobs, barely stack, tree trunks, grasses, stand of maize cribs, grain sacks, coffee husks, logs, polythene bags
Microtermes nr. *vadschaggae* (Sjost.)	S	Maize, sunflower and haricot bean roots and stems; maize stubble, *Eucalyptus* roots, soil sheeting on *Eucalyptus* and juniper stumps, wood baits, pegs, wall of *Macrotermes* mounds.
Microtermes aethiopicus Barnett *et al.*	S	Maize, pepper, sunflower, haricot bean and cassava roots and stems, maize stubble, *Eucalyptus* and juniper roots, tree stumps, coffee mulch, wood pegs and baits, wall of *Macrotermes* mounds.
Odontotermes sp. D	S/M	Maize roots, tef stacks, leaf litter, logs and mounds
Odontotermes sp. E	S/M	Maize roots, pepper stem and roots; *Eucalyptus* roots; *Eucalyptus* and juniper trunk; grass roots; wooden houses; fences; baits.
Odontotermes sp. I	S	Runways and sheeting on *Eucalyptus* and mango trunks and on stems of coffee seedlings, coffee mulch, wood pegs, wood baits, cow dung.

Nest type: M = mound
S = subterranean

Table 3.1 cont'd

Species	Nesting type	Foraging site
Pseudacanthotermes militaris (Hagen)	S	Maize roots, stalks and stubbles; pepper, grass and *Eucalyptus* roots; tree trunks, structural wood, wood litter, wood pegs, wood bait, cow dung
Apicotermitinae		
Astratotermes nr. *pacatus* (Silvestri)	S	Soil
Adaiphrotermes nr. *scapheutes* Sands	S	Soil
Alyscotermes trestus Sands	S	Soil
Ateuchotermes rastratus Sands	S	Soil
Firmitermes abyssinicus (Sjostedt)	S	Soil

Table 3.2 *Macrotermes* damage on field crops and forestry seedlings

Crop	Growth stage	Nature of damage	% Damage (mean±se)
Maize	Vegetative	Stem cutting	4.8 ± 0.7
	Young cob	,, ,,	2.8 ± 0.4
Tef	Vegetative	,, ,,	4.8 ± 0.3
	Heading	,, ,,	11.6 ± 1.2
Millet	Vegetative	,, ,,	2.0 ± 0.6
	Heading	,, ,,	7.7 ± 0.7
Sorghum	Vegetative	,, ,,	2.4 ± 0.4
Wheat	Heading	,, ,,	4.6 ± 0.5
Pepper	Seedling	,, ,,	2.9 ± 0.6
	Podding	,, ,,	10.6 ± 0.4
Head cabbage	Heading	Head covered with soil sheeting	4.0 ± 0.7
Sugar cane	Maturity	Partial root destruction	42.0 ± 3.7
Tobacco	Seedling	Stem cutting	< 1
Eucalyptus	Seedling	ring-barking stem and roots	10.3 ± 2.6
Juniper	Seedling	,, ,,	4.0 ± 0.4

No *Macrotermes* damage was recorded in Didesa state farms and Bako Agricultural Research Centre where land preparation is done fully by tractors. Whereas on the peasant farms where land is prepared either by oxen or hoe damage was widespread. This clearly showed that *Macrotermes* is less of a problem in areas cultivated by tractor. The main reason for lack of *Macrotermes* damage on tractor ploughed fields is presumably due to the destruction of termite colonies and their permanent shallow subterranean galleries. In most of these areas neither the farmers can afford to purchase tractor nor the land is suitable for tractor ploughing. Therefore, there is no practical use for this method of termite control.

The *Microtermes* species observed attacking crops were *M.* nr. *vadschaggae* and *M. aethiopicus;* however the former species was more wide spread in the study areas. Both species have subterranean nests and are usually found foraging in the roots of their host plants and on wood litter lying on the soil surface. Occasionally they were observed foraging under soil sheeting on tree trunks and structural woods.

The crops attacked and the extent of damage caused by the two species is shown in Table 3.3. Pepper and cassava were only attacked by *M. aethiopicus*. The highest level of attack by both species was recorded on sunflower and the lowest on *Eucalyptus* and junipers. Both were observed attacking the root system and occasionally the attack extended into the stem for several centimetres. On maize attack was often restricted to the root system before crop harvest. However, on sunflower stem penetration extending more than 15 cm were commonly seen at the time of crop harvest. Maize cobs that had fallen on the ground were also observed being attacked. Fortunately, *Microtermes* attack was not observed on the two most widely grown crops, tef and finger millet. Perhaps, this may be due to the small diameter of the root system which is too narrow for *Microtermes* to penetrate. Tef is also an indigenous crop to the region; and this could be another possible reason for lack of attack by *Microtermes*.

Table 3.3 *Microtermes* attack on field crops and forestry seedlings

Species	Crop	Growth stage	% Attack (mean±s.e.)
M. nr. *vadschaggae*	Maize	Harvest	63.7 ± 5.5
	Sunflower	,,	75.1 ± 3.1
	Haricot beans	,,	63.8 ± 4.7
	Eucalyptus	seedling	6.8 ± 1.2
	Junipers	,,	3.5 ± 0.6
M. aethiopicus	Maize	Harvest	38.4 ± 4.9
	Sunflower	,,	75.1 ± 3.1
	Haricot beans	,,	63.8 ± 4.7
	Pepper	Podding	5.5 ± 1.7
	Cassava	Maturity	5.0 ± 0.0
	Eucalyptus	Seedling	2.0 ± 0.0
	Junipers	,,	2.0 ± 0.0

Odontotermes species identified in the regions were species D, E, I. They have been designated with letters as indicated by Barnett *et al.* (1987) since there are no agreed names. *Odontotermes* species D is relatively small in size with head width ranging from 1.3 to 1.5 mm. It has a nearly rectangular head and 16 segmented antennae. Generally, it is not a well spread species in the region. Species E is medium sized with head width ranging from 1.5 to 2.8 mm. The head is narrowed anteriorly, has relatively slender mandibles and 17 antennal segments. Relatively it is the dominant species in the regions. Species I is larger than the other two species and has head width larger than 2.9 mm. It has pyriform head, 17 antennal segments and robust mandibles. It has not been recorded in any of the earlier studies and may be a new species. The three species were observed foraging in a variety of habitats which include plant roots, leaf litter and wood lying on the soil surface. Occasionally species D and E build mounds which are short and dome - shaped. Mounds of species E were also seen in Addis Ababa at an altitude of 2300 m. The occurrence of *Odontotermes* mounds in the region was also reported by Barnett *et al.* (1987). All areas where *Odontotermes* mounds were seen had dark grey soils indicating the effect of soil types on the mound building behaviour of *Odontotermes*.

The crops attacked by the three species of *Odontotermes* are shown in Table 3.4. Species D was recorded on maize; species E on maize, pepper, grasses and trees. Species I was recorded exclusively on established forestry and fruit trees. On annual crops they feed either on the root system or on the stem under the cover of soil sheeting. They cause damage on forestry seedlings by ring barking the roots and the base of stems, whereas on established trees they exclusively feed on the barks under the cover of soil sheeting. The extent of damage was very low throughout the study areas. All the species were observed causing more damage on wooden structures and rural houses than on growing plants.

Table 3.4 *Odontotermes* attack on field crops, trees and grasses

Species	Crop	Growth stage	% Attack
Species D	Maize	Maturity	3
	Tef	Stack	31
Species E	Maize	Seedling	4
		Maturity	2
	Pepper	Flowering	3
	Grass	Maturity	5
	Eucalyptus	Seedling	4
		Tree	Bark feeding
	Juniper	Tree	Bark feeding
	Syzygium	Tree	Bark feeding
Species I	Mango	Tree	Bark feeding
	Eucalyptus	Tree	Bark feeding
	Coffee	Seedling	Bark feeding

Pseudacanthotermes militaris was more wide spread on undisturbed natural woodlands than on cultivated fields. The crops attacked and extent of attack are shown in Table 3.5. Generally, damage was low throughout the study areas. Its foraging sites included plant roots, crop stubbles, tree trunks, wood pieces lying on the soil surface and cow dung. It is more of a problem on structural wood than on growing crops. Like *Odontotermes*, its damage was wide spread on rural houses particularly in those built in recently cleared woodlands, such as Keto settlement.

Table 3.5 *Pseudacanthotermes* attack on crops, trees and grasses

Crop	Growth stage	Nature of attack	% Attack
Maize	Seedling	Root feeding	2
	Maturity	,, ,,	1
Tef	maturity	,, ,,	1
Sorghum	Seedling	,, ,,	2
Millet	Flowering	,, ,,	1
Pepper	Podding	Stem cutting	1
Grasses	Dry	Shoot feeding	10
Eucalyptus	Seedling	Ring-barking	2
Mango	Tree	Bark feeding	-
Acacia	Tree	Bark feeding	-
Syzygium	Tree	Bark feeding	-

3.3.2 Flight of Alates

Flight times of some of the dominant termites found in western Ethiopia are shown in Table 3.6. All termites were observed swarming during the rainy season, but never two different termite species were observed flying the same day at the same time.

Macrotermes subhyalinus and *Microtermes* spp. swarming occurred at the beginning of the rainy season between March and early June. The period of swarming was always from 19.00 - 19.30 hours local time in the early evening and the duration was for about 30 minutes throughout the study areas. The only exception for *Microtermes* was at Asosa and for *Macrotermes* at Mendi when both species occurred in the same day. During this time the swarming of *Macrotermes* occurred half an hour later. The occurrence of swarming at different times of the year or at different times of the day has been reported for termite species that belong to the same genus (Wood, 1981).

The period and duration of *Odontotermes* swarming was the same as the above two species except the times of the year. In the case of *Odontotermes* swarming took place between the middle and end of the rainy season from late July to early September.

Unlike termites of the subfamily Macrotermitinae which swarm during the early evening, the soldierless termite *Alyscotermes* was observed swarming in the early afternoon from 13.00 - 13.30 hours local time. It was also observed swarming for much longer months from May to the early September. The flight time of *Firmitermes* occurred during the night, but the exact time was not known.

The occurrence of swarming over a long period of time for the same termite indicates that swarming is not a single day phenomenon, it could last for several days. For example, *Microtermes* has been observed to swarm for about two months at Ghimbi between March and May 1988. From the data, it was not possible to conclude whether these termites were from the same colony or different colonies.

The termite species recorded in the region all have subterranean nests. The occurrence of their swarming during the rainy season makes the excavation of the soil very easy for the adults during the initial stage of colony establishment. Ruelle (Nutting, 1969) has shown that wetting of the soil triggers swarming. By repeatedly wetting the nests of *Macrotermes natalensis*, he induced swarming of the colony. The occurrence of swarming by Macrotermitinae in the early evening could be due to behaviourial adaptation in order to avoid predators because predators are known to destroy over 99% of termite alates (Wood and Sands, 1978).

Following swarming, the alates fall to the ground, shed their wings and formed tandem pairs. Tandem pairing continued for a few minutes until suitable nesting sites were located. At one occasion at Bako, a string of up to eight *Microtermes* individuals were seen following one another.

On 20 August 1987 at about 15.30 hours local time in the afternoon some 5000 workers, soldiers and immatures of

Macrotermes were observed migrating above ground on barren lands near Mendi. This is a rare method by which certain termite species establish new colonies and is known as 'sociotomie'.

3.3.3 Abundance of *Macrotermes* mounds and foraging holes

The abundance of *Macrotermes* mounds both on cultivated and grasslands in Menesibu and Ayra-Guliso provinces are shown in Table 3.7. The density of mounds was greater on grasslands than on cultivated lands because farmers regularly destroy termite mounds that are found on cultivated lands by using various traditional methods such as digging and removing the queen or flooding the mounds. Land cultivation by oxen or hoe does not seem to have any effect on *Macrotermes* colonies since the farmers generally avoid ploughing the spots where there are termite mounds. However, mechanical cultivation is known to eliminate mound building termites such as Macrotermes (Wood *et al.*, 1977). The density of *Macrotermes* mounds reported per ha. in the region was 2-3 (Sands, 1976) and 305 (Sanna, 1973). The density reported by the later author was highly exaggerated and seems at least 30 times higher than the actual density.

The result obtained in this study agrees with that reported elsewhere in Africa. The density of *M. subhyalinus* and *M. michaelseni* mounds recorded at Kajiado, Kenya were 8.5 and 9 mounds per ha. respectively (Pomeroy, 1983), 6.45 per ha. for *M. bellicosus* in Southern Guinea Savanna in Nigeria

(Collins, 1981) and 2.2 to 37.5 per ha. in Ivory Coast (Lepage, 1984).

The density of *Macrotermes* foraging holes in Menesibu and Ghimbi provinces were significantly higher on grazed lands as compared to ungrazed adjacent areas (Table 3.8). In areas where there is good vegetation cover the probability of finding food is very high. Therefore, there is no need for foragers to expend large amount of energy by making several foraging holes. In contrast on barren lands or in overgrazed areas the probability of locating food is very low. As a result the foragers are forced to make several attempts before locating food supply.

Wood (1986a) reported 15-20 foraging holes per m^2 in Mendi, whereas Sands (1976) reported 6 foraging holes per m^2 on bare grasslands near Mendi.

Table 3.6 Alate flight dates and times in western Ethiopia

Genera	Locality	Date	Time (hours)
Macrotermes	Mendi	15/5/88	19.30-20.00
	Didesa	30/5/87	19.00-19.30
	Ghimbi	11/3/88	,, ,,
Microtermes	Ghimbi	14/5/87-3/6/87	,, ,,
		11/3/88-8/5/88	,, ,,
	Bako	27/5/87	,, ,,
	Mendi	15/5/87	,, ,,
	Asosa	14/6/87	19.30-20.00
	Nekempt	8/6/87	19.00-19.30
Odontotermes	Nekempt	22/7/87-30/8/87	,, ,,
		29/8/88	,, ,,
	A.Gutin	12/8/87	,, ,,
	Ghimbi	1/6/87-21/8/87	,, ,,
	Nedjo	4/7/88-3/9/88	,, ,,
	Mendi	17/8/87	,, ,,
Alyscotermes	Sasiga	11/5/87	13.30-13.50
	Nedjo	17/5/88	13.00-13.30
Firmitermes	Nekempt	29/8/87	?

Table 3.7 Abundance of *Macrotermes* mounds on cultivated and grasslands

Province	No. of samples	Mound density / ha (mean $\pm$ s.e.) cultivated	grassland
Menesibu	10	5.4 $\pm$ 0.6	6.3 $\pm$ 0.5
Ayra Guliso	15	5.7 $\pm$ 0.4	9.5 $\pm$ 0.8

Menesibu χ^2- test, ns

Ayra Guliso χ^2- test, P < 0.5

Table 3.8. Density of *Macrotermes* foraging holes on grasslands

Site	No. of samples	Foraging holes / m^2 (mean $\pm$ s.e.) grazed	ungrazed
Ghimbi	8	25.4 $\pm$ 2.2	18.1 $\pm$ 2.6
Mendi	8	32.8 $\pm$ 3.2	19.5 $\pm$ 2.2

Ghimbi χ^2- test, P < 0.05

Mendi χ^2- test, P < 0.001

Sampling date

Ghimbi 19/11/87

Mendi 4/12/87

CHAPTER FOUR : PERIODIC VARIATIONS IN FORAGING ACTIVITY

4.1 INTRODUCTION

The various food materials eaten by termites have been reviewed by Noirot and Noirot-Timothee (1969), Lee and Wood (1971), Wood (1978) and Wood and Johnson (1986). The major food resources include plant materials, either living or dead and humus, soil rich in organic matter. Occasionally, some other materials such as fungi, algae, lichens, parts of termite nest and skins of vertebrate corpses are also eaten by termites (Wood, 1978; Wood and Johnson, 1986).

Some termites such as *Mastotermes*, *Psammotermes* and many Macrotermitinae are polyphagous and in consequence they feed on a wide variety of living and dead plant materials (Wood, 1978). Some others such as *Hodotermes*, *Anacanthotermes*, *Drepanotermes*, *Trinervitermes*, certain *Nasutitermes*, *Tumulitermes* and *Syntermes* are specialized grass feeders (Wood and Johnson, 1986). Their diet consists of grass which is harvested during foraging activity. Still some others are also specialized soil feeders and are known only in the family Termitidae and subfamilies Termitinae, Nasutitermitinae and Apicotermitinae. The workers of these groups have mouthparts adapted for soil feeding (Wood, 1978).

Certain lower termites, particularly the families Kalotermitidae and Termopsidae, live and feed entirely inside their food and in consequence do not travel and search for food outside their nest. Such behaviour is also witnessed among many soil feeders in the family Termitidae (Wood and Johnson, 1986). The populations of these termites are usually small and as a result do not require a large amount of food. In contrast, most termites live away from their food and need to travel in search of it. The populations of some of these termites are quite large and require large amounts of food, so they search extensive areas to satisfy their requirements.

Foraging activity is primarily carried out by the worker caste or pseudoworkers which also have the responsibility of feeding the reproductives and soldier castes as well as the immatures, all of which are incapable of feeding themselves. Although searching for food resources is mainly the task of the worker castes, in certain termites soldier castes have been also noted to act as scouts in addition to their main task of defending the colony. Such behaviour has been observed in the Neotropical termite, *Nasutitermes costalis* (Holmgren) where the soldiers search for new food resources and also regulate foraging activities by laying trail pheromone (Traniello, 1981).

Studies have shown that different termites follow different strategies to locate their food. Certain termites such as *Hodotermes mossambicus* (Hagen) **relocate their foraging holes**. means since they have functional compound eyes (Heidecker and Leuthold, 1984). In contrast, many termites are blind and cannot use visual methods; instead they rely on various other techniques. For example, the Formosan subterranean termite, *Coptotermes formosanus* Shiraki has been observed to locate its food at random without any preference for a particular site (Su and Lafage, 1984). *Macrotermes carbonarius* (Hagen) has also been found to use a similar technique to locate its food resources (Matsumoto and Abe, 1979). Other termites, such as the desert subterranean termite, *Gnathamitermes tubiformans* (Buckley) and *Amitermes wheeleri* (Desneux) locate relatively large size surface foods such as herbivore dung and logs by detecting thermal gradients produced by the food; however, they could not locate the same food deeply buried in the ground presumably due to the absence of thermal gradients (Ettershank *et al.*, 1980). Olfactory senses are less effective in locating food sources except when the food is only a few centimetres away, but gustatory senses play an important role once the food is located (Abushama, 1967). Malaka (1980) reported that the distance of food from the nest (14 and 8 cm) has no effect on *Amitermes evuncifer* Silvestri mass foraging when the food is reasonably large.

The way food is available also affects its location by termites. According to French and Robinson (1980), stakes lying on the soil surface were severely attacked by *Heterotermes ferox* (Froggatt) and several other subterranean termites compared to those placed vertically in the ground. In contrast, Usher and Ocloo (1974) reported greater damage by *Amitermes*, *Ancistrotermes*, *Odontotermes* and *Pseudacanthotermes* on the stakes deeply buried in the ground. Similar results were also reported by Wood and Johnson (1986) for *Microcerotemes parvulus* (Sjostedt) in Nigeria. However, El

Bakri (1986) did not find any difference in the foraging activity of *Microtermes* spp. between surface laid baits and vertical baits.

The presence and direction of food resources are communicated to foragers by contact movement and laying trail pheromone between the food and the nest (Stuart, 1969). The trail pheromone is produced by a sternal gland which is located in most species at the base of the fifth abdominal sternite and is considered species specific (Moore, 1974). Trail pheromones serve different functions in other insects. In the case of Hymenoptera, particularly among some parasitoids, trail pheromones are used to prevent other members from searching the same areas (Hassell and Southwood, 1978 ; Greany and Oatman, 1972). According to Stuart (Moore, 1974), certain lower termites such as *Zootermopsis* (Hodotermitidae) lay trail pheromones for recruiting soldiers in times of danger.

Certain termites such as *Macrotermes subhyalinus* and *M. michaelseni* also construct permanent subterranean galleries from their nest to their foraging territories (Lepage, 1983). An excavation study conducted by Darlington (1982b) showed that a colony of *Macrotermes michaelseni* could construct about 6 km of subterranean galleries and 72,000 storage pits in an area of 8000 m^2. Some species also construct Subterranean galleries down to the water table. Lepage (1974) reported the occurrence of Macrotermitinae foraging galleries at a depth of 50 m, close to the water table in Senegal.

With the exception of *Hodotermes*, termites that feed on surface foods construct covered runways between nest hole and the food source (Stuart, 1969). These runways are constructed from soil particles or excreta cemented together by saliva or excreta and protect termites from desiccation and predators (Lee and Wood, 1971; Sands, 1981). The height and width of runways vary depending on the species that construct them and the nature of building materials found in the area. Usher (1974) found that the height of runways constructed by *Pseudacanthotermes militaris* is determined by the size of the minor worker and the width by the nature of the building material and the size of the major workers. The length of runways extend for considerable distances and may not follow the shortest distance to their food source.

The distance foragers travel in search of food varies depending on the species, time of the year and maturity of the colony. A mature colony of *Macrotermes michaelseni* is known to travel up to 50 m from the nest to search for food (Darlington, 1982b). This indicates if there are termite colonies within 50 m distance from a field, the foragers could attack crops. A closely related species *Macrotermes subhyalinus* was noted to forage near the nest just after the rain and further away from the nest during the dry season (Lepage, 1977b). Such foraging strategy would help to protect foragers from being washed away by flood and systematically exploit food resources. A colony of *Macrotermes michaelseni* has been reported to forage in an area of 130 to 600 m^2 per month (Lepage, 1981). Smaller termites such as *Microcerotermes* and *Microtermes* were found to have smaller foraging territories which is estimated at 31.8 m^2 and 18.2 m^2 per colony respectively (Badawi *et al.*, 1984). A positive correlation was also found between the height of *Odontotermes redemanni* (Wasmann) mounds and the area foraged (Banerjee, 1975). Large mounds generally indicate large colonies that require a large amount of food.

The food collected by the foragers is transported to the nest via different means depending on the species. Certain grass harvesting termites, such as *Trinervitermes*, carry small pieces of grass on their mandibles to the nest (Sands, 1961; Ohiagu, 1979). Others such as *Macrotermes michaelseni* carry the collected food to the nest in two different ways (Lepage, 1977b). They either ingest food in their digestive tube or carry pieces of food to their nest. Knowledge of the way termites transport their food to the nest is essential the bait method of pesticide application is to be improved.

Termites are known to exhibit seasonal variations in their foraging activities (Lepage, 1983), mound building behaviour (Sheppe, 1970) and swarming (Lee and Wood, 1971). Bouillon (1970) suggested that seasonal variations in foraging activities are more evident in savanna than forest areas and in areas where there is considerable variation in climate, such as temperate regions as opposed to tropical areas and in areas where there is drastic change in food supply as opposed to areas where the changes in food supply are not so profound. Haverty *et al.* (1974) also reported that temperature and moisture are important factors controlling foraging activities in desert grassland in Arizona. Seasonal variation in foraging activity is also affected by the presence of sexual broods in a colony. Bodot (1967) reported the most foraging activity when reproductive nymphs are present in the colony and lowest after the swarming of winged reproductives.

Certain termites forage predominantly during the wet season, others forage during the dry season and still some others especially in the tropics forage throughout the year. The typical wet season foragers include the different species of *Microtermes* (Wood and Johnson, 1986; El Bakri, 1986) and the dry season foragers are *Odontotermes wallonensis* (Veeranna and Basalingappa, 1981), *Odontotermes* spp. (Collins, 1981; Bagine, 1982), *Trinervitermes biformis* (Patel and Patel, 1954) and *Trinervitermes geminatus* (Ohiagu, 1979). It is very difficult to generalize foraging activities of termites since they vary from one group of termites to another and even among closely related species as was observed among *Trinervitermes* spp. (Sands, 1961). Therefore, it is important to make continuous observations in order to understand the foraging behaviour of any particular species.

Diurnal variations in foraging activities have been studied mostly in those termites that forage in the open as they are convenient groups for making observation. Environmental conditions are the most important factors determining diurnal foraging activities, especially temperature. Termites are known to forage when the outside temperature does not vary considerably from that of the nest (Bouillon, 1970). The other factor that could affect diurnal foraging activity is predation. Generally, herbivorous insects are active during night time when their natural enemies are less active (Hassell and Southwood, 1978).

Nocturnal foraging was observed among certain termite species such as *Macrotermes michaelseni* (Lepage, 1981), *Odontotermes redemanni* (Banerjee, 1975) and *Odontotermes wallonensis* Wasman (Veeranna and Basalingappa, 1981). Some other termites such as *Trinervitermes geminatus* (Wasmann) were observed to forage at Mokwa, Nigeria during the dry season for 2-4 hours daily, either early in the morning, in the evening or during both periods (Ohiagu, 1979; Ohiagu and Wood, 1976).

The foraging behaviour of termites causing crop damage in Ethiopia is not known. As a knowledge of foraging activities can form the basis for understanding the damage caused by termites and for determining the best time and most effective method of applying control measures, particularly chemical control, field studies were conducted to determine the seasonal and diurnal foraging activities of termites damaging crops in western Ethiopia.

4.2 MATERIALS AND METHODS

4.2.1 Seasonal Variations in Foraging Activity

Foraging activity was studied on bushlands, fallow lands, afforestation areas and cultivated lands.

a) Bushland and fallow land - the bushland at Sasiga studied between June 1987 to June 1988 and fallow land at Ghimbi between June 1987 to December 1988. The trial plots in both areas were 45 x 95 m and were about 50 m away from the nearest cultivated fields. In each area 200 untreated *Eucalyptus* wood baits each 10 x 2 x 2 cm (Plate 4.1) were laid out on a 5 x 5 m grid on the soil surface and tamped down by foot so that they remained in position. The location of each bait was marked by placing wooden pegs at Sasiga and big stones at Ghimbi at about 25 cm distance from the baits so that they could be located at ease, particularly during the rainy season when grasses grow tall and hide the baits.

b) Afforestation site at Mendi - this study was conducted between June and December 1988 for seven months. The plot size was 45 x 45 m and a total of 100 *Eucalyptus* wood baits were placed on a 5 x 5 m grid, as above.

c) Cultivated land in 1987 - this study was conducted at Sasiga, Ghimbi-1 and Ghimbi-2 on fields in which termite control trial were located. The wood baits were spaced at 2.25 m intervals between rows and 2 m within rows in the monitoring areas of eight control plots at Sasiga and Ghimbi-1 and four control plots at Ghimbi-2, where there were only four control plots. At Sasiga and Ghimbi-1 200 wood baits were used for the study while at Ghimbi-2 100 wood baits were used.

d) Cultivated land in 1988 - cultivated lands at Bako, Didesa, Ghimbi, Henna, Nedjo and Mendi were studied. At Bako, Didesa and Nedjo wood baits were placed in four control plots and in

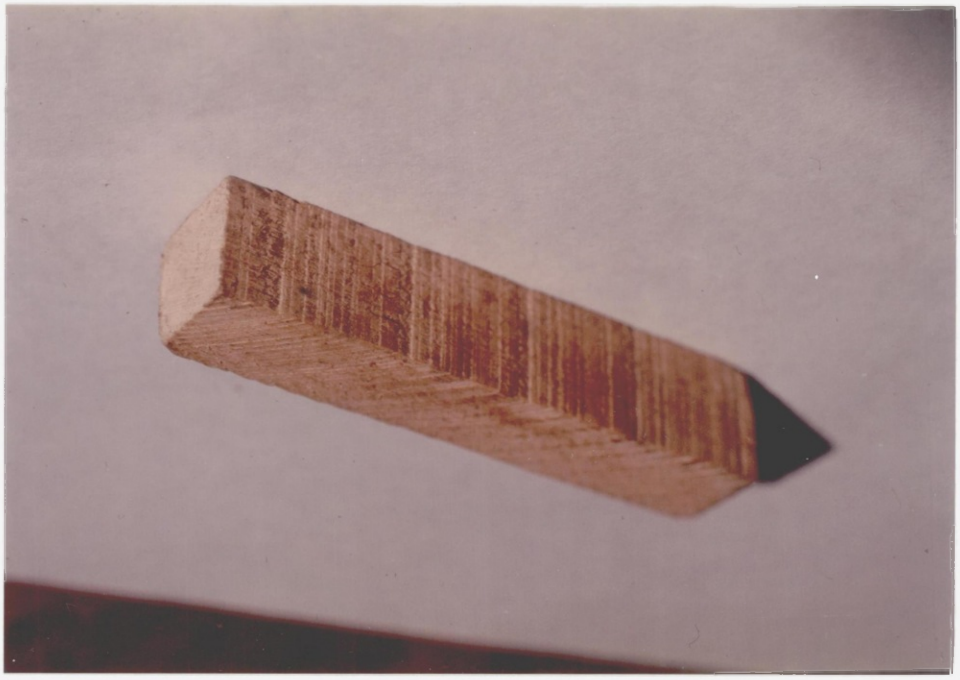


Plate 4.1 Wood baits used to monitor foraging activity

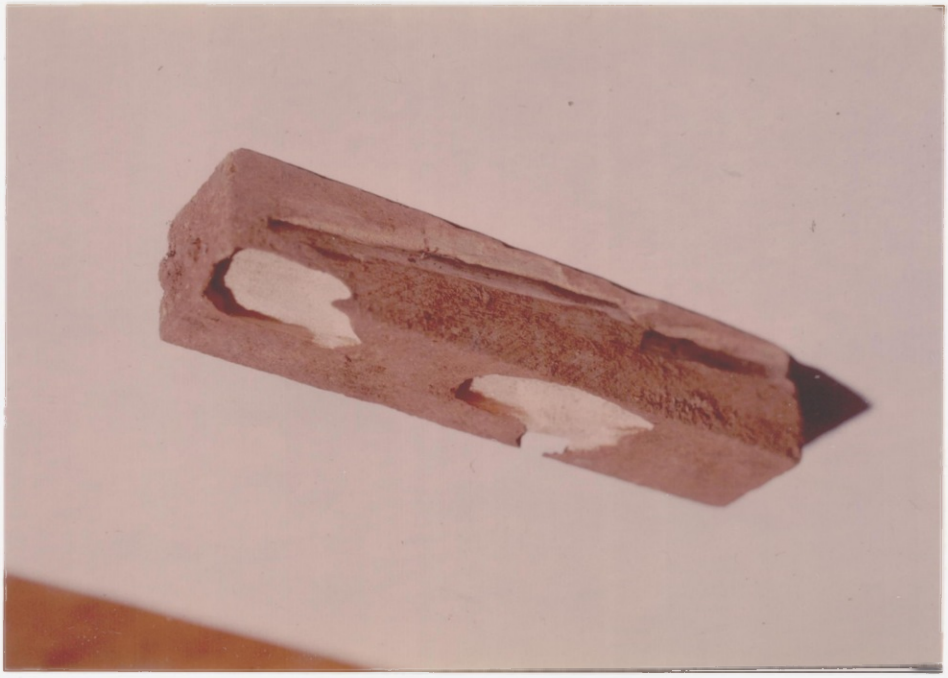


Plate 4.2 Wood baits attacked by *Microtermes* spp.

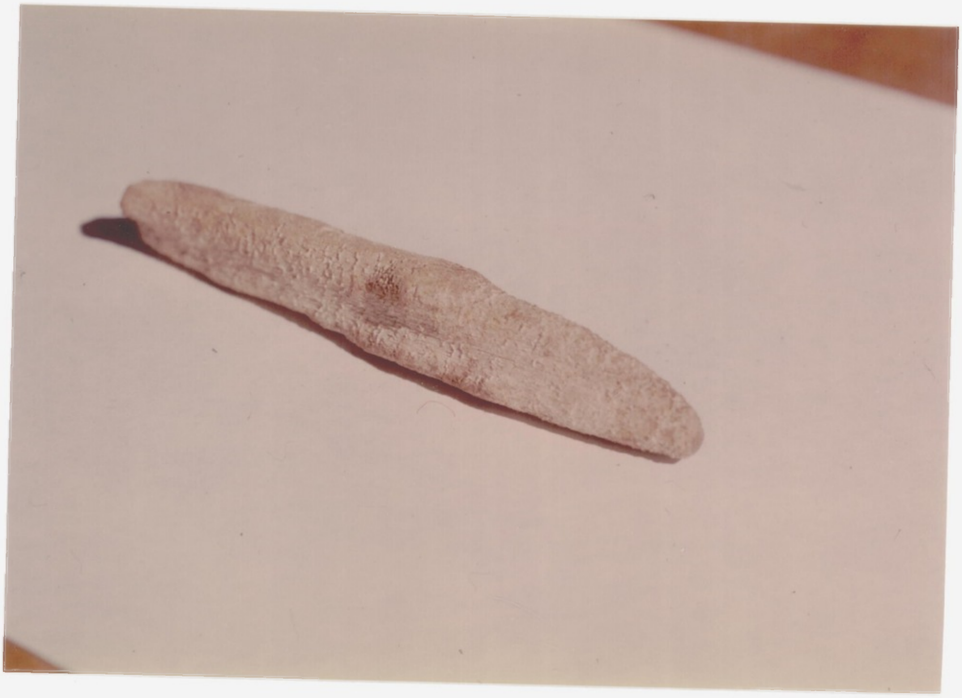


Plate 4.3 Wood baits attacked by Macrotermes subhyalinus

each control plot 12 baits were spaced at 1.5 m interval between rows and 2 m interval within rows. At Mendi, Henna and Ghimbi 8 wood baits were placed on five control plots at an interval of 1.5 m between rows and 4 m within rows.

Inspections in all areas were made at about three to four week intervals, either early in the morning or late afternoon to minimize the probability of not finding the foraging population of some termites which might suspend their activities during the hottest period of the day. During inspection, each wood bait was lifted up and carefully checked for the presence or absence of attack, the species of termite present and the approximate numbers of them both on the baits and the ground. If there was an attack on the bait and termites were not present at the time of data collection, their identities were determined by the characteristic feeding marks left by the foraging workers. Baits which had been attacked considerably were removed and replaced with a new bait. Baits slightly attacked, especially by *Microtermes*, were placed on an unattacked side.

The percentage of baits attacked and the mean foraging population per inspection period were recorded. From these data, the mean percentage of baits attacked and the mean foraging population per month were also calculated and correlated with total monthly rainfall. Foraging activity variations between different sites and between 1987 and 1988 were analyzed by using an analysis of variance after arcsine transformation of the data.

4.2.2 Diurnal Variations In Foraging Activity

These studies were carried out on bushland at Sasiga and fallow land at Ghimbi-1 on the same fields where seasonal foraging activity studies were conducted. Inspections were made at about four month intervals. At Sasiga inspections were made in July and November 1987 and in March 1988. At Ghimbi inspections were made in August and November 1987 and in March 1988. The 200 wood baits placed at each site were grouped into 50 blocks each with four baits. Every two hours for 24 hours continuously, four blocks consisting of 16 baits were selected partially at random as none of the baits were checked more than once during the 24 hour inspection period. The presence or absence of attack, termite species present and their approximate number were checked. Baits attacked were replaced with a new one.

4.2.3 Seasonal Feeding Habits

This study was conducted at two sites, Ghimbi-1 and Melka Hola both of which are in Ghimbi Province. Ghimbi-1 was located on grassland and occupied an area of about two hectares. Melka Hola was located on a steep sloping afforestation site where *Eucalyptus* seedlings have been planted for several years and most had been damaged by termites. In both sites 20 quadrats each 4 m^2 were selected at intervals of 10 m across a diagonal of the field. At each site termite species present and their food resources were recorded. The plant materials in both areas were categorized into woody litter, dead tree, standing grass, grass litter, dung etc. and observations were made five times in both areas.

4.3 RESULTS AND DISCUSSION

4.3.1 Seasonal Foraging Activity

The most abundant foraging species in the study areas were *Microtermes* nr. *vadschaggae*, *Microtermes aethiopicus*, *Macrotermes subhyalinus* and *Pseudacanthotermes militaris*.

Microtermes nr. *vadschaggae* and *Microtermes aethiopicus* were observed attacking wood baits in a similar way and occasionally both species were found foraging on the same bait at the same time. They attacked wood baits starting from the points of contact with the soil and penetrated inside the bait by excavating and filling the attacked parts with fine soil particles (Plate 4.2). Unless the baits were lifted up and the lower side checked, it was not possible to determine whether there had been attack or not. The baits that were not in firm contact with the soil were rarely attacked.

Microtermes nr. *vadschaggae* foraged at a considerably higher rate than *Microtermes aethiopicus* in all areas where the study was conducted; however, both species showed similar trends in their foraging activities (Figures 4.1-4.12). They foraged at a significantly higher rate during the wet season as compared to the dry season (Tables 4.1-4.2). Their foraging during the dry season was negligible in all sites except at

Ghimbi where there was greater activities. Even here, the activity was significantly lower during the dry season.

Table 4.1 Variations in wood bait attack by *Microtermes* nr. *vadschaggae* between wet and dry seasons

		% baits attacked (mean ± s.e.)	
Locality	Habitat	wet season	dry season
Sasiga	Woodland	19.3 ± 2.4	3.2 ± 1.3
Sasiga	cultivated	17.3 ± 2.3	1.7 ± 1.2
Ghimbi-1	Fallow	42.8 ± 2.0	36.0 ± 2.6
Ghimbi-2	cultivated	40.3 ± 2.2	28.0 ± 5.7

Table 4.2 Variations in wood bait attack by *Microtermes aethiopicus* between wet and dry seasons

		% baits attacked (mean ± s.e.)	
Locality	Habitat	wet season	dry season
Sasiga	woodland	5.0 ± 0.5	1.2 ± 0.4
Ghimbi-1	fallow land	18.4 ± 1.0	11.5 ± 1.4

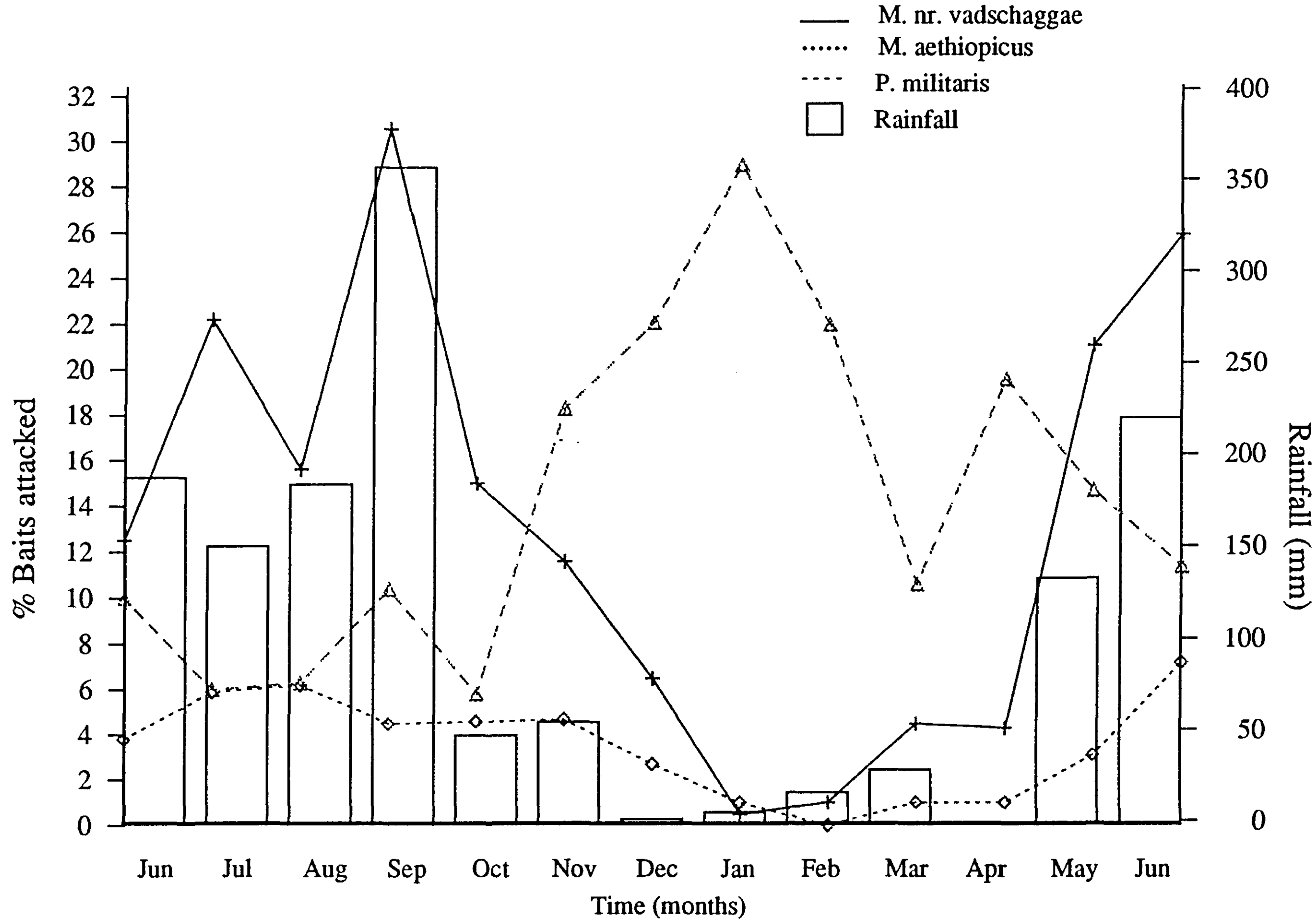


Figure 4.1 Relationship between seasonal foraging activities of Microtermes nr. vadschaggae, M. aethiopicus and Pseudacanthotermes militaris and monthly rainfall on woodland at Sasiga

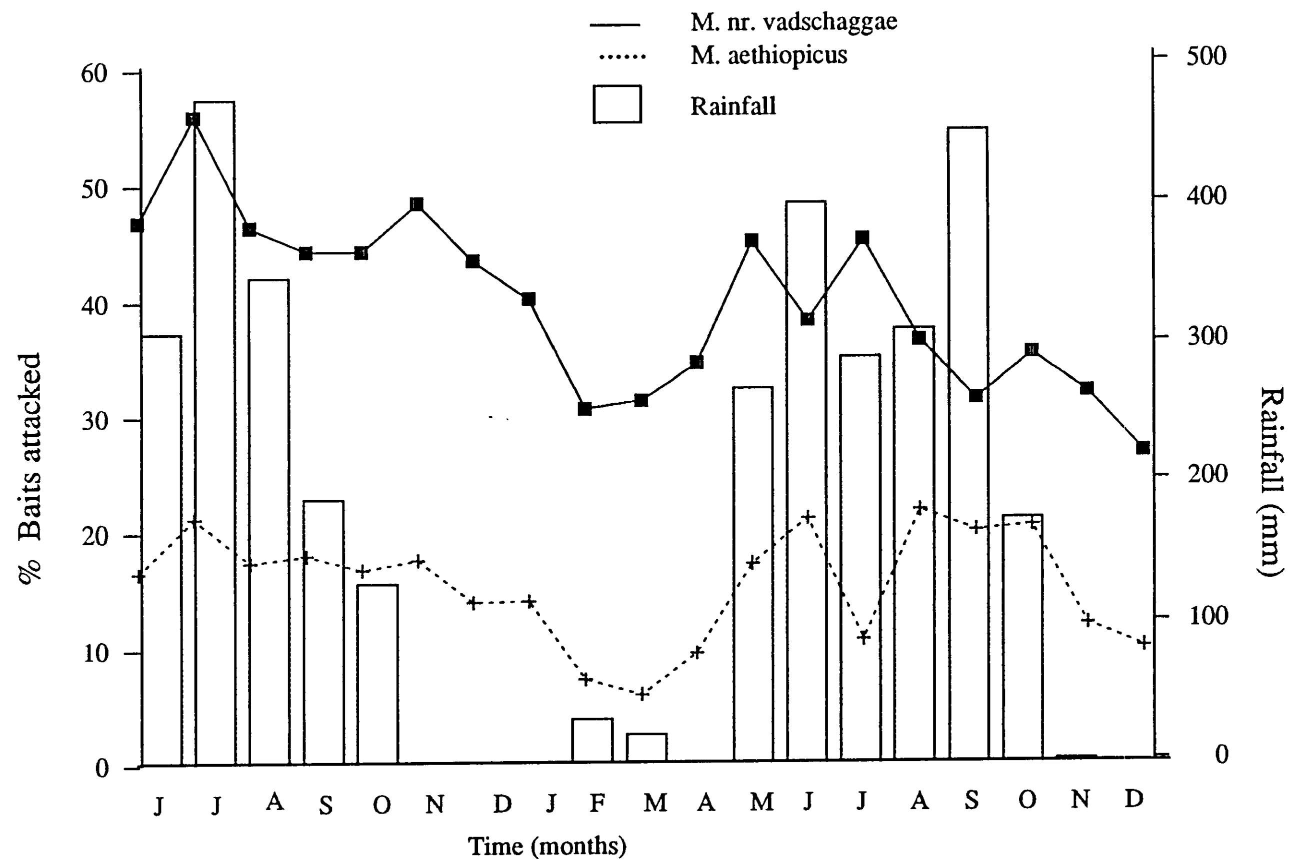


Figure 4.2 Relationship between seasonal foraging activities of <u>Microtermes</u> nr. <u>vadschaggae</u> and <u>M.</u> <u>aethiopicus</u> and monthly rainfall on fallow land at Ghimbi - 1

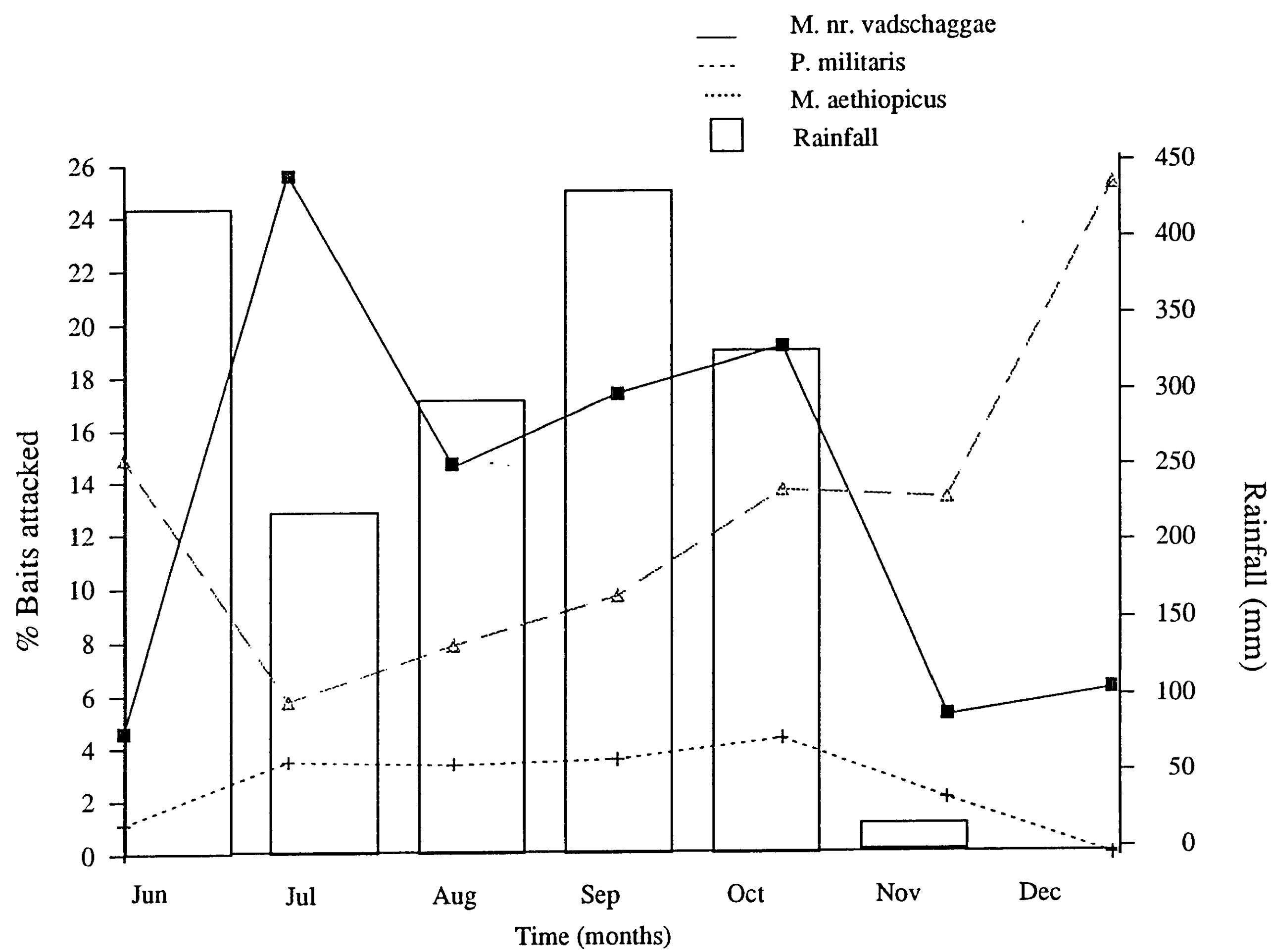


Figure 4.3 Relationship between foraging activities of Microtermes nr. vadschaggae, M. aethiopicus and Pseudacanthotermes militaris and monthly rainfall on afforestation site at Mendi

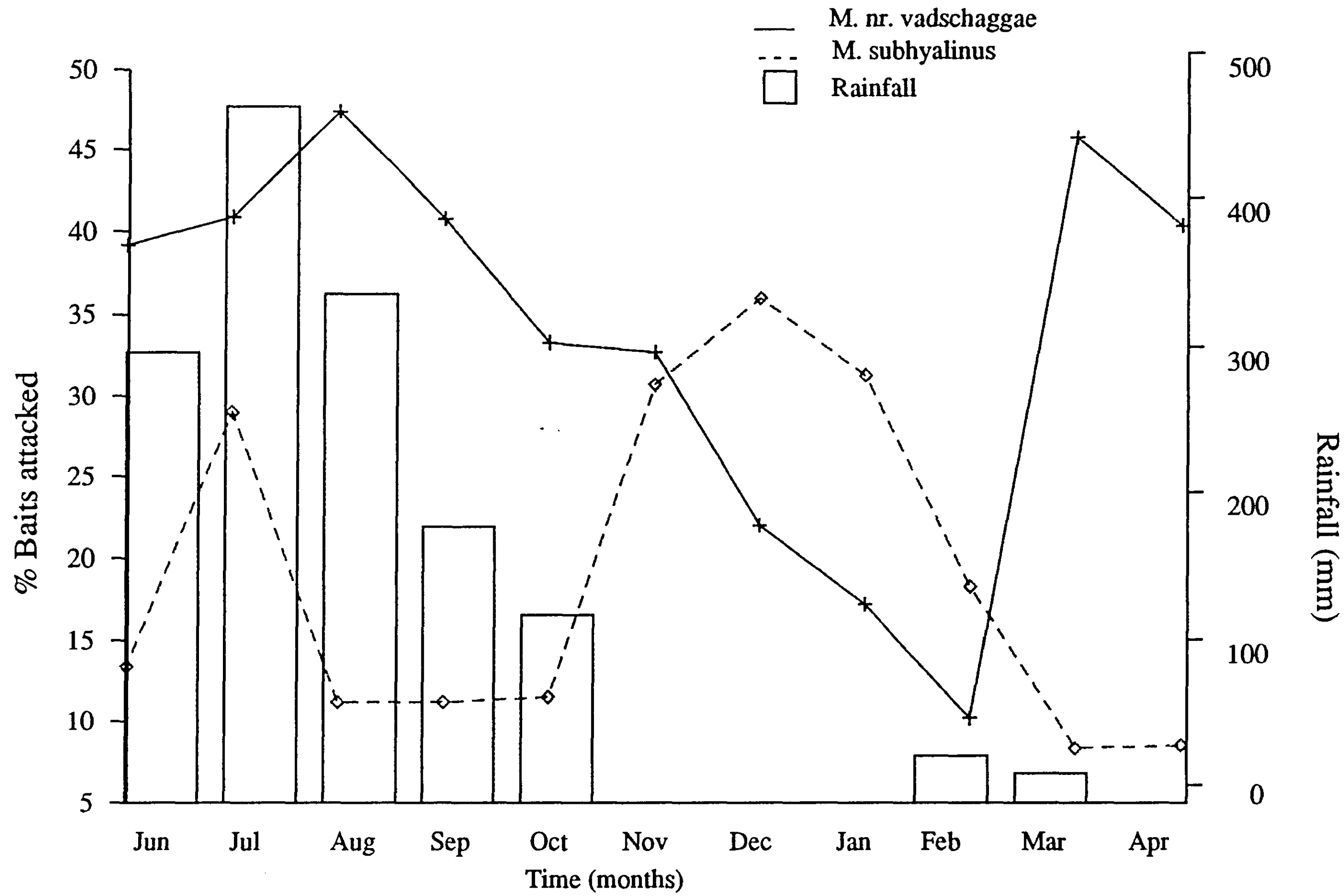


Figure 4.4 Relationship between foraging activities of Microtermes nr. vadschaggae and Macrotermes subhyalinus and monthly rainfall on cultivated land at Ghimbi-2

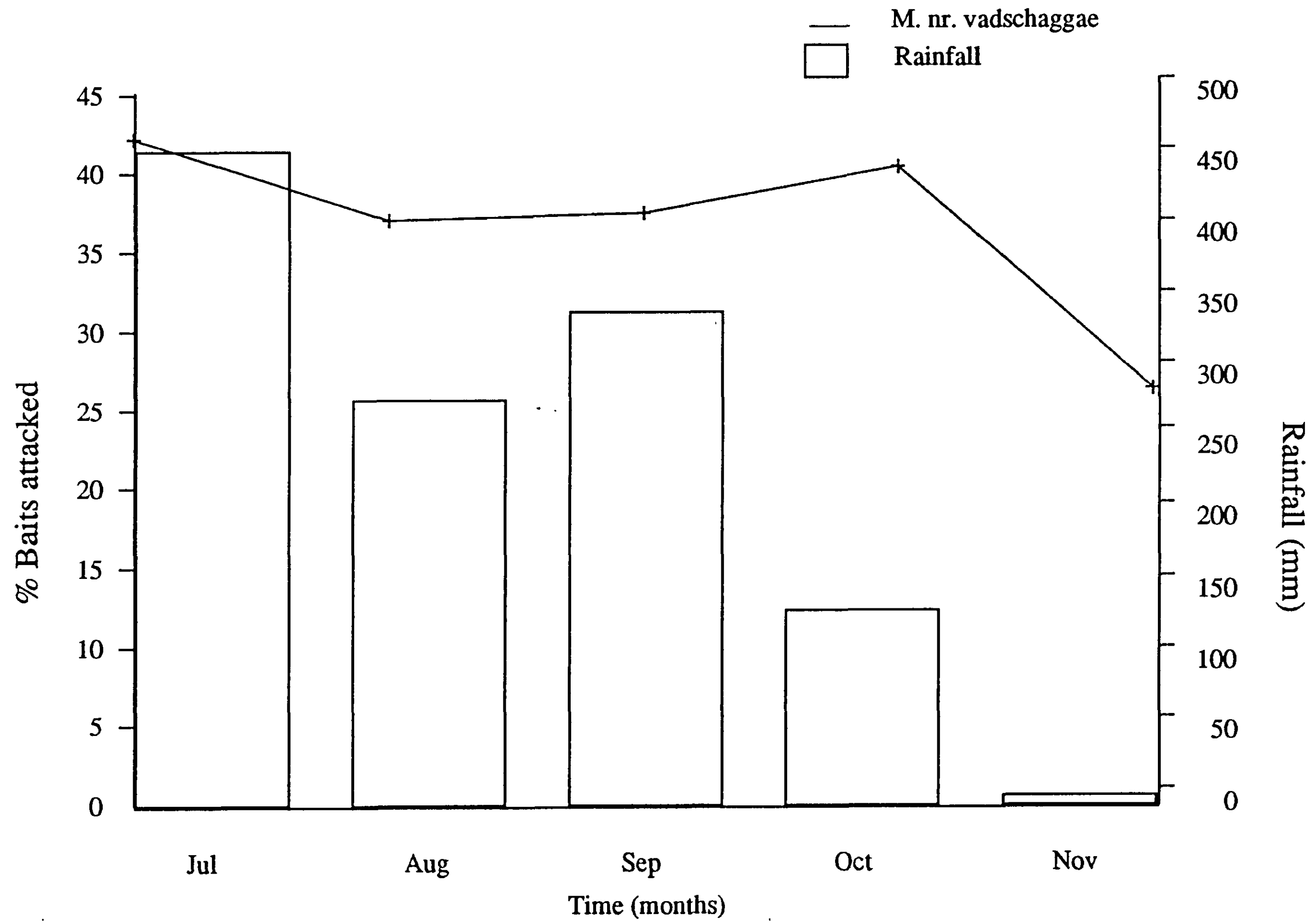


Figure 4.5 Relationship between foraging activities of Microtermes nr. vadschaggae and monthly rainfall on cultivated land at Nedjo

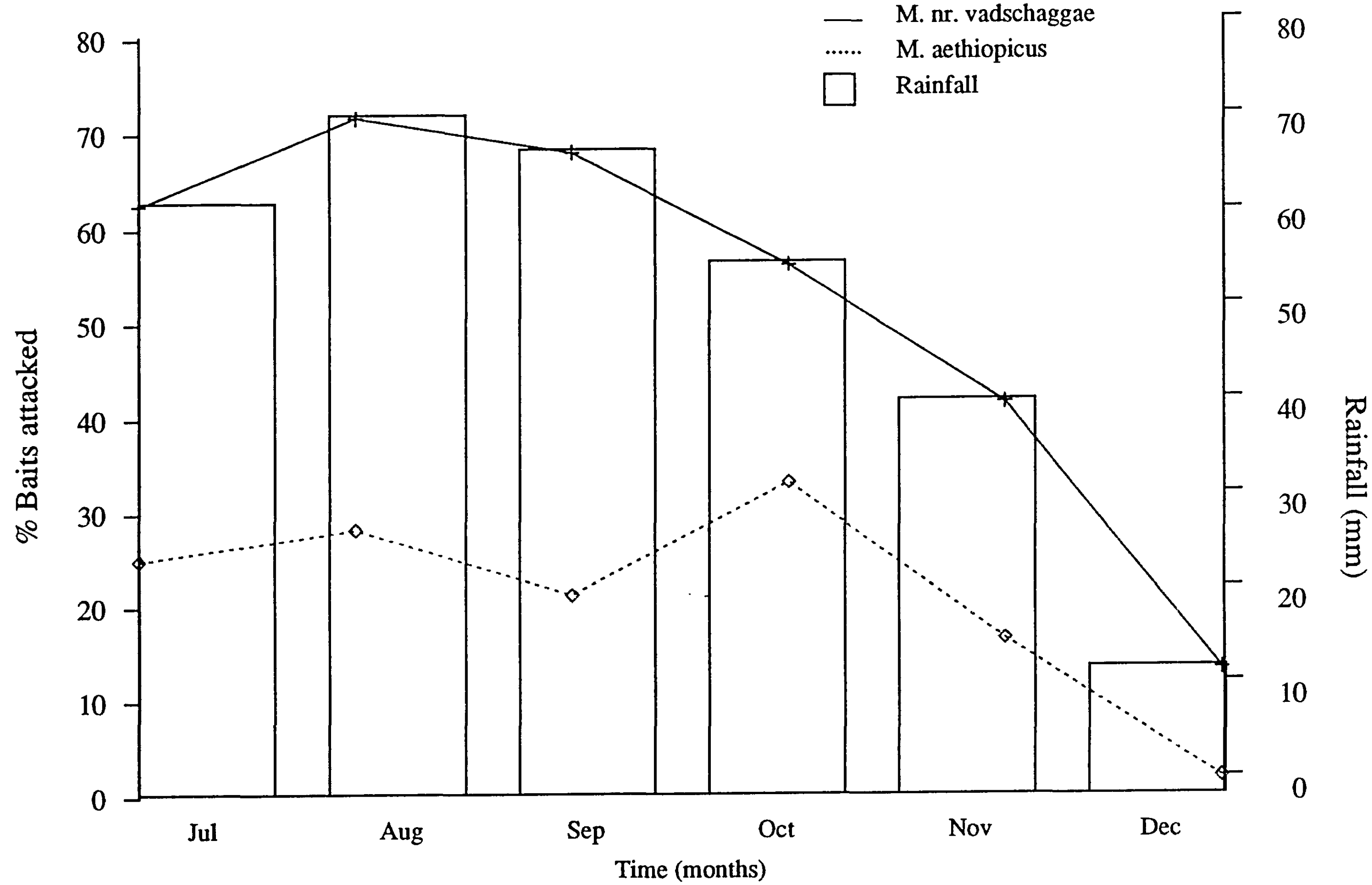


Figure 4.6 Relationship between foraging activities of Microtermes nr. vadschaggae and M. aethiopicus and monthly rainfall on cultivated land at Didesa

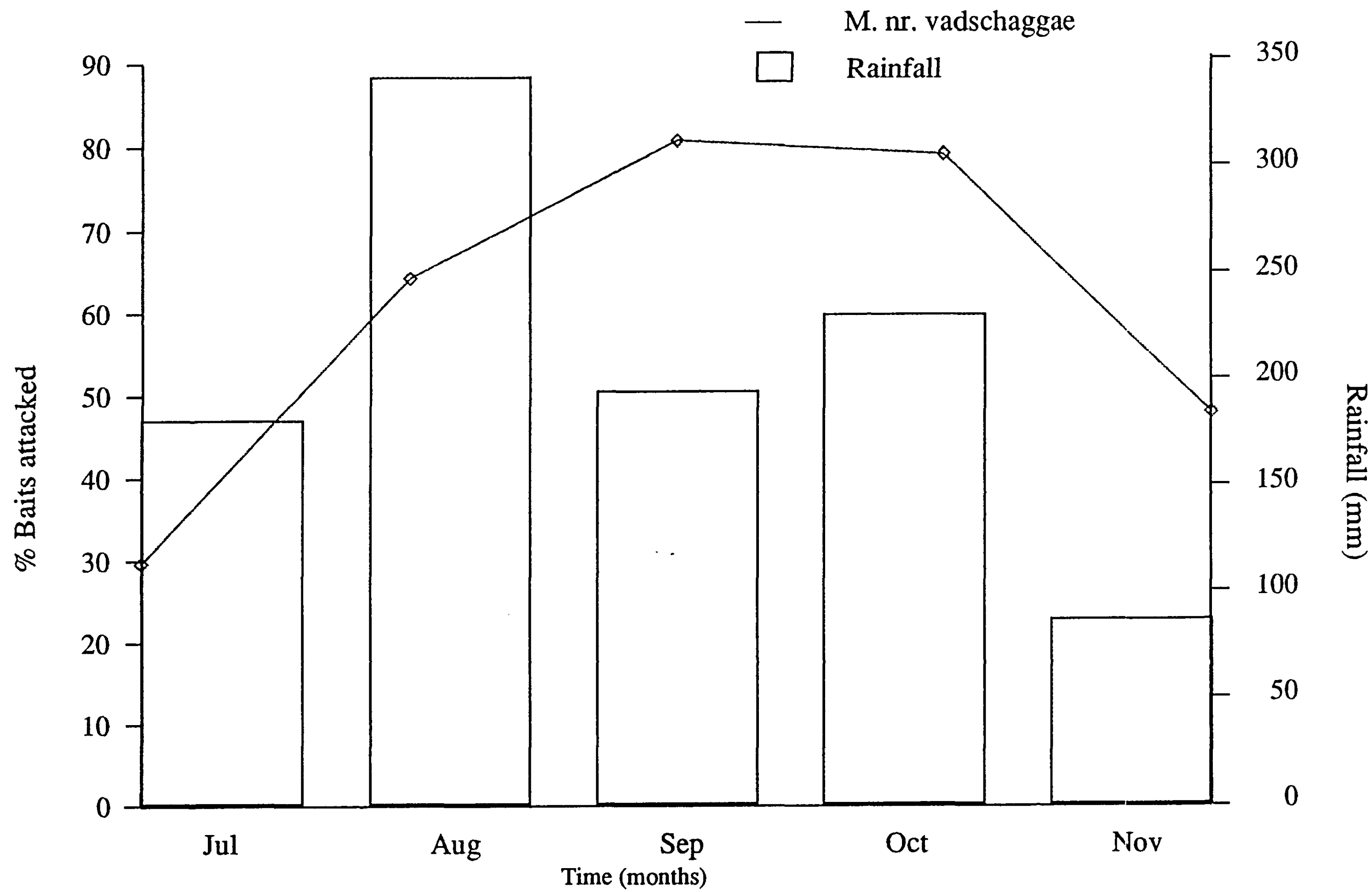


Figure 4.7 Relationship between foraging activities of <u>Microtermes</u> nr. <u>vadschaggae</u> and monthly rainfall on cultivated land at Bako Agricultural Research Center

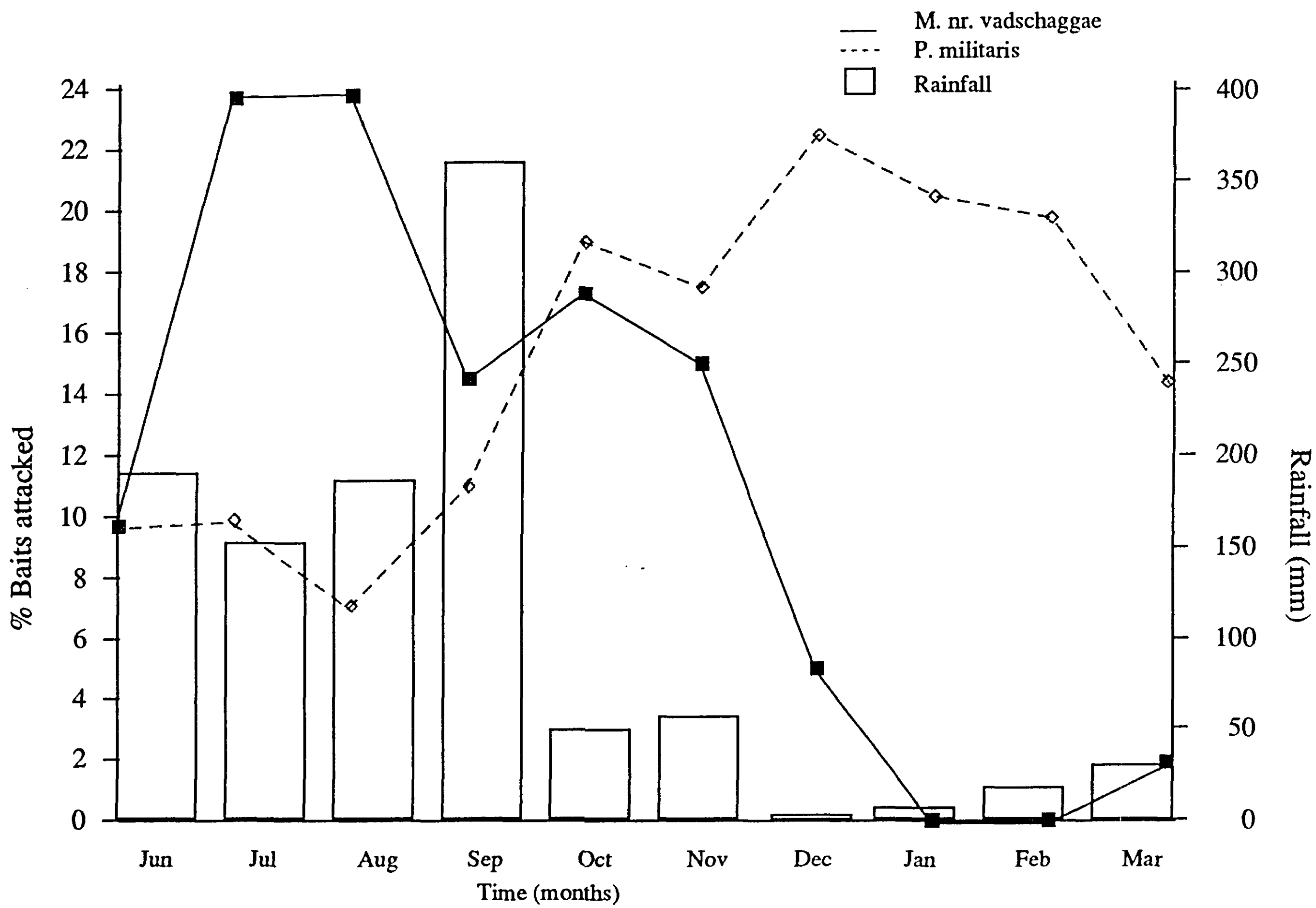


Figure 4.8 Relationship between seasonal foraging activities of Microtermes nr. vadschaggae and Pseudacanthotermes militaris and monthly rainfall on cultivated land at Sasiga

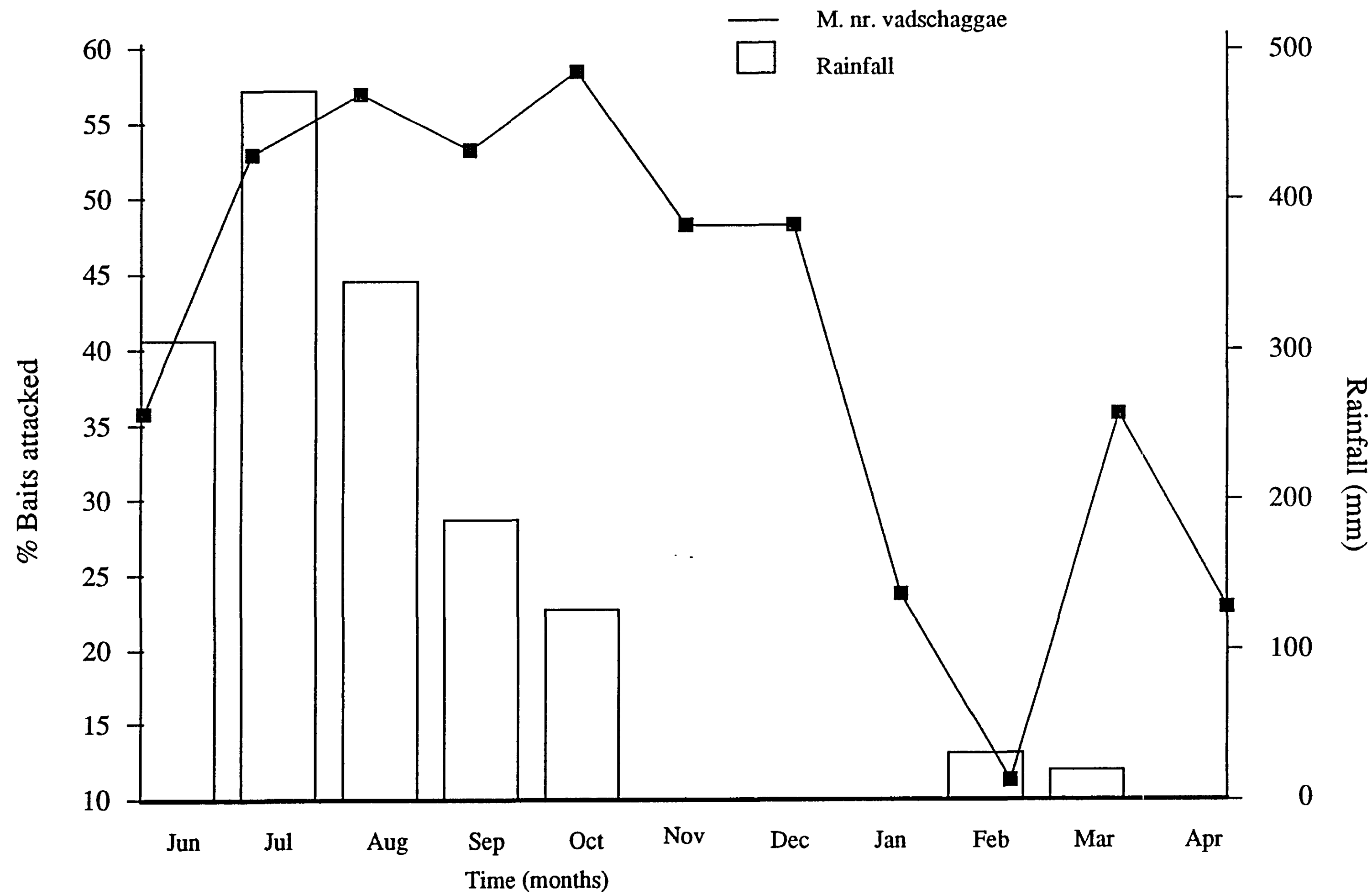


Figure 4.9 Relationship between seasonal foraging activities of Microtermes nr. vadschaggae and monthly rainfall on cultivated land at Ghimbi-1

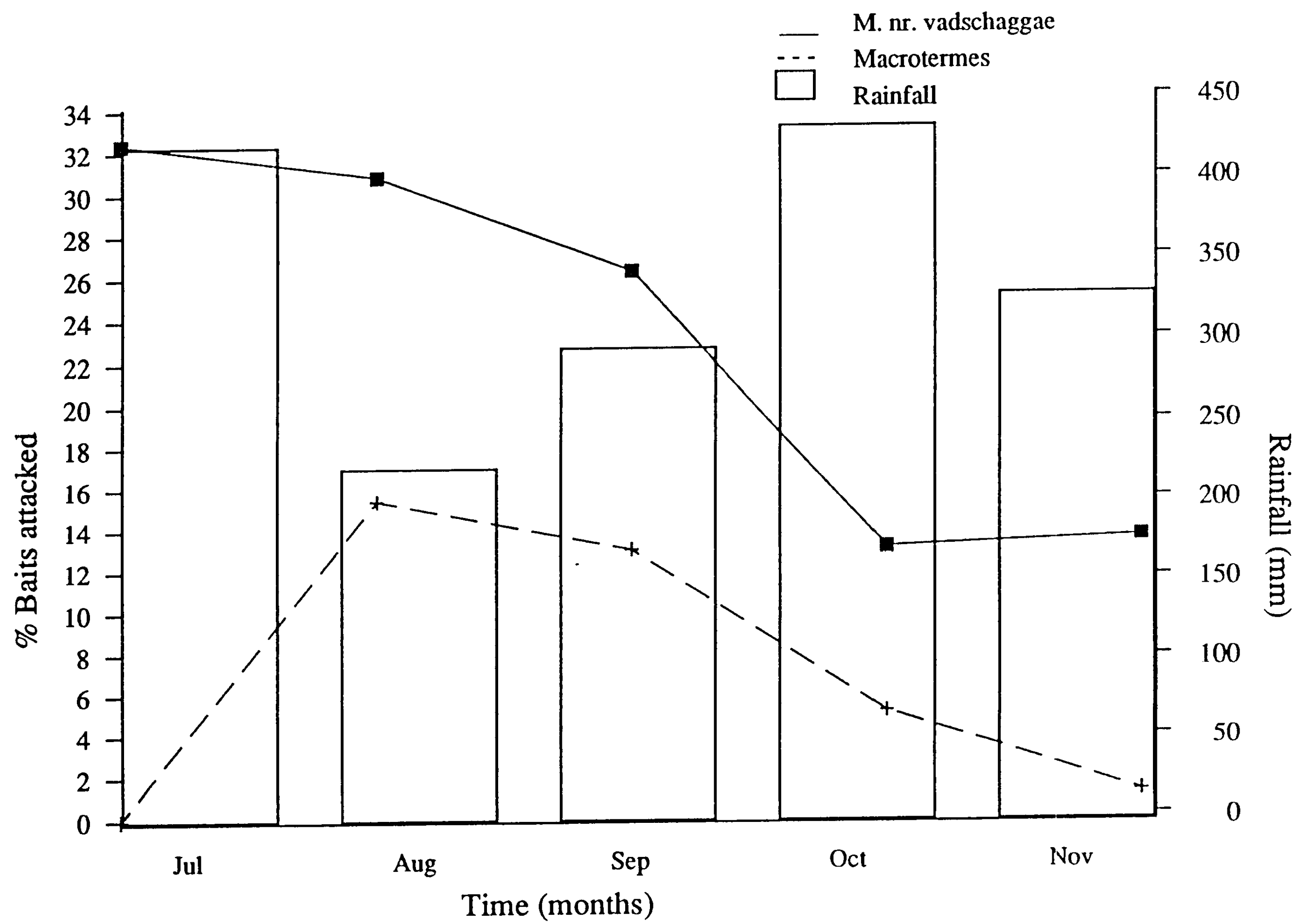


Figure 4.10 Relationship between foraging activities Of Microtermes nr. vadschaggae and Macrotermes subhyalinus and monthly rainfall on cultivated land at Mendi

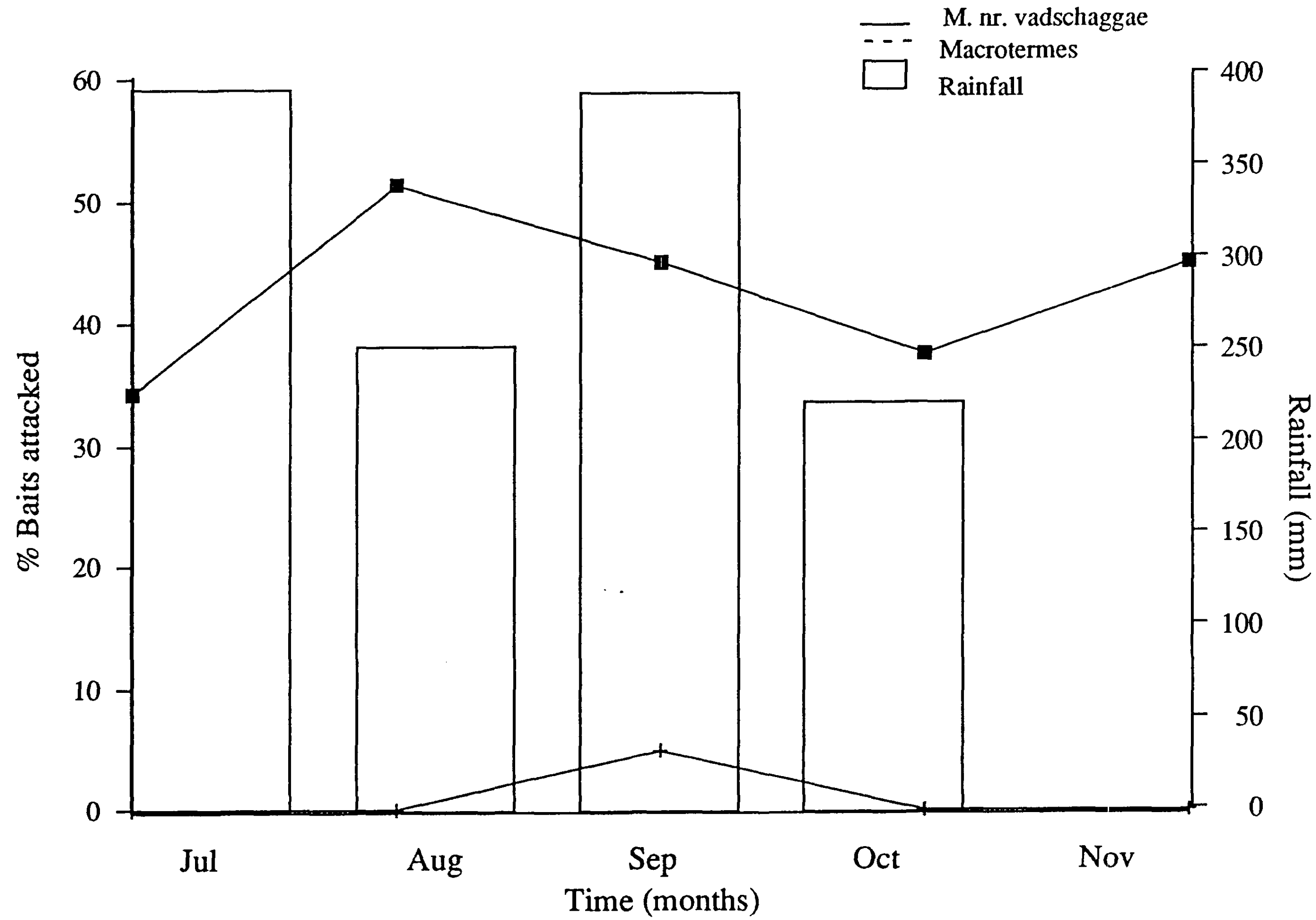


Figure 4.11 Relationship between foraging activities of Microtermes nr. vadschaggae and Macrotermes subhyalinus and monthly rainfall on cultivated land at Henna

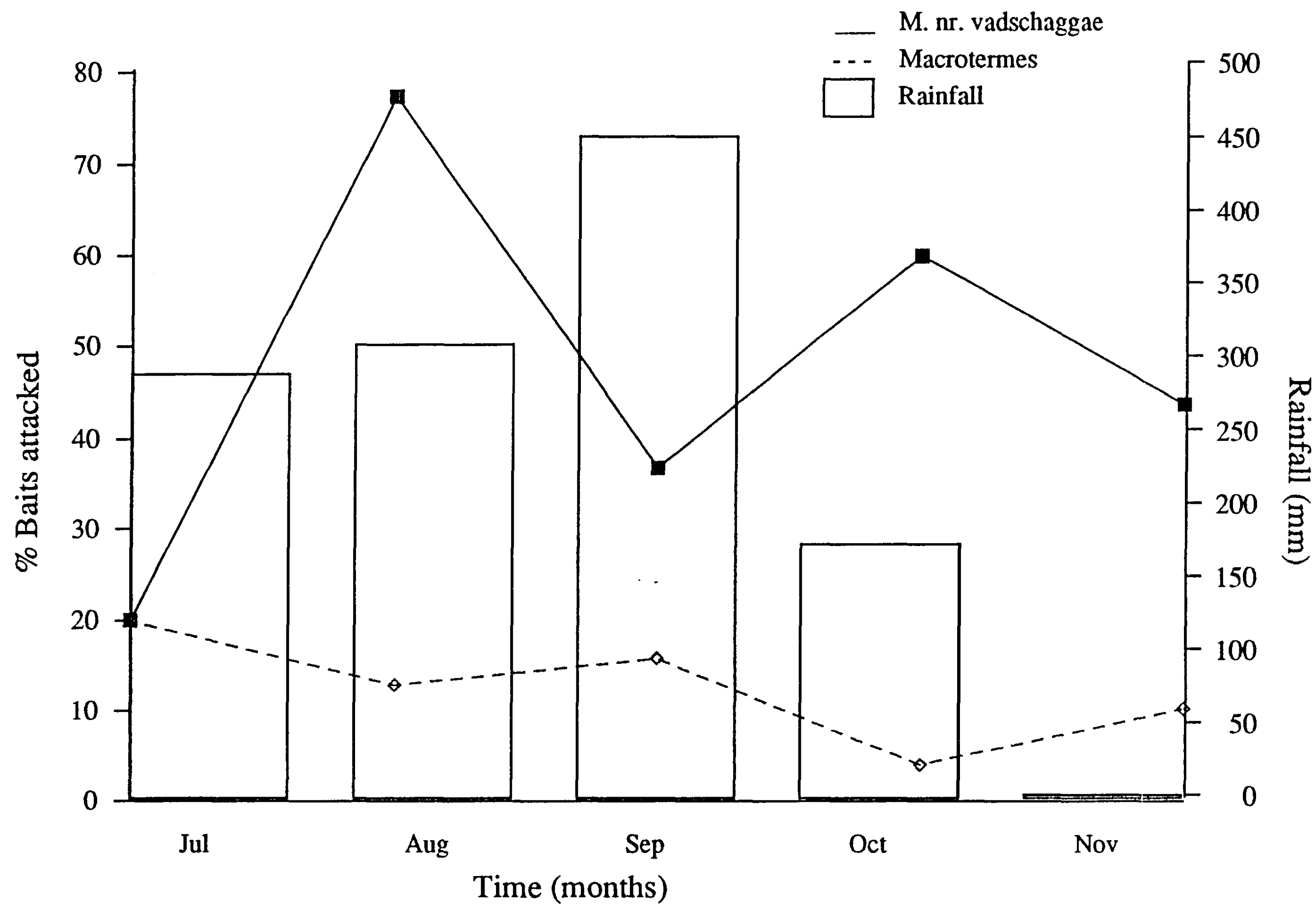


Figure 4.12 Relationship between foraging activities of Microtermes nr. vadschaggae and Macrotermes subhyalinus and monthly rainfall on cultivated land at Ghimbi-2

There was a positive relationship between the percentage of baits attacked by both species of *Microtermes* and monthly total rainfall (Figures 4.13-4.14). Especially in hot lowland areas such as Sasiga and Didesa over 88% of the variation in foraging activity of *M.* nr. *vadschaggae* was due to rainfall. Lack of significant relationship at Bako (Fig. 4.7) seems due to lack of changes in the rainfall between the different months. In the case of *M. aethiopicus* the effect of rainfall was not as strong as it was on *M.* nr. *vadschaggae*, only about 66% of the variation could be attributed to variations in monthly rainfall.

In over 80 % of the study sites, peak foraging activities of *Microtermes* nr. *vadschaggae* were recorded after the beginning of heavy rain (July and August). It was also noted that the further the area was to the west the earlier the peak foraging activity occurred (Figures 4.1 - 4.12). This can be explained by the difference of the time at which the onset of rainfall occurred. In areas with early rainfall, peak foraging activity also occurred early and vice versa.

This result showed that rainfall is one of the most important factors that determine the foraging activities of *Microtermes* spp. However, why *Microtermes* spp. prefer the wet period for their foraging activity is not known. Collins (1981) suggested that the reason could be to minimize the risk of desiccation since they are susceptible to dehydration. This is very unlikely to be the sole reason since other termites that forage in the dry season are also susceptible to

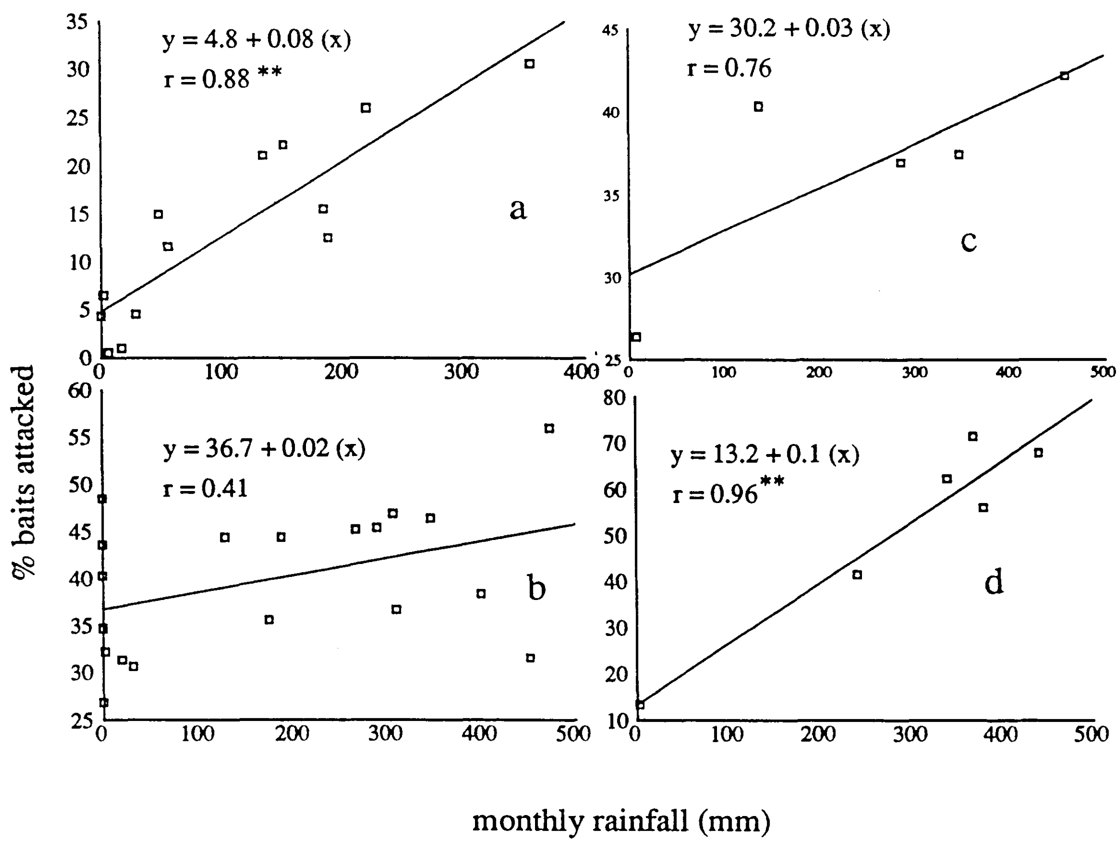


Figure 4.13 Relationship between <u>Microtermes</u> nr. <u>vadschaggae</u> foraging activity and total monthly rainfall

(a) Sasiga bushland (c) Nedjo cultivated land

(b) Ghimbi fallow land (d) Didesa cultivated land

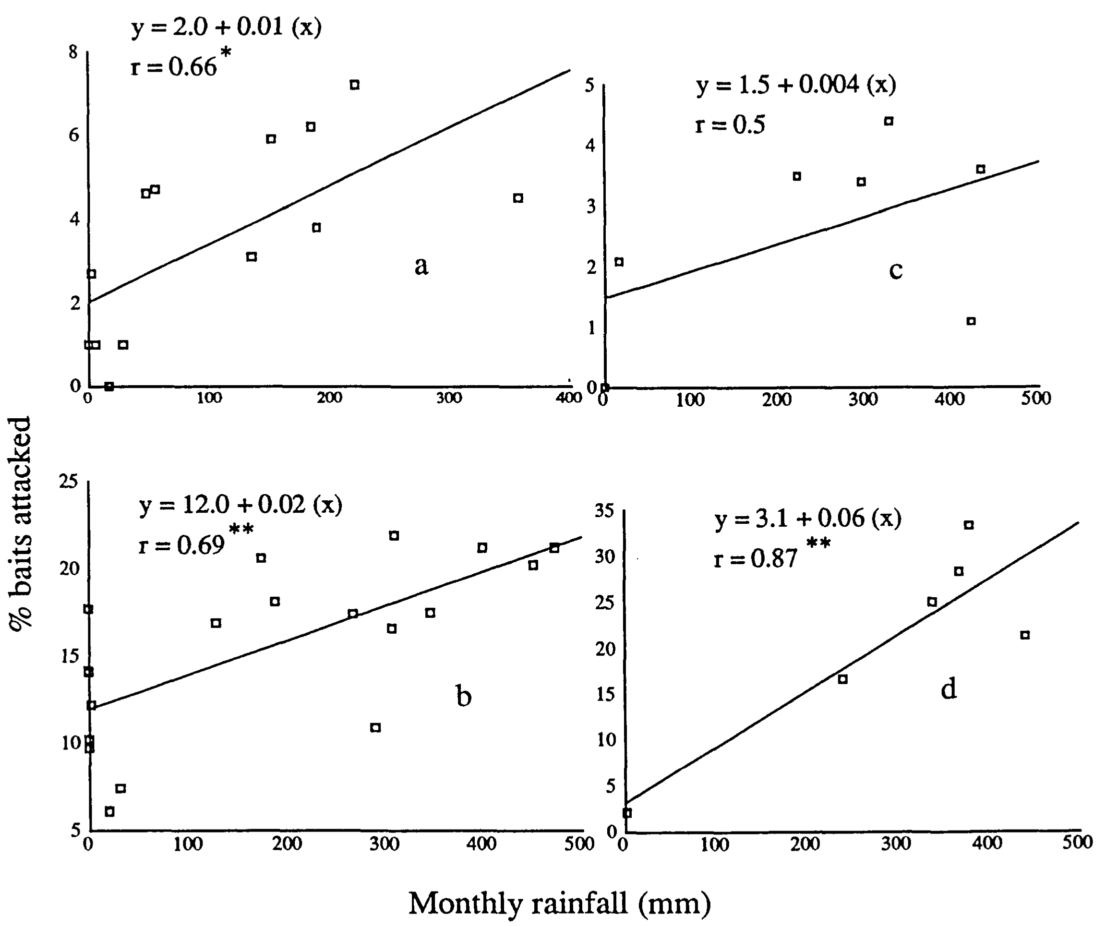


Figure 4.14 Relationship between Microtermes aethiopicus foraging activity and total monthly rainfall

(a) Sasiga bushland
(b) Ghimbi fallow land
(c) Mendi afforestation
(d) Didesa cultivated land

desiccation in the dry season. Whatever the cause might be, the increased activities of *Microtermes* spp. during the rainy season indicate that these termites are more likely to be a pest during the rainy season as opposed to the dry season.

Irrigation in an area extended the foraging activities of *Microtermes* into the dry season (Wood and Kambal, 1986). Wood and Johnson (1978) have shown that during the dry season *Microtermes* spp. move down into the soil and forage in plant roots. In Sudan, *Microtermes najdensis* Harris fungus combs have been found at depths of 8-10 m (Pearce *et al.*, 1986).

The occurrence of more foraging activity of *Microtermes* spp. during the wet season was also reported by Wood *et al.* (1977), Wood and Johnson (1978), Collins (1981), Johnson *et al.* (1981), Ferrar (1982), El Bakri (1986) and Wood and Kambal (1986).

Some other termites have also been reported to prefer the wet season for their foraging activities. A positive correlation was observed between the foraging activity of *Anacanthotermes vagans* (Hagen) and soil moisture (Abushama and Al-Houty, 1988). A rise in soil moisture due to rainfall has been found to increase the foraging activity of a desert subterranean termite, *Gnathamitermes perplexus* (Banks) (La Fage *et al.*, 1976).

Macrotermes subhyalinus foraging activity recorded in wood baits in different areas are shown in Figures 4.4, 4.10-4.12. The wood baits were attacked after being covered with a layer of soil. The attack started from the outer part of the wood bait and continued towards the centre. The biting marks left on the wood baits, together with extensive attack throughout the external part of the baits were found to be a characteristic of a *Macrotermes* attack (Plate 4.3). These characteristic feeding marks left on the wood baits could be used to identify the species when they were absent at the time of inspection.

Macrotermes foraging activity was observed throughout the year on cultivated land at Ghimbi-2 (Figure 4.4). There was no significant difference in the percentage of baits attacked between the dry and the rainy seasons (Table 4.3); however, slight increase was noted during the dry season (Figure 4.4).

Table 4.3 Variations in wood bait attack by *Macrotermes subhyalinus* between wet and dry seasons

Season	% baits attacked (mean $\pm$ s.e.)
Wet	15.3 $\pm$ 3.4
Dry	22.2 $\pm$ 5.0

F = 5.64 ns

The occurrence of *Macrotermes* crop damage throughout the crop growing period can be attributed to the foraging behaviour of the termite. The main reason for more damage at the seedling stage on annual crops such as maize seems due to greater foraging activities during June and July.

Similar experiences were reported in the foraging activity of *Macrotermes michaelseni* in semi arid range land in Kenya (Lepage, 1977b). However, Matsumoto and Abe (1979) reported increased surface foraging activity of *Macrotermes carbonarius* two days after rainfall.

Pseudacanthotermes militaris was the least commonly seen foraging species in the study areas. Its foraging activities were observed on cultivated and bushlands at Sasiga and the afforestation area at Mendi (Figures 4.1, 4.3, 4.8). It attacked wood baits in the same way as *Macrotermes subhyalinus*, and in the absence of termites themselves it would be very difficult to distinguish the activities of the two species. Foraging activities were observed throughout the year at Sasiga but it was significantly higher during the dry rather than the wet season (Table 4.4). The relationship between the percentage of baits attacked and the total monthly rainfall was negative (Figure 4.15). About 60% of the variation in foraging activity was due to rainfall. The main reason for lower foraging activity during the rainy season seems due to physical destruction of above ground runways constructed by the termite. Lower *P. militaris* activity during the wet season indicate that it is very unlikely to pose a threat to agricultural crops grown under rainfed conditions.

Table 4.4 *Pseudacanthotermes militaris* foraging activity variations between wet and dry seasons

		% bait attacked (mean ± se)	
Locality	Habitat	wet season	dry season
Sasiga	woodland	10.4 ± 1.6	20.7 ± 3.0
Sasiga	cultivated land	12.4 ± 1.9	19.3 ± 1.7

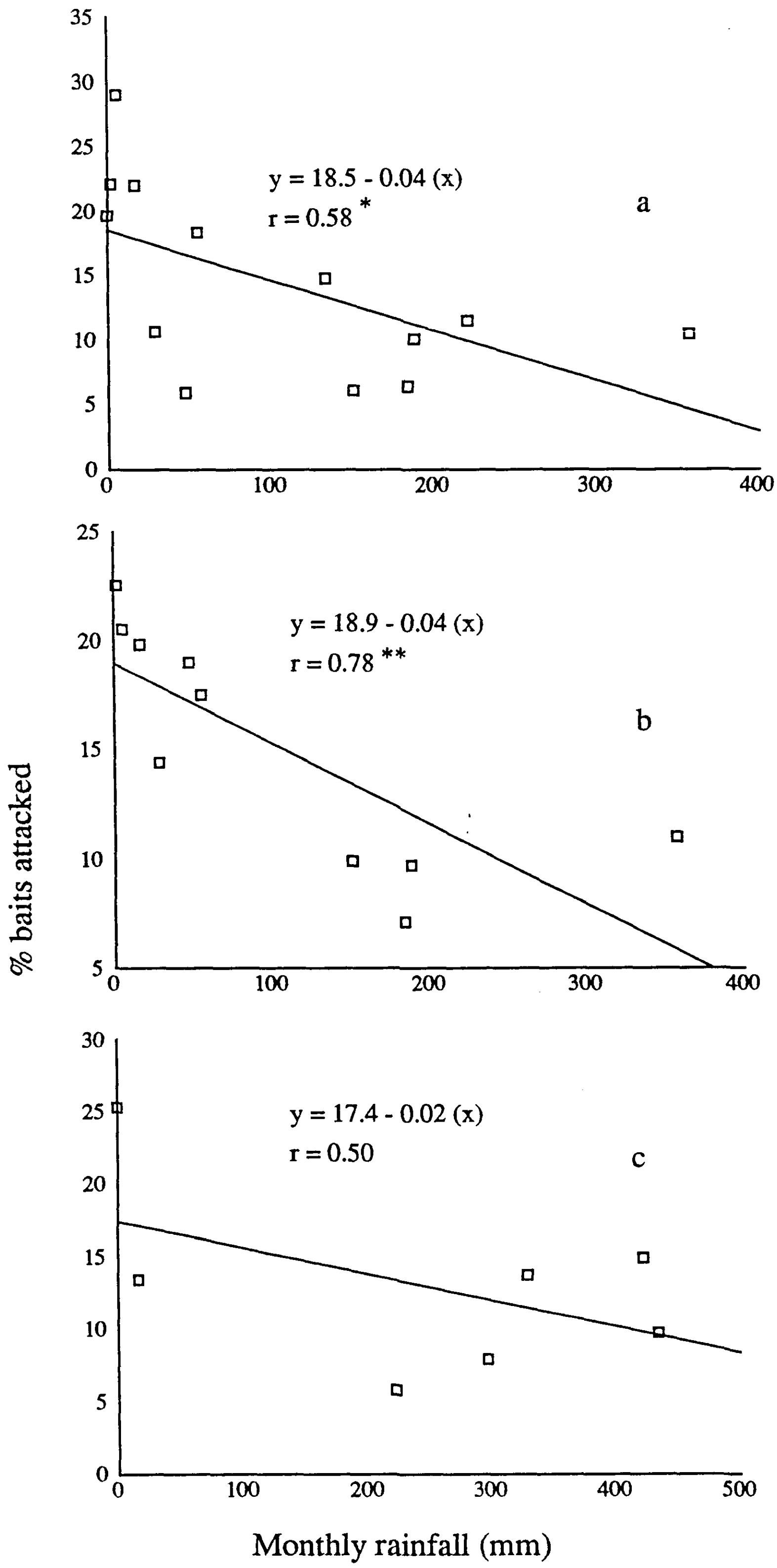


Figure 4.15 Relationship between Pseudacanthotermes militaris foraging activity and total monthly rainfall
(a) Sasiga bushland (c) Mendi afforestation site
(b) Sasiga cultivated land

4.3.2 Spatial Variations In Foraging Activity

The foraging activities of *Microtermes* nr. *vadschaggae* in six different sites are shown in Table 4.5. Significantly more foraging activity was observed at Ghimbi-2, Didesa and Bako than at Mendi ($P < 0.05$). These sites are different from each other in various aspects such as soil type, rainfall and years of cultivation. The site at Mendi was especially different from the other sites as it had been under cultivation only for about five years. In contrast, the other sites have been cultivated for more than 15 years, and the site at Ghimbi-2 for over 30 years. The number of years the lands had been under cultivation seems the most important factor which affects foraging activities. The longer the area is cultivated the greater the foraging activity. This indicates that *Microtermes* is more likely to be a problem in areas cultivated for several years than in newly opened farm lands.

More wood baits were attacked at Bako and Didesa compared to the other sites largely due to mechanical cultivation which is known to eliminate mound building termites (eg. *Macrotermes*) and leave subterranean termites such as *Microtermes* (Wood *et al.*, 1977). In the absence of competition, an increase in the population of *Microtermes* spp. is more likely to occur and as a consequence forage more extensively.

Table 4.5 Foraging activities of *Microtermes* nr. *vadschaggae* in six different sites in western Ethiopia

Site	Years of cultivation	Methods of cultivation	% baits attacked
Mendi	5	oxen	28.42[c]
Nedjo	>15	oxen	37.22[bc]
Henna	>15	oxen	40.72[abc]
Ghimbi-2	>30	oxen	43.55[ab]
Didesa	>15	tractor	44.77[ab]
Bako	>15	tractor	51.40[a]

Data was transformed to arcsine and analyzed using analysis of variance and the percentages show transformed data

Means followed by the same letter are not significantly different at 5 % level

4.3.3 Foraging Activity Variations Between 1987 and 1988

The comparison of foraging activities of *Microtermes* nr. *vadschaggae* on fallow land at Ghimbi between 1987 and 1988 showed significantly greater activity during 1987 than 1988 (Table 4.6). In the two years of study, the most significant difference in the factors that affect termite foraging activity was the amount of rainfall. During 1988 total rainfall was about 12% higher than in 1987. The result indicated more foraging occurs in years when the rainfall is low. As a consequence more crop damage could occur in years of low rainfall.

Similar observations were made on other species of Macrotermitinae. Lepage (1977b) observed two different relationships between *Macrotermes subhyalinus* foraging activity and monthly rainfall. Between 0.0 to 20.5 mm monthly rainfall the correlation was positive and significant, but between 20.5 to 97.2 mm the correlation was negative and non significant. A negative relationship was also observed between the percentage of baits attacked and the duration of rainfall (Johnson *et al.*, 1981). Buxton (1981) also observed at Tsavo National Park (Kenya) that the highest consumption of wood bait by Macrotermitinae was in areas that had the lowest five year mean rainfall.

Table 4.6 *Microtermes*. nr. *vadschaggae* foraging activity variation between 1987 and 1988 at Ghimbi-1

	% baits attacked		monthly rainfall (mm)	
Mont	1987	1988	1987	1988
June	46.9	38.4	307.9	400.5
July	56.0	45.4	474.5	290.4
August	46.4	36.7	347.3	310.4
September	44.4	31.6	187.9	452.6
October	44.4	35.6	128.5	174.2
November	48.5	32.2	0.0	2.2
December	43.6	26.9	0.0	0.0
mean ± S.E.	47.2±1.6	35.2±2.2	-	-
Total	-	-	1446.1	1630.3

4.3.4 Foraging Population of *Microtermes*

The mean foraging population of the two species of *Microtermes* in the study areas are shown in Table 4.7. The figures represent the mean and standard error per baiting station (bait and ground).

There was no significant difference in the foraging population of the two species of *Microtermes* either during the dry or the rainy seasons. However, the population density of both species were generally higher during the rainy season as compared to the dry season. This is mainly due to their foraging more during the wet season in contrast to the dry season. In addition the population density showed an increase depending on the use of the land. Thus a higher population was recorded on cultivated lands (eg. Ghimbi) as opposed to uncultivated woodlands (eg. Sasiga). This was probably due to an increase in the population of *Microtermes* in lands cultivated for several years.

Such a trend in the population density of *Microtermes* was also reported by Wood and Johnson (1978), who showed that the population of *Microtermes* moves down into the soil to below 50 cm during the dry season and moves up to the top 25 cm during the wet season.

Table 4.7 Foraging population (number per baiting station) of *Microtermes* in western Ethiopia

Species Locality	1987	1988	
	wet	dry	wet
M. vadschaggae			
Sasiga woodland	27.3 ± 3.2	10.1 ± 5.9	36.4 ± 9.8
Ghimbi fallow	48.0 ± 6.2	43.6 ± 3.0	35.8 ± 2.0
Mendi afforest.			18.4 ± 3.8
Ghimbi cultivated	61.4 ± 8.8	24.4 ± 8.5	
Nedjo cultivated			48.5 ± 6.2
Didesa cultivated			32.0 ± 3.7
Bako cultivated			41.2 ± 6.5
M. aethiopicus			
Sasiga woodland	42.9 ± 13.2	7.5 ± 4.6	33.8 ± 2.9
Ghimbi fallow	56.0 ± 10.9	37.7 ± 3.4	37.6 ± 2.1
Mendi afforest.			22.8 ± 7.3
Didesa cultivated			40.6 ± 5.9

4.3.5 Diurnal Foraging Activity

The diurnal foraging activities of *M. nr. vadschaggae* on bushland at Sasiga and fallow land at Ghimbi-1 are shown in Figures 4.16 and 4.17 respectively.

At Sasiga, foraging activities by *Microtermes* occurred continuously during the day and night throughout the rainy season. Rainfall does not seem to restrict foraging activities of *Microtermes*, because the foraging parties were seen foraging while heavy rain was falling. However, during the dry season, foraging activities were restricted to specific times of the day or night. In November, at the beginning of dry season, there were no foraging from 12.00 - 14.00 hours as well as from 20.00 - 22.00 hours. In the former case, lack of foraging seems to be due to the high temperatures which normally occurs at this time of the day. In March in the middle of dry season, less foraging generally occurred. From 02.00 - 04.00 hours late at night and from 12.00 - 16.00 hours in the early afternoon, no foraging activities were observed probably due to unfavourable temperature.

At Ghimbi, *Microtermes* foraging activities were observed throughout the day and night during all observation periods. Throughout the observation period foraging was lower during early afternoon probably due to high temperature.

Comparison between Sasiga and Ghimbi clearly indicate that diurnal foraging activity of *Microtermes* nr. *vadschaggae* varies from one locality to another perhaps due to differences in the number of years the area had been under cultivation. As

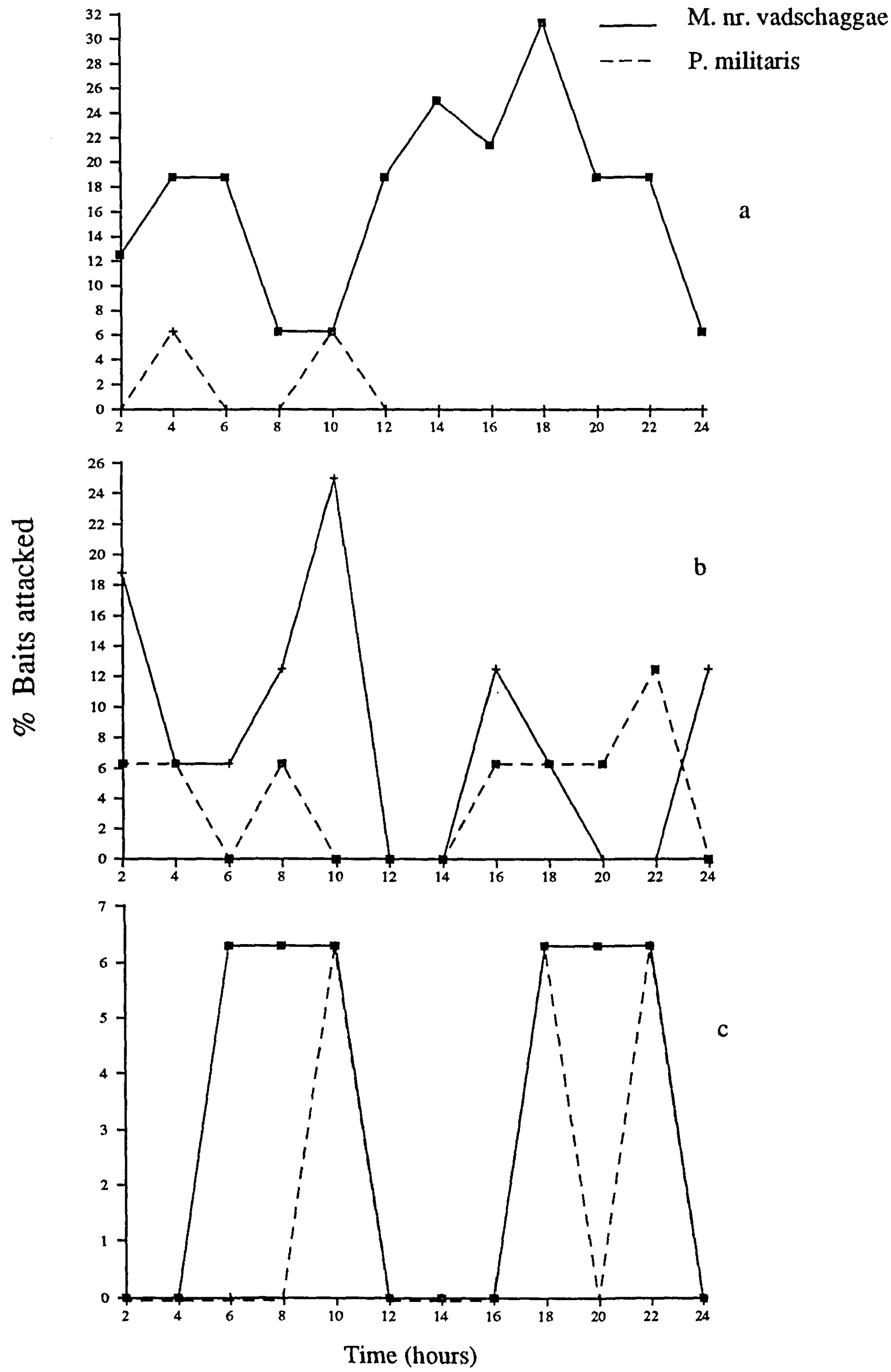


Figure 4.16 Diurnal foraging activity of Microtermes nr. vadschaggae and Pseudacanthotermes militaris on bushland at Sasiga (a) 22/7/87 (b) 30/11/87 (c) 9/3/88

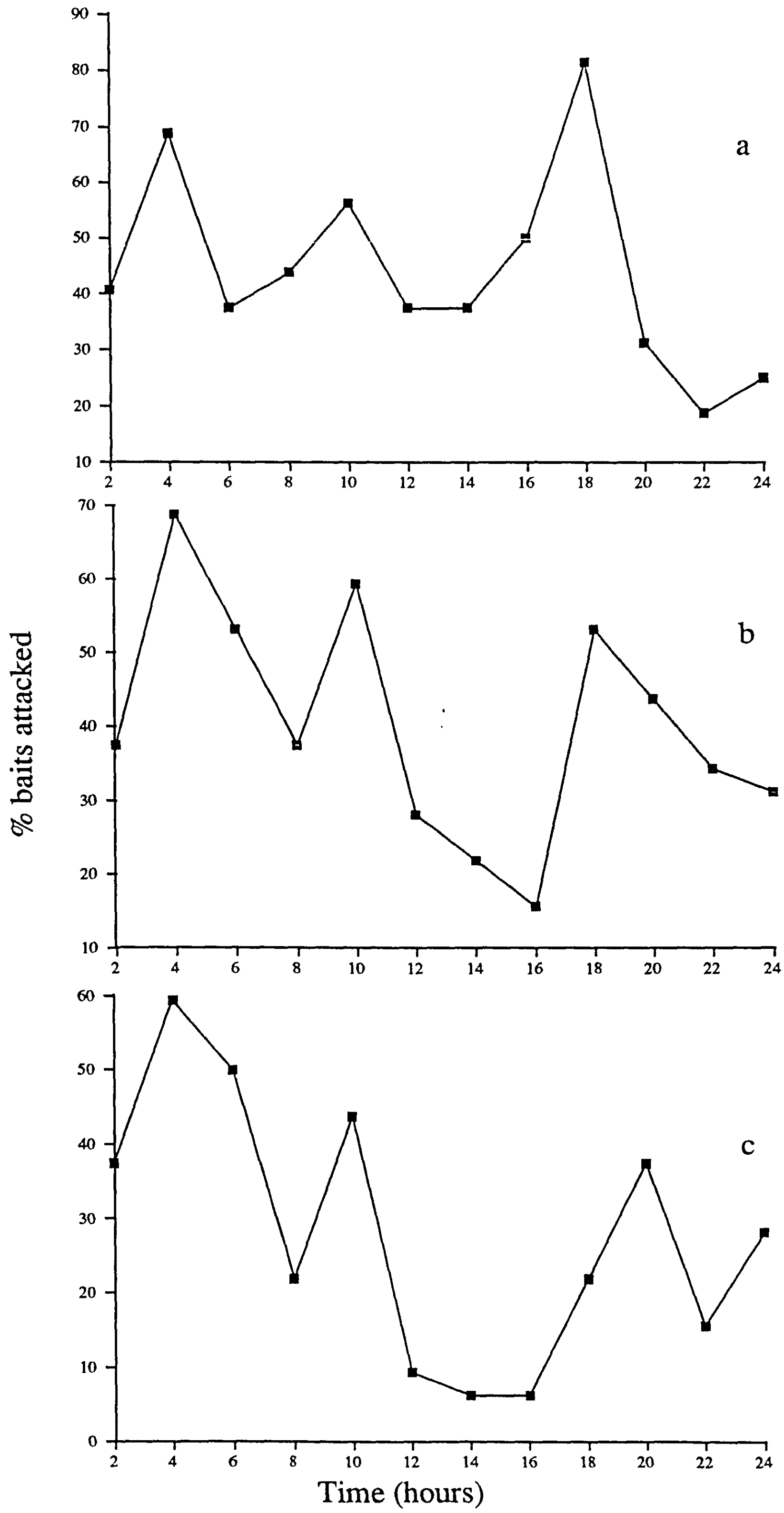


Figure 4.17 Diurnal foraging activity of Microtermes nr. vadschaggae on fallow land at Ghimbi-1 (a) 15/5/87 (b) 24/11/87 (c) 13/3/88

indicated earlier, Sasiga site was woodland cleared and was in its first year of cultivation, whereas the Ghimbi site was under cultivation for several years until it was impossible to produce crops. Such areas support large populations that have to forage continuously in order to satisfy the food requirements of the colony.

Compared to *Microtermes*, foraging by *Pseudacanthotermes militaris* was not continuous and occurred only at specific times of the day or night both during the wet and dry seasons (Figure 4.17). In the rainy season there was no foraging activity except from 02.00 - 06.00 hours and from 08.00 - 12.00 hours. As it was shown in the seasonal foraging activity section, this species does not forage at any appreciable level during the rainy season. In November, beginning of the dry season, foraging was observed during most times of the day and night except at 06.00 hours when it is normally cold and from 10.00 - 14.00 hours when it is hot. Peak foraging was recorded at 10.00 hours. In March, mid - dry season, foraging were observed at 10.00, 18.00 and 22.00 hours only.

Other studies have confirmed that diurnal foraging activity is largely affected by variations in temperature. La Fage (1973) found that the threshold temperature for *Gnathamitermes perplexus* (Banks) and *Heterotermes aureus* foraging was between 9.0 - 49.0 ^{o}C and 7.6 - 47.0 ^{o}C respectively. Ohiagu (1979) also determined the lower and upper threshold temperature for *Trinervitermes geminatus* to be 20 ^{o}C and 35 ^{o}C respectively. Variations in the occurrence of peak foraging activities, noted by Abushama and Al-Houty (1988), were that the peak foraging of *Anacanthotermes vagans* occurred at mid-night and early morning during summer and winter, whereas in the spring the peak foraging was at mid-day, after noon and early evening.

4.3.6 Seasonal Feeding Habits

The range of food materials eaten by *M.* nr. *vadschaggae*, *M. aethiopicus* and *Macrotermes subhyalinus* during the different times of the year were investigated on grazing land and afforestation site at Ghimbi. The major difference in the food resources between the two areas was the presence of leafy litter in the afforestation site. In both areas foods were available throughout the year.

The various food resources eaten by *M.* nr. *vadschaggae* are shown in Table 4.8. These included woody litter, leafy litter, dead tree and cow dung. Feeding activity was relatively low during the dry season from December to March as compared to the rainy season. This is due to the occurrence of lower foraging activities during the dry season. In grazing land, woody litter was the most widely consumed food resource while in afforestation site, leafy litter constituted the major diet of the species followed by woody litter. Cow dung was not frequently found in the areas; however, whenever it was available it contributed to the diet of the species.

The diet of *M. aethiopicus* also consisted similar food resources like that of *M.* nr. *vadschaggae* (Table 4.9).

However, the frequency of its occurrence on the food resources was lower than *M.* nr. *vadshaggae*. Woody litter was the preferred food resource on gazing land whereas in afforestation area leafy litter was the major diet. The two species of *Microtermes* were not recorded feeding on grasses. During crop damage survey also *Microtermes* spp. had not been found on the most widely cultivated grain crop, tef which is also closely related to the grass species found in the region.

Unlike the two species of *Microtermes*, *Macrotermes subhyalinus* was recorded feeding on a wide range of food resources (Table 4.10). On grazing land the major food resources were standing grass both during the dry and wet seasons followed by cow dung. In afforestation area standing tree was the most preferred food resource, particularly during the wet season. The termite was widely seen feeding on the barks of trees, especially *Eucalyptus* under the cover of soil layers. Standing grass was the next widely attacked plant material in this area.

Elsewhere in its geographical distribution areas *Macrotermes* has been found to prefer grass litter on the ground if available (Lepage, 1981a, 1977a; Wood *et al.*, 1977).

Table 4.8 Seasonal feeding habits of *Microtermes*. nr. vadschaggae on grazing and afforestation land

	% Frequency of occurrence				
	1987		1988		
Food source	July	Dec	Mar	July	Sept
Grazing land					
Woody litter	25		5		
Dead tree			5		
Dung		5		10	
Afforestation site					
Woody litter				5	
Dead tree		5			
Leafy litter	10	10		15	10

Table 4.9 Seasonal feeding habits of *Microtermes aethiopicus* o n grazing land and afforestation land

	% Frequency of occurrence				
	1987		1988		
Food resource	July	Dec	Mar	July	Sept
Grazing land					
Woody litter	5				5
Dead tree				5	
Dung		5			
Afforestation site					
Woody litter				10	
Dead tree			5	5	
Leafy litter	5			25	
Dung			5		

Table 4.10 Seasonal feeding habits of *Macrotermes subhyalinus* on grazing and afforestation land

	% Frequency of occurrence				
	1987		1988		
Food resource	July	Dec	Mar	July	Sept
Grazing land					
Woody litter	5	5			
Dead tree				5	
Standing grass	10	25		5	35
Grass litter		5			
Dung	5	5	10	5	
Afforestation site					
Dead tree	5	10			
Standing tree	35	5	5		
Standing grass		5	15		
Dung	5				

CHAPTER FIVE : CROP DAMAGE AND YIELD LOSS ASSESSMENT

5.1 INTRODUCTION

Crop losses caused by termites are often reported as percentage of plants attacked; however, this does not indicate the magnitude of the problem since there is no relationship between the percentage of plants attacked and yield losses (Wood and Cowie, 1988). A survey conducted at Mokwa and Samaru in Nigeria showed that when over 50% of the maize plants standing in the field were attacked there was less than a 10% yield loss (Johnson and Wood, 1979). Similarly in the Sudan, over 31% infestation in cotton caused only about 3% loss of yield (Harris, 1961). This lack of a relationship between damage and yield loss indicates that other factors determine yield losses. According to Wood and Cowie (1988) the intensity of damage and stage of the crop infested are the most important factors that determine crop losses, especially as many crops can compensate for some damage.

Different methods are used to assess crop losses caused by insect pests, plant diseases and weeds (Chiarappa, 1971). Walker (1987a) has reviewed some of the methods used to assess crop losses caused by insect pests. Recently Wood and Cowie (1988) have discussed some of the techniques used to determine losses caused by soil insect pests. Some of the most commonly used methods to assess crop losses are:-

(1) Percentage of plants attacked

(2) Comparison of yield of attacked and unattacked plants

(3) Comparison of grain yield of pesticide treated and untreated plots

(4) Simulation of damage

(5) Artificial infestation

Most of these methods are either used singly or in combination with other methods depending on the type of the pest species concerned. Generally comparison of yield from attacked and unattacked plants is regarded as a reliable method of estimating yield losses caused by termites when damage caused by other pests can be delineated (Wood and Cowie, 1988).

Annual crops are not usually attacked by *Microtermes* spp. until the later part of crop development. In maize, infestation does not begin until 9 to 12 weeks after planting (Bigger, 1966; Wood *et al.*, 1980). In groundnuts an attack does not generally commence until 4-5 weeks prior to harvest (Johnson *et al.*, 1981). In certain crops, such as soybean, damage is not restricted to mature crop but can also occur at any stage during crop development (Bigger, 1966). Sugar cane was susceptible to *Microtermes tragardhi* during three periods. First when the seed pieces are planted; second at crop maturity and third after crop harvest (Abushama and Kambal, 1977). Generally, when termites infest crops after full seed formation there is no significant effect on grain yield.

The main reason for the occurrence of *Microtermes* infestation on annual crops towards crop maturity is related to the foraging behaviour of the species. In the early part of the crop season, while there is good rainfall and the soil is wet, these termites forage on the surface, but when the top soil gets dry they are forced to forage below the soil surface. It is this subsurface foraging activities together with their preference for more woody tissues that predispose the root system to termite attack. An increase in subsurface foraging activity also occurs in areas having well drained soils or have a short rainy season and as a result greater damage is expected in these areas (Johnson *et al.*, 1981). Similarly more damage is expected during periods in the rainy season when the top soil gets dry due to interruption in the rainfall for a long time; this also could force termites to forage below the soil surface.

Microtermes spp. attack on mature crops begins from the root system and occasionally extends into the stem for several centimetres. In severe cases in maize, *Microtermes* spp. can penetrate up to a meter high into the stem by excavating and filling the excavated portions with subsoil (Wood *et al.*, 1980). The symptoms of attack vary from crop to crop and is not usually apparent until after considerable damage. For instance, an infestation on newly planted cassava and sugar cane setts is not evident until the planting materials have failed to germinate (Johnson and Wood, 1979). Similarly in groundnuts an infestation may not be recognized until much later in the season when plants wilt and die (Johnson *et al.*, 1981). In the case of maize *Microtermes* attack is occasionally manifested in the form of lodging due to extensive damage on the root system and the weakening of the stems; however, very frequently no symptom is evident despite the occurrence of a heavy attack. With tuber crops such as yams, termite attack is often not known until the crop has been harvested by which time the tubers may be made either partially or entirely inedible or unmarketable (Wood *et al.*, 1980).

Yield loss on plants may be the result of plant mortality, reduced translocation of water and nutrients, infection by pathogenic microorganisms or due to lodging which makes fallen grains easily accessible to various vertebrate and other invertebrate pests (Wood and Cowie, 1988).

The extent of *Microtermes* spp. damage varies from location to location and from year to year. Generally plants growing under poor agronomic conditions are more prone to termite damage than those growing under optimum conditions. Johnson and Wood (1979) observed greater damage on groundnuts, wheat and sugar cane grown on poor soils in dry areas. The intensity of attack also varied depending on the number of years the land had been under cultivation. In Nigeria, yield losses caused by *Microtermes* on maize grown on lands cultivated for 1-3 years was only 0.1 to 3.0%, compared to 3.9 to 9.5% on lands cultivated for 10-27 years (Wood *et al.*, 1980).

Drought, poor rainfall, high temperature and low soil fertility are some of the factors believed to intensify termite damage (Verma and Kashyap, 1980). Extensive damage was recorded in groundnuts during years of poor rainfall and late planting (Johnson and Wood, 1980). Late planting extends the time the crop remains in the field well into the period when subsurface foraging activity is greatest. Bigger (1966) has also observed considerable damage in Tanzania when rainfall was low and poorly distributed.

Termite damage also varies from crop to crop. A survey conducted in India to determine the relative susceptibility of major dry land crops to termite attack showed that groundnuts are most susceptible, compared to ragi (*Eleusine coracana*), maize, niger (*Guizotia abyssinica* Cass) and sunflower (Sudhakar and Veeresh, 1985). Generally, indigenous crops are rarely attacked by *Microtermes* spp. when they are grown in the same locality with exotic crops. This was clearly seen in Nigeria where groundnuts were severely destroyed by *Microtermes* spp. while cowpea (*Vigna unguiculata* (L) Walp) and bambara groundnuts (*Vaandzeia substerranea* (L)) were not infested (Johnson *et al.*, 1981). Groundnuts are exotic crops introduced to West Africa from Brazil by the Portuguese around 1500 whereas cowpea and bambara groundnuts are indigenous crops (Johnson *et al.*, 1981).

Similar variations were also observed among the indigenous and exotic crops grown in western Ethiopia. Tef, which is an indigenous crop to Ethiopia is not attacked by *Microtermes* spp., whereas exotic crops such as maize and *Eucalyptus* are severely damaged. Coffee which is another indigenous crop to

Ethiopia is also rarely attacked by *Microtermes* and other termites. Heavy destruction was also reported on certain experimental crops such as groundnuts, wheat and sesame introduced to the Tihama region of the Yemen Arab Republic (Wood *et al.*, 1987).

According to Cowie *et al.* (1989) the main reason for lack of damage on the indigenous crops is due to the selective evolution of defensive mechanisms by these plants against the termites. Bigger (1966), however, explained lack of attack on certain crops in terms of crude fibre content. According to Bigger (1966) soybean is attacked more than maize because of its high crude fibre content. The crude fibre content of soybean ranged from 25.7 to 60.8% from the first week to 13th week after emergence. For the same period, the crude fibre content of maize ranged from 14.9 to 30.3%.

There are several studies that show the extent of crop damage or losses caused by *Microtermes* spp.; unfortunately, most of the studies do not differentiate between damage and actual yield losses (Table 5.1). The highest attack was recorded in yams (70%) followed by groundnuts and cassava (40%) (Johnson and Wood, 1979) and lowest damage (less than 2% stand loss) in tobacco, millet, sorghum and vegetable crops (Wood *et al.*, 1987).

The occurrence of loss on lodged maize depends on the farming system practised in the area. Under a peasant farming system, maize cobs from lodged plants are picked by local farmers before they are attacked by rodents, microorganisms or

Table 5.1 Crop damage/losses caused by *Microtermes* spp. on different field crops

Species crops	% Damage or loss	Country	Author
M. lepidus			
Groundnuts	40	Nigeria	Johnson *et al.* (1981)
	10-30	Sudan	Wood & Kambal (1986)
M. najdensis			
Green pepper	21-31	S. Arabia	Badawi & Faragalla (1986)
Cotton, maize	20-30	Yemen AR.	Wood *et al.* (1987)
Pepper, okra, tomato	10-20	Yemen AR.	Wood *et al.* (1987)
Tobacco, millet sorghum	< 2	Yemen AR.	Wood *et al.* (1987)
Cotton	4-46	Sudan	Tiben (1986)
M. obesi			
Sugar cane	2.5	India	Harris (1961)
Wheat	6-25	India	SenSerma (1974)
Maize	22	India	Sudhakar & Veeresh (1985)
Ragi	36	India	,, ,,
Groundnuts	51	India	,, ,,
Niger	38	India	,, ,,
M. tragardhi			
Sugar cane	18	Sudan	Abushama & Kambal (1977)
M. spp.			
Maize	5-10	Nigeria	Johnson & Wood (1979)
	27	Tanzania	Bigger (1966)
	50	Ethiopia	Wood (1986a)
Cotton	3	Sudan	Harris (1961)
Cassava	40	Nigeria	Johnson & Wood (1979)
Groundnuts	40	Nigeria	Johnson & Wood (1979)
Yams	70	Nigeria	Johnson & Wood (1979)
Sugar cane	30	Nigeria	Johnson & Wood (1979)
Soybean	33	Tanzania	Bigger (1966)
Wheat	20	Nigeria	Johnson & Wood (1979)
Pepper, groundnuts	20-25	Ethiopia	Wood (1986a)
Sweet potato	12-18	Nigeria	Wood *et al.* (1977)

termites. As a result these yield losses are avoidable. In contrast, in large scale farms where mechanical harvesting is practised maize cobs from lodged plants are not picked by machines so the cobs are completely lost (Wood *et al.*, 1977).

In certain crops, such as groundnuts the presence of *Microtermes* spp. in addition to causing yield losses can also predispose crops to different species of pathogenic microorganisms (Johnson and Wood, 1980; Wightman and Amin, 1988). Scarification predisposes the pods and kernels to the infection of pathogenic fungi such as *Fusarium, Macrophomina* and *Aspergillus* which are known to produce carcinogenic toxins such as aflatoxin.

There is a lack of published information regarding monetary losses caused by termites on crops. The only information, quite frequently quoted, is from India where annual losses caused by termites to crops are estimated at £20 million (Harris, 1961; Sankaran, 1962) and on sugar cane at £1.4 million per annum (Harris, 1961). The lack of information on economic losses clearly indicate how difficult it is to estimate yield losses since there is no strong relationship between crop damage and yield. Generally it is under a few cases that crop damage result in yield losses.

Unlike *Microtermes* spp. which infest the roots, *Macrotermes* spp. cut the base of the stem at the ground level causing stand losses, so a reduction in yield may occur depending on the stage at which the crops are attacked. Generally moderate stand losses caused by *Macrotermes* spp. on cereal crops at the earlier stage of crop development can be compensated by increased growth of the remaining plants and yield losses are prevented. However, when crop mortality occurs later compensation is unlikely and yield losses are unavoidable (Wood and Cowie, 1988).

Very little quantitative information is available regarding losses caused by *Macrotermes* spp. This indicates that it has not been regarded as economically important in much of the area of its geographical distribution. However, in certain localized areas it was reported as a serious pest. In Zanzibar, Tanzania *Macrotermes bellicosus* together with *Odontotermes amanicus* have prevented replanting of clove trees by destroying the seedlings during the first year (Harris, 1961). In Niger State, Nigeria *Macrotermes subhyalinus* and *Odontotermes smeathmanni* have caused over 27% germination failure in upland sugar cane (Collins, 1984). Also in Nigeria, *Macrotermes* spp. were reported causing about 8% losses on maize seedlings four weeks after emergence (Wood *et al.*, 1977).

In the settlement areas in western Ethiopia, *Macrotermes herus* has been reported to cause 50% damage in maize and pepper (FAO, 1984a). A survey conducted by Wood (1986b) in the same areas in western Ethiopia showed about 6% damage to maize seedlings and 8% damage on tasselling plants and on plants at the young cob stage. The loss recorded in sorghum was less than 3% and was usually considered non significant.

The importance of understanding crop losses caused by different pests are discussed in detail by Walker (1987b). A knowledge of crop losses is the basis for making rational decisions in crop protection, and helps to allocate scarce national resources, both financial and manpower, to the most serious pest problems of a region or a country. Most important of all it helps to decide whether pest control is necessary or not. In fact the whole concept of pest management is based on crop losses that are likely to occur in the absence of control and the cost of control measures. Control measures are justified only when the value of the crop that can be saved is greater than the cost of control. Any control measures undertaken without this vital information may be economically unjustified.

The crop losses caused by termites in Ethiopia have not yet been defined. Very often the losses are expressed as 'very high', 'significant', 'serious' etc. Such qualitative information hardly helps to make rational decisions in pest management. Therefore, this study was initiated to determine the extent of yield losses caused by the two dominant crop damaging termites, namely *Macrotermes subhyalinus* and *Microtermes* spp. which causes stand losses and considerable root infestations respectively in western Ethiopia.

5.2 MATERIALS AND METHODS

5.2.1 *Microtermes* Loss Assessment

This study was conducted on maize (*Zea mays*), pepper (*Capsicum* spp.), haricot beans (*Phaseolus vulgaris*) and sunflower (*Helianthus annus*) which were reported to be highly susceptible to *Microtermes* infestation by the local extension agents and state farm managers.

The loss assessment on maize was carried out on several varieties and under different farming systems which included farmers fields, settlement areas, Didesa State Farm and Bako Agricultural Research Centre. On farmers' fields, land preparation was done by oxen and local seed was sown. Chemical fertilizer is rarely used by farmers for maize production in the area as they rely on pen manure to improve soil fertility, particularly that of maize fields. In contrast, state farms, research farms and farms in the settlement areas are often very large and these are ploughed by tractors. Chemical fertilizers and improved varieties are widely used. In addition, herbicides are commonly applied, particularly in the state farms.

The assessment on pepper was on farmers' fields and in the recently established settlement areas. Each of these areas allotted for pepper production on farmers fields are extremely small; often less than 100 m^2, and local cultivars are planted. On settlement areas, pepper fields are relatively large and improved varieties are planted.

On haricot beans and sunflower, the loss assessment were made at Didesa state farm on improved varieties. The fields were very large and planted with single varieties. For example, during the 1988 crop season sunflower was grown on 178 ha. in the state farms in the Welega region.

For each crop 2-5 sampling areas, depending on the size of the farm, were randomly selected in each locality across the diagonal of the field. On large farms more samples were taken compared with the small farms. The varieties, number of samples, sample sizes and type of farms on which the assessment were carried out were as follows:

Crop variety	Number of samples	Sample size (m)	Type of farm
Maize			
Local	15	3 x 3	Farmers field
KCC	9	3 x 3	Settlement farm
KCB	5	3 x 3	,,
A-511	1	3 x 3	,,
BC	2	3 x 3	,,
BC	5	3 X 3	Research farm
H625	2	3 x 3	State farm
H511	4	3 x 3	,,
Pepper			
Local	6	1 x 1	Farmers field
Local	5	1 x 1	Settlement farm
Mareko Fana	10	1 x 1	,,
Haricot bean			
Mexican 142	10	1 x 1	State farm
Sunflower			
Super 400	10	1 x 1.6	,,

In addition crop losses caused by *Microtermes* were assessed on other maize sown for termite control studies, and the results are included in this section.

At harvest, all plants in the sampling areas were pulled by hand and the roots were checked for *Microtermes* attack. In the case of maize the plants were removed by digging out the roots. The plants attacked and unattacked were separately counted, the cobs or the pods were picked by hand and weighed.

In maize the whole cob was weighed after removing the sheaths on the farmers fields, but on the trial sites the actual grain weight was recorded after sufficiently drying. Similarly in haricot beans and sunflower the grain weight was recorded after shelling. The data collected was analyzed using the generalized loss estimation method used by ODNRI Termite Ecology and Control Section.

$$\% \text{ yield loss} = \frac{\text{expected yield in the absence of attack} - \text{actual yield}}{\text{expected yield in the absence of attack}} \times 100$$

The relationship between the percentage of plants attacked and yield losses was analyzed by using simple linear regression.

5.2.2 Simulation of *Macrotermes* Damage

As it was not known how much natural termite damage would occur, it was decided to simulate different amounts of damage to determine how extensive the damage could be before yields were affected as well as establish the critical period in crop development. Thus losses caused by *Macrotermes subhyalinus* were simulated on maize since it is the most widely cultivated crop and was reported to be the most severely attacked crop in western Ethiopia. The study sites were Bako Agricultural Research Centre, Didesa state farm and Nedjo demonstration field. These sites were free from *Macrotermes* damage at the time of the investigation. At Bako and Didesa ploughing, harrowing and land levelling were done by tractors, whereas at Nedjo ploughing was done by oxen and land levelling by hired labour. The experimental design, agronomic practices used and the treatments tested were as follows:

Design	:	Randomized complete block
Replications	:	4
Plot size	:	6 x 8 m
Crop	:	Maize
Variety	:	Bako Composite
Spacing		
Between rows	:	75 cm
Within rows	:	30 cm
Fertilizer	:	DAP 100 Kg/ha at planting
Sowing dates		
Bako	:	27 - 28 May
Didesa	:	25 May
Nedjo	:	17 May

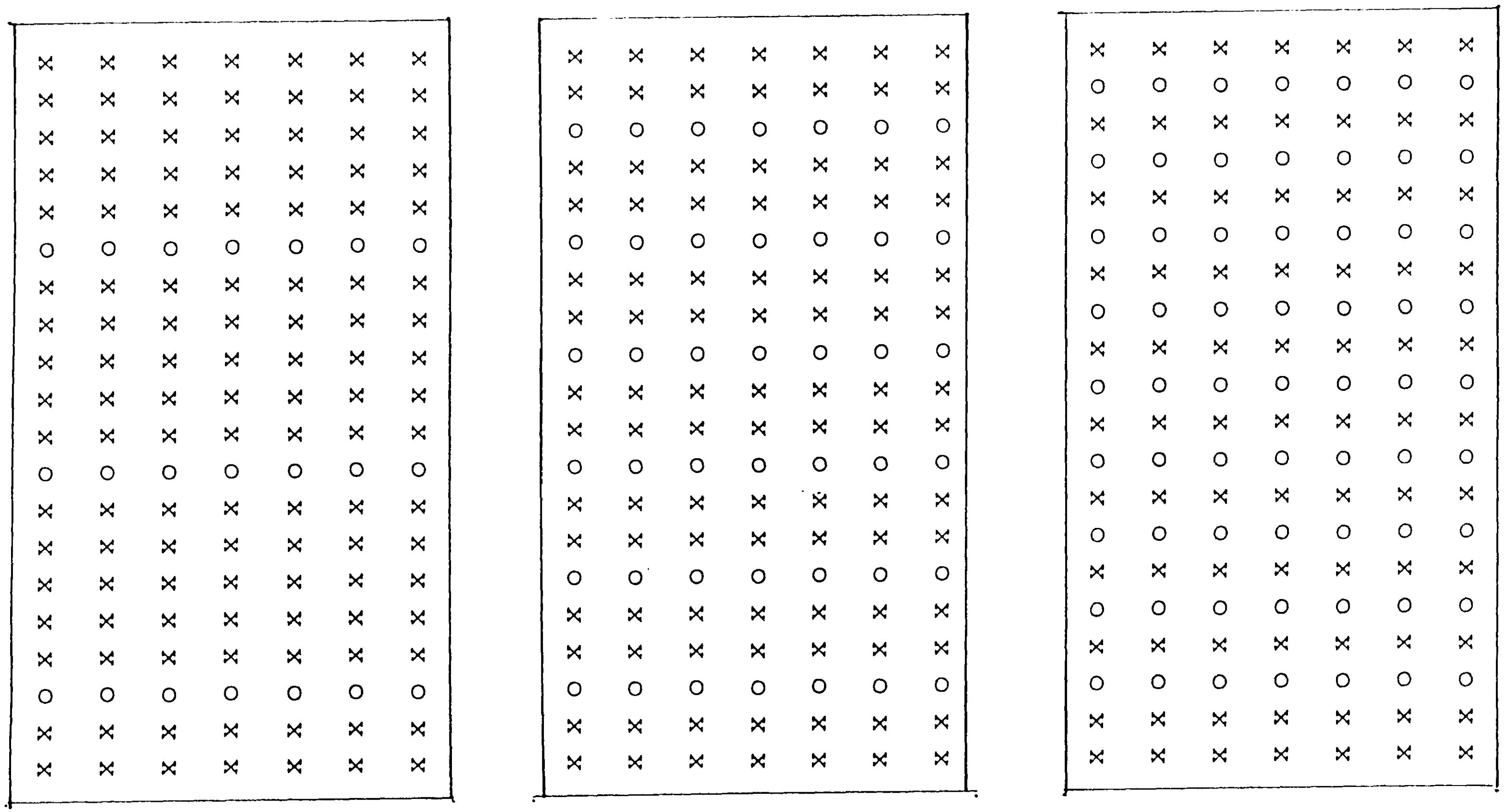
Treatments (Plants removed) :

1. 15% at 6 - leaf stage
2. 30% ,, ,,
3. 45% ,, ,,
4. 15% 9 - leaf stage
5. 30% ,, ,,
6. 45% ,, ,,
7. 15% tasselling stage
8. 30% ,, ,,
9. 45% ,, ,,
10. Control 1 (Check)
11. Control 2 (Aldrin seed treatment)
12. Control 3 (Aldrin furrow treatment)

Macrotermes can cut the base of maize stems at ground level so reducing the plant stand. Damage surveys conducted the first year in the region showed that maximum stand losses caused by *Macrotermes* at any one particular time was about 10% but most farmers believe that total stand losses could reach over 50%. This information was taken into account when the trial to simulate damage was designed. The main part of the trial involved removing plants at different stages of crop development. The control plots included treatments with aldrin as a seed and furrow treatment aimed at getting the highest yield without any termite damage. For seed treatment aldrin 40% WP was thoroughly mixed at the rate of 6.25 g actual product per 1 Kg of seed just before sowing. For furrow treatment aldrin 40% WP was applied at the time of sowing at the rate of 3 g product per plot (250 g a.i./ha) after mixing with about 2 Kg of fine dry sand.

The number of plants was checked in monitoring areas (4.5 x 6 m) in seven central rows two weeks after planting. Where necessary gaps were replanted, but there was no significant failure of germination so little replanting was necessary. At the 6-leaf, 9-leaf and tasselling stages a different number of maize plants were removed according to the treatments. To simulate 15% stand loss every sixth plant in a row was pulled by hand and removed; for 30% every third plant was removed and for 45% stand loss every other plant but one was removed in a row (Figure 5.1).

At harvest every plant in the monitoring areas was removed by digging out the roots and checked the roots for *Microtermes* infestation. The plants attacked and unattacked were separately counted. The cobs were picked by hand, counted, dried, shelled by hand and the grain weight was recorded. The results were analyzed using analysis of variance to check if



15% of plants removed 30% of plants removed 45% of plants removed

Figure 5.1 The location of maize plants removed in planting rows
(o shows plants removed)

there was any significant yield difference among the treatments.

5.3 RESULTS AND DISCUSSION

5.3.1 *Microtermes* Attack in Maize

The extent of *Microtermes* spp. attack and the effect on maize yield under different farming systems are shown in Tables 5.2-5.3. Table 5.2 shows the effect of attack on maize cobs while the other table shows the effect on grain yield. The percentage of plants attacked varied considerably between different varieties and methods of ploughing. The level of infestation on improved varieties was greater than on local cultivars. On local maize, far more plants were attacked at Nedjo-Jarso compared to Menesibu (Table 5.2) but on the improved varieties, damage was generally great (Table 5.2). The low level of attack on local maize may be due to the development of defence mechanisms as a result of co-evolution in the same areas for several years. Wood and Cowie (1988) have also reported more lodging caused by termites on improved varieties of maize compared to local cultivars.

Greater *Microtermes* attack was also recorded on fields in which tractor were used for ploughing compared to oxen ploughed fields. Thus more plants were attacked at Bako Agricultural Research Centre and Didesa state farms where fields were ploughed by tractor compared to farmers fields where oxen drawn plough are used (Table 5.2). Mechanical cultivation destroys termites that build mounds or have shallow subterranean nests while those with deep subterranean nests are not affected. Also some subterranean termites such as *Microtermes* can utilize crop residues and growing crops as food resources. As a result their population increase on fields cultivated for several years by tractor.

The relationship between percentage of plants attacked and yield losses was not linear. Generally a greater amount of crop damage would be expected to cause higher yield losses. At some sites, slight yield increases were recorded possibly due to plant growth being stimulated in response to the damage.

Heavy infestation did not always cause a significant yield reduction, especially if the termite attack occurred after full seed formation. In western Ethiopia rainfall is high with the rainy season lasting for several months, so *Microtermes* foraging in the root zone is not expected until the soil is drier by which time the grain is fully developed. This restriction of damage in the root system confirms that the main attack by termites occurred during the latter part of the crop development.

This study has shown that *Microtermes* spp. were not economically important pests of maize in western Ethiopia despite very high infestation.

Several studies have shown similar yield increases on plants attacked by insect pests. Wood *et al.*, (1977) observed maize plants attacked by *Microtermes* in Nigeria yielded more grain. They have suggested this might be either due to the occurrence of more *Microtermes* infestation on vigorously growing plants or the infestation might have stimulated greater plant growth. Walker (1987c) also reported that in some cases pest damage that affect the growing parts of plants can cause an increase in crop yield by producing more fruiting bodies (eg. cotton) or more tillers (eg. sorghum). He also reported that the destruction of excess leaves can increase crop yield by allowing more light to reach the leaves. It has also been reported that pest attack might stimulate plant growth or metabolism or enhance drying and maturity.

Table 5.2 Relationship between *Microtermes* attack and maize yield under different farming systems

Farming system	Variety	% plants attacked	% weight loss (cobs)	termite spp.
Farmers field				
Menesibu-1	local	6.5 ± 4.3	1.3 ± 0.7	1,2
Menesibu-2	local	16.2 ± 8.8	0.7 ± 2.8	1,2
Nedjo-Jarso-1	local	26.1 ± 7.6	0.2 ± 0.7	1,2
Nedjo-Jarso-2	local	54.8 ± 7.1	-1.3 ± 3.3	1
Settlement				
Jarso	KCB	55.3 ± 5.6	-5.9 ± 1.1	1
	BC	59.0 ± 7.7	-4.3 ± 0.1	1
Keto	KCC	57.1 ± 4.9	5.0 ± 2.0	1,2
	KCB	54.5 ± 8.5	-5.4 ± 1.7	1,2
State farm				
Didesa	H625	16.2 ± 10.8	2.2 ± 2.6	1,2
	H511	67.8 ± 8.1	4.2 ± 5.0	1,2
Bako Research	BC	79.4 ± 12.5	5.1 ± 5.2	1

1 = *M.* nr. *vadschaggae*
2 = *M. aethiopicus*

Table 5.3 Relationship between *Microtermes* spp. attack and maize yield in different trial sites

Area	% attack	% yield loss
Bako	70.3 ± 2.3	-1.4 ± 2.8
Didesa	62.3 ± 3.4	-1.4 ± 3.1
Nedjo	11.1 ± 1.9	-6.0 ± 1.3
Mendi	10.1 ± 1.8	-0.4 ± 0.4
Henna	12.4 ± 1.2	3.4 ± 0.6
Ghimbi	32.2 ± 2.9	1.7 ± 2.0

5.3.2 *Microtermes* Damage Survey in Pepper

Extensive damage surveys conducted in over 21 different sites on farmers' fields and newly established settlement areas (3-4 years old) both on local and improved varieties of pepper failed to reveal any evidence of *Microtermes* infestation (Table 5.4). Farmers who were asked about *Microtermes* problems during the field surveys also confirmed a lack of damage on pepper plants. The field surveys conducted during 1987 crop season showed an occurrence of *Microtermes* attack on pepper in Asosa and Anger Gutin settlement areas which have been cultivated by tractors for the past 10 years. The manager of Didesa state farm (pers. comm.) also expressed the seriousness of *Microtermes* on pepper grown in the state farms in the region. He stated that the severity of the problem had forced the state farm to take pepper out of production. This suggested that *Microtermes* problem was more likely to develop in areas cultivated for several years by tractor which eliminated alternative food resources and forced the termite to feed on cultivated crops such as pepper. According to Badawi and Faragalla (1986) and Wood *et al.* (1987) *Microtermes* spp. can severely attack pepper in several parts of the tropics and subtropics.

Table 5.4 *Microtermes* damage survey in pepper on farmers field and settlement areas

Locality	Variety	plants checked	%Plants attacked
Menesibu Province			
Kiltu Jale	Local	18	5.5
		16	0.0
		6	0.0
Wajeti Mendi	Local	16	0.0
		7	0.0
Kiltu Kara	Local	6	0.0
Jarso settlement			
Sirba - 1	Mareko Fana	10	0.0
		7	0.0
Sirba - 3	Local	13	0.0
		10	0.0
	Mareko Fana	10	0.0
Keto settlement			
Village - 11	Local	5	0.0
	Mareko Fana	4	0.0
		8	0.0
		5	0.0
		7	0.0
Village - 7	Local	15	0.0
		12	0.0
	Mareko Fana	8	0.0
		6	0.0
		7	0.0

5.3.3 *Microtermes* Damage in Haricot Beans

Both species of *Microtermes*, *M.* nr *vadschaggae* and *M. aethiopicus* were observed attacking haricot beans at Didesa state farm where this assessment was conducted. They attacked the root system and the lower part of the stem that was below the soil surface. The seeds from attacked plants were shrivelled and smaller compared to that of normal plants. The percentage of attack ranged from 7.2 to 32.9% and the yield reductions from 4.5 to 12.8% as in Table 5.5. The relationship between yield loss and the percentage of plants attacked was positive and highly significant (Figure 5.2).

This indicated that there was a strong association between the crop damage and yield loss. Among the crops assessed, the crop of haricot beans was the only crop one showed a positive relationship between *Microtermes* infestation and yield loss. This was presumably due to the occurrence of infestation at an early stage of crop development, before seed formation.

Bigger (1966) in his termite control plots observed the occurrence of Infestation on soya beans throughout crop growing period. Tsedeke *et al.* (1982) have also reported *Microtermes* infestation on haricot bean seedlings in the Melkasa region of central Ethiopia.

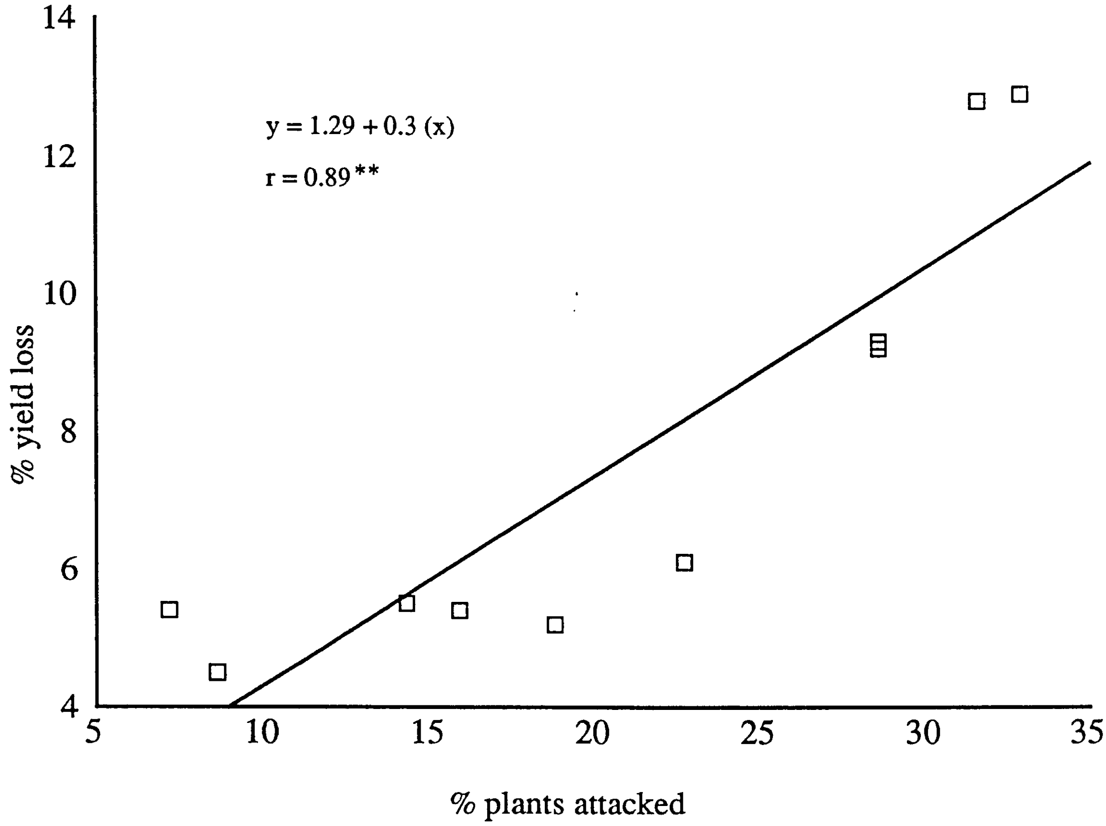


Figure 5.2 Relationship between percentage of plants attacked by Microtermes and yield loss in haricot beans

Table 5.5 Effect of *Microtermes* attack in haricot bean yield at Didesa state farm

Variety	Site	% Plants attacked	% Yield loss
Mexican 142	1	14.3	5.5
	2	28.6	9.2
	3	32.9	12.9
	4	7.2	5.4
	5	8.6	4.5
	6	31.6	12.8
	7	28.6	9.3
	8	15.9	5.4
	9	22.7	6.1
	10	18.8	5.2
Mean $\pm$ se	-	20.9 $\pm$ 3.0	7.6 $\pm$ 1.0

5.3.4 *Microtermes* Attack in Sunflower

Sunflower was attacked by both species of *Microtermes*, *M.* nr. *vadschaggae* and *M. aethiopicus*. The intensity of attack was considerably higher compared to other crops grown in the region. The percentage of infestation ranged from 62.5 to 88.9% as shown in Table 5.6. In most cases the roots were so severely damaged that the plants were easily pulled by hand without requiring much force. Some of the infested plants had also their stems excavated up-to 15 cm above the ground and filled with soil. Despite such severe and widespread infestation no yield reduction was observed. On the contrary, a higher yield was recorded on plants attacked than unattacked plants.

There are two possible explanations for lack of yield losses in sunflower despite the heavy infestation. The first possible explanation is that the attack occurred after full seed formation had taken place in which case no yield reduction would be expected no matter how heavy the infestation might be. The second explanation could be that the termites attacked selectively the most vigorously growing plants. Field observations made during harvesting supported the later explanation. During harvesting unattacked plants were rarely found; the only unattacked plants were those that were weak and stunted.

This study clearly showed that *Microtermes* infestations on growing crops in western Ethiopia do not always result in yield losses. It is very important to distinguish attack and yield losses, because this would help to avoid unnecessary control measures.

The occurrence of termite infestation on sunflower without yield losses was also reported by Sudhakar and Veeresh (1985). Harris (1961), however, reported 66% attack on green and mature sunflower plants. Rajagopal and Veeresh (1983) have also reported highest level of infestation, 91.10%, on sunflower root stubble compared to niger (88.97%), maize (42.72%) and finger millet (7.66%). This is not unexpected considering the occurrence of extensive attack at maturity.

Table 5.6 Effect of *Microtermes* attack in sunflower yield at Didesa state farm

Variety	Site	% Plants attacked	% Yield loss
Super 400	1	63.6	-17.6
	2	78.6	-17.9
	3	64.3	-16.9
	4	85.7	-17.3
	5	88.9	-15.0
	6	85.7	-8.1
	7	77.8	-14.6
	8	62.5	-16.6
	9	72.7	-9.8
	10	71.4	-18.2
Mean $\pm$ se	-	75.1 $\pm$ 3.1	-15.2 $\pm$ 1.1

5.3.5 Simulation of *Macrotermes* Damage

Significant yield differences were observed due to both the time of stand reduction and the number of plants removed. At 6-leaf and 9-leaf stages stand losses of up to 30% and at tasselling stage 15% stand loss did not cause significant yield losses (Table 5.7). The other treatments resulted in yield losses and these are shown in Table 5.8.

The removal of 45% of plant population at all three stages of crop development resulted in significant yield losses. The highest yield loss was observed when plant population was reduced at the tasselling stage. Reducing plant population by 30% caused significant yield loss only at the tasselling stage.

There is no strong relationship between stand reduction and yield losses, particularly at the early stage of crop development. For example, 45% crop removal at the 6-leaf stage resulted in only 16.5% yield loss whereas at the tasselling stage the same amount of stand reduction caused 39.9% loss. This indicated that the yield loss depended not only on the extent of stand reductions but also on the growth stage of the crop.

Table 5.7 Effect of the extent and time of stand reduction in maize yield at Bako and Didesa (combined analysis)

% Crop removal	yield, quintals/ha		
	6-leaf	9-leaf	Tasselling
15%	22.96^{abc}	21.57^{bc}	19.40^{bcd}
30%	21.34^{bc}	19.40^{bcd}	18.00^{cd}
45%	19.44^{cd}	17.91^{cd}	14.00^{d}
Control	23.29^{ab}		

Table 5.8 Yield loss in maize due to stand reductions at three different growth stage of maize

% Crop removal	% yield loss		
	6-leaf	9-leaf	Tasselling
15%	*	*	*
30%	*	*	22.7%
45%	16.5%	23.1%	39.9%

* indicates no significant yield loss

Table 5.9 Effect of stand loss on grain weight per cob

Treatment	Mean grain weight / cob (g)	
	Bako	Didesa
1. 15% at 6-leaf	88.8	79.3
2. 30% ,,	95.9	106.6
3. 45% ,,	117.5	117.4
4. 15% 9-leaf	88.7	83.8
5. 30% ,,	105.4	94.9
6. 45% ,,	116.3	82.1
7. 15% tasselling	94.8	81.5
8. 30% ,,	97.1	83.3
9. 45% ,,	103.9	94.4
10. Control (check)	97.2	85.1

Lack of yield reduction due to stand losses early in the season was due to compensation. The loss of plant stand was compensated to a large extent by each plant producing more yield. The extent of compensation was higher when plant population was reduced at the early stage of crop development (Figure 5.3). Similarly the greater the number of plants removed the higher the compensation. The effect of compensation was also noted in cob weight. Since there was generally one cob per plant, cob weight was heavier where plant population was reduced (Table 5.9).

Higher plant density at the early stage of crop development reduced plant growth due to competition between plants for nutrients, moisture and sunlight. The reduction of plant population at this stage will minimize competition between plants so that the remaining plants could grow more

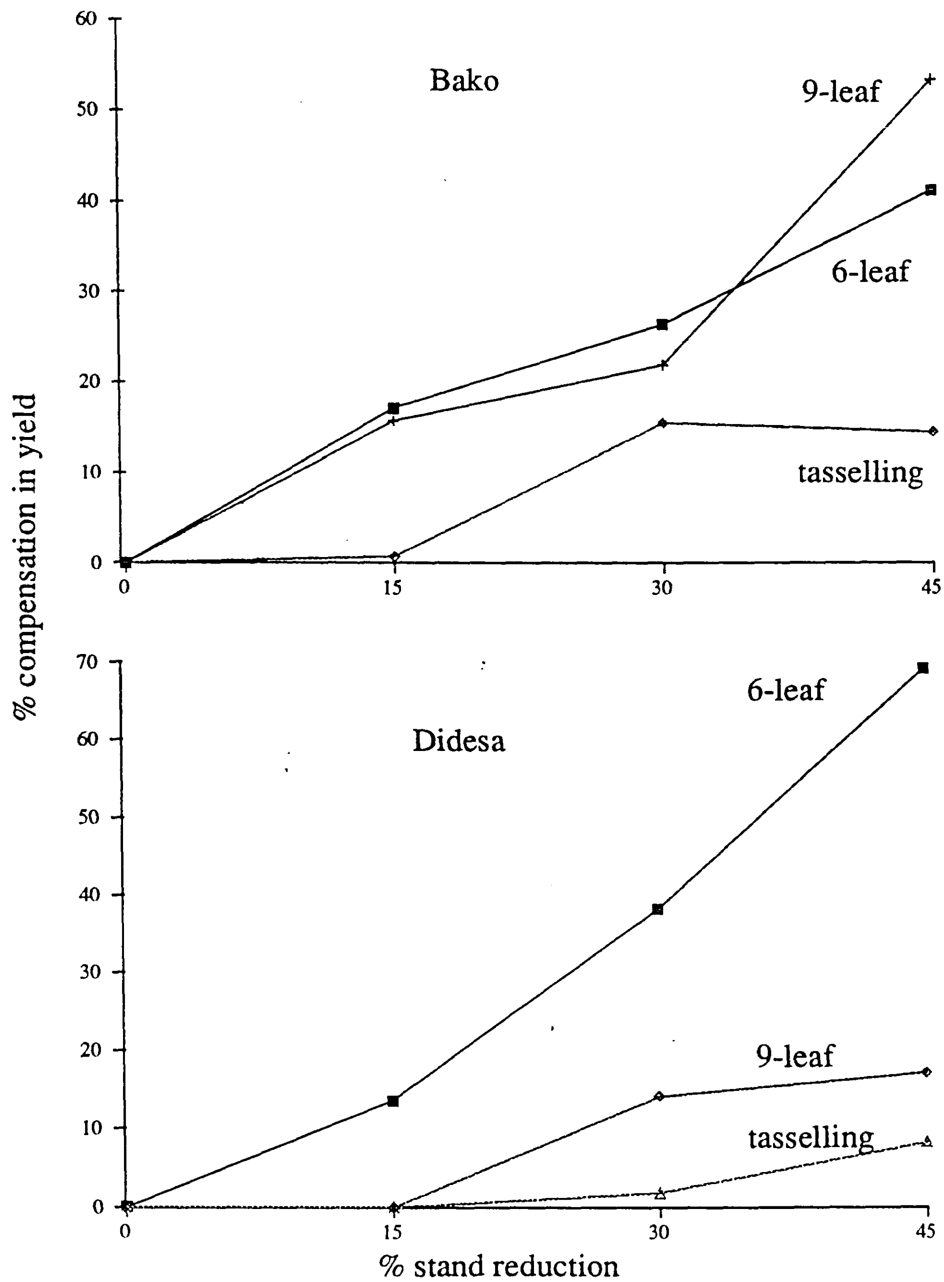


Figure 5.3 Relationship between stand reduction and compensation in maize

vigorously and produce more yield. As shown in Figure 5.3, the level of compensation was greater when plant population was reduced at the early stage of crop development.

Compensation at the tasselling stage was not significant mainly due to lack of active growth of the plant and lack of sufficient time for the remaining plants to compensate for stand losses.

Comparison of compensation between Bako and Didesa showed greater compensation at Bako than at Didesa (Figure 5.3). The main reason for the variation seems related to soil fertility differences. Bako soil is more fertile than that of Didesa. This indicates that compensatory growth on farmers fields would be less important as the soil fertility is extremely poor. Therefore, stand losses cause relatively higher yield losses.

The trial indicated that stand losses that occur towards the later stage of crop development causes more yield losses than at the earlier stages. Up to 9-leaf stage, 30% stand loss has not caused significant yield reduction mainly due to compensation. However, when stand losses occur at the later stages, especially after seed formation the plants would not have sufficient time to compensate and stand reductions would result in significant yield losses.

In several parts of western Ethiopia much of stand losses caused by *Macrotermes* occurs towards the earlier stage of crop development and the magnitude of stand losses are well below the level that can be compensated. In such areas, there is no need for control measures. However, in a few areas such as

Chuta Gelel in Ghimbi Province where more than 30% stand losses were observed, yield losses are likely to occur. In these areas control measures would be necessary. In areas where *Macrotermes* is causing a serious problem, farmers tend to sow a high plant population to compensate for stand losses. In the absence of crop damage this practice would create competition between plants and reduce yield.

The occurrence of compensatory growth in maize has been also reported in some other studies. Harris (1962) reported that stand loss caused by Lepidopterous stem borers in maize is compensated for by the production of heavier cobs. One of the major characteristics of maize and other cereal crops, compared to fruits and vegetable crops, is their ability to tolerate higher level of insect damage (Chiang, 1978). As a result it has been suggested that the economic threshold should be raised to the level where the value of the crop saved is twice the cost of control. Cowie and Wood (1988) have postulated that the compensation in maize is at its maximum at a plant density of 75 % of the recommended seeding rate. Harris (1962) also reported that stand loss is compensated only when the loss is not very high and soil fertility is not a limiting factor. Compensatory growth is not unique to maize, it was also observed in other cereals and field crops. In the case of cotton, stand reductions are compensated by producing more sympodial nodes per main node (Matthews *et al.* 1972). Also in okra (*Abelmoschus esculentus*) no yield reduction was recorded when 25% of the leaves were removed (Olasantan, 1988).

CHAPTER SIX : TERMITE CONTROL IN CROPS

6.1 INTRODUCTION

Various traditional methods of termite control are used by small farmers to prevent crop damage caused by termites in the tropics and sub-tropics. For example, the traditional methods used by the farmers in western Ethiopia include flooding mounds, digging mounds and removing the queen or excavating the top parts of the mounds and burning straw to suffocate and kill the colony. Harvested crop is protected by placing the produce on wooden beds raised few centimetres above the ground (Ghimbi Province Ministry of Agriculture, unpublished). Malaka (1972) described 23 traditional methods of termite control used by farmers in Nigeria. These methods include burying dead animals such as goats and dogs in the middle of infested fields, or planting different species of grasses such as *Vetiveria nigritana* (Benth.) Stapf., *Digitaria* spp. and *Cymbopogon shoenanthus* Spreng at several spots in the farm to repel termites. The traditional methods are less likely to provide an effective termite control. However, they would help to develop improved termite control methods appropriate to the small farmers as traditional methods are considered the basis for any insect pest management programme (Matteson *et al.*, 1984).

In areas where crop production is threatened by termites, the use of recommended termite control methods would be

Plate 6.1 *Macrotermes* mound flooding in Didesa valley

necessary to prevent crop damage. Termites that cause crop damage in Ethiopia can be grouped into mound building and subterranean nesting termites. 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 the type of termites causing crop damage.

6.1.1 Mound Building Termites

In areas where mound-building termites are involved in crop losses, destruction of termite colonies is considered beneficial (Schmutterer, 1969). Several methods are used to destroy the colony of mound-building termites. Some farmers have removed the queen from termite mounds, but the size and hardness of the mound structure makes this an arduous task. Alternatively mounds are flooded to destroy the colony. Queen removal is not considered effective because of the ability of certain species to develop substitute queens under favourable conditions (Harris, 1971; Schmutterer, 1969). 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 (Harris, 1954; Darlington, 1985). Removal of a queen, therefore, does not necessarily lead to colony mortality.

Harris (1971) and Coaton (1950) also recommended the destruction of mounds to protect crops and buildings. In India, although destruction of termite mounds is recommended, soil treatment is also required (Sankaran, 1962). Mechanical removal of mounds by bulldozers or other methods is considered expensive and non-effective unless it is followed by chemical treatment (Schmutterer, 1969).

Organochlorine insecticides such as aldrin, dieldrin and heptachlor are most commonly used for mound poisoning. However, other less persistent insecticides can be used provided they are effective against the termites. Diazinon, fenthion (Bohlen, 1973; FAO, 1985) have been reported to be effective. Sanna (1973) tested hydrogen phosphide tablets, but only the queen and the workers were killed while soldiers and nymphs survived, irrespective of whether 1, 2 or 3 tablets per nest were used. The insecticides are applied into the nest as emulsions or fumigants after removing the top portion of mounds to expose the main galleries that lead to the central hive or by making 2-3 holes through the mound walls.

Mound poisoning is relatively simple to carry out and less likely to pollute the environment since small amount of insecticide is used per nest, but it had several limitations. It cannot be carried out in areas where there is shortage of water since large amount of water is needed for mixing the insecticides. Also it cannot be conducted during the dry season as the mounds get too hard to dig. However, the most important limitation 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.

An economic analysis conducted to find if mound levelling is economical or not showed that in the case of small mounds it was economical to drive over them with tractor and use the area for crop production, but in the case of large mounds on which tractors or cultivation equipment cannot be driven over mound levelling was not economical (Boer, 1975). According to Sands (1976) most of the termite species that cause crop damage in western Ethiopia are completely subterranean and the one species that build mounds also exist as subterranean at its earlier stage of development. As a result he did not support extensive mound poisoning programme. Since the effect of mound poisoning on crop yield is not known, an assessment of the method is quite important.

6.1.2 Subterranean Nesting Termites

The control of subterranean termites require a different approach from mound-building termites. Since they do not build mounds and the location of their nest is not known, the colony cannot be attacked directly. Therefore, the most appropriate strategy is to protect crops from being attacked. Such control measures require a persistent insecticide that would protect crops throughout their susceptible period.

In consequence, termite control has depended for the last 40 years on the use of cyclodiene organochlorine insecticides namely aldrin, dieldrin, chlordane and heptachlor. The persistence of these insecticides made them ideal for termite control especially to protect timber in dwellings (Beal and Miller, 1980; Mauldin *et al.*, 1987). Bennett *et al.* (1974) found chlordane and dieldrin 21 years after application on soils to control termites destroying buildings in the USA. Sands (1962) also recovered in the tropics under conditions exposed to the sun and rain about one-fifth of aldrin and dieldrin deposits in the soil 33-34 months after application. Bioassays have shown that aldrin and dieldrin in soil treatment was effective six years after treatment whereas sodium arsenite and lindane had lost much of their toxicity (Bess *et al.*, 1966).

Organochlorine insecticides were also reported effective against the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) 15 years after application (Hetrick, 1962). The vertical and horizontal movement of these insecticides is very much restricted, therefore, the possibility for environmental contamination was considered remote (Bennett *et al.*, 1974). Nevertheless soil moisture at the time of application could enhance penetration of these insecticides into the soil to a limited extent (Beal and Carter, 1968).

Different methods of insecticide application are used for termite control in crops. The most appropriate methods for farmers are seed and soil treatments.

a) Seed treatment:- has been known as long ago 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 amounts 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.

However, the effectiveness of seed treatments is variable. In Sudan seed treatment was found effective against *Microtermes najdensis* (Tiben, 1985) and a cost benefit ratio of 1:46 was reported for seed dressing in cotton (Wood and Kambal, 1986). This shows a very high economic return that can be obtained using seed treatment. Although cereals are more susceptible to termites, effective control of *Microtermes obesi* Holmgren was obtained in wheat by treating the seed with aldrin 30% EC at the rate of 125 g actual per quintal (Verma *et al.*, 1975).

Other studies have shown that the effect of seed treatment seldom persists sufficiently long enough to give effective control of termites attacking mature crops. For example, a survey in Nigeria showed that seed treatment failed to provide adequate protection against *Microtermes* spp. which generally attacks annual crops late in their growing period (Johnson *et al.*, 1981). A similar survey showed groundnut seeds treated with either aldrex T or Fernasan D suffered up to 40% yield losses (Johnson and Wood, 1980).

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

In addition to lack of effective control, seed treatment is often reported to cause a reduction in seed germination. HCH 10% seed treatment reduced the germination of wheat seeds to less than 40%. Similarly aldrin and heptachlor at the rate of 8 ml product per kilogramme seed also reduced germination to 43% and 35% respectively (Sandhu and Sohi, 1981). Aldrin, dieldrin and gamma HCH when used alone or in combination with fungicides also retard seedling growth in maize, reduce development of roots and weaken seedlings under unfavourable conditions. These undesirable effects were observed more commonly in single cross than double cross hybrids of maize (Kommedahl and Windels, 1986). The variations in the effectiveness of seed treatments clearly indicate that it is important to determine which insecticide at what dosage should be used for a particular crop and extent of its effectiveness during the season before any recommendation can be made to the farmers.

b) 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. For example in the Sudan, treatment of the planting hole was much more effective than seed treatment for the control of *Microtermes najdensis* in cotton (Tiben, 1985).

Soil treatment is considered highly effective against fungus - growing termites since they are repelled by insecticides (Coaton, 1950). However, successful control depends on an even distribution of insecticides through the soil to create an effective barrier around the crop (Sands, 1973). Using soil treatment, significant control was reported against termites that attack crops in India (Sankaran, 1962; Verma *et al.*, 1974) and in Tanzania (Bigger, 1966). Aldrin 30% EC at the rate of 0.625 to 1.250 litre product per hectare mixed with 50 kilogramme sand or soil and broadcasted on the soil surface also provided effective control both in irrigated and rainfed wheat. In addition to the control of termites, soil application of aldrin and HCH was reported to improve the general condition of crops (Sandhu and Sohi, 1977).

The effectiveness of soil treatment also depends on the method of application used. Furrow treatment with heptachlor, chlordane, lindane and HCH was more effective against *Odontotermes obesus* Rambur on groundnuts compared with a broadcast application at the time of sowing or by application around plants followed by earthing 50 days 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). Pre - sowing soil treatment with organochlorine insecticides also controlled termites in the Tihama region of the Yemen Arab Republic (Wood *et al.*, 1987), in ragi, Niger and maize in India (Sudhakar and Veeresh, 1985) and in maize and soybean in Tanzania (Bigger, 1966).

Soil treatment requires large amount of insecticides and so the method is relatively more expensive compared to seed treatments. Therefore, subsidy would be required in order to encourage farmers to adopt the technique.

c) Cultural control:- various recommendations, based on general observations rather than on field trials and hence without quantifiable benefits, have been made for termite control. Some of the methods believed to discourage the build up of large populations particularly that of *Microtermes* are discussed below:

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

Ideally the farmer should rotate crops so that the same crop is not planted the following season. The rotation should include a crop which is tolerant or resistant to termite infestation. 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).

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

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, cotton termites 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 (eg., *Microtermes*) 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 sunflowers (Harris, 1961) and groundnuts (Harris, 1954).

Generally, termite damage is considered to be greater in crops grown on poor soils probably the crops tend to be more woody due to lack of moisture. Where farmers can improve water retention by increasing the humus content of soil termite damage has been reduced (Harris, 1954). Unfortunately few farmers have sufficient cattle manure to maintain adequate humus levels.

6.1.3 Environmental Hazards

The persistence of the organochlorine insecticides in the environment and effects on non target organisms has led to their being banned in many countries (United Nations, 1987). Other studies have indicated that insecticides such as aldrin and dieldrin are carcinogenic in rats and mice (Watterson, 1988). Export agricultural products from developing countries are also rejected by developed countries if they contain detectable residues of cyclodienes (Wood and Kambal, 1986). In consequence their use for termite control has been discontinued in the USA, western Europe and a number of other countries. These legal and economic restrictions have led researchers and chemical companies to seek alternative products and/or methods of termite control.

6.1.4 Alternative insecticides and methods

Laboratory and field studies have examined the effectiveness of organophosphates, carbamates and pyrethroids against termites. The most common field test method is to apply a known concentration and volume of an insecticide to the soil surface and then place an untreated wood block in the centre of the treated area for monitoring termite activities and determining the effectiveness of the insecticides. This ground-board method may be modified by covering the treated area with polyethylene vapour barrier to simulate termite damage under concrete slabs in buildings.

a) Organophosphates:- as an alternative to the organochlorine insecticides, the organophosphate chlorpyrifos was registered in 1980 by the US Environmental Protection Agency (EPA) for the prevention and control of subterranean termites in buildings (Mauldin *et al.*, 1987). It was introduced by the Dow Chemical Company under the code number 'Dowco 179', the trade name 'Dursban' and 'Lorsban'. The chemical name of chlorpyrifos is 00-diethyl 0,3,5,6-trichloro-2-pyridyl phosphothioate (Worthing and Walker, 1987). Its mode of action is on the nervous system and the typical symptoms of poisoning are cholinomimetic, hyperactivity and paralysis (Hutacharern and Knowles, 1974).

Khoo and Sherman (1981) tested the toxicity of chlorpyrifos both on normal and defaunated Formosan subterranean termites in which the intestinal protozoa was removed by increased oxygen tension and found that chlorpyrifos was more toxic on defaunated termites. Subterranean termites were effectively controlled by chlorpyrifos at 1 and 2% concentrations in the modified ground board method (Mauldin *et al.*, 1987; Beal and Smith, 1972). In Saudi Arabia successful control of *Microtermes* spp. was also obtained by using chlorpyrifos on green peppers (Badawi and Faragalla, 1986).

Chlorpyrifos has also shown a considerable potential for use in timber preservation (Howick and Creffield, 1981).

Ultra violet light, high temperature and direct rainfall are some of the factors that reduce the efficacy of chlorpyrifos. Beal and Miller (1980) reported a 20% reduction in the efficacy of chlorpyrifos at 1 and 2% concentrations when exposed to ultra violet light and direct rainfall. Failure in the chlorpyrifos treatment was also recorded when the soil surface was exposed to high temperature (120 to 150 ^{0}F) and ultra violet light (Beal, 1980).

Isofenphos (0-ethyl-0-(2-isopropoxy-carbonyl)phenyl isopropylphosphoramidothioate) (Worthing and Walker, 1987) is another organophosphate insecticide effective against termites. It was registered in 1982 by the EPA for the prevention and control of subterranean termites in buildings. It was 100% effective at .5, 1.0 and 2.0% concentrations in the modified ground board method at three different sites in the USA, but in the ground board method its performance was poor perhaps due to vapour loss (Mauldin *et al.*, 1987).

b) Synthetic pyrethroids:- permethrin, cypermethrin, deltamethrin and fenvalerate are also effective against termites damaging structural timber (Baker and Berry, 1980). Currently permethrin is registered by the EPA for subterranean termite control and has provided 100 percent control in five locations in ground board tests (Mauldin *et al.*, 1987). As a wood preservative, it is considered to be better than chlordane

(Inoue, 1983). Deltamethrin also proved superior to gamma HCH in the control of *Reticulitermes* and other wood boring insects (Baker and Berry, 1980). Cypermethrin is regarded the most promising termiticide which has performed exceptionally well in all the test sites in the USA. It has remained 100% effective at 1.0% concentration since the test began four years ago. Fenvalerate was also 100% effective at 1.0% concentration for four years and the test is still in progress (Mauldin *et al.*, 1987). Whether synthetic pyrethroids can persist for a sufficiently long period of time under field conditions in the tropics has yet to be investigated.

c) Insecticide impregnated baits:- some progress has also been made in improving methods of application by impregnating baits with pesticides. This technique is based on trophallaxis which is the process of food exchange from workers to other members of the colony. Poisoned baits placed at suitable sites are attacked by foraging workers which in turn distribute the pesticide through their characteristic grooming and trophallactic behaviour to other members of the colony, particularly the dependent castes of nymphs, soldiers and reproductives. The major advantage of the technique compared to conventional methods of pesticide application is that there is less risk to natural enemies of termites. It is also considered environmentally safe and economically sound since small amount of pesticide is required (Ostaff and Gray, 1975).

Pesticides used in the baiting method have to be non repellent and slow acting so that termites that feed on baits leave treated areas before they die. Among the insecticides tested mirex (dodecachloroactahydro-1,3,4,-metheno-2H cyclobuta (cd) pentalene) had the desirable characteristics of non repellency and delayed toxicity. It was effective against *Mastotermes darwiniensis* Froggatt (Paton and Miller, 1980) and *Reticulitermes spp.* (Esenther and Beal, 1974; Esenther, 1979; Ostaff and Gray, 1975; Esenther and Beal, 1978). Although it had the desirable characteristics and was effective against termites, it has been banned in some countries, such as the USA, Canada, Sweden and Ecuador since it is an organochlorine insecticide (United Nations, 1987).

Amdro, an amidinohydrazone compound, developed for the control of fire ants, *Solenopsis spp.* was found to have the desirable characteristics for bait method of termite control and considered the best alternative for mirex (SU *et al.*, 1982). Effective control was obtained against *Reticulitermes santonensis* (Feytaud) in laboratory (Abood, 1984) and the Formosan subterranean termite in Hawai (Su *et al.*, 1982).

Other groups of insecticides have also been tested against termites in bait methods and found effective. A field trial conducted in South Africa showed that sodium fluosilicate, endosulfan, carbaryl, bromophos and dieldrin are effective when used as baits in the control of *Hodotermes mossambicus* (Finlay, 1971). Wood infected with the brown rot fungus *Gloeophylum* *trabeaum* (Pers. ex-Fr) Murr. is more effective in baiting than sound wood (Smith, 1982).

Control of fungus-growing termites has been attempted using fungicides in baits as a selective method. Out of 25 fungicides tested only three were found suitable for the baiting technique (Wood and Kambal, 1986). In Sudan an encouraging progress has been made in the control of *Microtermes spp.* using carboxin and fenfuram in cotton (Tiben, 1985) and fenfuram and biloxazol (EL Bakri *et al.*, 1989).

The banning of mirex also led to the development of w - fluorofatty acid derivatives for use in bait method against subterranean termite control and fluoroalchol-2 showed least repellency at the doses that provided substantial kill (Prestwitch *et al.*, 1983).

Successful control has been achieved under laboratory conditions using the baiting technique; however, under field condition there has been little success (Wood and Thomas, 1989). Lack of success in the field seems due to the availability of food choices which would dilute the effect of insecticides. More research is needed to refine the technique so that the termites feed more on the baits than natural food sources.

d) Controlled-release formulations:- some progress has been made also in developing formulations that could persist long from non persistent. These new controlled-release formulations are currently being tested for termite control in forestry. In

South Africa, controlled-release granules of carbosulfan, carbofuran and phorate were as effective as chlordane EC in the control of *Macrotermes natalensis* Haviland on *Eucalyptus* when used at the rate of 1.0 g a.i./tree mixed with the surrounding soil at the time of planting (Atkinson, 1989).

e) Insect growth regulators (IGR):- hydroprene and methoprene have also been tested to explore their potential for use in termite control. They had concentration dependent morphogenetic and lethal effects on *Reticulitrmes spp.* but no effect on *Coptotermes spp.* The lethal effect of methoprene on *Reticulitermes flavipes* was mainly due to the elimination of symbiotic protozoans which assist termites in their food digestion and the production of large number of soldier castes which are unable to feed themselves and the colony (Haverty and Howard, 1979). As a result the colony dies due to starvation. Insect growth regulators have a good potential for use in termite control since they are target specific and environmentally safe.

f) Biological control:- no biological method has been developed which controls termites. Nematodes (Mix, 1985) and a nuclear polyhedrosis virus (Al-Fazairy and Hassan, 1988) were effective under laboratory conditions, but failed to provide satisfactory control in the field. 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 these 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 the prospects for biological control of termites does not seem promising.

Whereas farmers in Ethiopia could easily obtain and did use organochlorine insecticides for termite control, their banning in many countries, has led to difficulties in the supply. Prices have also increased. Some of the international agencies such as the World Bank are now reluctant to finance the purchase of cyclodienes. In view of the prevailing situation in Ethiopia, this study was initiated to seek for alternative insecticides and methods of application suitable to farmers. Chlorpyrifos and isofenphos were included as possible alternatives to organochlorine insecticide as they have been registered for termite control in buildings in the USA (Mauldin *et al.*, 1987). Chlorpyrifos has also given an effective termite control in green peppers in Gizan area of Saudi Arabia (Badawi and Faragalla, 1986).

6.2 MATERIALS AND METHODS

6.2.1 Termite Control in Maize

Three different termite control trials were conducted on maize to determine the most effective methods. The aim of the first trial was to evaluate different chemical and non chemical methods against termites damaging maize. The trial was conducted during the 1987 crop season at Sasiga and Ghimbi-1 and the experimental details are given in Table 6.1.

The aim of the second trial was to determine the effectiveness of chlorpyrifos and isofenphos as seed treatment when applied at the same rate with aldrin and at three times higher rate. The trial was conducted at Ghimbi-2 and the experimental details are given in Table 6.2

The third trial was conducted to test the effectiveness of chlorpyrifos and isofenphos in three different methods of application namely seed treatment, furrow treatment and the combination of seed and furrow treatments as these are the methods suitable to small farmers. Aldrin was included in the trial as standard insecticide to compare the two test insecticides. This trial was conducted during the 1988 crop season on farmers fields at Ghimbi, Henna and Mendi where *Macrotermes* was reported to cause heavy crop mortality. The experimental details are given in Table 6.3.

Table 6.1 Experimental design used to test the effectiveness of different termite control methods in maize

Design : Randomized complete block
Replication : 4
Plot size : 20 x 20 m
Variety : Local maize and improved variety 'KCC'
Sowing dates : Sasiga 10 - 12 May
Ghimbi 18 - 20 May

Treatments :

(1) Fertilizer with local cultivar
(2) Improved variety
(3) Local cultivar and aldrin 40% WP soil treatment at 1 kg a.i./ha
(4) Improved variety and aldrin 40% WP soil treatment at 1 kg a.i./ha
(5) Local cultivar and aldrin 40% WP seed treatment at 25 g a.i./10 kg seed
(6) Local cultivar and chlorpyrifos 5% seed treatment at 125 g a.i./10 kg seed
(7) Local cultivar and isofenphos seed treatment at 125 g a.i./10 kg seed
(8) Local cultivar and double the recommended seeding rate
(9) Control (local cultivar without fertilizer)

Table 6.2 Experimental details for testing chlorpyrifos and isofenphos seed treatment

Design : Randomized complete block
Replications : 4
Plot size : 15 x 20 m
Crop : Local maize
Sowing date : 23 - 25 May, 1987

Treatments :

(1) Aldrin 40% WP seed treatment at 25 g a.i./10 kg seed
(2) Chlorpyrifos 5% seed treatment at 25 g a.i./10 kg seed
(3) ,, ,, ,, 75 g a.i./10 kg seed
(4) Isofenphos 40% WP seed treatment at 25 g a.i./10 kg seed
(5) ,, ,, ,, 75 g a.i./10 kg seed
(6) Control (without insecticide)

Table 6.3 Experimental details for testing the effectiveness of chlorpyrifos and isofenphos in three different methods of application

Design	: Randomized complete block
Replications	: 10 at Mendi and Henna; 8 at Ghimbi
Plot size	: 6 x 8 m
Crop and variety	: Improved maize variety 'Bako Composite'
Sowing dates	: Mendi 14-15 May; Henna 19-20 May; Ghimbi 22-23 May

Treatments :

(1) Chlorpyrifos TC seed treatment at 12.6 g a.i./kg seed
(2) ,, furrow treatment at 1 kg a.i./ha
(3) ,, seed and furrow treatment as (1) & (2)
(4) Isofenphos 40% seed treatment at 12 g a.i./kg seed
(5) ,, furrow treatment at 1 kg a.i./ha
(6) ,, seed and furrow treatment as (1) and (2)
(7) Aldrin 40% WP seed treatment at 2.5 g a.i./kg seed
(8) ,, furrow treatment at 500 g a.i./ha
(9) ,, seed and furrow as (1) and (2)
(10) Control (check)

At all experimental sites land was prepared using ox ploughs and hand hoeing. For the plots with aldrin, chlorpyrifos and isofenphos treated seed the amount of seed required for each plot was weighed separately, placed in a tray and wetted by adding tap water. The required amount of insecticide for each plot was weighed, added to the wetted seed and thoroughly mixed. Similarly for soil treatment the insecticide required for each plot was weighed and mixed in 2-4 kilogramme of pure sand depending on the area to be treated and uniformly broadcast by hand on the treated plots. The insecticides were then incorporated with the soil by hoeing. Diammonium Phosphate (DAP) fertilizer was applied at the rate of 100 kg/ha at the time of sowing and soil incorporated. Additional urea was applied at the rate of 50 kg/ha when maize reached knee-height. Maize was sown in rows at 75 cm spacing between rows and 30 cm within rows. To double the recommended seeding rate, the spacing within the row was reduced to 15 cm. The spacing between replications was 1.5 m and between plots 1.0 m.

Plant population was counted just after germination and re-sown where there was germination failure. Data on crop damage was recorded at about three week intervals. The number of plants cut by *Macrotermes* were counted and removed from plots.

The presence of economically important termite species in the trial areas and their seasonal foraging activities were monitored using *Eucalyptus* wood baits each 10 x 2 x 2 cm., placed in the monitoring areas. In the first trial 200 baits, in the second 100 baits were placed in the control plots and in the third 120 baits were placed in chlorpyrifos, isofenphos furrow treatments and the control plots. Data on baits attacked, termite species present and their approximate number were recorded at about three week intervals and the baits attacked were replaced with a new bait. When termites that attacked the baits were not present at the time of data collection, their identity was determined by their characteristic feeding marks.

In trials one and two, at tasselling stage 20 plants were randomly selected outside the sampling areas, pulled by hand and checked the roots for *Microtermes* infestation. In the third trial every plant was pulled at harvest by hand and checked the roots for *Microtermes* infestation. At maturity, the cobs were harvested, removed the sheaths and dried in the sun for a week. After they were sufficiently dry they were shelled and the grain weighed. The data on *Microtermes* root infestation and stand losses caused by *Macrotermes* were transformed to either square root or arc sine depending on the data and analyzed using analysis of variance by a 'SX' programme. The yield data was analyzed using analysis of variance.

6.2.2 Termite Control in Tef

The aim of this trial was to determine if protecting tef against *Macrotermes* at its susceptible stage could improve grain yield. The trial was carried out during the 1988 season on farmers field at Mendi, Gori, Jarso and Henna and heptachlor 40% WP was applied as a general soil treatment when tef reached heading stage.

At each locality, five tef fields were selected where *Macrotermes* had been observed causing significant loss of plants. All these fields were sown with the local tef cultivar by broadcasting the seed in the conventional manner. The plot sizes were 5 x 10 m with 2 m between plots. The plots treated with heptachlor were randomly selected. Heptachlor at the rate of 1 kg a.i./ha was mixed with about 2 kg of fine - dry soil just before application and broadcasted at the base of the crop at heading stage. This is the stage when heavy plant mortality begins on tef. The insecticide was applied around the base of the crop so that the adjacent control plots were not contaminated. At maturity a sampling area of 2 x 2 m was harvested in the centre of each plot. The harvested crop was dried for a week, threshed by hand, winnowed and the grain weight was recorded.

6.2.3 Termite Colony Destruction

The effectiveness of different termite colony destruction methods were investigated at Wajeti Mendi, Gori (Nedjo) and Henna during 1988 just before tef sowing. The experimental design was a completely randomized design with four replications. The treatments tested were as follows:

(1) Chlorpyrifos TC at 20.2 g a.i./mound

(2) Diazinon 60% EC at 19.2 g a.i./mound

(3) Queen removal

(4) Control

For insecticide treatment the top portion of termite mounds were dug with a pick-axe until the main 2-3 ventilation galleries that lead to the central part of the hive were exposed. The treatments were carried out only on live mounds after checking the presence of live termites in the nest. The amount of insecticides required for each mound was measured and mixed with 20 litres of water. The solution was poured into the nest through the main galleries. These were immediately covered with soil and tramped on foot to prevent evaporation of the insecticides and to reduce the risk of birds being poisoned by eating dead termites.

The queen was exposed by digging the mounds until the royal chamber was located. The soil was then replaced after removing the queen. The control mounds were dug until the main galleries were exposed and then 20 litres of water was poured into the nest. These mounds were also covered by returning the removed soil. The efficacy of the treatments were assessed one month after the treatments by digging each mound and checking whether the termites were alive or dead. A treatment was considered 100% effective if no live termites were found in the nest.

6.2.4 Evaluation of Mound Poisoning

The effectiveness of mound poisoning was assessed in terms of crop yield and the appearance of new mounds. The assessment on crop yield was on tef since it was sown in the area after the mound treatments were completed. Four localities each having treated and untreated adjacent areas were selected. The criteria followed for selecting these sites were that the treated and untreated areas were not more than 300 m apart, sown at about the same time with the same local varieties and the crops received similar management practices. At approximately one month before harvest both in treated and untreated areas five plots each 2 x 2 m were randomly selected across the diagonal of the field and marked the plots with wood pegs. At maturity each plot was separately harvested, dried, threshed and weighed.

The re-appearance of new termite mounds was assessed in Menesibu Province where extensive mound destruction campaigns were conducted twice; the first in 1983 by the Ethiopian Ministry of Agriculture and the second five years later in 1988 by the Ministry of Coffee and Tea Development. Every visible mound was destroyed and treated with aldrin 40% WP during the first campaign and with heptachlor 40% WP during the second campaign. At both times the number of mounds treated on cultivated lands and grazing lands were counted and registered. The difference in the number of termite mounds in 20 randomly selected peasant associations were analyzed.

6.3 RESULTS AND DISCUSSION

6.3.1 Effect of Insecticides and Methods of Application on Maize Seed Germination

The effect of chlorpyrifos, isofenphos and aldrin in seed, furrow and combination of seed and furrow methods of application on the germination of maize seed is shown in Table 6.4. Chlorpyrifos seed treatment significantly reduced germination, but there was no significant difference between aldrin and isofenphos seed treatments. No significant difference was also noted between the three insecticides applied in the furrow, except at Mendi, where there was higher germination in the aldrin furrow treatment. In the combination of seed and furrow treatments, germination was again significantly low where chlorpyrifos was applied; there was no difference between isofenphos and aldrin with this method.

Lack of differences between the insecticides in the furrow method clearly showed that chlorpyrifos phytotoxicity is related to seed treatment method. In the 1987 trial, maize seed germination was not affected when treated with chlorpyrifos 5% dust, so suppression of seed germination is probably due to using a liquid formulation.

Other studies reporting suppression of germination by different insecticides used as a seed treatment include Sandhu and Sohi (1981) who reported reduced germination following treatment of wheat seed with HCH and high doses of aldrin. Verma *et al.* (1974) also reported 69.7% reduction in wheat germination with a wet seed treatment method compared with 49.7% using dry method when HCH 50 WP was applied at 0.25 kg a.i. per 10 kg of seed.

6.3.2 *Microtermes*: Effectiveness of Control Methods

Considerable variation in the percentage of maize root infestation has occurred at the different sites. Lowest infestation was recorded at Sasiga, Henna and Mendi possibly due to a relatively short period that these areas have been under cultivation. Particularly at Sasiga a primary woodland had been cleared only recently and cultivated for one year.

Table 6.4 Effect of insecticides and methods of application on maize seed germination

Treatment		% mean germination		
		Mendi	Henna	Ghimbi
Chlorpyrifos	S*	32.0[d]	41.6[b]	32.3[d]
,,	F	79.3[bc]	91.3[a]	81.3[abc]
,,	SF	37.1[d]	42.4[b]	34.0[d]
Isofenphos	S	78.9[bc]	90.8[a]	87.7[a]
,,	F	76.5[c]	89.4[a]	80.5[abc]
,,	SF	78.9[bc]	87.1[a]	83.9[ab]
Aldrin	S	84.1[ab]	93.0[a]	79.1[bc]
,,	F	86.4[a]	90.0[a]	79.6[abc]
,,	SF	85.7[ab]	91.3[a]	83.1[ab]
Control		75.3[c]	90.7[a]	68.5[c]
F ratio		(38.5)**	(17.5)**	(16.6)**
S.E.		(2.8)	(5.1)	(4.6)

Figures in parenthesis refer to transformed test statistics

Means followed by the same letter are not significantly different at 1% level

*, S = seed treatment, F = furrow treatment

Higher infestation was recorded at Ghimbi since the area had been under cultivation for several years. *Microtermes* infestation is known to be higher in areas that have been under cultivation for several years than newly opened farm areas (Wood *et al.*, 1980).

Compared to the local cultivar, higher number of plants were attacked when the untreated improved varieties of maize were sown and the infestation reached 6.3% at Sasiga and 40.0% at Ghimbi (Table 6.5). The local cultivar sown on aldrin treated soil, at Ghimbi, had a significantly lower level of infestation than all other treatments except the improved variety also sown on aldrin treated soil (Table 6.5).

Lack of significant differences between the seed treatments, high seeding rate, application of fertilizer and the control treatments showed that none of these methods provided effective control against *Microtermes* (Table 6.5). Generally it is believed that plants grown in fertile soils are less likely to be attacked by termites (Harris, 1954); however, no such effect was observed in fertilized plots as opposed to unfertilized ones. There was no significant difference among chlorpyrifos 5% and isofenphos 40% WP applied at 25 g a.i./10 kg seed and 75 g a.i./10 kg seed, aldrin at 25 g a.i./10 kg seed and the control (Table 6.6). Similarly, no significant difference was observed among chlorpyrifos TC, isofenphos 40% WP and aldrin 40% WP applied as seed treatment, furrow treatment and in combination of seed and furrow treatments (Table 6.7).

The differences in mean percentage infestation between the two rates of chlorpyrifos (Table 6.6) was greater than the least significant differences (LSD), but the F test was not statistically significant. Thus differences cannot be accepted as significant (Gomez and Gomez, 1984). Both seed and furrow treatments have failed to provide the necessary protection against *Microtermes* attack in maize. The main reason for the failure of seed treatment is probably due to lack of effective barrier around the plant parts that lie below the soil surface. Seed treatment only protects the part of the root near the treated seed and possibly its surroundings. As a result the termite can penetrate the plant at any point where there is no insecticide barrier. Similarly lack of effective control in furrow treatment is also due to the absence of effective barrier. Maize roots that outgrow from the treated area can be attacked by the termite. In Nigeria also, seed treatment has not provided adequate protection for annual crops against *Microtermes* (Johnson et *al.*, 1981).

Generally, maize is infested by *Microtermes* starting from the tasselling stage, so, insecticides that are persistent for at least 4-5 months until seed formation are needed to prevent damage. Unfortunately, neither chlorpyrifos nor isofenphos are sufficiently persistent. Gas chromatography analysis carried out on soil samples taken from maize roots at harvest showed no traces of chlorpyrifos and isofenphos; whereas 0.09 ppm of dieldrin was recovered where aldrin treated seeds were sown since aldrin converted to dieldrin after application to the soil. Sands (1962) also reported the conversion of aldrin to dieldrin soon after application to the soil. Beal and Miller (1980) and Beal (1980) also reported lack of persistence of chlorpyrifos under direct rainfall and sunlight. The formulations of chlorpyrifos and isofenphos tested did not have the persistence required for termite control in agriculture. Probably the controlled-release formulations that are currently under trials in forestry may help to overcome the problem of persistence.

Table 6.5 Effect of different termite control methods in maize root infestation by *Microtermes*

	% mean infestation	
Treatments	Sasiga	Ghimbi
Improved variety	6.3 (2.3)	40.0 (39.1)[a]
Local variety + soil tmt[x]	1.3 (1.1)	8.8 (16.8)[c]
Improved variety + soil tmt[x]	5.0 (2.2)	20.0 (26.2)[bc]
Aldrin seed tmt	2.5 (1.3)	25.0 (29.5)[ab]
Chlorpyrifos seed tmt	2.5 (1.5)	28.8 (32.3)[ab]
Isofenphos seed tmt	5.0 (1.9)	32.5 (34.1)[ab]
Double seeding rate	5.0 (1.9)	33.8 (35.5)[ab]
No fertilizer	3.8 (1.5)	26.3 (30.1)[ab]
Control (local + fertilizer)	3.8 (1.5)	25.0 (29.4)[ab]
F ratio	(0.36)[ns]	(2.57)[*]
S.E.	(0.94)	(5.62)

Figures in parentheses are transformed data
Means followed by the same letter are not significantly different at 5% level
x = Aldrin
tmt = treatment
fert = fertilizer

Table 6.6 Effectiveness of chlorpyrifos and isofenphos seed treatments on *Microtermes* control at Ghimbi - 2

Insecticides/10 kg seed		% with roots infested by *Microtermes*
Aldrin 25 g a.i.		10.5 (3.2)
Chlorpyrifos	25 g a.i.	6.3 (2.5)
,,	75 g a.i.	15.0 (3.7)
Isofenphos	25 g a.i.	12.5 (3.5)
,,	75 g a.i.	13.8 (3.6)
Control		10.0 (3.1)
F ratio		$(1.37)^{ns}$
S.E.		(0.56)

Figures in parentheses show transformed data

Table 6.7 Effectiveness of insecticides and their methods of applications in the control of *Microtermes*

Treatments		% maize root infestation		
		Mendi	Henna	Ghimbi
Chlorpyrifos	S	6.6 (10.2)	9.7 (12.7)	31.1 (32.6)
,,	F	7.1 (10.9)	11.2 (16.9)	41.1 (39.8)
,,	SF	4.6 (7.1)	7.7 (11.9)	23.9 (27.3)
Isofenphos	S	19.2 (22.7)	17.1 (23.3)	34.8 (34.0)
,,	F	15.3 (17.8)	16.6 (21.2)	45.3 (42.3)
,,	SF	5.5 (8.6)	13.1 (15.0)	34.0 (34.9)
Aldrin	S	7.9 (11.2)	7.6 (14.2)	21.2 (23.6)
,,	F	4.9 (6.6)	6.7 (11.9)	16.3 (21.6)
,,	SF	14.5 (16.6)	12.2 (17.1)	25.7 (28.4)
Control		8.4 (13.5)	14.7 (19.3)	46.8 (43.3)
F ratio		$(1.47)^{ns}$	$(0.99)^{ns}$	$(1.96)^{ns}$
S.E.		(6.02)	(5.59)	(7.64)

Figures in parentheses show data transformed to arc sine
S = seed treatment
F = furrow treatment

6.3.3 *Macrotermes*: Effectiveness of Control Methods

In the control of *Macrotermes,* no significant differences were observed in seed treatment method between the two rates of chlorpyrifos and isofenphos, aldrin and the control (Table 6.8). Similarly with seed treatment and combination of seed and furrow treatment there was no significant difference between chlorpyrifos TC, isofenphos 40% WP and aldrin 40% WP in the control of *Macrotermes* (Table 6.9). Also there was no significant difference between the insecticides using the furrow method at Henna and Ghimbi.

Lack of effective control of *Macrotermes* by seed treatment seems due to the absence of insecticide barrier around the plant parts attacked. This is not surprising considering that *Macrotermes* forages just below the soil surface horizontally and cuts maize stems just below or at the soil surface causing complete loss of plants. The site where the insecticide is on the seed and the part of the plant attacked are thus separated and so the termites do not come into direct contact with the insecticide. As a result maize stem is cut at the base regardless of seed treatments.

Furrow treatment was expected to provide adequate protection against *Macrotermes;* however, contrary to what is expected all the insecticides tested failed to provide satisfactory control at all sites. This could be possibly due to soil cultivation which could have covered treated soil with untreated one over which termites moved and attacked maize.

This trial has, therefore, demonstrated that neither seed treatment nor furrow treatments provide effective control against *Macrotermes.*

Table 6.8 Effectiveness of dose rates of chlorpyrifos and isofenphos seed treatments on *Macrotermes* control

Insecticides/10 kg seed	% cut by *Macrotermes*
Aldrin 25 g a.i.	19.37 (4.35)
Chlorpyrifos 25 g a.i.	18.79 (4.23)
,, 75 g a.i.	18.70 (4.22)
Isofenphos 25 g a.i.	13.24 (3.60)
,, 75 g a.i.	14.25 (3.55)
Control	14.50 (3.75)
F ratio	$(0.50)^{ns}$
S.E.	(0.71)

Figures in parentheses show transformed mean to square root

6.3.4 Period of *Macrotermes* Attack

Stand losses caused by *Macrotermes* was observed throughout the maize growing period from crop emergence to harvest (Figure 6.1). However, variations were noted between different sites in the period of maximum damage occurrence. At Mendi and Henna maximum crop damage was recorded at 40-50 days after emergence (DAE) and thereafter declined until the beginning of the cob formation stage with only a slight increase towards crop maturity. The maximum plant mortality recorded at any one observation period was 2.9% at Mendi and 1.3% at Henna.

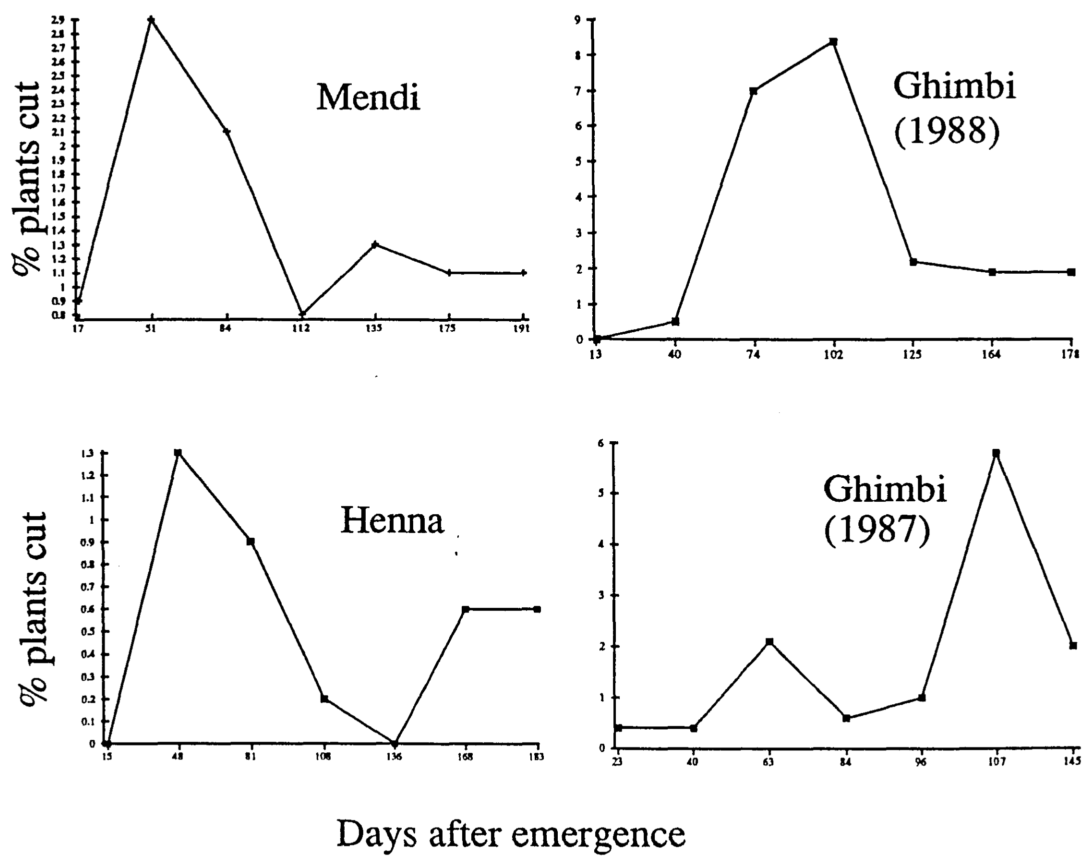


Figure 6.1 Maize plants cut by Macrotermes subhyalinus on untreated plots at different times after crop emergence

Table 6.9 Effectiveness of insecticides and methods of application on *Macrotermes* control in maize

Treatments		% cut by *Macrotermes*		
		Mendi	Henna	Ghimbi
Chlorpyrifos	S	8.7[cd]	2.8	20.4[d]
,,	F	20.7[a]	5.9	34.1[ab]
,,	SF	7.0[cd]	10.4	32.8[abc]
Isofenphos	S	13.8[abc]	5.8	25.5[bcd]
,,	F	11.5[abc]	3.3	35.5[ab]
,,	SF	11.4[abc]	3.4	37.7[a]
Aldrin	S	17.4[ab]	3.3	26.7[bcd]
,,	F	3.2[d]	1.7	37.1[a]
,,	SF	6.3[cd]	2.1	31.8[abc]
Control		9.9[bcd]	3.1	22.7[cd]
F ratio		(3.04)**	(1.60)[ns]	(2.47)*
S.E.		(3.85)	(3.32)	(3.61)

Figures in parentheses refer to transformed test statistics

Means followed by the same letter are not significantly different at 5% level

S = seed treatment, F = furrow treatment

At Ghimbi the number of plants cut during the first two months of growth were very few but increased to a maximum at about 100 DAE before declining. The highest number of plants cut at any one observation period was 5.8% during 1987 and 8.4% during 1988. The number of plants cut throughout crop growing period was also relatively high at Ghimbi compared to the other two sites. At Ghimbi the total percentage of maize plants cut was 14.4% in 1987 and 21.9% in 1988, whereas at Mendi and Henna it was only 10.2% and 3.6% respectively. More crop damage at

Ghimbi was possibly due to the occurrence of termite attack over a longer period than at the other two sites. The occurrence of *Macrotermes* attack on maize both at the seedling and mature stages were also reported in Nigeria (Wood *et al.*, 1980).

6.3.5 Effect of Insecticides in Foraging Activity

Foraging activity of *Microtermes* as indicated by attack of wood baits placed in chlorpyrifos, isofenphos and control plots showed no significant difference between the insecticides and the control, but variations were noted between sites (Table 6.10). At Mendi and Henna, chlorpyrifos was more effective in protecting wood baits than the control. However, at Ghimbi there was less bait attack on the control plots rather than those treated with chlorpyrifos or isofenphos.

The percentage of wood baits attacked by *Microtermes* on the untreated control plots were generally high at the beginning of the observation period in July and early August and declined gradually thereafter. In contrast, in chlorpyrifos and isofenphos treated plots few baits were attacked at the beginning of the observation period but increased gradually thereafter. This indicated that the insecticides could have an effect on the activity of *Microtermes* for the first few weeks following the placement of the baits, the period being perhaps related to the degree of persistence of the insecticides.

Table 6.10 *Microtermes* attack on wood baits

Date	% wood baits attacked		
	Chlorpyrifos	Isofenphos	Control
Mendi			
4/7/88	16.1	13.3	32.4
6/8/88	23.7	40.5	30.8
3/9/88	2.6	27.6	26.3
1/10/88	10.0	20.0	13.1
5/11/88	18.1	11.3	22.1
20/11/88	2.5	7.5	5.0
Mean ± S.E	12.7 ± 3.5	20.0 ± 5.0	21.6 ± 4.4
Henna			
6/7/88	11.3	7.9	34.2
8/8/88	32.4	25.7	51.4
4/9/88	37.5	40.0	45.0
2/10/88	42.4	42.0	37.5
3/11/88	45.0	52.5	50.0
18/11/88	25.0	32.5	40.0
Mean ± S.E	32.3 ± 5.1	33.4 ± 6.3	43.0 ± 2.8
Ghimbi			
1/7/88	11.1	21.4	20.0
4/8/88	38.5	44.8	12.9
1/9/88	40.9	33.4	15.8
3/10/88	34.5	43.3	4.0
2/11/88	53.1	51.7	9.7
16/11/88	45.2	37.8	10.7
Mean ± S.E	37.2 ± 5.8	38.7 ± 4.3	12.2 ± 2.2
Overall mean±se	27.2 ± 3.7	30.7 ± 3.4	25.6 ± 3.6

Table 6.11 *Macrotermes subhyalinus* attack on wood baits

Date	% wood baits attacked		
	Chlorpyrifos	Isofenphos	Control
<u>Mendi</u>			
4/7/88	9.7	0.0	0.0
6/8/88	29.0	8.1	15.4
3/9/88	38.5	7.9	13.0
1/10/88	10.0	2.5	5.2
5/11/88	13.9	10.0	0.0
20/11/88	2.5	10.0	2.5
Mean ± S.E	17.3 ± 5.6	6.4 ± 1.7	6.0 ± 2.7
<u>Henna</u>			
6/7/88	0.0	0.0	0.0
8/8/88	0.0	2.9	0.0
4/9/88	0.0	7.5	5.0
2/10/88	0.0	0.0	0.0
3/11/88	0.0	0.0	0.0
18/11/88	0.0	0.0	0.0
<u>Ghimbi</u>			
1/7/88	33.3	21.4	20.0
4/8/88	26.9	31.0	12.9
1/9/88	22.7	19.0	15.8
3/10/88	10.3	10.0	4.0
2/11/88	12.5	13.8	9.7
16/11/88	12.9	3.1	10.7
Mean ± S.E	19.8 ± 3.8	16.4 ± 4.0	12.2 ± 2.2
Overall mean±se	18.5 ± 3.2	11.4 ± 2.5	9.1 ± 1.9

Foraging activity of *Macrotermes* is shown in Table 6.11. The data at Henna was not included in the analysis due to the low level of attack on wood baits. However, at Mendi and Ghimbi, more wood baits were attacked on the chlorpyrifos treatment than isofenphos and the untreated control. There was no significant difference between isofenphos and the control. This result showed that both chlorpyrifos and isofenphos were not effective enough to reduce the foraging activity of *Macrotermes* which would agree with the results obtained for *Macrotermes* control in maize.

6.3.6 Effect of Different Termite Control Methods in Maize Yield

At Sasiga significant yield differences were recorded between different termite control methods tested (Table 6.12). Doubling the recommended seeding rate significantly lowered the yield by about 40 per cent, due to competition between plants mainly for soil nutrients and moisture. Competition was highly visible in the field by stunting plant growth and yellowing of leaves. The data showed that the use of higher than the recommended sowing rate which is widely used by many farmers in the area could have a negative effect on crop yield when the plant population is ultimately too high in relation to soil moisture and the nutrient status of the soil.

The improved variety also gave lower yield at Sasiga (Table 6.12), but this did not seem to be due to the occurrence of a higher *Microtermes* infestation as there was no relationship between grain yield and level of infestation. The poor yield of the improved variety seems to be due to its poor agronomic performance at the trial site.

There were no significant yield difference between chlorpyrifos, isofenphos and aldrin in the seed treatment method at Mendi, Henna and in two different trials at Ghimbi (Table 6.13 and 6.14). This is probably due to lack of differences between the treatments in the control of *Macrotermes* as there was no relationship between *Microtermes* attack and grain yield. The use of chlorpyrifos and isofenphos at the rate of 75 g a.i. per 10 kg of maize seed have not improved the grain yield. Even the recommended insecticide aldrin at the recommended rate has not provided any yield increment compared to the control.

Lower yield was recorded in chlorpyrifos TC seed and furrow treatments combined obviously due to the suppression of seed germination; however, the yield reduction was not significantly different from the control. One possible explanation for lack of significant yield reduction is due to compensation effect since the stand losses occurred at very early stage of crop development. As was shown in damage simulation, maize could compensate for stand losses that occur particularly at the earlier stage of crop development.

In furrow treatment method also no significant difference was observed between chlorpyrifos, isofenphos and aldrin at Henna and Ghimbi, but at Mendi aldrin provided significantly higher yield than isofenphos. Both chlorpyrifos and isofenphos were not found to prevent crop damage and improve crop yield compared to the control. In the contrary, the use of chlorpyrifos in the liquid formulation was found to suppress seed germination and there by reduce crop yield.

Table 6.12 Effect of different termite control methods in maize yield at sasiga

Treatments	Mean yield Q/ha
Improved variety	16.69[abc]
Local variety + soil tmt	20.83[ab]
Improved variety + soil tmt	15.86[bc]
Aldrin seed tmt	19.96[ab]
Chlorpyrifos seed tmt	21.11[a]
Isofenphos seed tmt	20.04[ab]
Double seeding rate	11.88[c]
No fertilizer	19.16[ab]
Control (local variety + fert)	19.99[ab]
F ratio	3.04*
S.E.	2.48

Means followed by the same letter are not significantly different at 5% level
tmt = treatment
fert = fertilizer

Table 6.13 Effect of chlorpyrifos and isofenphos seed treatments on maize yield at Ghimbi

insecticides/10 kg seed		Mean yield Q/ha
Aldrin	25 g a.i.	8.89
Chlorpyrifos	25 g a.i.	6.79
,,	75 g a.i.	9.43
Isofenphos	25 g a.i.	7.31
,,	75 g a.i.	7.21
Control		5.24
F ratio		0.67[ns]
S.E.		2.60

Table 6.14 Effect of insecticides and methods of application in maize yield

Treatments		Mean yield Q/ha Mendi	Henna	Ghimbi
Chlorpyrifos	S	18.13^{cd}	7.69	2.96^{cd}
,,	F	24.12^{bcd}	15.33	9.13^{a}
,,	SF	15.58^{cd}	10.20	1.30^{d}
Isofenphos	S	26.12^{bcd}	13.32	5.92^{abc}
,,	F	22.09^{cd}	15.42	6.23^{abc}
,,	SF	27.68^{bc}	12.58	7.83^{ab}
aldrin	S	19.09^{cd}	15.25	5.86^{abc}
,,	F	34.19^{ab}	17.02	5.30^{abcd}
,,	SF	43.07^{a}	13.98	6.48^{abc}
Control		25.23^{bcd}	12.25	3.89^{bcd}
F ratio		4.26^{**}	1.24^{ns}	2.04^{*}
S.E.		5.58	3.53	2.27

Means followed by the same letter are not significantly different at the 5% level
S = seed treatment, F = furrow treatment

6.3.7 Effect of Heptachlor in Tef Yield

Tef grain yields recorded at different sites both on treated and untreated plots were very variable (Table 6.15). As expected the lowest yields were recorded in areas where soil fertility was very poor and where no fertilizer had been applied by farmers. Out of 17 sites where this investigation was carried out, higher yields were recorded on treated plots at 16 sites. In addition very few *Macrotermes* runways were observed on the plots treated with heptachlor. However, there was no significant yield increment on treated plots despite reduced termite activities.

Generally, tef suffers greater plant mortality caused by *Macrotermes* starting from the heading stage on wards (Plate 6.2). Therefore, the protection of tef at its susceptible stage was expected to reduce yield losses, but no significant yield difference was observed. Lack of significant yield differences indicate either the application of heptachlor was not very effective or that the termite does not cause significant yield losses as was seen in other crops. In the absence of data on yield loss, no definite conclusion can be drawn. Therefore, it is necessary to undertake loss assessment studies in order to establish the pest status of *Macrotermes* on tef.

Table 6.15 Effect of heptachlor application before seed forming stage in tef yield on farmers field

		Grain yield Q/ha (mean±se)	
Province	Locality	Treated	Untreated
Menesibu	Kiltu Jale	4.44 ± 1.32	4.05 ± 1.36
	Wajeti Mendi	2.25 ± 0.70	1.98 ± 0.68
Nedjo-Jarso	Wera Jiru	3.49 ± 0.21	2.75 ± 0.22
	Gida Chando	1.56 ± 0.19	1.38 ± 0.13
Boji	Henna	2.32 ± 0.16	2.23 ± 0.19

Plate 6.2 Macrotermes attack in tef

6.3.8 Termite Colony Destruction

At all sites where chlorpyrifos was applied on termite mounds, complete colony mortality was obtained (Table 6.16). But on mounds where either diazinon was applied or the queen was removed, only partial kill was obtained. In contrast, no colony mortality was observed in the untreated (control) mounds where only water was applied.

This experiment showed that chlorpyrifos was the best of the insecticides evaluated for killing *Macrotermes* colonies. Since it does not persist long in the environment, it can replace organochlorine insecticides which are widely used in the mound poisoning programme in Ethiopia.

The application of diazinon has not given consistent results throughout the trial sites and on all mounds; the effectiveness of diazinon apparently being related to the size of the colony population. Effective kill was obtained when diazinon was applied on small mounds. Probably the dose rate applied was only enough to kill small colonies. Darlington (1987) showed that there is a positive correlation between colony population and mound parameters in *Macrotermes michaelseni*; this relation could also apply to other species of *Macrotermes*. Apparently the same rate is also recommended for mound poisoning in Tanzania (Bohlen, 1973). However, in the Fouta Djallon area in the Guinea Republic a considerably higher rate (400 g a.i./mound) is recommended for poisoning *Macrotermes* mounds (FAO, 1985).

The removal of the queen from the nest did not give consistent results. Perhaps this could be due to the development of substitute queens because certain termite species are known to produce substitute queens under favourable conditions when the primary queen is lost (Harris, 1971; Schmutterer, 1969). It was evident from this study that queen removal is not the reliable method of destroying *Macrotermes* colonies. In addition it takes a considerably long time and energy to dig a mound and remove the queen. In this study it took four local farmers about 20.15 minutes (n = 14) on average to dig a mound and remove the queen. At first it took very long time, but after digging few mounds the farmers got experience and the time required was shortened considerably.

Table 6.16 Effectiveness of chlorpyrifos, diazinon and queen removal in colony mortality in western Ethiopia

	% colony mortality		
Treatments	Wajeti Mendi	Henna	Wera Jiru
Chlorpyrifos	100	100	100
Diazinon	50	25	0
Queen removal	50	50	0
Control	0	0	0

6.3.9 Effect of Mound Poisoning in Tef Yield

Significant yield improvement in tef yield due to mound poisoning were not obtained in areas where all visible mounds were poisoned (Table 6.17). This is obviously due to the continuation of *Macrotermes* activity and damage even in areas where mounds had been poisoned.

Macrotermes is known to persist in subterranean nests at its early stage of development without showing any evidence of its presence above ground (Sands, 1976). In Nigeria, Collins (1981) reported that *Macrotermes* bellicosus remains below the ground up to the age of 1 - 1.5 years. In western Ethiopia where it is relatively cold *Macrotermes* could remain below the ground level for much longer time without building mounds. Termite mounds therefore, indicate the presence of older colonies; so the poisoning of termite mounds killed the mature colonies without affecting young colonies, that continue to cause crop damage. Therefore, in the short term it seems there is not much benefit that can be gained by mound poisoning. If this practice is carried out continuously for 4 - 5 years as soon as new mounds appear above ground it may be possible to eventually alleviate the problem. However, the validity of this hypothesis needs to be confirmed by appropriate field studies.

Surprisingly many farmers, extension agents and local government officials in western Ethiopia regard mound poisoning as the most effective method of controlling *Macrotermes*. They believe that considerable improvements have occurred in the areas after the 1983 campaign. They have reported that crop harvests that could not be left in the field for a day before the campaign now can be left for up to two weeks without being attacked and there is less damage on wooden structures with regeneration of denuded grasslands.

Table 6.17 Effect of Mound Treatments in Tef Yield

	Yield Q/ha	
Locality	Treated	Untreated
Gida Buruso (T) Gida Boji (U)	2.06 ± 0.10	2.34 ± 0.16
Henna - 1	4.44 ± 0.39	4.70 ± 0.74
Henna - 2	4.88 ± 0.44	4.04 ± 0.22
Mucho Ayra (T) Boti Ayra (U)	1.96 ± 0.35	2.22 ± 0.16

T = Treated
U = Untreated

6.3.10 Effect of Mound Poisoning in Colony Development

There was no significant difference in the total number of *Macrotermes* mounds before and after mound poisoning on cultivated lands; however, on grasslands a significant reduction was recorded although in some localities more mounds appeared after mound poisoning (Table 6.18). Despite successfully killing all visible colonies, new mounds continued appearing in treated areas. Farmers believe new termites have migrated from neighbouring districts where mound poisoning campaign had not been carried out. Considering the weak flying behaviour of alates and relatively short flight periods it is very unlikely that termites dispersed from the untreated areas.

Of course they could be blown by wind, but again the possibility for such widespread is remote. Therefore, the only possible explanation could be that the termites have been present in the area even after the campaign. This argument is strongly supported by the continued occurrence of crop damage the same season after all visible mounds were poisoned.

Table 6.18 Total number of termite mounds before and after mound poisoning in Menesibu (Mendi) Province

	Cultivated land		Grassland	
Locality (PA)	Before	After	Before	After
Kiltu Kara	1750	695	2474	370
Igu Bechi	1657	1389	5562	1360
Wanki Gebeya Fechasa	2396	1475	4218	3669
Telamso Jirma	1186	1269	4565	4768
Wato Dale	691	2056	5287	2335
Tenki	1224	770	3785	1420
Ula Ganti	2370	1414	2839	855
Guyo Sechi	3560	1247	2556	558
Kiltu Jale	1500	2017	5910	2055
Haro Korke	2500	5098	7494	6569
Bijit	730	1249	8682	3836
Bari Komis	1293	1452	5272	1221
Buke Akache	5026	1938	4433	3513
Idaro Agamsa	2238	110	974	252
Taiba Guangul	794	1471	1785	1131
Bachera Gudi	598	395	4702	670
Guyo Dale	3305	1549	4479	2978
Dangule Dabus	71	418	122	510
Kela Dabus	2272	1320	1400	1156
Serbi	535	664	1581	629
Mean ± S.E.	1785 ± 271	1400 ± 229	3906 ± 492	1992 ± 383

CHAPTER SEVEN : VARIATIONS IN PEST STATUS OF MACROTERMES

7.1 INTRODUCTION

The genus *Macrotermes* is found throughout the Ethiopian and Indo-Malayan zoogeographical regions and so far 12 species have been described in the Ethiopian Region (Ruelle, 1970). In Africa they build large mounds which are a characteristic feature of many grasslands and savanna woodlands. The size and shape of the mounds vary depending on the species and the climatic conditions of the area. For example, in Kajiado District, Kenya, 'open mounds' are built by *Macrotermes subhyalinus* (Rambur) while 'closed mounds' are that of *M. michaelseni* (Van der Werff, 1981; Pomeroy, 1983). A tall mound also known as 'cathedral mounds' are built by *M. bellicosus* (Smeathman) in West Africa and its height reach about 9 m (Collins, 1981). Termite mounds having a similar height have also been reported in Ethiopia (Lee and Wood, 1971).

Their basic food is dead plant materials such as dead wood, dead grass and herbivore dung. However, in certain parts of Africa, they also attack growing crops. Crop damage has been reported in Nigeria (Collins, 1984; Wood *et al.*, 1977, 1980) Tanzania (Harris, 1961) and some other countries including Ethiopia.

In Ethiopia crop damage caused by *Macrotermes* on agricultural crops had been recorded mainly in the western part, particularly in the Welega and Asosa administrative regions. Cutting the base of the stem just at or below the soil surface caused stand losses on several crops grown in the regions, especially on maize, tef and *Eucalyptus*. At Ghimbi, about 20% stand loss has been recorded on maize from emergence to harvest. The economic significance of such damage will vary depending on the type of the crop, growth stage and extent of attack. Thus in a cereal crops such as maize, when stand loss occurred at an early stage of crop development no significant yield losses were recorded due to compensation effect. However, when the damage occurred at later stages of their development stand losses were quite important. Any loss of tree seedlings can be important since there will not be compensation.

In contrast to the western area an economic damage has ever been reported on agricultural crops in Meki-Ziway area of central Ethiopia, even though the density of *Macrotermes* mounds is considerably higher and the rainfall is much lower, an ideal condition for termite damage. Intensive crop damage surveys conducted in the area have failed to reveal the occurrence of damage even on highly susceptible crops such as maize and hot peppers. Local farmers and area crop protection staff have also confirmed lack of crop damage caused by *Macrotermes*. The only incidence of damage reported was on crops which were left in the field for drying. However, farmers in the area did mention other problems related to the presence of mounds in agricultural lands. These included in their opinion that mounds created obstacles for ox ploughing and provided a favourable hiding place for poisonous snakes that often attack the farmers, their families and domestic animals. Crops around the perimeter of mounds were also reported to be stunted and suffer yield losses.

The principal cause of termite problem in grazing lands is lack of food resources and competition between grass-feeding termites and grazing animals. For example, *Macrotermes michaelseni* has developed into a pest when grass litter which is the basic diet of this species is not available due to drought (Lepage, 1977b, 1979, 1980, 1981). *M. subhyalinus* which feeds largely on grass litter and dung has been observed to attack standing grass when grass production is high and litter production is low (Collins, 1982). Similar changes were also observed on *Odontotermes.* Bagine (1982) reported that *Odontotermes* spp. which normally feed on dead plant materials could attack standing plants as the habitat becomes denuded because of overgrazing. The development of termite problem in the South African veld was believed to be the result of intensive cultivation which have reduced the natural food resources of termites (Wilson, 1972).

Grazing animals have been also noted to affect termite population of pasture by either destroying surface foraging galleries or breaking mounds and exposing termites to predators (Holt and Coventry, 1988).

The primary cause of denudation of grazing lands in western Ethiopia is overgrazing (Sanna, 1973; Sands, 1976; Wood, 1986a) and the termites have exacerbated the problem by consuming the remaining grasses. Damage has often extended to the root stocks which increased exposure of the land to severe and widespread erosion. This was confirmed by the condition of grass growth in areas protected from cattle grazing. Both at Mendi and Guliso a good grass cover was maintained in areas protected from cattle grazing. Adjacent unprotected areas were denuded and suffered serious erosion. Visual observations clearly indicate that the stocking density particularly in Mendi and Jarso are quite high. Wood (1986a) estimated the stocking density in Menesibu Province at 4.7 stock per hectare when the carrying capacity of the area is probably not more than 1.0 stock per hectare.

Local farmers are reluctant to accept that denudation on grazing lands is caused by overgrazing. Surprisingly they believe that termites follow the foot steps of grazing cattle and problems appear wherever grazing occurs. The farmers associate denudation to termites because they see them taking the last piece of grasses. The South African farmers are also found to have similar attitude about termite problem on range lands. They have attributed denudation of grasslands to harvester termites, When in fact the primary cause of the problem was overgrazing, soil erosion, invasion by inferior vegetation and sparse plant cover (Nel, 1971).

Several reasons have been given regarding the development of termite problem on cultivated lands. Clearing trees and cultivating the land destroy termites that build epigeal nests such as *Macrotermes*, but do not have a significant effect on termites that have deep subterranean nests such as *Microtermes* (Wood *et al.*, 1977). Thus termites with deep subterranean nests could develop into a pest and attack growing crops in the absence of their preferred food.

Clearing natural vegetation also affects the composition of termite fauna of an area. In Nigeria, Wood *et al.* (1977) recorded 23 species in undisturbed woodland, 22 in secondary woodland, 20 in grazing land, 8 in the first year maize and only 4 in lands that had been cultivated for 24 years. Similar changes in the termite fauna following removal of trees have been also reported by Sands (1965) and Holt and Coventry (1988). The species that depended entirely on trees and shrubs for food and nesting had disappeared due to lack of food and shelter.

Different explanations have been given for the occurrence of crop damage in western Ethiopia. Some agricultural scientists believe that large scale deforestation and uncontrolled annual fires which have considerably disturbed the ecology of the area are the primary cause of the problem. Obviously these activities may have a profound effect on the termite fauna of the area but it is unlikely to be the major factor responsible for the problem since similar activities have been taking place in the Meki-Ziway area perhaps at a much larger scale without the occurrence of crop damage.

Sanna (1973), Sands (1976) and Wood (1986a) have made an attempt to explain the cause of termite problems in western Ethiopia. According to Sanna (1973) the different factors that are responsible for the problem are overgrazing, low soil fertility and human activity which has reduced the natural enemies of termites such as antbear, the red meer cat and insectivorous birds which includes plover and bustard. As indicated above similar activities have been taking place in the other area as well without the development of termite problem. Therefore, this reason also seems very unlikely to be the main cause of the problem.

Sands (1976) attributed termite problem in western Ethiopia to the ecology of the area which has a high capacity to support large populations of *Macrotermes* and other grass feeding termites, so that when such natural vegetation is cleared to grow crops termites are forced to attack growing crops in the absence of their usual food. This explanation also needs further investigation as there are other areas which have similar ecological conditions, but do not have a termite problem.

Wood (1986a) considered the small size of the farms and the interrelationship between cultivated and the surrounding uncultivated grassland as a factor that may have created favourable conditions for *Macrotermes* damage to occur since these termites could enter cultivated fields while travelling over long distances to forage. However, in Meki-Ziway also, where farms are small and surrounded by uncultivated grazing lands, there is no damage to agricultural crops.

The above explanations are based on observations rather than field studies. Therefore, this investigation was conducted both in the western Ethiopia and Meki-Ziway area of central Ethiopia to determine whether the removal of natural vegetation or differences in the termite population is responsible for variations in the pest status of *Macrotermes*.

7.2 MATERIALS AND METHODS

7.2.1 Removal of Natural Vegetation

This study was conducted to determine if removal of natural vegetation and subsequent cultivation of the land has led to the development of *Macrotermes* crop damage in western Ethiopia as believed by many agricultural scientists in the country. Aerial photographs taken at a height of about 9000 m in Menesibu Province during 1957 and 1980 were obtained from the Ethiopian Mapping Authority. The year 1957 was about the time when widespread *Macrotermes* damage was reported in the area. For Meki - Ziway aerial photographs for the same period were not available. As a consequence photographs taken in 1967 and 1971 were used instead to assess the general land use patterns in the area. From the aerial photographs 1 : 50,000 land use land cover maps were prepared for both areas and years. The extent of change that has taken place in the natural vegetation in both areas was estimated.

7.2.2 Termite Population

Macrotermes populations found both in western Ethiopia and Meki-Ziway were reported as the same species (Barnett *et al.*, 1987). This investigation was carried out to determine if there are significant differences in the various characters used to identify *Macrotermes*. Five *Macrotermes* mounds were randomly selected and excavated in both areas. From each nests, five samples of the different castes were collected at random.

All the characters for which good differential qualities were reported by Van der Werff (1981) and the characters used for *Macrotermes* identification by Ruelle (1970) were measured or counted depending on the characters. In addition two characters, the presence of red spots around the fontanelle and shape of lateral side of mesonotum, that were found to be consistently different during the course of this work in the two populations were also included in the case of major soldiers. The number of characters that were measured for each caste were as follows:

Major soldiers : 15
Minor soldiers : 11
Major workers : 4
Minor workers : 1

A stereomicroscope using an ocular micrometer was used to measure the different characters. The mean and standard errors were calculated for testing the significant differences between measurements of the characters in the two populations.

The mound building behaviour of the two *Macrotermes* populations were also studied to check if there are significant differences between them. A total of 34 mounds were randomly selected at Mendi, Henna and Wera Jiru (Nedjo) in western Ethiopia and 10 mounds between Meki and Ziway. Observations were made on the shape of the mounds and photographs were taken. The heights of the mounds were measured as well as the diameter at its base at the widest part. The depth at which the royal chamber is located was measured from the soil surface after digging the mounds with pick axe and shovel until the royal chamber was located.

7.3 RESULTS AND DISCUSSION

7.3.1 Effect of Removing Natural Vegetation

Land use maps prepared from aerial photographs taken both at Mendi and Meki-Ziway showed a reduction in natural vegetation and an increase in cultivated lands (Figures 7.1 - 7.4). In Mendi area, the reduction in natural vegetation between 1957 and 1980 was about 60%, whereas in Ziway area the reduction was about 80% only over four year period between 1967 and 1971.

According to the widely accepted opinion, crop damage should occur in Meki-Ziway area where large scale removal of natural vegetation has taken place. On the contrary, the areas where there is *Macrotermes* problem is where less vegetation had been removed.

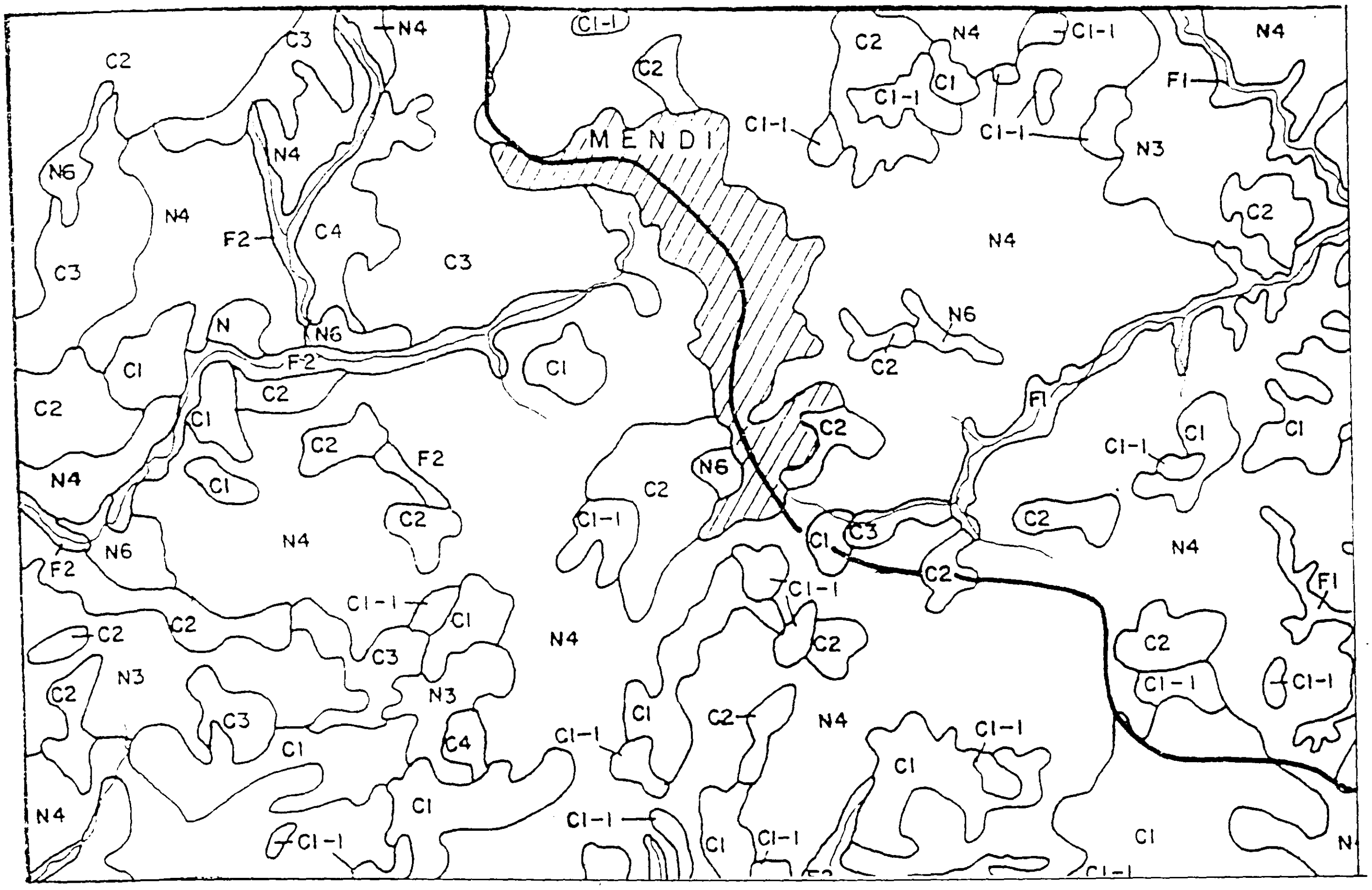


Figure 7.1 Land use/land cover map of Mendi - 1957

LEGEND

C Cultivation

C1 Intensively cultivated
C1-1 Intensively cultivated around the homestead
C2 Moderately cultivated
C4 Sparsely cultivated

N Natural vegetation

N3 Wooded-shrub grassland bushland
N4 Shrub grassland
N6 Grassland
F1 Riverine forest
F2 Riverine woodland

Study area boundary
Road
Town

Scale 1 : 50,000

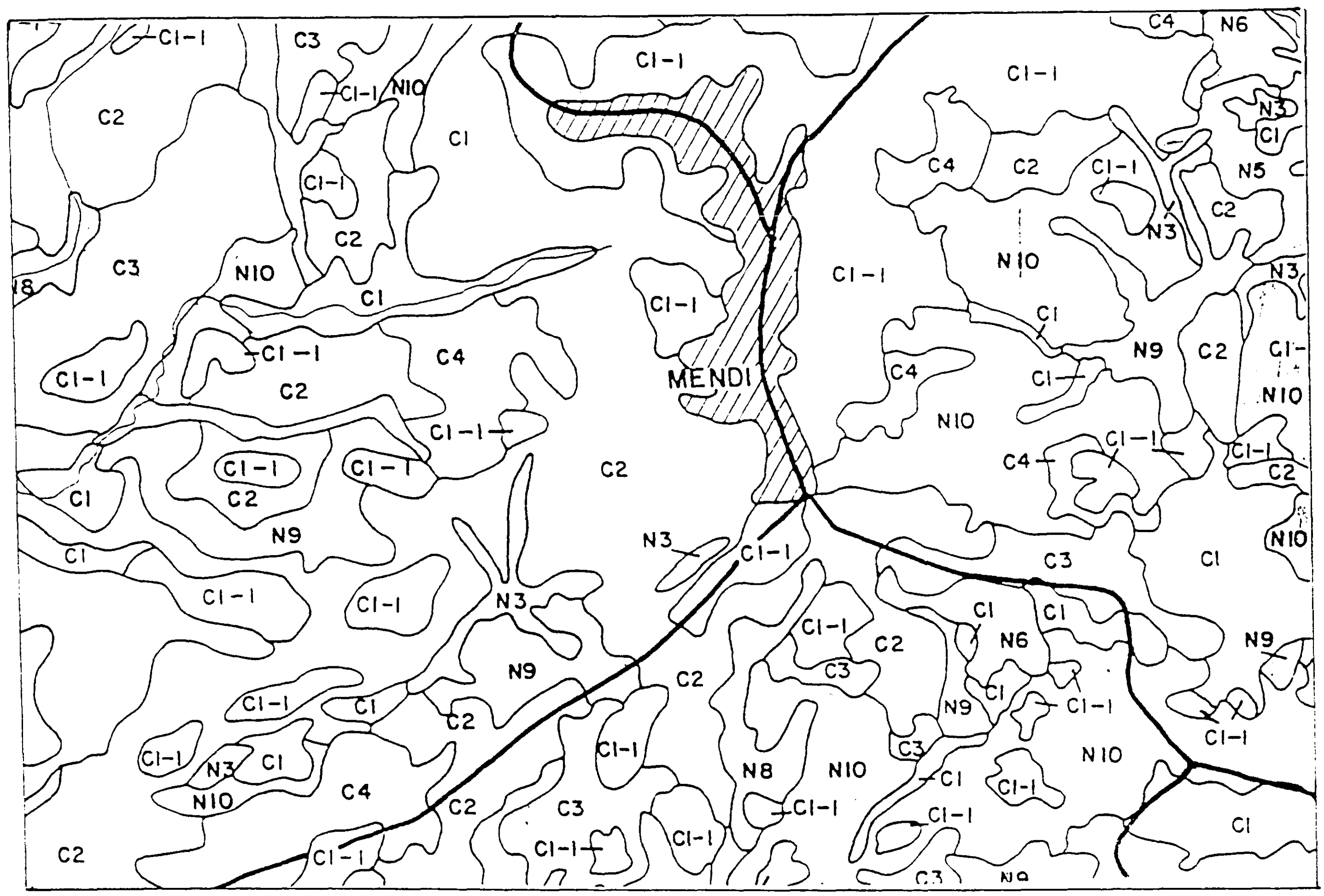


Figure 7.2 Land use/land cover map of Mendi - 1980

LEGEND

C Cultivation

C1	Intensively cultivated
C1-1	Intensively cultivated around the homestead
C2	Moderately cultivated
C3	Less moderately cultivated
C4	Sparsely cultivated

N Natural vegetation

N3	Riverine woodland
N5	Wooded bushland
N6	Wooded shrub grassland
N8	Shrub grassland
N9	Wooded grassland
N10	Grassland

Study area boundary

Road

Town

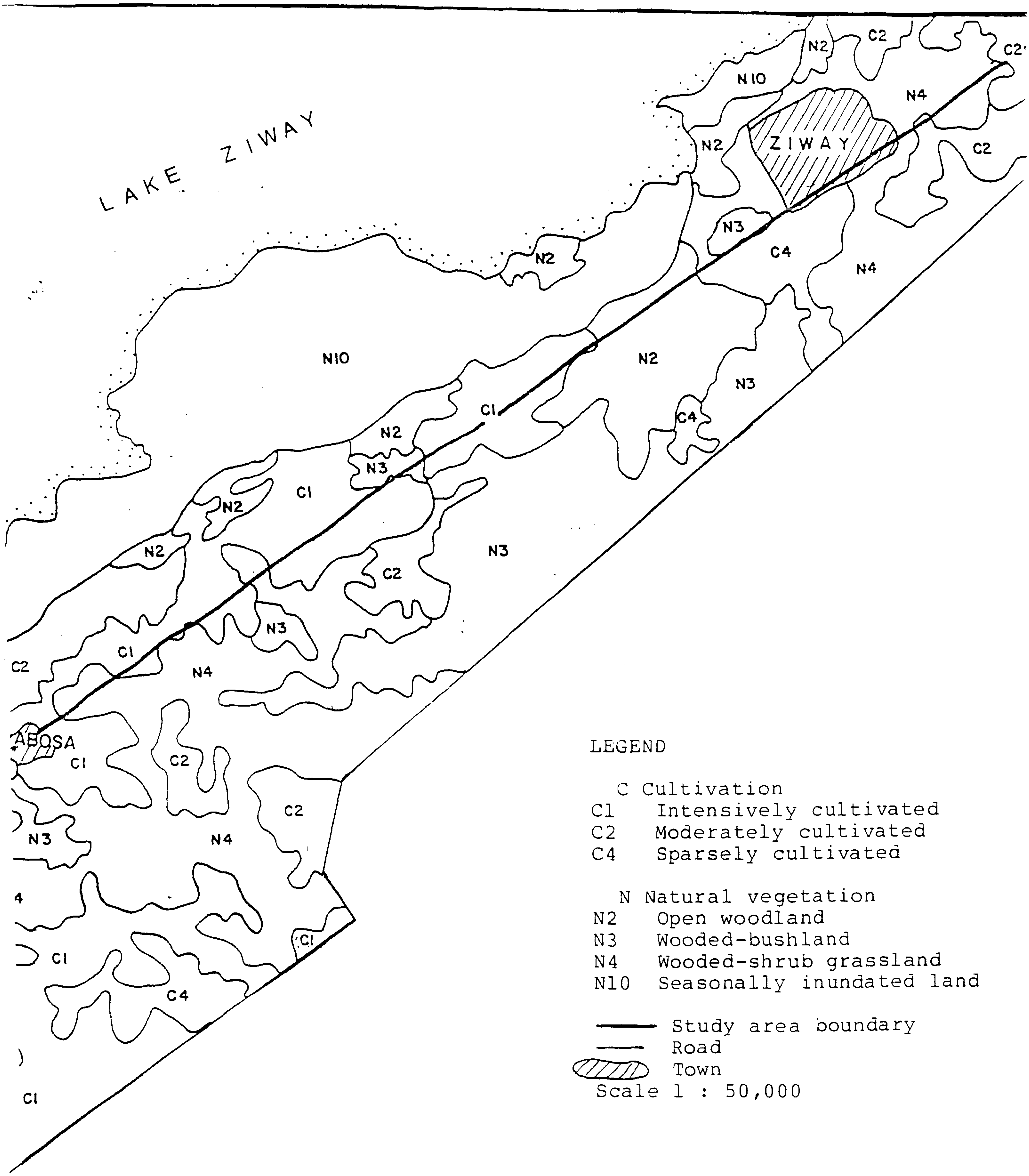


Figure 7.3 Land use/land cover map of Ziway area - 1967

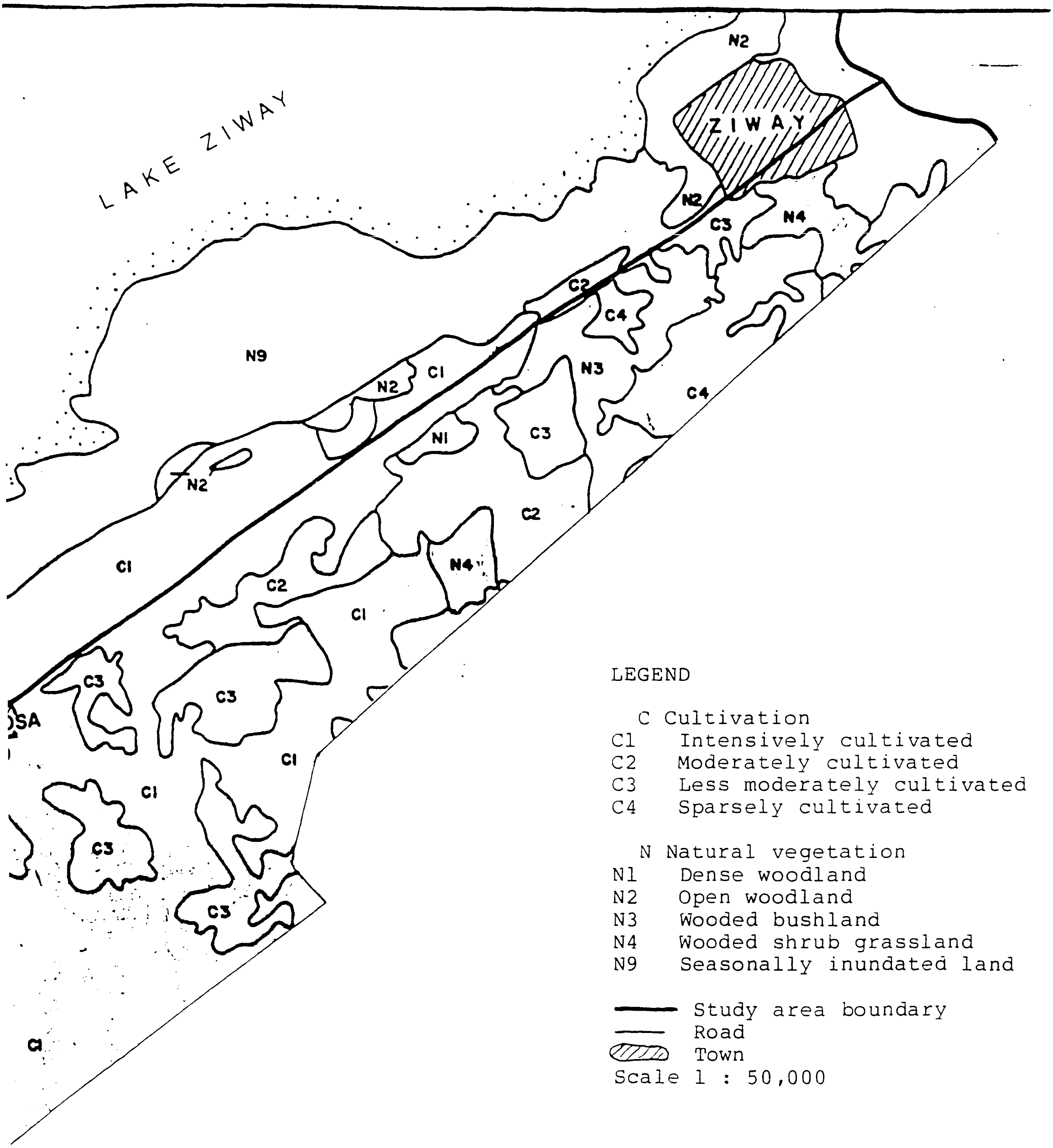


Figure 7.4 Land use/land cover map of Ziway area - 1971

Removal of trees and shrubs per se may not have a significant impact on *Macrotermes* populations since they are mainly grass and grass litter feeders. However, if clearing is followed by mechanical cultivation they may be eliminated due to the destruction of their nests and foraging galleries (Wood *et al.*, 1977). Lack of crop damage by *Macrotermes* in the state farms and agricultural research station also supports this argument. In Mendi and Meki - ziway agricultural lands are generally ploughed in the traditional way by ox ploughs. Therefore, no significant effect is expected on *Macrotermes*. Hence, there is no strong evidence that would suggest that *Macrotermes* problem in western Ethiopia has developed as a result of removing natural vegetation.

7.3.2 Morphometric Analysis

All the characters on major soldiers measured or counted for *Macrotermes* populations, except the length of the left mandible were significantly larger in western Ethiopia than in Meki - Ziway. Similar differences were present in minor soldiers and major workers (Tables 7.1 - 7.3). There was no significant difference in the character measured on minor workers (Table 7.4). This confirmed similar findings reported by Van der Werff (1981) in the characters measured on minor workers for two nest types found at Kajiado, Kenya.

The characters of major soldiers were consistently larger in the west than in Meki - Ziway but there was still considerable overlap between the two populations (Figure 7.5).

In some characters such as head width and minimum width of the gula, the overlap was minimal.

The morphometric analysis indicated that the populations are different in size. Whether these indicate that the two populations are different species or strains is not known. The taxonomy of *Macrotermes* is extremely difficult and at present not properly worked out. Similar difficulties were encountered in identifying *Macrotermes subhyalinus*, *M. michaelseni* and *M. jeanelli* in Kajiado District (Kenya) using conventional keys on sterile castes since they are not morphologically distinct (Bagine *et al.*, 1989).

Morphometric analysis has been used as one of the techniques in separating closely related species. Together with other information such as alate flight time, defence secretions of soldiers and nest shape, *Macrotermes subhyalinus* and *M. michaelseni* were separated in the Kajiado District, Kenya (Van der Werrf, 1981). Chhotani (1981) also reported that morphometric analysis can help to separate the four sympatric *Odontotermes* spp. that build different types of mounds in India, but expressed doubts whether the result indicated different species or not.

Bagine *et al.* (1989) have identified the three morphologically identical species of *Macrotermes* by using isoenzyme electrophoresis. A similar analysis needs to be considered in order to identify whether the two populations are the same species or not.

Table 7.1 Major soldiers: measurements[a] and counts of different characters of *Macrotermes* in western Ethiopia and Meki - Ziway

Character	Mean ± S.E. Mendi	Meki - ziway
Head length	74.6 ± 0.76	66.1 ± 0.88
Maximum head width	64.3 ± 0.72	56.9 ± 0.68
Head depth including gula	37.9 ± 0.64	35.4 ± 0.58
Length of gula	50.1 ± 0.48	46.5 ± 0.58
Maximum width of gula	18.8 ± 0.24	17.8 ± 0.26
Minimum width of gula	13.0 ± 0.16	11.0 ± 0.18
Length of left mandible	34.9 ± 0.80	33.7 ± 0.60
Length of hind tibia	42.5 ± 0.84	38.4 ± 0.76
Maximum pronotum length	25.4 ± 0.36	22.5 ± 0.28
Maximum pronotum width	50.0 ± 0.62	44.2 ± 0.70
Maximum metanotum width	47.9 ± 0.60	40.1 ± 0.62
Dist. fontanelle-clypeus	22.4 ± 0.44	18.7 ± 0.58
Red spots around fontanelle[b]	0.9 ± 0.04	0.04 ± 0.04
Lateral side of mesonotum[c]	0.9 ± 0.06	0.32 ± 0.10
No. setae right half pronotum	36.3 ± 0.78	32.4 ± 1.20

a - means of measurements (x 0.077 mm for 1 -12)
b - 1 = present, 0 = absent
c - 1 = pointed, 0 = round

Table 7.2 Minor soldiers: measurements[a] and counts of different characters of *Macrotermes* in western Ethiopia and Meki - Ziway

Character	Mean ± S.E. Mendi	Meki - Ziway
Head length	40.4 ± 0.40	32.8 ± 0.50
Maximum head width	35.7 ± 0.44	29.9 ± 0.50
Head depth including gula	22.8 ± 0.25	19.1 ± 0.28
Length of gula	27.9 ± 0.34	22.2 ± 0.46
Maximum width of gula	10.7 ± 0.12	9.5 ± 0.12
Length of left mandible	26.8 ± 0.42	23.4 ± 0.40
Length of hind tibia	30.0 ± 0.66	26.2 ± 0.54
Maximum length of pronotum	16.1 ± 0.22	13.8 ± 0.34
Maximum width of pronotum	29.3 ± 0.34	23.9 ± 0.40
Maximum width of mesonotum	25.6 ± 0.46	20.1 ± 0.32
No. setae right half pronotum	28.8 ± 0.78	25.6 ± 0.84

a = means of measurements (x 0.077 mm for 1 - 10)

Table 7.3 Major workers: measurements[a] and counts of different characters of *Macrotermes* in western Ethiopia and Meki - Ziway

Character	Mean ± S.E. Mendi	Meki - Ziway
Maximum head width	34.0 ± 0.24	31.0 ± 0.40
Distance between eye spots	28.2 ± 0.22	26.0 ± 0.34
Dist. between antennal sockets	21.5 ± 0.16	19.8 ± 0.28
No. setae right half pronotum	30.7 ± 1.00	27.4 ± 0.78

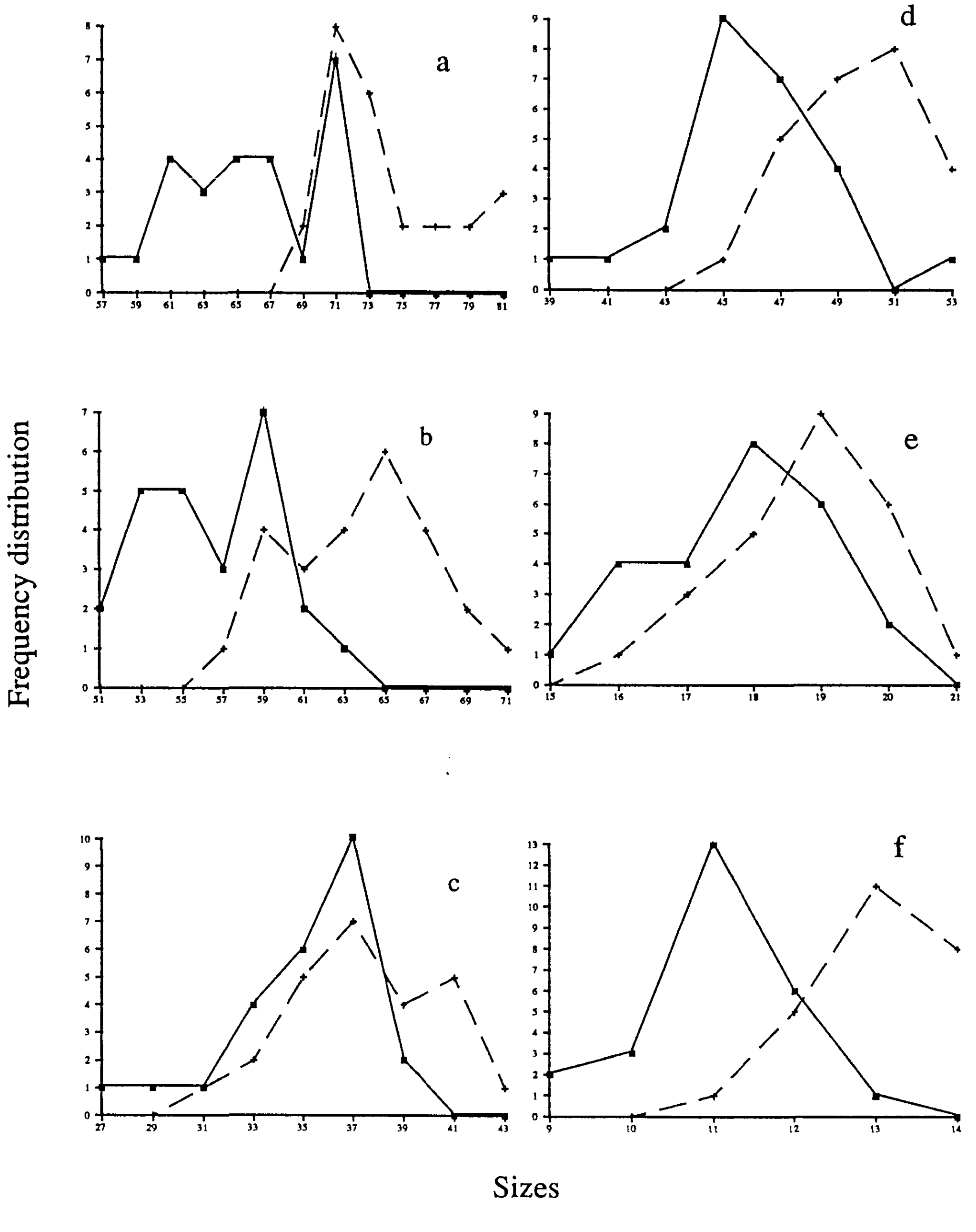


Figure 7.5 Frequency distribution of major soldier sizes
a = head length, b = head width, c = head depth
d = gula length, e = gula max width, f = gula min width

——— Meki - Ziway

--- Mendi

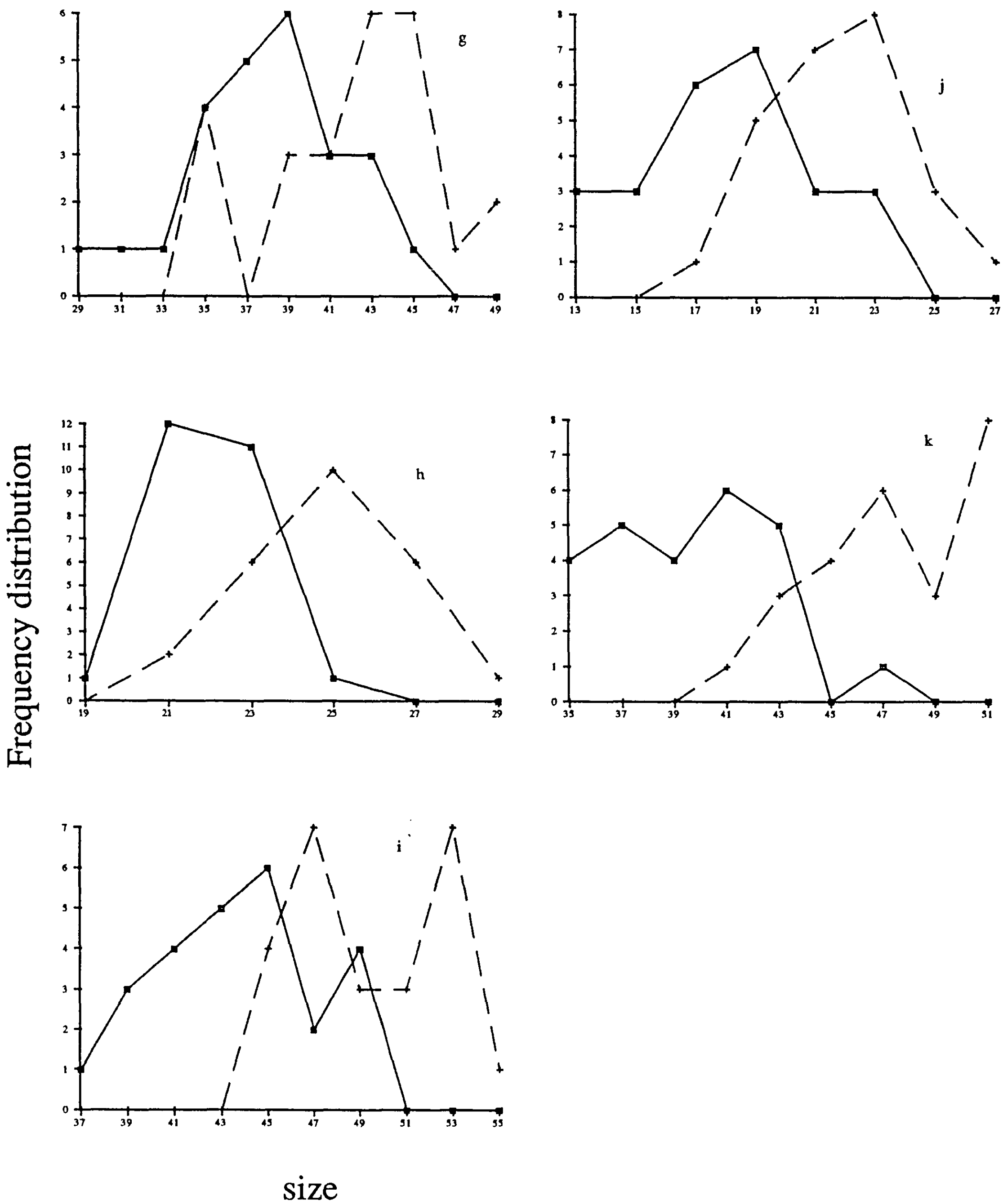


Figure 7.5 continued

g = hind tibia length, h = pronotum maximum length
i = pronotum maximum width, j = dist, font. clypeus
k = metanotum maximum width

___ Meki Ziway --- Mend

Table 7.4 Minor workers: measurements[a] of Macrotermes head width in western Ethiopia and Meki - Ziway

Character	Mean ± S.E.	
	Mendi	Meki - Ziway
Maximum head width	21.7 ± 0.18	21.2 ± 0.54

a = means of measurements (x 0.077 mm both for major and minor workers)

7.3.3 Differences in Mound Structure and Size

Macrotermes mounds found in western Ethiopia and Meki - Ziway were significantly different both in size and shape (Plate 7.1). In western Ethiopia the mounds are typically dome-shaped often containing burrows of aardvarks whereas in Meki-Ziway the mounds are conical shaped. In both areas no external openings were observed on the mounds.

The two types of mounds were significantly different in their height (Table 7.5); those in western Ethiopia, being considerably smaller (mean height and se 22.4 ± 2.0 cm) than those in Meki-Ziway (mean height and se 156.2 ± 14.6 cm). There was no significant difference in the diameter of the two types of mounds (Table 7.5) but the depth at which the royal chamber was located was significantly deeper in the western area. The royal chamber which was easily recognized by the presence of moist thin walled galleries was usually near or at the centre of the nest floor. In contrast in Meki-Ziway, part of the hive was above ground but the royal chamber was below the soil surface.

This study showed that the mound building behaviour of the two populations are quite different. Again there are different opinions regarding whether differences in mound shape and size indicate different species or not. According to Hesse (1954) and Harris (1956) sizes do not indicate different species since these will vary depending on the soil type and climate of the area. In Nigeria, Collins (1979) also reported that two different types of nests could be built by *Macrotermes bellicosus* (Smeathman) in the same area under similar soil type, climate and drainage conditions. In contrast in Kajiado District (Kenya) Van der Werff (1981) and Pomeroy (1983) attributed the two nest types to two different species, the 'open' type to *Macrotermes subhyalinus* and the 'closed' mounds to *M. michaelseni*.

Table 7.5 Size of *Macrotermes* mounds in western Ethiopia and Meki - Ziway

	Western Ethiopia		Meki - Ziway	
Structure	No.	Mean±S.E	No.	Mean±S.E
Mound height (cm)	34	22.4 ± 2.0	10	156.2 ± 14.6
Mound diameter (cm)	34	170.9 ± 9.1	10	185.5 ± 11.2
Depth of royal cell	14	82.0 ± 6.9	10	49.3 ± 11.2

Plate 7.1 <u>Macrotermes</u> mounds (upper) Mendi (lower) Ziway

CHAPTER EIGHT : SUMMARY

Twelve species of termites belonging to nine genera and two subfamilies were identified in the Welega and Asosa administrative regions in western Ethiopia. Seven of the species in the subfamily Macrotermitinae were observed attacking crops. These were *Macrotermes subhyalinus* (Rambur), *Microtermes* nr. *vadschaggae* (Sjost.), *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.

Macrotermes subhyalinus was the only important pest on farmers fields. It damaged crops by cutting the base of the stem at ground level. The crops most severely attacked included maize, tef, finger millet, pepper, sugar cane and *Eucalyptus*. The other species of termites were of minor economic importance.

The swarming by *Macrotermes* and *Microtermes* spp. occurred at the beginning of the rainy season, whereas that of *Odontotermes* spp. took place from the middle-end of the rainy season. The swarming period for all three genera was always from 19.00 - 19.30 hours local time and the duration was for about 30 minutes.

The density of *Macrotermes* mounds (mean ± se) on cultivated land and grassland was 5.6 ± 0.35 and 8.2 ± 0.62 per ha. respectively.

Foraging by *Microtermes* nr. *vadschaggae* and *M. aethiopicus* was similar. Both species foraged significantly more during rains compared to the dry season. There was a positive relationship between monthly total rainfall and the percentage of baits attacked. In contrast, *Pseudacanthotermes militaris* foraging activity was significantly greater during the dry season and the relationship between monthly total rainfall and the percentage of baits attacked was negative. As opposed to the above species, *Macrotermes subhyalinus* was observed foraging throughout the year, but it was more active during the dry season.

The diurnal foraging activity of *Microtermes* nr. *vadschaggae* varied between the wet and dry seasons. During the wet season it foraged throughout the day and night even in the middle of heavy rain. However, during the dry season its activity was restricted to certain times of the day or night. In contrast, *P. militaris* foraged only at certain times of the day or night both during the wet and dry seasons.

Spatial and temporal variations in the foraging activity of *Microtermes* nr. *vadschaggae* was observed. More foraging occurred in areas cultivated for several years and in 1987 when rainfall was low compared to 1988.

There was no significant difference in the foraging population of the two species of *Microtermes* either during the dry or the rainy seasons. However, the population density of both species were generally greater during the rainy season as compared to the dry season.

The major food resources of *Microtermes* spp. in the natural vegetation consisted of woody litter and leafy litter. They were not observed feeding on grasses. In contrast, *Macrotermes subhyalinus* was feeding on a wide range of food resources including grass litter and standing grasses.

Microtermes infestation was minimal in pepper grown on farmers fields and very little yield loss occurred in maize and sunflower despite many plants being infested. There was no relationship between *Microtermes* attack and yield loss in maize and sunflower. However, in haricot beans yield losses ranged from 4.5 to 12.8%.

Simulation of *Macrotermes* damage on maize showed that yield loss depends both on the extent of stand reductions and the stage of the crop. Up to 30% stand reduction at the 6-leaf and 9-leaf stages and 15% stand reduction at the tasselling stage had no significant effect in maize yield mainly due to compensation by the remaining plants. Where plant population was reduced at different rates, proportionately heavier cob per plant was produced. Reduction of plant population at the later stage of crop development or greater stand reductions did significantly reduce crop yield. 45% crop removal at the 6-leaf stage resulted in only 16.5% yield loss whereas the same reduction at the tasselling stage caused 39.9% yield loss.

The cultural and chemical control methods tested did not provide satisfactory protection against *Microtermes* and *Macrotermes* attacking maize. Sowing improved varieties and the application of fertilizer did not reduce *Microtermes* attack in maize. Doubling the recommended sowing rate reduced maize yield by about 40%.

Seed treatment of chlorpyrifos, isofenphos and the standard insecticide, aldrin, failed to provide adequate protection against *Microtermes* and *Macrotermes* attacking maize. Furrow treatment using chlorpyrifos and isofenphos also consistently failed to protect maize from *Microtermes* primarily due to lack of persistence. Seed treatment with liquid formulation of chlorpyrifos also reduced maize seed germination significantly.

Chlorpyrifos at the rate of 20.2 g a.i. per mound was effective for killing *Macrotermes* colonies in their nests. Application of diazinon and removing the queen from the nest provided only partial control.

Mound poisoning resulted in no reduction in crop damage or yield losses. The number of mounds had not changed five years after poisoning due to the survival of young colonies that had not yet built mounds. While poisoning kills old colonies, the young termite colonies can continue to cause crop losses.

Soil treatment with heptachlor did reduce both crop damage and foraging activity of *Macrotermes* on treated plots; however, no yield improvement was observed on treated plots.

Widespread stand loss of crops caused by *Macrotermes* was observed only in the Welega and Asosa administrative regions of western Ethiopia, but not in other parts of the country at least not in the same magnitude. The removal of natural vegetation was not found to be the cause for the development of *Macrotermes* crop damage in western Ethiopia because more natural vegetation was removed in Meki-Ziway area where there was no crop damage than Mendi. Between 1967 and 1971 about 80% of the natural vegetation was removed in Ziway compared with about 60% of the vegetation in Mendi in the 23 years between 1957 and 1980.

Morphometric analysis and studies on the mound building behaviour of the two populations showed that they are different. Whether these differences indicate different species is not yet well known.

CONCLUSION

1. *Microtermes* spp. found in the Welega and Asosa administrative regions were not observed attacking tef or cause yield loss in maize despite heavy infestation. Therefore, control measures are not required.

2. The termite species that has caused the greatest concern and alarm in western Ethiopia is *Macrotermes subhyalinus*. This species has been observed causing stand losses in several crops grown in the region, but not all stand losses resulted in yield reduction. In maize up to 30% stand loss at the 6-leaf and 9-leaf stages had no effect in grain yield, whereas 45% stand loss at all the stages tested did reduce yield. Therefore, crop loss assessments are needed to determine whether control measures are necessary.

3. Seed treatment was not effective for preventing *Macrotermes* crop damage since the untreated part of plants is not protected.

4. Removal of the queen from the nest was not an effective method of killing *Macrotermes* colonies. Mound treatment with chlorpyrifos was effective; however, the effect of

long-term mound poisoning in crop damage and grain yield needs further investigation.

5. Further taxonomic research is needed to determine whether variations in the pest status of *Macrotermes* is due to differences in the species or due to some other factors. Perhaps isoenzyme analysis reported to be useful for separating morphologically similar species of *Macrotermes* would be worth considering.

ACKNOWLEDGEMENTS

I am grateful to the United Nations Food and Agriculture Organization for sponsoring my studies and to the Ministry of Agriculture of the People's Democratic Republic of Ethiopia for granting study leave to take this study.

I am greatly indebted to my supervisor, Dr. G.A. Matthews for his advice and encouragement throughout the study period. I would particularly like to thank him for his guidance during the preparation of the thesis.

I would like to thank my advisor, Dr. T.G. Wood for his advice and guidance during the establishment of the field trials, the preparation of the thesis and his visit twice to Ethiopia for supervision of the research programme.

I am grateful to the Ministry of Agriculture for the financial support and generous provision of transport facilities throughout the study period.

My thanks are due to the Ministry of Coffee and Tea Development, Ministry of State Farms Development, the Institute of Agricultural Research (IAR) and the Peasant Associations in the study areas for their cooperation to conduct field trials in their farms and for the provision of labour force for managing the trials.

I wish to thank many field staff and development agents in the Welega Administrative Region for their assistance during the establishment of the field trials and data collection.

It is acknowledged that the insecticides used in the field trials were kindly supplied by Dow Chemical Company Ltd and Bayer Pflanzenschutz; the seeds and fertilizer by the Ministry of Agriculture and Ministry of Coffee and Tea Development.

I wish to thank Drs. S. Bacchus and W.A. Sands, British Museum of Natural History, ODNRI for their advice in the identification of termite samples collected in Ethiopia.

I would like to express my thanks to Dr. Hailu Kassa, Head of Crop Protection and Regulatory Department in the Ministry of Agriculture for his encouragement and cooperation throughout the study period.

I wish to thank the staff and fellow students at IPARC for their assistance in many ways and friendship during the preparation of the thesis. I would like to thank also my friend S. Zakaria for his friendship and moral support during the preparation of the thesis.

Finally, I would like to extend my special thanks to my wife, Anisa and daughter, Mawardi for their unfailing support and encouragement throughout the study period.

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APPENDICES

Appendix A1 Monthly total rainfall in the study sites during 1987 and 1988

Month	Rainfall (mm)						
	Mendi	Nedjo	Henna	Ghimbi	Didesa	Bako	Sasiga
1987							
Jan.	0.0	0.0	0.0	0.0	3.5	4.3	0.1
Feb.	0.0	0.0	0.0	0.0	3.0	6.1	3.8
Mar.	0.4	98.1	94.5	54.9	25.0	129.2	30.4
Apr.	58.0	11.5	24.2	53.4	28.5	63.2	29.3
May	154.2	323.5	221.6	249.4	141.2	172.7	200.3
Jun.	237.8	280.9	254.5	307.9	399.0	260.3	236.6
Jul.	303.5	286.0	479.1	474.5	428.4	175.6	267.1
Aug.	371.7	222.8	379.3	347.3	295.6	120.0	236.9
Sep.	351.6	217.0	356.2	187.9	214.8	94.1	278.4
Oct.	148.6	128.6	171.8	128.5	97.2	76.9	85.4
Nov.	0.7	3.6	2.3	0.0	54.4	3.8	5.5
Dec.	na	0.0	0.0	0.0	0.5	25.5	2.6
Total	1626.5	1572.0	1983.5	1803.8	1691.1	1131.7	1375.8
1988							
Jan.	1.4	0.0	3.9	na	0.6	21.9	8.5
Feb.	0.0	19.5	31.5	31.6	8.5	na	36.5
Mar.	35.9	45.9	30.1	20.0	31.9	3.2	16.9
Apr.	0.0	0.0	0.0	0.0	8.0	11.5	1.6
May	203.8	184.1	287.3	268.0	275.2	100.1	139.8
Jun.	422.5	403.8	464.7	400.5	339.9	180.9	213.7
Jul.	222.7	459.7	392.7	290.4	369.2	341.3	362.3
Aug.	297.2	285.4	253.2	310.4	441.5	194.5	366.7
Sep.	434.4	346.9	390.7	452.6	380.1	230.7	480.2
Oct.	329.8	137.6	222.7	174.2	241.3	87.2	205.4
NOV.	16.5	6.9	0.9	2.2	2.8	6.4	0.0
Dec.	0.0	0.3	0.0	na	0.0	0.2	0.0
Total	1947.7	1883.2	2077.7	1949.9	2099.0	1177.7	1831.6

na = Data not available

Appendix A2 Monthly mean maximum temperature in the study areas during 1987 and 1988

	Temperature °C						
Month	Mendi	Nedjo	Henna	Ghimbi	Didesa	Bako	Sasiga
1987							
Jan.	31.2	27.9	27.9	27.9	33.4	29.3	33.6
Feb.	32.1	28.8	29.2	29.3	34.8	28.9	34.7
Mar.	32.3	28.5	28.8	28.6	34.6	29.9	34.6
Apr.	31.7	28.5	28.9	28.9	34.3	30.1	34.9
May	27.2	25.2	25.8	25.0	31.3	28.4	31.7
Jun.	24.3	23.2	23.6	23.7	28.8	26.3	28.7
Jul.	24.9	23.1	23.4	24.0	28.4	25.9	28.5
Aug.	24.6	22.8	22.7	23.7	27.9	24.8	27.3
Sep.	25.7	24.7	24.2	25.4	29.5	27.0	29.4
Oct.	26.2	24.1	23.9	25.1	30.3	27.5	29.8
Nov.	27.3	24.9	24.5	25.8	31.1	28.6	32.1
Dec.	na	27.1	25.9	26.9	32.5	29.5	32.7
Mean	28.0	25.7	25.7	26.2	31.4	28.0	31.5
1988							
Jan.	30.6	28.2	26.9	na	33.7	30.2	33.1
Feb.	31.4	27.4	27.9	28.4	34.2	na	34.5
Mar.	33.3	29.7	29.3	29.9	36.1	32.6	36.0
Apr.	33.4	30.1	30.0	30.3	36.0	33.6	36.9
May	27.9	25.5	31.4	25.7	31.4	30.3	32.0
Jun.	24.4	23.2	22.2	23.4	28.3	26.7	28.6
Jul.	23.6	20.7	24.3	22.6	25.8	23.5	26.1
Aug.	23.4	21.1	21.3	23.0	26.0	23.9	25.7
Sep.	24.8	21.8	21.6	23.8	27.7	24.3	27.9
Oct.	24.6	23.8	23.6	25.1	29.8	27.6	25.9
Nov.	27.8	25.1	24.5	25.5	31.2	27.8	30.3
Dec.	29.9	26.3	25.4	26.9	31.9	29.0	31.3
Mean	27.9	25.2	25.7	25.9	31.0	28.1	30.7

na = Data not available

Appendix A3 Monthly mean minimum temperature in the study sites during 1987 and 1988

Month	Temperature °C						
	Mendi	Nedjo	Henna	Ghimbi	Didesa	Bako	Sasiga
1987							
Jan.	13.5	8.7	12.9	14.5	10.8	11.7	11.5
Feb.	15.8	10.1	14.0	16.2	13.9	13.8	15.1
Mar.	17.2	12.7	13.8	16.1	17.3	15.6	16.9
Apr.	17.7	14.2	13.8	17.0	18.9	16.0	18.3
May	17.0	14.3	12.5	16.0	18.2	16.2	17.6
Jun.	15.6	14.0	11.0	14.1	17.3	15.5	15.8
Jul.	15.2	13.9	10.7	13.9	16.7	15.5	15.7
Aug.	15.3	13.7	10.5	14.1	16.4	15.4	15.6
Sep.	15.0	12.7	10.1	14.9	16.3	14.7	15.2
Oct.	15.2	12.4	10.0	14.8	16.0	14.0	14.5
Nov.	15.5	10.1	9.7	15.3	14.3	12.2	14.2
Dec.	na	9.1	10.4	15.1	13.1	12.4	13.6
Mean	15.7	12.2	11.6	15.2	15.8	14.4	15.3
1988							
Jan.	14.0	8.9	12.6	na	12.9	12.6	13.6
Feb.	15.0	11.0	13.3	15.4	16.1	na	15.7
Mar.	16.5	12.4	13.8	16.5	17.5	14.7	17.8
Apr.	17.8	11.8	13.9	17.0	17.7	14.9	18.3
May.	16.5	14.5	12.9	15.0	18.1	16.4	17.9
Jun.	15.1	13.8	12.8	14.0	17.0	15.4	16.2
Jul.	15.0	13.6	12.6	13.9	16.7	15.2	15.8
Aug.	14.8	13.2	12.1	13.7	16.2	14.9	14.8
Sep.	14.5	13.1	12.1	13.9	16.4	15.1	15.4
Oct.	14.4	12.3	12.8	14.3	15.2	13.6	12.7
Nov.	13.9	9.7	13.0	14.7	13.0	10.3	13.6
Dec.	13.5	7.6	12.8	14.8	10.0	9.4	11.7
Mean	15.1	11.8	12.9	14.8	15.6	13.9	15.3

na = Data not available

Appendix B1 Seasonal foraging activity of *Microtermes* nr. *vadschaggae, M.aethiopicus* and *Pseudacanthotermes militaris* on woodland at Sasiga

	% Baits attacked			Foraging population/bait		
Months	M. vad	M. aeth	Pseud	M. vad	M. aeth	Pseud
1987						
Jun.	12.5	3.8	10.0	25.6	61.3	18.7
Jul.	22.2	5.9	6.0	38.6	86.2	27.4
Aug.	15.6	6.2	6.3	27.9	25.3	19.3
Sep.	30.6	4.5	10.4	27.9	20.2	15.9
Oct.	15.0	4.6	5.8	18.6	22.8	18.7
Nov.	11.6	4.7	18.3	13.1	16.0	16.6
Dec.	6.5	2.7	22.1	14.0	25.0	20.8
1988						
Jan.	0.5	1.0	29.0	5.0	7.5	19.6
Feb.	1.0	0.0	22.0	0.0	0.0	20.0
Mar.	4.5	1.0	10.6	0.0	0.0	0.0
Apr.	4.3	1.0	19.6	31.3	5.0	18.3
May	21.1	3.1	14.7	46.2	36.7	20.9
Jun.	26.0	7.2	11.4	26.6	30.9	28.8

M. vad = *Microtermes* nr. *vadschaggae*
M. aeth = *Microtermes aethiopicus*
Pseud = *Pseudacanthotermes militaris*

Appendix B2 Seasonal foraging of *Microtermes* nr. *vadschaggae* and *Microtermes aethiopicus* on fallow land at Ghimbi

	% Baits attacked		Foraging population/bait	
Mont	Mi. vad	M. aeth	M. vad	M. aeth
1987				
Jun.	46.9	16.6	66.2	120.2
Jul.	56.0	21.2	69.7	70.6
Aug.	46.4	17.5	32.9	32.6
Sep.	44.4	18.1	44.1	51.7
Oct.	44.4	16.9	38.9	42.5
Nov.	48.5	17.7	29.6	27.1
Dec.	43.6	14.1	40.4	32.0
1988				
Jan.	40.3	14.2	41.6	34.6
Feb.	30.7	7.4	51.7	51.7
Mar.	31.4	6.1	41.5	26.1
Apr.	34.7	9.7	48.3	46.8
May	45.2	17.4	37.0	43.3
Jun.	38.4	21.2	36.1	29.1
Jul.	45.4	10.9	45.5	40.2
Aug.	36.7	21.9	37.9	30.6
Sep.	31.6	20.2	30.5	39.0
Oct.	35.6	20.6	31.1	40.2
Nov.	32.6	12.2	32.6	41.1
Dec.	26.9	10.2	40.9	36.4

Appendix B3 Wet season foraging activity of *Microtermes* nr. *vadschaggae*, *Microtermes aethiopicus* and *Pseudacanthotermes militaris* on afforestation site at Mendi

	% Baits attacked			Foraging population/bait		
Month	M. vad	M. aeth	Pseud	M. vad	M. aeth	Pseud
1988						
Jun.	4.6	1.1	14.9	0.0	8.0	0.0
Jul.	25.6	3.5	5.8	20.5	13.3	35.0
Aug.	14.6	3.4	7.9	26.5	16.7	32.9
Sep.	17.4	3.6	9.7	15.5	20.0	27.8
Oct.	19.2	4.4	13.7	31.2	16.7	42.7
Nov.	5.3	2.1	13.4	20.0	65.0	38.8
Dec.	6.3	0.0	25.3	25.8	0.0	37.9

Appendix B4 Seasonal foraging activity of *Microtermes* nr. *vadschaggae* and *Macrotermes subhyalinus* on cultivated land at Ghimbi-2

	% Baits attacked		Foraging population/bait	
Month	M. vad	Macro	M. vad	Macro
1987				
Jun.	39.2	13.4	91.9	79.5
Jul.	40.9	29.0	87.4	33.8
Aug.	47.4	11.2	54.0	16.6
Sep.	40.8	11.2	48.8	22.7
Oct.	33.3	11.5	42.4	5.7
Nov.	32.7	30.7	25.1	3.1
Dec.	22.0	36.0	16.1	4.8
1988				
Jan.	17.2	31.3	24.3	4.0
Feb.	10.2	18.3	52.0	30.0
Mar.	45.8	8.3	29.8	0.0
Apr.	40.4	8.5	0.0	0.0

Appendix B5 Wet season foraging activity of *Microtermes* nr. *vadschaggae* on cultivated land at Nedjo

	% Baits attacked	Foraging population/bait
Month	M. vad	M. vad
1988		
Jul.	42.2	52.1
Aug.	37.0	35.4
Sep.	37.5	68.0
Oct.	40.4	41.3
Nov.	26.4	47.2

Appendix B6 Wet season foraging activity of *Microtermes* nr. *vadschaggae* and *Microtermes aethiopicus* on cultivated land at Didesa

	% Baits attacked		Foraging population./bait	
Month	M. vad	M. aeth	M. vad	M. aeth
1988				
Jun.	62.5	25.0	44.3	66.6
Jul.	71.7	28.3	37.0	47.7
Aug.	68.1	21.3	22.8	29.0
Sep.	56.3	33.3	38.0	33.1
Oct.	41.7	16.7	26.8	36.9
Nov.	13.5	2.1	23.1	30.0

Appendix B7 Wet season foraging activity of *Microtermes* nr. *vadschaggae* on cultivated land at Bako Agricultural Research Centre

	% Baits attacked	Foraging population/bait
Month	M. vad	M. vad
1988		
Jul.	29.7	14.1
Aug.	64.3	39.8
Sep.	80.8	46.4
Oct.	79.2	49.6
Nov.	47.9	57.3

Appendix B8 Seasonal foraging activity of *Microtermes* nr. *vadschaggae* and *Pseudacanthotermes militaris* on cultivated land at Sasiga

	% Baits attacked		Foraging population/bait	
Month	M. vad	Pseud	M. vad	Pseud
1987				
Jun.	9.7	9.7	49.4	29.4
Jul.	23.7	9.9	48.1	19.9
Aug.	23.8	7.1	30.1	22.5
Sep.	14.5	11.0	24.2	23.2
Oct.	17.3	19.0	18.4	18.0
Nov.	15.0	17.5	15.4	7.0
Dec.	5.0	22.5	4.3	5.0
1988				
Jan.	0.0	20.5	0.0	4.0
Feb.	0.0	19.8	0.0	5.0
Mar.	1.9	14.4	37.5	0.0

Appendix B9 Seasonal foraging activity of *Microtermes* nr. *vadschaggae* on cultivated land at Ghimbi-1

	% Baits attacked	Foraging population/bait
Month	M. vad	M. vad
1987		
Jun.	35.8	186.5
Jul.	52.9	74.6
Aug.	56.9	60.0
Sep.	53.2	44.3
Oct.	58.4	33.8
Nov.	48.2	25.4
Dec.	48.2	23.6
1988		
Jan.	23.7	22.2
Feb.	11.2	33.9
Mar.	35.7	26.9
Apr.	22.8	43.9

Appendix B10 Wet season foraging activity of *Microtermes* nr. *vadschaggae* and *Macrotermes subhyalinus* on cultivated land at Mendi

	% Baits attacked		Foraging population /bait	
Month	M. vad	Macro	M. vad	Macro
<u>1988</u>				
Jul.	32.4	0.0	28.3	35.0
Aug.	30.8	15.4	17.0	22.0
Sep.	26.3	13.0	20.2	21.0
Oct.	13.1	5.2	27.7	20.0
Nov.	13.6	1.3	23.2	6.6

Appendix B11 Wet season foraging activity of *Microtermes* nr. *vadshaggae* and *Macrotermes subhyalinus* on cultivated land at Henna

	% Baits attacked		Foraging population/bait	
Month	M. vad	Macr	M. vad	Macr
<u>1988</u>				
Jul.	34.2	0.0	26.1	0.0
Aug.	51.4	0.0	40.6	0.0
Sep.	45.0	5.0	69.8	10.0
Oct.	37.5	0.0	60.0	0.0
Nov.	45.0	0.0	54.7	0.0

Appendix B12 Wet season foraging activity of *Microtermes* nr. *vadschaggae* and *Macrotermes subhyalinus* on cultivated land at Ghimbi

	% Baits attacked		Foraging population/bait	
Month	M. vad	Macr	M. vad	Macro
<u>1988</u>				
Jul.	20.0	20.0	40.3	21.7
Aug.	77.5	12.9	90.0	39.7
Sep.	36.8	15.8	78.6	28.9
Oct.	60.0	4.0	70.4	30.0
Nov.	43.7	10.2	43.2	12.2

Appendix B13 Diurnal variations in foraging activity of *Microtermes* nr. *vadschaggae* in fallow land at Ghimbi

Time (hours)	% Baits attacked			Foraging population/bait		
	15/8	24/11	13/3	15/8	24/11	13/3
02.00	40.6	37.5	37.5	35.1	26.3	37.1
04.00	68.8	68.8	59.4	28.6	33.4	29.5
06.00	37.5	53.1	50.0	17.2	19.1	67.5
08.00	43.8	37.5	21.9	56.4	18.3	66.3
10.00	56.3	59.4	43.8	47.2	57.1	35.7
12.00	37.5	28.1	9.4	31.3	12.8	6.0
14.00	37.5	21.9	6.3	25.8	16.0	10.0
16.00	50.0	15.6	6.3	28.1	13.2	10.0
18.00	81.3	53.1	21.9	26.2	27.6	28.3
20.00	31.3	43.8	37.5	51.0	33.3	71.7
22.00	18.8	34.4	15.6	9.7	37.3	26.4
24.00	25.0	31.3	28.1	40.0	27.5	21.7

Appendix B14 Diurnal variations in the foraging activity of *Microtermes* nr. *vadschaggae* in bushland at Sasiga

Time (hours)	% Baits attacked			Foraging population/bait		
	22/7	30/11	9/3	22/7	30/11	9/3
02.00	12.5	6.3	0.0	25.5	15.0	0.0
04.00	18.8	6.3	0.0	28.3	20.0	0.0
06.00	18.8	0.0	6.3	35.7	0.0	30.0
08.00	6.3	6.3	6.3	2.0	5.0	5.0
10.00	6.3	0.0	6.3	80.0	0.0	30.0
12.00	18.8	0.0	0.0	21.0	0.0	0.0
14.00	25.0	0.0	0.0	63.5	0.0	0.0
16.00	21.4	6.3	0.0	50.0	5.0	0.0
18.00	31.3	6.3	6.3	53.0	10.0	1.5
20.00	18.8	6.3	6.3	14.0	30.0	0.0
22.00	18.8	12.5	6.3	38.3	10.0	20.0
24.00	6.3	0.0	0.0	20.0	0.0	0.0

Appendix B15 Diurnal variations in the foraging activity of *Pseudacanthotermes militaris* in bushland at Sasiga

Time (hours)	% Baits attacked			Foraging population/bait		
	22/7	30/11	9/3	22/7	30/11	9/3
02.00	0.0	18.0	0.0	0.0	10.0	0.0
04.00	6.3	6.3	0.0	0.2	5.0	0.0
06.00	0.0	6.3	0.0	0.0	15.0	0.0
08.00	0.0	12.5	0.0	0.0	17.5	0.0
10.00	6.3	25.0	6.3	40.0	16.3	30.0
12.00	0.0	0.0	0.0	0.0	0.0	0.0
14.00	0.0	0.0	0.0	0.0	0.0	0.0
16.00	0.0	12.5	0.0	0.0	25.0	0.0
18.00	0.0	6.3	6.3	0.0	40.0	15.0
20.00	0.0	0.0	0.0	0.0	0.0	0.0
22.00	0.0	0.0	6.3	0.0	0.0	10.0
24.00	0.0	12.5	0.0	0.0	12.5	0.0

Appendix B16 Analysis of variance for the spatial variations in foraging activity

Source	DF	SS	MS	F	p
Treatments	5	1507.2	301.43	3.27	0.0255
Error	20	1842.1	92.103		
Total	29	4062.7			

Appendix C1 Unweighted least squares linear regression of yield loss and *Microtermes* infestation in maize under different farming systems

Predictor variables	Coefficient	Std. error	Student's T	P
Farmers' field				
Constant	5.1097E-02	1.9030	0.03	0.9790
Infestation	-2.9816E-03	5.0217-02	-0.06	0.9536

Cases included	15	Missing cases	0
Degrees of freedom	13		
Overall F	3.525E-03	P value	0.9965
Adjusted R squared	-0.0766		
R squared	0.0003		
Resid. mean square	19.01		

Settlement farms				
Constant	-4.5559	6.16068	-0.75	0.4665
Infestation	6.3644E-02	1.0821E-01	0.59	0.5647

Cases included	18	Missing cases	0
Degrees of freedom	16		
Overall F	3.459E-01	P value	0.7127
Adjusted R squared	-0.0400		
R squared	0.0212		
Resid. mean square	41.76		

Didesa State Farm				
Constant	-1.3.979	17.404	-0.80	0.4405
Infestation	2.0252E-01	2.7472E-01	0.74	0.4779

Cases included	12	Missing cases	0
Degrees of freedom	10		
Overall F	5.435E-01	P value	0.5970
Adjusted R squared	-0.0433		
R squared	0.0515		
Resid. mean square	117.9		

Appendix C1 cont.

Predictor variables	Coefficient	Std. error	Student's T	P
Bako Research				
Constant	-9.5416	26.307	-0.36	0.7244
Infestation	1.1576E-01	3.7171E-01	0.31	0.7619

Cases included	12	Missing cases	0
Degrees of freedom	10		
Overall F	9.698E-02	P value	0.9084
Adjusted R squared	-0.0894		
R squared	0.0096		
Resid. mean square	102.6		

Appendix C2 Un-weighted least squares linear regression of yield loss and *Microtermes* infestation in haricot beans in Didesa State Farm

Predictor variables	Coefficient	Std. error	Student's T	P
Constant	1.2896	1.2613	1.02	0.3365
Infestation	3.0308e-01	5.5479E-02	5.46	0.0006

Cases included	10	Missing cases	0
Degrees of freedom	8		
Overall F	29.84	P value	0.0002
Adjusted R squared	0.7622		
R squared	0.7886		
Resid. mean square	2.439		

Appendix C3 Unweighted least squares linear regression of yield loss and *Microtermes* infestation in sunflower in Didesa State Farm

Predictor variables	Coefficient	Std. error	Student's T	P
Constant	-29.113	9.6718	-3.01	0.0168
Infestation	1.6657E-01	1.2778E-01	1.3	0.2286

Cases included	10	Missing cases 0
Degrees of freedom	8	
Overall F	1.699	
Adjusted R squared	0.0721	
R squared	0.1752	
Resid. mean square	14.07	

Appendix C4 Pooled analysis of variance for yield in simulation of *Macrotermes* damage in maize at Bako and Didesa

Source	DF	SS	MS	F	P
Stage (A)	3	76.747	25.582	13.66	0.0000
Stand reduction (B)	2	5.2975	2.6487	1.41	0.2481
Sites (C)	1	184.26	184.26	98.35	0.0000
Replications (D)	3	4.6575	1.5525	0.83	0.4845
Interaction					
A*B	6	17.960	2.9933	1.60	0.1577
A*B*C*D	80	149.88	1.8735		
Total	95	438.80			

Error term used: A*B*C*D, 80 DF

Appendix D1 Analysis of variance for the effect of chlorpyrifos, isofenphos and aldrin in maize seed germination

Source	DF	SS	MS	F	P
Mendi					
Treatments	9	1.4002E+04	1555.8	38.58	0.0000
Error	90	3629.0	40.323		
Total	99	1.7631E+04			
Henna					
Treatments	9	2.0307E+04	2256.3	17.52	0.0000
Error	90	1.1593E+04	128.81		
Total	99	3.1900E+			
Ghimbi					
Treatments	9	1.2895E+04	1432.7	16.60	0.0000
Error	70	6041.0	86.301		
Total	79	1.8936E+04			

Appendix D2 Analysis of variance for the control *Microtermes* infestation in maize

Source	DF	SS	MS	F	P
Sasiga					
Treatments	8	5.125	6.407E-01	0.36	0.9327
Error	27	48.10	1.782		
Total	35	53.23			
Ghimbi-1					
Treatments	8	1299.5	162.44	2.57	0.0314
Error	27	1703.8	63.102		
TOTAL	35	3003.3			
Ghimbi-2					
Treatments	5	4.251	8.502E-01	1.37	0.2830
Error	18	11.20	6.223E-01		
Total	23	14.45			
Mendi					
Treatments	9	2.394E+03	266.0	1.47	0.1707
Error	90	1.629E+04	181.0		
Total	99	1.868E+04			
Henna					
Treatments	9	1.395E+03	155.0	0.99	0.4511
Error	90	1.404E+04	156.0		
Total	99	1.543E+04			
Ghimbi-1					
Treatments	9	4.114E+03	457.1	1.96	0.0575
Error	70	1.635E+04	233.6		
Total	79	2.047E+04			

Appendix D3 Analysis of variance for the control of *Macrotermes* in maize

Source	DF	SS	MS	F	P
Ghimbi-2					
Treatments	5	2.531	5.062E-01	0.50	0.7709
Error	18	18.15	1.008		
Total	23	20.68			
Mendi					
Treatments	9	2026.3	225.14	3.04	0.0033
Error	90	6663.7	74.041		
Total	99	8689.9			
Henna					
Treatments	9	795.0	88.33	1.60	0.1265
Error	90	4967.6	55.196		
Total	99	5762.6			
Ghimbi					
Treatments	9	1161.4	129.04	2.47	0.0164
Error	70	3652.7	52.182		
Total	79	4814.1			

Appendix D4 Analysis of variance for the control of *Microtermes* foraging activity

Source	DF	SS	MS	F	P
Mendi					
Treatments	2	212.04	106.02	1.46	0.2625
Error	15	1086.2	72.411		
Total	17	1298.2			
Henna					
Treatments	2	173.85	86.926	1.34	0.2918
Error	15	974.01	64.934		
Total	17	1147.9			
Ghimbi					
Treatments	2	1263.3	631.66	12.17	0.0007
Error	15	778.31	51.887		
Total	17	2041.6			

Appendix D5 Analysis of variance for the control of *Macrotermes* foraging activity

Source	DF	SS	MS	F	P
Mendi					
Treatments	2	483.56	241.78	2.79	0.0936
Error	15	1301.8	86.785		
Total	17	1785.3			
Ghimbi					
Treatments	2	105.62	52.808	1.15	0.3436
Error	15	690.01	46.001		
Total	17	795.63			

Appendix D6 Analysis of variance for maize yield in termite control trials

Source	DF	SS	MS	F	P
Sasiga					
Treatments	8	298.88	37.36	3.04	0.0144
Error	27	332.3	12.31		
Total	35	631.1			
Ghimbi-2					
Treatments	5	45.49	9.098	0.67	0.6507
Error	18	244.1	13.56		
Total	23	289.6			
Mendi					
Treatments	9	435.85	48.427	4.26	0.0001
Error	90	1023.9	11.376		
Total	99	1459.7			
Henna					
Treatments	9	45.678	5.0754	1.24	0.2830
Error	80	327.62	4.0952		
Total	89	373.30			